REVIEW ARTICLE

Recent trends in utilization of rice and value addition to its byproducts

Vasudeva Singh
CSIR - Central Food Technological Research Institute, Mysore, Karnataka, India
Email : singhva2003@yahoo.co.in

ABSTRACT

Rice is the staple food grain for majority of population in the world. In India, rice is being used in raw as well as parboiled form. In southern states of India, rice is also used in the form of "cured rice". From harvesting to drying, shelling and milling in raw, and parboiled form is practiced. CSIR-CFTRI has intervened in converting paddy to rice and then products. Paddy is parboiled by wet heat as well as dry heat treatments. Several properties of both rice are similar, however, some are different. Rice is also converted into different products by using parboiled rice. It is converted into expanded and popped rice. Among the latest products- noodles, diabetic rice as well as diabetic rice noodles are developed. Structure of amylopectin of rice starch is studied with gel permeation chromatography and related to behavior of cooking of rice. Energy consumption during cooking of rice by different methods have been reported. Rice is also converted into starch after removing fiber and protein, and then converted into low degree substituted acetylated starch for food applications and high degree substituted acetylated starch for the preparation of biodegradable plastics. Rice bran, an important byproduct of rice milling industry is along with husk and broken. After defatting the bran, protein is extracted and its properties have been studied. Rice is also extruded and properties of extruded products have been studied. Medicinal rice and their properties have been reported, and its different nature compared to normal rice is also discussed.

Key words: *rice, raw, parboiled, extruded, noodles, bran, pigmented, byproduct, value addition*

INTRODUCTION

Rice is being produced to a greater extent as a staple food grain in India, next to wheat in the World among the fine grains of food grains. To a greater extent rice parboiled, almost 50 to 55% of the produced paddy in India, compared to any other part of the world. The parboiled rice produced is being used generally by people who are living in coastal areas like West Bengal, Orissa, Kerala, Mangalore a part of Karnataka etc. Rice is used in brown form to a lesser extent and to a greater extent in milled rice form, in some parts of country in the form of hand pounded rice. This rice is also used in the form of partial milled rice or optimally milled brown rice. This generally is not available at market. CFTRI has come out with a technology, viz. Mini Rice Mill, which can be used for producing minimum quantity of brown or partial milled rice. This equipment consumes least electrical power, almost to that extent of a mixie at home level. Design drawings of this equipment has been sold and the fabrication work are in progress by one of the company in Northern India. Now a days, significance of pigmented rice is well recognized, as it has been observed that this rice is having high amount of nutraceuticals compared to normal rice. General review of rice technology mostly carried out at CFTRI, Mysore is covered in this review.

Properties (hydration, physicochemical, thermal, wet grinding and viscographic)

Rice hydrates at a moderate rate, whereas processed one hydrates in a different way. Paddy hydrated very slowly, hydration rate was slow in brown rice but fast in milled rice and highest in waxy rice (Table 1) In most of the rice varieties, maximum absorption occurred at the end of 30 min. The data were tested on the Peleg's equation, which gave a reasonable fit to experimental data. Peleg's constants K1 and K2 were calculated for the rice grain and its hydration behavior has been predicted. The model fitted very well to milled rice hydration data where the coefficient of variance ranged from 0.9982 to 0.9995. Generalized equations have been formulated for prediction of moisture content of cereals(Singh *et al.,* 2010).

Two recently released rice varieiteis viz., Mandya Vijaya and IR 30864 were tested for their field yield, milling yield, breakage, cooking and organoleptic properties.The yield in the field remained 7.5 tons ha^{-1} , husk content 20.1 and 18.4 % milling yield: ~ 74 and 75.6% for MandyaVijaya and I R 30864, respectively. Both varieties largely satisfy technological norms and cooking and eating qualities desirable under Indian conditions (Bhashyam and Vidyachandra, 1991).

Brabender viscograms of rice flour from aged paddy of two high amylose fine grain cultivars showed higher paste viscosities than that from the paddy stored at 4-6^0 C for the same period. The differences were almost eliminated in case of isolated starches. The total amylose content was same for the starches from both aged (RT stored and cold stored) paddy. However, the hot water soluble amylose content was less in starches from aged paddy. The number average molecular weight (M_n) as well as the swelling power and solubility of the starches from RT stored (aged) paddy were also less indicating that the ageing of rice could partly be associated with the changes in the physicochemical properties of its starch (Rajendrakumar and Ali, 1991).

Three types of rice, namely Thailand (Indica), Nipponbare (Japonica) and Himenomochi (Japonica waxy) in grain, flour and starch forms have been studied for their thermal and physicochemical properties. In grain form, Indica was slender and Japonica rice were bold and thick. Indica had the highest protein and amylose equivalent. Protein contents in isolated starches varied from 0.2 to 0.9%. Cooked Indica grain was hardest and waxy rice was softest; stickiness was highest in Japonica rice. Glass transition temperature (T_g) was highest in Indica rice flour (~222^{0}C) and almost the same in Japonica rice flours. Melting point was highest for Japonica (~ 264^{0}C) and almost the same for Japonica waxy and Indica rice flours. T_g values of starches were almost the same in Indica and Japonica waxy (~ 237^{0}C); defatting caused reduction in this property in all of the starches. Highest melting point was shown by Indica starch (~ 276^{0}C) and was almost the same for the other two starches. Protein and fats play a critical role in glass transition and melting points of rice flours and their respective starches.

Grinding of rice

A colloidal mill was comparatively evaluated with domestic wet grinding systems, namely, a mixer grinder and a stone grinder for grinding of raw rice, parboiled rice and black gram. The wet ground samples were also compared with dry ground samples. The finer the particle size the greater was the starch damage both in dry and wet grinding. Wet grinding generally resulted in a much lower average particle size (~79-131 micrometer) than dry grinding (221-297 micrometer). The starch damage was the least in black gram (~ 3%) followed by raw rice (~ 8%) and parboiled rice (~ 11%) in dry grinding. In wet grinding, the starch damage in black gram (~ 1-2%) as well as raw rice (0.5-2%) remained more or less same whereas the parboiled rice (21-35%) showed greater damage. Parboiled rice required 2.5-3 times the energy (216-252 kJ kg^{-1}) as that of raw rice (72-108 kJ kg^{-1}) for grinding in the mixer grinder and the stone grinder. The colloid mill appears to have a potential for industrial adoption (Solanki *et al.*, 2005).

Four varieties of paddy were subjected to shelling and milling analysis. Their proximate composition, poly-phenol, vitamin, phosphorus contents, viscosity changes on cooking by Brabender Viscograph, swelling and solubility behavior were studied. Under similar conditions of milling, these varieties have shown different degree of polish, indicating the differences in removal of various bran layers. Highest EMC was registered by husk compared to other parts of the grain (Table 1). Among the varieties studied, MTU-1001 indicated highest ash content in brown as well as in milled rice. Riboflavin content was low in de-husked rice of Jyothi and least in other parts of this grain compared to other varieties, however, niacin was high in this particular variety. Phosphorus content remained almost same in MTU – 1001, in its rough rice, de-husked rice and milled rice (~200 mg $100g^{-1}$). In all the varieties phosphorus was highest in bran compared to other parts of the grain. About 50% loss of phosphorus was seen in all milled rice samples compared to their respective de-husked rice. Poly-phenol content was high (0.056-0.078g %) in bran compared to other parts of the grains (Table 2 and 3). Swelling and solubility values were

Table 1. Moisture content and equilibrium moisture content of different parts of paddy

Variety	Moisture content (%)				Equilibrium moisture content (%)			
	Paddy	Husk	Brown rice	Milled rice	Paddy	Husk	Brown rice	Milled rice
IR – 64	12.0 ± 0.0	9.9 ± 0.0	13.8 ± 0.4	13.7 ± 0.2	27.3 ± 0.3	48.0 ± 2.0	28.9 ± 0.4	27.8 ± 0.2
BPT 5204	12.8 ± 0.2	1.3 ± 1.2	13.6 ± 0.1	13.6 ± 0.1	32.3 ± 2.4	52.0 ± 0.1	29.8 ± 0.1	28.8 ± 0.1
MTU-1001	13.7 ± 0.5	9.4 ± 0.1	12.4 ± 0.2	11.9 ± 0.1	31.9 ± 0.2	44.1± 0.5	31.6 ± 0.1	31.6 ± 0.6
Jyothi	12.4 ± 0.1	10.6 ±0.1	13.5 ± 0.1	14.1 ± 0.2	32.0 ± 1.5	49.0 ± 1.9	30.0 ± 0.4	28.7 ± 0.2

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high at all temperatures in MTU 1001 variety compared to others and pasting profile parameters were different in BPT 5204 rice compared to other varieties (Deepa and Singh 2010).

Pasting profile of coarse rice, fine rice as well as black gram was carried out individually, in combination, in flour as well as in batter form, before and after fermentation by Brabender Viscoamylograph. Lowest gelatinization temperature was seen in black gram among the three commodities studied. Coarse rice registered a peak viscosity (PV) of 1,300 BU, fine rice 1030 BU and black gram 1,080 BU. Cold paste viscosity (CPV) was highest in fine rice, lowest in black gram and intermediate in coarse rice. Breakdown (BD) was least in fine rice, highest in coarse rice and black gram lay in between. Values of total setback indicated the strong reason for use of coarse rice in parboiling as well as in idli and dosa preparations. Physical combination of black gram, with fine as well as coarse rice, reduced PV on an average to an extent of 26-30%. CPV was highest in fine rice and black gram combination compared with that of coarse rice and black gram. BD was high in the physical mix of coarse rice and black gram. In comparison with physical mix of fine rice and black gram, in the batter form before fermentation, the PV and CPV reduced by 23 and 34%, respectively, but there was no BD in this mix, indicating restricted swelling behavior in the batter before fermentation. Almost all viscographic parameters reduced before fermentation in coarse rice and black gram compared with their physical combination. Highest relative BD (BD_r) was noticed in the pasting profile of black gram alone, probably because of the presence of mucilaginous principle. BD_r values increased in batter form to various extents, before and after fermentation, compared with physical combination of rice and black gram. After fermentation, in coarse rice and black gram, the BD_r value was low compared with that in fine rice and black gram (Koh and Singh, 2009).

Table 2. Phosphorus content and Polyphenol content in different parts of paddy

Variety	Phosphorus content (mg %)			Polyphenol content (mg %)			
	Paddy	Brown rice	Bran	Milled rice	Brown rice	Bran	Milled rice
IR-64	290.2 ± 0.2	314.9 ± 2.5	1574.5 ± 0.4	174.2 ± 1.0	50 ± 1.33	58 ± 0.15	44 ± 0.1
BPT 5204	308.0 ± 4.8	318.9 ± 0.2	1658.7 ± 0.4	175.2 ± 0.7	52 ± 1.48	58 ± 0.02	51 ± 0.1
MTU1001	211.4 ± 0.1	211.4 ± 0.1	1142.0 ± 0.8	196.1 ± 1.2	44 ± 0.78	60 ± 0.85	40 ± 0.2
Jyothi	306.9 ± 0.0	430.8 ± 0.7	1153.6 ± 0.7	216.9 ± 3.2	60 ± 0.30	78[a,b,c]± 0.11	51 ± 0.5

[a,b,c] Jyothi values were significantly different from IR – 64 at $P < 0.05$, BPT 5204 at $P < 0.05$ and MTU 1001 at $P < 0.05$
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Medicinal rice

Njavara is a medicinal rice strain, endemic to Kerala, South India, bestowed with medicinal qualities. It was assessed for its nutrient composition and physicochemical properties, in order to understand its therapeutic properties. Dehusked Njavara rice consisted of 73% carbohydrates, 9.5% protein, 2.5% fat, 1.4% ash and 1628 kJ $100g^{-1}$ of energy(Table 4)

Table 3. Protein content (%) in different parts of the paddy

Name	Brown rice	Bran	Milled rice	Husk
IR-64	8.11± 0 42	11.92 ± 0.33	7.13 ± 0.13	2.83 ± 0.33
BPT 5204	7.47 ± 0.22	13.65 ± 0.25	7.24 ± 0.25	3.42 ± 0.04
MTU-1001	9.56 ± 0.49	12.41± 0.33	7.13 ± 0.13	3.26 ± 0.26
Jyothi	8.82 ± 0.49	10.36[a,b,c]± 0.25	6.91± 0.09	2.72 ± 0.17

[a,b,c] Jyothi values were significantly different from IR – 64 at P < 0.05, BPT 5204 at P < 0.05 and MTU 1001 at P < 0.05
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Physicochemical properties and nutritive components of dehusked rice of Njavara were evaluated and compared with two commonly consumed non-medicinal rice varieteies Jyothi (red coloured) and IR 64 (brown coloured). The carbohydrates, fats, apparent amylose equivalent, fatty acid profile and triglycerides of Njavara were comparable to Jyothi and IR 64. However, Njavarairce had 16.5% higher protein and contained higher amounts of thiamine (27-32%), riboflavin (4-25%) and niacin(2-36%) compared to the other two rice varieties. The total dietary fibre content in Njavara was found to be 34-4% higher than that of Jyothi and IR 64. Significantly higher phosphorus, potassium,, magnesium, sodium and calcium levels were found in Jjavara rice compared to the other two varieties. The cooking time of dehusked Jyothi and IR 64 varieties were found to be 30 min., while Njavara needed longer time to cook (38 min.). The cooked rice of Njavara was slimy in nature, probably due to the presence of non-starchy polysaccharides (Deepa *et al.*, 2008).

Genetic variations and some of the physicochemical properties were studied using standard molecular protocols and compared with those of non-medicinal rice varieties: Jyothi and IR 64. Njavara showed 11 unique positive and 36 unique negative markers to differentiate it from Jyothi and IR 64. Genetic similarity coefficient studies showed two well-defined clusters separating Njavara from Jyothi and IR 64. All the three varieties had waxy gene Wx_a allele. Njavara had $(CT)_n$ repeats at $(CT)_{10,}$ while Jyothi and IR 64 had repeats at $(CT)_{11}$ in the 5 '–un translated region of waxy gene. Njavara showed a CGTG sequence, while Jyothi and IR 64 had a CGCG sequence at the 14[th] exon of Sbe 1 gene. Njavara, Jyothi and IR 64 have similar amylose equivalent (AE), which was confirmed by microsatellite markers. The SSR primers for protein content and setback viscosity primer (RM 4608) were observed to be polymorphic in case of Njavara. Njavara rice, with a distinct gene pool and medicinal properties, can be exploited as a nutraceutical rice (Deepa *et al.*, 2009).

Bamboo rice

Bamboo seeds resemble wheat in appearance. In contrast, the seed, called Bamboo rice, obtained on de-

Table 4. Proximate composition of dehusked rice of Njavara and non-medicinal rice varieties

Components	Njavara	Jyothi	IR 64
Moisture (%)	13.10±0.15 [a]	13.00±0.24 [a]	13.60 ± 0.32 [a]
Total carbohydrate(g/100 g)	73.54±13.21[a]	72.81±11.10[a]	74.06 ± 17.6 [a]
Protein (g/100g) (N x 5.95)	9.52±0.34[a]	7.97±0.50 [b]	7.95 ± 0.17 [b]
Crude lipid (g/100g)	2.48±0.50 [a]	2.60±0.54 [a]	2.06 ± 0.14 [a]
Ash (g/100 g)	1.42 ±0.06	1.54±0.09	1.27 ± 0.09
Total fibre (g/100g)	8.80±0.03[a]	5.82±0.02[b]	4.96 ± 0.01 [c]
Insoluble fibre (g/100g)	7.56±0.05 [a]	5.39 ±0.04[b]	4.43 ± 0.04 [c]
Soluble fibre (g/100g)	0.52±0.03 [a]	0.43±0.02 [b]	0.53 ± 0.03 [a]
Energy value (kJ/100 g)	1627.97±76.18 [a]	1568.30±72.85 [a]	1658.20 ± 69.3 [a]

Values are mean ± SEM of five determinations; Means having a different letter are significantly different (P<0.05)
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husking and milling, appears like milled rice and its isolated starch also resembles that of rice in many respects. It contains about 11% protein, ~ 1% fat and ~ 81% starch (Table 5) The polished seed are characterized by high amylose content (~ 27%), typical non-waxy rice. Starch from the milled bamboo rice was isolated and characterized its viscographic behavior in comparison with bamboo rice flour was studied. The iodine binding capacity and the molecular weight of bamboo rice starch was also studied. Fractionation of bamboo rice starch by gel permeation chromatograpy revealed that it contains two fractions viz a high molecular weight polymers (i.e amylopectin) and a low molecular weight amylose fraction, typical to that of linear and branched portion of rice starch (Singh *et al.*, 2011)

Table 5. Physico-chemical properties of bamboo seeds

Sl.No.	Properties	Seed Dehusked	Seed Milled	Starch
1.	Moisture %	12.5	12.5	12.5
2.	Protein % (N x 5.95)	11.2	9.6	0.31
3.	Fat %	1.0	0.46	
			6.96*, 5.98**	0.23
4.	Equilibrium moisture content on soaking at RT	33.60***		
		32.40	31.20	-
5.	Cooking time (minutes)	-	23.00	-
6.	Starch content % (db)	-	80.80	98.30
7.	Iodine binding capacity (IBC) (mg/100mg polysacho)	-	-	4.30
8.	Amylose equivalent	-	-	22.30
9.	Amylose content % (db)	-	27.3	32.80
10.	Insoluble amylose %(db)	-	10.3	14.70
11.	Gelatinization temperature (C) (using Brabender at 10% (db) concentration	-	76.5	ND
12.	Number average molecular weight (M_n)Iodine binding capacity (mg/100 mg polysacharride)Amylose equivalent (%)	1.8×10^{-5}	4.30	22.30

*Fat content in 2 minutes polished bran; ** fat content in 5 min. milled bran.
*** bamboo un-dehusked grains, ND : could not be read properly from the viscogram.
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Morphology and structure

In S-199 variety of rice a true breeding selection designated as FT-199C was developed by intra-varietal selection. The plants of this line had all the agronomical and morphological characteristics identical to that of S-199. The grains of this line had complete expression of chalkiness in the entire endosperm where as the variety S-199 constituted a mixture of translucent and white core grains. The cracking and breakage resistance of this selection was phenomenally higher and those of white core grains (fractioned from S-199) was considerably lower as compared to translucent grains of S-199. The degree of polish required to the level of consumers acceptance was 4% for the grains of FT-199C and 6% for the grains of S-199. Milled rice of FT-199C cooked flakey even when fresh and required 3 min. less time to cook and gave about 8% more volume expansion of cooked grains than those of S-199. The grains of FT-199C exhibited lower GT and higher values for alkali score, amylose, protein and lysine contents and EMC- S% than those of S-199. The bulk density of the grains of FT-199C was 4% less than those of S-199. In the transverse section the aleurone and pericarp layers on the ventral side were thicker in FT-199C than in S-199. Partially expressed chalkiness is an undesirable character in rice. However, the chalkiness when expressed completely, confers on the grains exceptionally superior technological, nutritional and culinary properties which could be exploited by the breeder in the improvement of rice varieties (Srinivas *et al.*, 1984).

The frequency of grains with scutellum in the 14 varieties of milled rice varied from 12 to 86%. In the high scutellum retention varieties, a cementing material was present between the epithelial layer and endosperm cells. In low SR varieties, this material was absent. SR in milled rice increased with a decrease in the initial moisture of raw brown rice, by parboiling, and occurred more with Satake than McGill polisher. Broken in the brown rice prior to milling was associated with low SR in milled rice. The thiamine content of milled rice with scutellum was more (124 to 138 microgram $100g^{-1}$) than that without scutellum(80 to 84 microgram $100g^{-1}$. High SR variety retained more thiamine than the low SR variety even after washing. Scutellum retention in milled rice is thus nutritionally beneficial and can be enhanced by improving varietal and processing factors. (Raju *et al*, 1990).

Microscopic examination of sections of rice grain from 2 Basmati and 3 non-Basmati varieties has revealed that the cell walls of non-Basmati varieties tend to cleave more easily along the cell wall lines than the Basmati varieties. Data suggest that in Basmati rice, the compact cell walls hold up the pressure until maximum expansion of the cooked grains takes place. In non-Basmati rice pressure gets leaked even before the expansion is complete due to loose cell walls (Beerh and Srinivas 1991)

Popped rice is a widely prepared product in India. Variety, processing conditions, age of paddy, preformed cracks and maturity play an important role in the popping volume. Popping of paddy at 14% moisture was done at 275^{o}C for 40 sec with sand of 0.3 to 0.6 mm size at a ratio of 1 paddy : 2 sand in an electrical roaster. Late harvesting and preformed cracks, immaturity, reduce the poping volume whereas ageing of paddy improves popping. Completely chalky grains, germinated or parboiled paddy were poor in popping quality. Crack resistant isogenic line of Vani variety and also Intan variety perform very well. Their range of popping volume was 900 -1300 ml $100g^{-1}$ paddy (Bhashyam and Srinivas, 1991)

In rice, different types of chalkiness occur. White belly (WB) i.e., chalkiness on the ventral side of the cereal is a varietal factor modified by environment. Reduction of rice breadth during development, by artificial means in a WB variety led to elimination of chalkiness and reduction of kernel weight. Similarly, moisture stress in the field, during grain maturation reduced the proportion of WB and also reduction in the grain breadth in Pankaj and Mangala varieties. Microscopic studies of translucent variety S 199 and its sister variety FT 199C (which is completely chalky) showed variation in sugar content in boot leaf, stalk and grain. Starch granules are spherical in chalky grains and polygonal in translucent grain (Raju and Srinivas, 1991).

Kernels that developed within loosened glumes in 3 varieties of paddy were darker in colour and had smoother surface than those grown under normal conditions. The thickness of the pericarp plus seed coat layers was 33.6± 2.8 micrometer, and the thickness of the aleuronic layers was 21.7±2.5 micrometer in grains of the first type, while in the normal grains, these dimensions were 13±1.4 and 26.9±2.9 micrometer, respectively. The kernels which developed within loosened glumes tended to taper towards the distal end. They were lighter in weight than normal grains by 32 to 67 per cent, the weight loss being less in the bolder variety. The lemma-palea interlocking depth was positively correlated with the groove depth on the kernel and with the clearance between husk and kernel. All three parameters showed a positive correlation with grain breadth. A low lemma-palea interlocking depth and a smaller clearance between husk and kernel are technologically desirable characteristics in rice. The reclasping of the two glume components after pollination was essential for the normal development of the rice grain (Raju and Srinivas, 1991).

Different terminologies are used to identify several kinds of chalkiness. In rice, chalkiness on the ventral side of the grain, is called 'white belly'(WB), whilst at the central portion is is known as 'white core' or white center' and on the dorsal side it is termed as 'white back'. The whole grain may also be chalky in some rare varieties. In maize, depending on the expression of chalkiness, the varieties are classified as dent, flint, floury and popcorn. Most of the small millets are chalky millets are chalky in nature. For measuring the intensity of chalkiness certain optical and electronic devices have become popular. Visual rating is, however, still in vogue as it is easy. The association of grain dimensions with chalkiness has been demonstrated in some cereals, in rice, for example, grains with less than 2.3 mm breadth are free of WB and in maize there is a positive relation of chalky area with grain size. Chalkiness may be due to genetic and /or environmental factors. Nutrition and moisture stresses in the soil and in the plant system are the major environmental factors, which greatly modify the expression of chalkiness. In rice, a morpho-physiological basis for the expression of different types of chalkiness has been suggested. The cells of the chalky or floury portion are round or oval in shape, with interstitial spaces between the cells and have loosely filled spherical starch granules embedded in this sheets of protein matrix. In the translucent, corneous portion of the grain the cells are more angular and compact without any interstitial air spaces between cells and with densely packed polygonal starch granules enmeshed by a matrix of protein. In general, chalky grains are softer in texture, are of lower density and show higher susceptibility to infestation than the translucent counterparts. The economic value of chalkiness may be reduced or increased depending on the purpose for which the grain is used (Raju *et al.,*1991).

Data on structural features of 25 varieties of paddy revealed that grain breadth was positively correlated with white belly (chalkiness on ventral side) and negatively with the tightness of husk interlocking. The later could be indexed inversely by the ease of shelling of paddy; but shellability was influenced positively by grain breadth also. Rice hardness was adversely affected by grain chalkiness but hardness also differed among varieties due to other reasons. Grain cracking was correlated positively with grain chalkiness and negatively with grain hardness and husk interlocking score. A maximum brown rice breadth of 2.3 mm, a maximum shellability of 75% and a minimum popping expansion of 12 times could be useful as simple screening indices for acceptable technological quality of rice and for rapid screening of breeding lines (Murugeshan and Bhattacharya, 1994).

Progress in rice genetics in technological and quality aspects has been rather slow. The grain parameters associated with technological characteristics include size, shape, thickness of husk and bran layers, topography, chalkiness, hardness and other endosperm characters, adherence of the germ to the grain and nutritional distribution (Srinivas and Bhashyam, 1994).

Curing and Parboiling

Sand roasting of freshly harvested high moisture paddy in a mechanical roaster for 1 to 1.5 min at 95 to 155^{o}C removed 8-10% moisture in the paddy. Tempering of the roasted paddy for 1.5 to 2 h healed the cracks to some extent which were formed during roasting. The rice processed in this method exhibited characteristics similar to that of cured or parboiled rice. Paddy with high initial moisture (> 22%) is better suited for parboiling while those with low moisture (18 to 21%) can be cured using this roasting equipment (Srinivas *et al.*, 1981).

Study was conducted to develop a new and appropriate technology applicable to the improvement of conventional parboiling methods in the developing countries. Discoloration characteristic of rice which is regarded to be one of the most important changes during parboiling treatment was investigated Kimura *et al.*, 1993). Parboiling brought about significant changes in the grain dimensions in rice, the extent varying with the type of parboiling. Roaster-parboiled and pressure parboiled rice had significantly greater length (L), breadth (B), L/B ratio, but lower thickness as compared to raw rice, and to that produced by normal steam parboiling. Ridges on lateral regions of grain in raw rice seem to smoothen out in case of normal parboiling, but get pronounced in case of other methods (Sowbhagya *et al.*, 1993).

All types of parboiled rice got degraded when immersed in very dilute alkali, but the appearance of the degraded grain differed among the 3 classes of parboiled rice. Open steam parboiled rice grains remained fairly chalky white; pressure steam parboiled grains became transparent; and dry heat parboiled grains remained chalky, but got longitudinally split. Alkali reaction could thus distinguish between the 3 classes of product. The reaction seemed independent of starch association (Mahanta and Bhattacharya, 1995).

Paddy (IR 20) was parboiled by soaking at 70^{o} C for 3h followed by steaming at different pressures (101-304 kPa, absolute pressure) for up to 60 min. The colour variables determined were Hunter L, a, b – values, chroma and total colour difference for the rice samples. Response surfaces for these colour variables against time and pressure of parboiling were developed. Most of the colour changes followed zero order kinetics. The activation energies for chroma and total colour difference were 22.1 and 11.1 kJ mol 1, respectively. The colour development due to parboiling was minimum at low steaming pressure and short times (Sila Bhattacharya, 1996)

Four types of paddy were shelled/milled, physico-chemical studies before and after various methods of parboiling were studied Starch's from these were isolated and they were individually modified with a strong and a weak acid (0.5N HCl, 0.5N Formic acid). Husk content and dehusked rice varied from 20 to 24% and 66 to 74%, respectivlely. Chalky grains were seen only in BPT. Green grain to an extent of 5% was seen in IR-64 as well as BPT. Highest breakage (41%) was seen in pigmented variety Jyothi and least in waxy variety, after dehusking. Shelling and milling breakage were almost negligible, in waxy rice. Equilibrium Moisture Contents at room temperature (EMC-S) ranged from 28 to 35% for paddy, brown and milled rice, respectively. In normal parboiling, EMC-S varied from 34 to 46% for non-waxy paddy, brown and milled rice, whereas for waxy it varied from 48 to 65%. In pressure parboiling the values were 34 to 63%; 46 to 81 %. In Parboiling under pressure EMC-S were 42 to 61% and 64 to 83%, respectively (Table 6). Thiamine content varied from 430 to 518 µg% . Milled rice of these retained approximately 50 to 60% thiamine. Normal parboiling retained almost all thiamine, however in other parboiling, reduced the content by 27 -33% in respective brown and milled rice. Status of total and soluble amylose, oryzanol after parboiling have been discussed. Hydrochloric acid modified starches increased alkali fluidity number (AFN) compared to formic acid. Turbidity and retro-gradation were seen in high amylose rice starches and not in waxy rice starch. Industrially parboiling is carried out only with non-waxy paddy varieties, usage of thin boiling starches in confectionary, paper industry are well known (Bharathi *et al.*, 2012).

Table 6. Equilibrium moisture content (%, w.b) of respective paddy, brown rice and milled rice at room temperature

Different varieties	Jyothi	IR64	BPT	Waxy
Raw paddy	31.3	28.5	31.8	32.4
Raw brown rice	29.9	29.3	30.1	35.4
Raw milled rice	30.4	28.9	28.5	34.6
Open atmosphere paddy	34.6	36.3	39.9	47.9
Open atmosphere brown rice	43.9	37.6	40.6	62.2
Open atmosphere milled rice	46.3	40.7	43.1	65.3
Pressure parboiled paddy	34.8	35.0	40.5	45.9
Pressure parboiled brown rice	55.0	58.3	50.3	74.8
Pressure parboiled milled rice	57.9	62.9	59.2	80.6
Parboiling under pressure paddy	42.0	46.5	50.6	64.4
Parboiling under pressure brown rice	55.8	59.9	57.2	77.9
Parboiling under pressure milled rice	58.6	61.0	54.5	82.6

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Changes in various physicochemical properties of rice upon parboiling of aromatic (Basmati) paddy as well as non-aromatic (IR 64) paddy were compared. Grain elongation and coefficient of dimensional changes decreased upon cooking. The decrease was more in case of basmati. Among different parboiling conditions, for Basmati highest decrease was observed in case of pressure parboiled rice (PPB) and parboiling under pressure (PBUP), followed by roasted parboiled (RPB) rice, while normal parboiled rice (NPB) showed least decrease. In case of IR 64 highest decrease was observed for RPB and PBUP, followed by PPB and NPB. Total amylose content decreased drastically in PPB and PBUP in both the varieties and to a considerable extent in RPB and NPB (Sashikala *et al.*, 2005)

Dietary fiber

Five different varieties of paddy (four pigmented and one non-pigmented) were shelled and milled inpre and post parboiled form, their dietary fiber contents were estimated. Under similar conditions of milling, raw rice showed a high degree of polish (DOP), 9-12 g $100g^{-1}$ and parboiled rice showed low DOP, 4.6-6.6 g $100g^{-1}$. Dietary fiber content was high in pigmented rice, 9-10 g $100g^{-1}$ compared to non-pigmented, ~ 6 g $100g^{-1}$ (Table 7). Soluble fiber content in pigmented head rice (de-husked) varied from 1 to 1.5 g $100g^{-1}$ and in its broken varied from 0.45 to 1.45 g $100g^{-1}$. Dietary fiber content was low by about 1% in parboiled rice. In the parboiled rice of pigmented varieties, the total fiber content varied from 7.95-0.15to 9.05-0.25 g $100g^{-1}$ and the soluble fiber content varied from 0.7 to 0.9 g $100g^{-1}$. In milled parboiled rice the respective values were 5 - 0.4 to 6 - 0.1 g $100g^{-1}$ and 0.85 - 0.05 to 1.25 - 0.05g $100g^{-1}$. However, the soluble fiber content in the non-pigmented brown rice, IR-64 remained same after parboiling,0.75-0.5 g $100g^{-1}$. Milled parboiled rice showed higher soluble dietary fiber compared to milled raw rice. Dietary fiber was high in pigmented rice varieties when compared with non-pigmented rice (Savitha and Singh, 2011).

Products

Twenty five varieties of paddy differing widely in their popping expansion were analysed for their chemical and physical characteristics. Non-starch polysaccharides (tested in 10 varieties), amylose and protein; grain length, thickness and weight; husk-to-kernel gap; and thickness of pericarp and aleuronic layer (in 10 varieties) were unrelated to popping expansion. Tightness of husk (lemma-palea interlocking and grain hardness were strongly positively correlated with popping and 'white belly' (grains containing opaque, chalky regions)was negatively correlated. Multiple correlation analysis showed that these three factors could explain 80% of the variation in popping expansion among the variations; these factors along with the content and thickness of husk, equilibrium moisture of paddy, and cracked grains together explained over 95% of the variation. Grain breadth was positively correlated to white belly and thus indirectly affected popping inversely (Murugesan and Bhattacharya, 1991).

production system of popped rice. Soaking in salt solution seems less practical and wetting of paddy is to be avoided. Cracks in rice did not seem to affect popping (Murugesan and Bhattacharya 1991).

Of the 16 varieties of rice, representing eight different cooking quality types, those having 22% amylose or more, either raw or parboiled were suitable for the preparation of idli and gave the desired soft and spongy texture. Low amylose and waxy rice yielded hard and sticky textured idli. Sennsory analysis corroborated with the results of objective tests. ldlis from aged rice had better appearance and texture compared to fresh rice idles (Sowbhagya *et al.*, 1991).

Four varieties of paddy were soaked in hot water, drained, roasted in an industrial roaster, tempered, flaked and passed through roller. Moisture content

Table 7. Dietary fiber of dehusked head rice of pigmented and non-pigmented rice varieties before and after parboiling*

Rice varieties		Insoluble fiber (%)	Soluble fiber (%)	Total fiber (%)
Jyothi	[a]RDHR	7.40 ± 0.10	1.50 ± 0.10	8.90±0.20
	[b]PDHR	7.25 ± 0.15	0.70 ± 0	7.95±0.15
Aishwarya	RDHR	9.25 ± 0.05	0.80 ± 0.10	10.05±0.15
	PDHR	8.15 ± 0.05	0.90 ± 0.20	9.05±0.25
Kar Bhatha (Medium)	RDHR	8.35 ± 0.15	0.80 ± 0.10	9.15 ± 0.25
	PDHR	7.65 ± 0.05	0.75 ± 0.15	8.40 ± 0.20
Kar Bhatha (Small)	RDHR	8.00 ± 0.20	1.00 ± 0.10	9.00 ± 0.10
	PDHR	7.80 ± 0.10	0.75 ± 0.15	8.55 ± 0.05
IR-64	RDHR	5.40 ± 0.30	0.75 ± 0.05	6.15 ± 0.25
	PDHR	4.90 ± 0.10	0.75 ± 0.05	5.60 ± 0.10

*Values are mean ± standard error of three determinations.
[a]RDHR = Raw dehusked head rice, [b]PDHR = Parboiled dehusked head rice.
(Reproduced with permission from Savitha and Singh, 2011)

Pre-drying of paddy (variety Intan) to 9% moisture before finally adjusting it to the optimum moisture of 14% greatly improved popping expansion. This benefit seemed to originate from improved lemma-palea interlocking and greater grain hardness brought about during pre-drying. Soaking paddy in 2% NaCl solution increased its popping expansion appreciably, but pre-drying it did not further improve popping, superficial application of salt solution suppressed popping . Soaking paddy in water drastically lowered its popping expansion, apparently due to loosened husk interlocking and a softened endosperm; pre-drying of water soaked paddy could not restore subsequent expansion. Hence pre-drying is recommended in the

reduced from about 35 % in paddy to 11-13% in the flakes. Equilibrium moisture content was high (83-85%) in roller pass flakes compared to edge runner flakes. Total amylose equivalent varied from 21 to 23% in flakes of edge runner (ER) while that of roller pass were ~ 22%. Soluble amylose equivalent varied from 10 to 14% in flakes of ER and 11 to 13% in flakes of ER+RP. Protein contents were high in ER flakes, but reduced to an extent of 6 to 30% in roller pass flakes. Significant changes in phosphorus, vitamins, riboflavin and niacin contents were not recorded among two types of flakes. Pasting profile parameters indicated that the initial viscosity ranged from 280 to 550 BU in all flakes. Peak viscosity was low compared to initial value in all flakes with exception in MTU 1001 variety. Swelling power remained almost same in both type of flakes, however the solubility was high in BPT 5204 variety inn ER + RP flakes. In MTU 1001, the solubility in ER flakes was high compared to ER + RP flakes. Considerable nutrient losses occurred in the flakes obtained after passing through the rollers, except whitening of the flakes (Deepa and Vasudeva Singh, 2011).

Paddy (*Oryza sativa* L) (variety 'IR – 64'), was parboiled, puffed by sand roasting and flaked by edge runner and roller flaker and variations in physical and physicochemical properties were studied. Moisture contents were lower (5.8–10.8%) in processed rice products compared to raw materials (11.8%). The equilibrium moisture content was 27.4% in raw rice while it was much higher (38.9–81.0%) in processed rice. Sedimentation volume was lowest (6.2 ml) in raw rice and highest (18.8 ml) in popped rice. Starch content was 84.8 and 76.5–83% in raw rice. Starch content was 84.8 and 76.5–83% in raw and processed rice, respectively. *In vitro* starch digestibility was highest in roller flaker flakes and lowest in raw milled rice. Among the ready to eat products, popped rice showed least starch digestibility (~30%) (Chitra *et al.*, 2009).

Noodles were prepared from brown and low-polished rice. Some of the functional properties of these rice noodles along with sensory profile of the respective raw forms were studied. Water absorption index was low in noodles compared to their native form but water soluble index was reverse. Total and soluble amylose and thiamine reduced in respective noodles compared to their respective native form. Solid loss was less in steamed rice noodles compared to their native. Rice had low solubility index but noodles showed 30 to 50% higher value. Gelatinization temperature decreased with increase in polish. Peak viscosity, hot paste viscosity was high for raw rice compared to steamed brown rice. Cold paste viscosity increased with increase in degree of milling, break down was least in steamed brown rice. Steamed brown rice noodles had high viscosity compared to other types of noodles like under milled, steamed under milled and steamed highly polished rice noodles. Sensorial test of steamed brown rice noodles were better compared to raw rice noodles (Utkarsh Kumar and Singh, 2011).

Composition of nutraceuticals and nutrients of two varieties of rough rice subjected to biotransformation by germination for 120h, drying and dehusking, compared to respective control brown rice. An increase in the content of free sugars and soluble fiber, and decrease in insoluble fiber and fat was observed in nutrient composition. Different forms (delta, gyama and alpha) of tocotrienols and tocopherols were present in both control and biotransformed brown rice. Gyamatocotrienol was the major form and its content increased and the total tocopherols, which was low in content, decreased. The gyamaoryzanol content and its fractions, namely, cycloartenylferulate and 24-methylene cycloartenylfurulate, did not show any significant alterations. However, the total antioxidant activity decreased. Scanning electron microscopic examination showed enlargement and distinct appearance of starch granules in the biotransformed rice. Biotransformed brown rice was also found to be superior to polished rice in nutritional and nutraceutical qualities (Jayadeep and Malleshi, 2011).

The dough, comprising a mix of rice and black gram, is shaped in a firming extruder followed by deep frying to obtain a crisp snack. Although it is a popular product in several oriental countries, the details of the role of raw materials and processing conditions are not known. Two different flour mixes obtained from rice and black gram were studied to investigate the influence of the raw material on product characteristics. Fine particles in one flour mix had a high water-holding capacity (1.7g g^{-1}) and gave product with low fat content (~ 16%), but had an undesirable hard texture coupled with a floury mouth feel. On the contrary, coarse particles (113 um) in another flour mix with a low water-holding capacity (1.5g g^{-1}) produced a snack with higher fat content (26-30%) with a desirable crisp texture. Addition of fat and the use of coarse flour can avoid bursting of the product during frying, which is a common problem associated with frying of such products while using fine flour. A mechanism for frying rice-black gram dough strands has been discussed and proposed.(Sila and Narasimha, 2008).

Extrusion

Effect of barrel temperature (80°–100°C) and amylose content (28.6 g kg^{-1}, 22.3 gk g^{-1} and 5.0 gk g^{-1}) of rice upon extrusion cooking on macromolecular profile of starch was studied by gel permeation chromatography (GPC) of the rice flour on Sepharose CL-2B. Starch in all rice samples was separated into two main fractions, viz. Fraction-I, a high molecular weight, was excluded by gel, amylopectin, and Fraction-II, a low molecular weight, that entered the gel, amylose. Extrusion cooking of rice led to the degradation of high molecular weight fraction of the starch, the extent of degradation increasing with increasing severity of extrusion conditions. The absorption maxima (λ_{max}) of iodine complex of the fraction-I showed an increase after extrusion cooking and this increase was more in the non-waxy variety of rice than in waxy. (Guha and Ali, 2001).

The effect of amylose content (5.0–28.6%) of rice and barrel temperature (80–120C) on extrusion system parameters torque and net specific mechanical energy and extrudate characteristics extrudate bulk density (ED), water solubility index, expansion ratio (ER) and Warner–Bratzler shear stress were studied using a twin-screw extruder. The feed rate (15 kgh^{-1}), moisture content (20.0% ± 0.2) of feed and the screw speed (400 rpm) were kept constant. ED and ER of the product suggested that a barrel temperature of 120C was desirable to generate an expanded extrudate rice product from low-amylose rice cultivar. Experimental data on system parameters and extrudate characteristics fit to second-degree polynomial regression equations (r e" 0.904, P d" 0.01) with the amylose content of rice and barrel temperature of the extruder (Guha and Ali, 2006).

Flour from two rice cultivars, one (IR-64) with a high (28.6%) and the other (Agonibora) with a low (5.0%) amylose content, having 20% moisture, was extruded at different barrel temperatures (80–120^{0}C), through a twin-screw extruder at a constant feed rate (15 kg/h) and screw speed (400 rpm). The effect of barrel temperature and amylose content of rice extrudates on pasting and rheological properties were examined using rapid visco-analyzer and a coaxial cylinder system, respectively. Extrudates from low-amylose rice exhibited lower paste viscosity than from high-amylose rice. Different rheological models (Power law, Herschel–Bulkley, Bingham and Casson) were examined for the best description of the shear rate/ shear stress data. The Herschel–Bulkley model fitted best (*r* e" 0.948–0.989, *P* d" 0.01) for the high-amylose rice, whereas the Power law model showed best fit (*r* e" 0.998–0.999, *P* d" 0.01) for the low-amylose rice extrudate.

The end use of pre-gelatinized rice flour prepared by extrusion cooking depends on the pasting and flow behavior characteristics of its starch that are largely controlled by the amylose content of rice cultivar. The present work offers a general approach for characterization of pasting profile and rheological behavior of pre-gelatinized extruded rice flour. The extruded flour from low-amylose rice exhibited lower pasting and apparent viscosity than from the high-amylose one. The low-amylose rice extrudates render itself more suitable as a base material in food formulations where a high solid density per unit volume is required. The extrudate from high-amylose rice, on the other hand, could be used as a thickener in convenience foods such as soup mixes. The results obtained may be useful to food industries for development of newer food formulations based on extruded rice flour. (Guha and Ali, 2011)

Cooking and Energy Conservation

Milled raw rice (IR 20, 2 years old) needed about 15 min. to cook in excess boiling water. Parboiled rice (normal pressure, roasted-parboiled) required longer time (21 to 32 min) for cooking depending upon parboiled condition. Cooked parboiled rice was, however, shorter (2-10%) in length, but thicker (15-20%), more firm (about 5%) and considerably more elastic (15-20%) than cooked raw rice. Presoaking at room temperature for 15 min of raw rice caused an increase in the length (about 20%) of cooked raw rice but a reduction in thickness (about 5%), firmness (about 10%) and elasticity (about 25%) as compared to un-soaked cooked control. Pre-soaking of parboiled rice did not significantly change these parameters (Sowbhagya and Ali, 1991).

Energy conservation in cooking rice is an important area for scientific investigation. Experiments were conducted to measure the energy consumption during normal and controlled cooking of both un-soaked and presoaked rice using two types of domestic cooking appliance, namely, an electric cooker and a pressure cooker. Cooking rice with controlled energy input, under pressure and with presoaking were the three approaches, which resulted in saving of energy. Electric rice cooker was found to be the most energy efficient among the different combinations of cooking appliance and the types of heat source used in the study. The energy consumption was much less (23-57%) compared to other methods. Prior soaking of rice generally reduced energy consumption as well as cooking time, more prominently during normal cooking. Controlled cooking offered more savings in energy compared to presoaking rice. Considering the energy consumption and cooking time, controlled cooking of presoaked rice was found to be the best among the several approaches investigated. Measurement of water evaporation loss appears to be a good indirect method of assessing the efficiency of heat utilization. Controlled energy input is another useful method that optimizes the energy utilization for cooking, besides presoaking and pressure cooking. Controlled cooking is desirable in all types of rice cooking (Tribeni Das *et al.*, 2006).

Microwave oven is a multi-utility kitchen appliance that can be used for cooking rice. An energy assessment was carried out under normal and controlled methods of cooking, with un-soaked and presoaked rice, in a microwave oven at various power levels. In controlled cooking, the energy consumption substantially reduced, in both un-soaked (14-24%) presoaked (12-33%) rice, whereas cooking time marginally increased (up to 2 min) compared to normal cooking. Presoaking rice resulted in energy savings in normal (5-11%) as well as controlled (3-18%) cooking. Although the absorption of microwave energy in water was 86-89%, the conversion efficiency of electrical to microwave energy was only ~ 50%. Performance of microwave oven was also compared with our earlier studies on electic rice-cooker (ERC) and pdressure cooker. Among the cooking appliances assessed, ERC was the most energy-efficient while microwave cooking offered the least cooking time (15-22min). Microwavce cooking was on par with pressure cooking, the most commonly followed method of cooking rice, in terms of energy consumption, besides, it offered shorter cooking time (Lakshmi *et al*., 2007).

Rice starch

Starches derived from 20 rice varieties containing from very low to very high total and hot water insoluble amylose equivalent (AE) were fractionated by gel permeation chromatography (GPC). Frn I (amylopectin) and Frn II (amylose) correlated well with the insoluble AE and soluble AE, respectively, of the parent rice. Thus soluble AE broadly represented the true rice amylose and insoluble AE the iodine affinity of amylopectin. Amylopectins of eight representative varieties were, therefore debranched and fractionated by GPC to study their chain profiles. Amylopectins from the highest-AE variety had the largest proportion of long B chains and the lowest proportion of short chains. While the reverse was true for waxy rice. Other varieties broadly followed this correlation between B chain length and AE. In addition, when the eight amylopectins were hydrolysed with amylase to remove the external chains and the beeta amylase limit dextrins were then debranched and fractionated, the greatest drop in the amount of long B chain was in y oryzanol, 21% by curcurmin and 24%occurred in the highest-insoluble-AE varieity and the smallest drop, in waxy rice. In other words, highest-insoluble AE (i.e high-iodine affinity) amylopectin had not only the highest amount of long B chains, but the largest proportion of these chains was in the exterior region (carrying non-reducing ends), and vice-versa. Difference in cooked rice texture seemed to be related to this difference in the fine structure of its amylopectin (Radhika Reddy *et al.,* 1993)..

In vitro starch digestibility and glycemic indices of three rice varieties- ‘Njavara’, ‘Jyothi’ (pigmented ricevarities) and ‘IR 64’ (non-pigmented rice) with similaramylose content were studied. Starch digestibility studies showed differences in glycemic response in three types ofrice. The rate of starch hydrolysis was maximum (67.3%) in‘Njavara’ rice compared to other two rice varieties.‘Njavara’ exhibited the lowest kinetic constant (k) indicating inherent resistance to enzymatic hydrolysis. The glycemicload (GL) and glycemic index (GI) of ‘Njavara’ were similar to ‘Jyothi’ and ‘IR 64’. Resistant starch content was high in pigmented rice varieties compared to ‘IR 64’. The resistant starch content of dehusked and cooked rice increased with the storage time at refrigeration temperature (4°C). ‘Njavara’is an easily digestible rice and can be used for baby and geriatric foods (Deepa *et al.*, 2010)

Biodegradable plastics from rice starch

Starches from three varieties of rice of high amylose (indica), intermediate amylose (japonica) and almost negligible amylose (japonica waxy) were isolated. They were acetylated by using four times their weight of acetic anhydride (11% sodium hydroxide as 50% aqueous solution as catalyst) for 15, 30 and 60 min. The acetyl content varied from 30 to 41% and degree of substitution (DS) from 1.63 to 2.55. Under similar conditions of acetylation, waxy rice starch showed highest acetyl content and highest DS. Dimethyl formamide was the solvent used for dispersing these modified starches. Films of indica modified starch of 30% acetyl content and 1.63 DS showed highest strenghth compared to other varieties of modified starch. Glass transition temperature (T_g) was highest in waxy rice starch (~ 232^0 C) followed by japonica non-wasyand indica rice starchy. After acetylation, the T_g values increased in waxy modified ones, remained almost same in indica modified ones, decreased to some extent in japonica non-waxy modified ones compared to that respective native starches. Difference in specific heat capacity between starting and ending of glass transition point of indica and its modified ones remained almost same, increase in japonica and its derivatives ones, decreased in waxy modified one compared to their respective native starches. Among the native starches, melting point was highest in waxy starch. Modification increased this property in all the starches under all periods of acetylation. Increment was highest in japonica waxy acetylated ones. Degradation or decomposition of these starches occurred at $3\text{-}10^0$ C higher than their respective melting points. Heat evolution was very high in japonica native (~ 203 mJ mg^{-1}) and heat absorption (~ 265 mJ mg^{-1}) was highest in indica 15 min modified one (Singh *et al.*, 2007).

Isolated starches from Indica, Japonica and Japonica waxy rices were acid modified by treatment at 50^0C for 1 h. These were acetylated using acetic anhydride and 11% sodium hydroxide added as 50% aqueous solution for 1 h. These starches were then combined with zein and chemically modified by acetylation for a period of 30 min as before. All acid modified and acetylated starches showed almost the same ontent of acetyl and same degree of substitution (DS), with acetyl percentage being around 39.5 and DS around 2.4. Starch-zein acetylated one showed almost same range of acetyl percentage and DS, the values being ~ 27% and 1.35, respectively. All these modified products dissolved easily in dimethyl formamide. Acid modified and aetylated starches were combined with zein protein. In a similar way, films were also prepared from starch-zein acetylated products. Among the native starches, japonica waxy showed the highest glass transition temperature (Tg) (~232^0C) followed by japonica non-waxy (224^0 C) and the lowest by indica (213^0C). Difference in specific heat capacity before and after T_g increased in general from native to acid modified one and acid modified one to acid modified starches cum acetylated one. However the melting points were in the reverse order compared to T_g. Among the acid modified and acetylated ones, the melting point of indica starch was the highest (~320^0C). Glass transition temperature increased to a greater extent acid in modified starches and acetylated japonica waxy starches. Crude corn zein showed three characterstic peaks in DSC thermogram. It has the highest Tg(~258^0C) and highest melting point (~306^0C) but lowest C_p. After acetylation of starch and zein, all DSC parameters increased along with their respective starch zein mixture values. Decomposition temperature was the highest in japonica-zein acetylated one. Zein showed only endothermic peak. Acetylated japonica-waxy and zein showed the highest heat holding capacity among the 3 zein starch acetylated ones (Singh *et al.*, 2007).

Rice bran

The extractbility profile of rice bran proteins under different conditions were studied to determine optimal conditions of extraction. Milling and differential sieving of rice bran increased the protein content in fine fraction by 7%. Maximum extractability of protein from defatted rice bran at pH 11 was 72%, out of which 70% could be precipitated at isoelectric pH 4. Increasing the time of extraction of using sodium chloride, sodium dodecyl sulfate or sodium hexa-metaphosphate were not effective in extraction more protein. The extraction and precipitation profiles of proteins from acid stablized rice bran were comparable to untreated rice bran. However, it was very low for heat stabilized and parboiled rice bran. Denaturation of protein due to heat treatment affected the extractability of protein. Protein contents of protein concentrates obtained from untreated rice bran and acid stabilized rice bran were on the range of 71-73% whereas protein concentrates from heat stabilized rice bran and parboiled rice bran had lower protein contents of ¬39 and ¬5%, respectively (Prakash and Ramanatham, 1994).

Fractional classification of rice bran proteins, the proximate composition and Protein Efficiency Ratio (PER) of untreated and stabilized brans have been stuidied . Rice bran proteins are rich in albumins (32%) and globulins (26%). Protein contents of defatted, milled and sieved bran flours ranged from 16.5-18.2%. Protein efficiency ratio of acid stabilized bran was highest (2.18) followed by untreated (2.09), heat stabilized (2.03) and parboiled rice brans (1.99) (Jamuna and Ramanatham, 1995).

Rice bran is a rich source of nutrients and nutraceuticals, which has bio-functional properties. De-oiled rice bran, a major byproduct of rice bran oil industry is not yet efficiently utilized for human consumption due to its poor edible quality. Various physical processing methods like sieving, pin milling and air classification were applied to upgrade the quality of bran and also to investigate its effect on particle size distribution, content of ash, protein, total dietary fiber, insoluble fiber, soluble fiber and oryzanol as well as total antioxidant activity in bran fractions. Sieve separation resulted in an increase in the content of protein and bio-functional components like soluble fiber and oryzanol as well as total antioxidant activity. Pin milling and sieving resulted in significant decrease in ash content with moderate increase in protein content and significant increase in the contents of oryzanol and soluble fiber and the total antioxidant activity. This resulted in quality improvement f commercial de-oiled bran viz., reduction in coarse bran fraction (size particles) from 65 to 0 %, content of ash from 14.3 to 13.1 g $100g^{-1}$ and insoluble fiber from 49.3 to 46.1 g $100g^{-1}$ and increase in the content of protein from 13.7 to 17g $100g^{-1}$, soluble fiber from 2.75 to 4.35 g $100g^{-1}$, oryzanol from 13.6 to 18.1 mg $100g^{-1}$, and total antioxidant activity from 61 to 96 mM alpha tocopherol equivalent g^{-1}. About 30% edible and nutrient rich rice bran, which can be used as an ingredient in the bakery products and health food formulations, was obtained from unutilized commercial de-oiled bran by this process (Jayadeep *et al*., 2009).

Germ from rice bran and its properties

Size separation, pneumatic air classification and saline separation procedures employed to separate germ from different types of rice bran (raw, steamed and parboiled) were collected from rice mills and were analyzed individually for physico-chemical and nutritional properties. The porosity of germ from steamed and parboiled rice bran were 51.42 and 54.05%, respectively where as that of raw rice germ exhibited higher value (65.81%).The protein, fat, and oryzanol content of steamed and parboiled germ showed an average increase of 5.28, 2.15, and 0.08%, respectively compared to raw rice germ. The free fatty acid content was <6.2% for pure germ. The thiamine content was highest in raw germ (1.61mg $100g^{-1}$) and least for parboiled germ (0.26mg $100g^{-1}$).Phosphorus content of parboiled germ was least (32.47%) compared to raw germ (72.1%). Rice germ could be utilized for food formulations, like geriatric food, mother food, and specialty foods (Asma Nazreen *et al.*, 2012).

Rice Bran Oil

The colour of bleached rice bran oil can be improved by silica gel treatment of the oil miscella before or after dewaxing. A silica gel/oil/solvent ratio of 1:5:5 (W/W/V) is suitable. Silica gel treatment can be carried out either by column percolation or by merely shaking the miscella with the gel followed by decantation. However, column percolation is more efficient, with 30 – 72% colour reduction vs. 19-36% reducation for shaking and decanting (Gopalakrishna, 1992).

To understand the chemical nature of the dark colouring constituents responsible for colour fixation in rice bran oil, crude and dewaxed rice bran oils of 6.8% free fatty acids were fractioned on a silica gel column to get a dark coloured material (0.57% of the oil). Thin layer chromatorgraphic analysis of the material showed a spot corresponding to monoglycerides, but there were no spots corresponding to other glycerides. Upon saponification it yielded 12% non-saponifiable matter. GLC analysis of the saponifiable matter (after acidification and methylation of fatty acids) showed the presence of palmetic, oleic and linoleic acids. Furthermore, on the basis of comparison with spectroscopic data of synthetic monoglyceride, the constituent was characterized to be a mixture of monoglycerides with side chains of oxidized unsaturated fatty acids (Gopalakrishna, 1993).

The role of viscosity on wax settling and refining loss in rice bran oil (RBO) has been studied with model systems of refined peanut oil and RBO of different free fatty acids contents. Wax was the only constituent of RBO that significantly increased the viscosity of the oil. Monoglycerides synergistically raised the viscosity of the oil and lowered the rate of wax settling. Although a reduction in the viscosity of the oil significantly decreased the refining loss, the minimum loss attained was still 20% more than theretically predicted value. This led to conclude that some chemical constituents, such as monoglycerides, must be removed before dewaxing; thereafter, oryzanol and phospholipids have to be removed. One can get an oil free of wax, recover other by-products and reduce processing losses (Gopalakrishna, 1993).

The hypocholesterolemic effect of oryzanol, a mixture of ferulic acid esters of sterols and triterpenols, isolted from rice bran oil was compared with that of curcumin (diferuloyl methane the yellow pigmenet of turmeric) and ferulic acid. Feeding 0.5% oryzanol, 0.15% curcumin or 75 mg%cholesterol containing diet (HCD) for 7 weeks caused a significant decrease in serum total cholesterol as well as (LDL+VLDL) cholesterol and an increase in HDL cholesterol. Serum lipoprotein (LDL+VLDL) concentration was also decreased. The ratio of LDL-cholesterol to HDL-cholesterol which was 24.9 on the HCD was decreased by 40% by oryzanol, 21% by curcumin and 24% by ferulic acid. Oryzanol and curcumin lowered iver choldesterol levels, whereas ferulic acid was not effective. Oryanol was a better hypocholesterolemic agent than curcumin or ferulic acid (Seethanramaiah and Chandrasekhara, 1993).

Storage of brown rice and free fatty acid development

Development of free fatty acids (FFA) in brown rice, obtained by shelling in rubber roll sheller and disc sheller, was monitored at various conditions of storage, viz. cold (4-6^{o}C), room temperature (RT), 27^{o}C at 62% RH, and at 37^{0}C at 92% RH, with and without insects, up to 13 months. The samples were stored in cloth bags and bottles. FFA, which were initially less than 3%, increased with period of storage; the increase was almost double in disc shelled rice compared to that in rubber roll shelled rice compared to that in rubber roll shelled rice. High temperature and RH of the environment increased FFA. Increase in FFA was slightly more when stored in cloth bags than in glass bottles. Insects did not survive at 37^{0}C at 92% RH, but multiplied rapidly at RT. Accompanied by increase in FFA, the insects spoiled the rice in 3 months (Indhudharaswamy *et al.*, 1993).

Storage in different containers

Mycological and insect penetration studies were evaluated on paddy and rice stored for six months (at RT and accelerated condition) in Jute, Poly Propylene (PP) and High Density Poly Ethylene (HDPE) woven sacks. Thirty different species of fungi belonging to the genus *Aspergillus, Mucor, Rhizopus, Alternaria, Penicillium, Cladosporium* and some mycelia sterile were isolated by decimal dilution technique. *Aspergillus* sp. was predominant in almost all the samples analysed. Total fungal counts varied considerably among the commodity and the paddy harbored higher number of fungal population than rice. The samples stored at accelerated condition exhibited total deterioration of the commodity with 15 days due to rapid fungal growth and at the end of 30 days of storage, visible fungal colonies were observed on the surface of the grain. Based on the mycological analysis and insect penetration studies it is evident that the HDFPE woven sacks are more suitable for storage of food grains than the traditional jute sacks (Ramaswamy *et al.*, 2009).

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