Review Article

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Breeding for superior morphological and physicochemical properties of rice to ensure best value to the end-product

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ABSTRACT

Rice breeders have devoted attention primarily to increasing farm yield. However, attention to yield and use-value of the ultimate rice product is equally important. High milled rice yield, low milling breakage, good storage and handling properties, faster cooking, and preferred flavour and taste of rice product are some of the desirable end-use properties. All these can be achieved by breeding for specific properties. Uniform flowering of plant and short panicle length will help in reducing milling breakage. Eliminating wide grains (brown rice kernels > 2.3 mm wide) which promote white belly that promotes grain cracking, selecting for crack resistance, selecting for hard kernels with shallow ridges, and selecting for low husk content will help in reducing grain breakage and increasing milling yield. Proper grain size and shape to obtain good storage and flow properties as well as short cooking time are desirable. Tight lemma-palea interlocking will promote insect and crack resistance. Appropriate chemical and physical properties required to produce best products (puffed rice, popped rice, preferred table rice texture and taste) should be kept in view.

Key words : *rice, breeding, quality, value added end-product, grain breakage, grain chalkiness, crack resistance*

Starting with the first domestication of plants by humans thousands of years back, agriculture has come a long way with many revolutionary advances made at periodic intervals. The latest such revolutionary step in the production of rice and wheat, the two main staple food crop of humankind, has been the development of semidwarf high-yielding varieties of the crops. In this step as in others gone in the past, breeders and farmer-selectors have played a major role in successive improvements in food production.

The main objective of breeders in all these steps have always been to increase the production of grains per unit of land, time, labour and water, apart from building resistance against biotic and abiotic stresses. Spectacular achievements have been made by breeders in regard to high yield and tolerance to different stresses. It has been noticed that the inherent properties of the grain strongly impact on its processing and product-making ability and consumer value. The ultimate use value of the grains produced by agriculture, be it in terms of quantitative output of the final product or the latter's qualitative value, thus strongly depends on the inherent properties of the grains produced. And these properties show abundant varietal variation, showing that they are amenable to manipulation by selection or breeding. It is therefore opportune that breeders should also pay attention to those technological and other physicochemical properties of the grains that will impact on its ultimate use value.

Plant characteristic for optimum harvest

It is well known that there is an optimum stage for harvest of paddy for best milling results (Fig 1). When rice is harvested too early, many grains remain immature. On the other hand, late harvest gives rise to excessive cracking of the grain as the mature rice grain is highly susceptible to moisture stress and therefore suffers cracking in stalk when subjected to cyclic drying by the sun during the day and wetting by dew during the night. Both early and late harvest thus reduce the value of the produce.

Grain moisture content, number of immature grains and those of cracked grains vary in a field of rice at any time from plant to plant, tiller to tiller, panicle

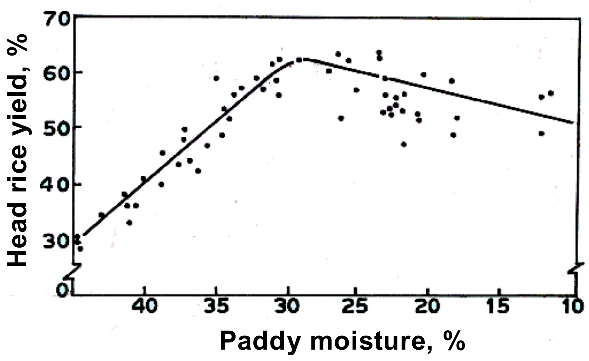

Fig 1. Effect of the stage at which paddy is harvested on the yield of unbroken grains (head rice) obtained from it upon milling (from Morse et al 1967)

to panicle and according to the position in a panicle. Mahadevappa *et al.* (1969) showed that there was no such thing as a fixed grain moisture in a field of rice; it was in a constant flux. It varied diurnally as per the time of the day and the grain moisture was always more at the bottom of a panicle than at the middle and more there than that at the tip of the panicle in a field at any given time (Table 1). Similarly Srinivas and Desikachar (1973) showed that, following from the above differential in grain maturity, the number of cracked grains were much more at the tip than at the middle

Table 1. Variation of the moisture content of paddy grains on stalk according to their position in the panicle

Variety	Mean grain moisture in field (%)	Grain moisture (%) at panicle Top	Middle	Bottom
S-701	21.7	21	23.3	27.4
	18.4	19	20.4	24.5
	16.6	17	19.5	22.9
T(N) 1	–	21	22.8	23.5
	21.6	20	21.5	23.8
	16.8	19	20.6	22.6

From Mahadevappa *et al* 1969.

and more so than that at the bottom of the panicle (Table 2). So in practice there was always a mixture of some immature and some cracked grains in a lot, for some grains were maturing and some were mature and overdried at any given time. If breeders can so ensure that the entire field flowers (hence matures) as uniformly as possible and the plants have the shortest possible panicles, they will thereby increase the output of whole milled rice.

Table 2. Variation of the number of cracked paddy grains on stalk according to their position in the panicle

Average grain moisture (%)	Cracked grains (%) Top	Middle-1	Middle-2	Bottom
20.0	14	8	4	0
15.5	38	27	22	2
14.5	52	54	48	32

From Srinivas and Desikachar 1973.

Physical and morphological properties of the paddy grain

Husk content: The paddy grain has on an average approximately 20-22% husk. The husk being inedible, obviously only the remaining 78-80% brown rice is the real edible matter. Hence, maximization of brown rice and not paddy should be the goal. The husk content of paddy has been found to vary from about 15% to about 26% (Sadanandeswara Rao and Bhattacharya, 1969). Such a wide difference clearly indicates the possibility of breeding for lower husk content, other things being equal.

Grain size and shape: It is well known that the paddy/ rice grains show wide variability in size (weight per grain) and shape (length:breadth ratio). It is interesting that these properties may seem innocuous but may actually influence certain use-value of the cereal and thus be kept in view for selection/breeding. The surface area per unit weight of a particle depends on its size and shape. The smaller a particle, the larger is its proportional surface area. Similarly a sphere has the least surface area for a particle of a given weight. Taking these two factors into consideration, it is clear that small and slender grains have a larger surface area per unit weight than big and round ones (Bhattacharya and Sowbhagya, 1971, Sowbhagya *et al.,* 1984). The rate of water uptake during cooking has been shown to increase with increasing surface area per unit weight of rice (Bhattacharya and Sowbhagya, 1971, Sowbhagya *et al.,* 1984). The cooking time of rice is affected by its size and shape. The smaller and the slenderer the grain, the faster does it cook (Fig 2).

A second property affected by the rice grain shape is its bulk density and surface friction. Bulk density is important in determining the storage volume while surface friction affects the flow behaviour of the grain. It is found that the porosity (i.e., the proportion of empty volume in the total volume occupied by a given

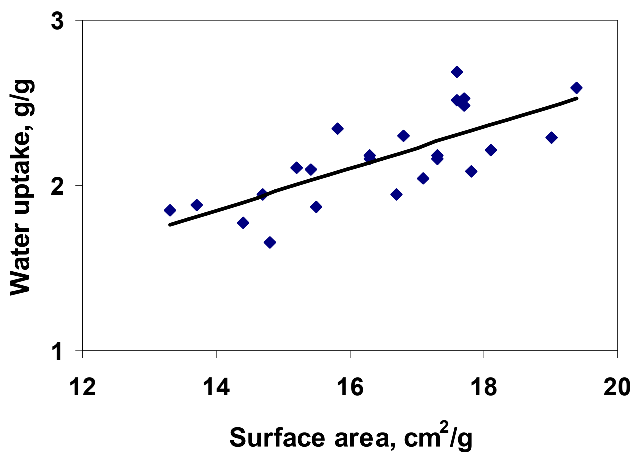

Fig. 2. Effect of grain surface area per unit weight of rice on its water uptake during cooking at 96°C (graph drawn from data in Bhattacharya and Sowbhagya 1971)

amount of grain), and hence inversely the bulk density of the material, increases with increasing length:breadth ratio of rice (Fig 3). The frictional property of the grain also increases accordingly. So grain shape of paddy/ rice impacts on its storage and flow behaviour.

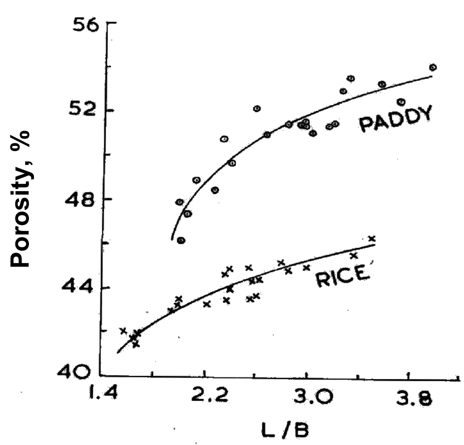

Fig. 3. Variation of rice grain porosity (empty space in a bulk) with its grain shape (length : breadth ratio) (from Bhattacharya *et al* 1972)

Another very important technological property influenced by the rice grain dimension is white belly. Rice grains often have certain chalky areas. A chalky area on the ventral side of the grain is called a white belly, while a chalky area at the centre is called chalky centre or white centre. While the chalky centre is largely determined by environmental and agronomic conditions, white belly is entirely dependent on the grain breadth. Srinivas and his colleagues showed that white belly was entirely a result of grain width (Bhashyam and Srinivas, 1981, Bhashyam *et al.,* 1985, Raju *et al.*, 1991). They showed that brown rice grains with over 2.5-2.8 mm width invariably had white belly, those with less than 2.0-2.3 mm width had none, and those in between had intermediate values (Fig 4). This has been confirmed

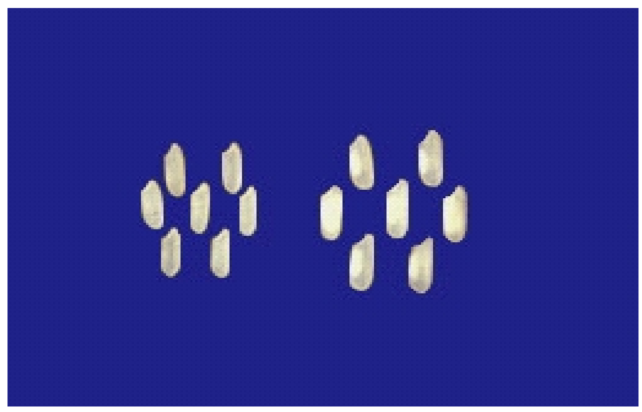

Fig 4. Photograph showing how wide rice grains (right) have white belly (chalky area in ventral side) but narrow grains (left) have none (from Bhashyam and Srinivas 1981)

also by Murugesan and Bhattacharya (1994) in their studies on popping of rice, who found 2.0 and 2.35 mm brown rice width as the critical threshold values (Fig 5). White belly is a highly determinatal grain quality in the sense that it makes the rice grain more susceptible to crack development than otherwise (Table 3) and hence

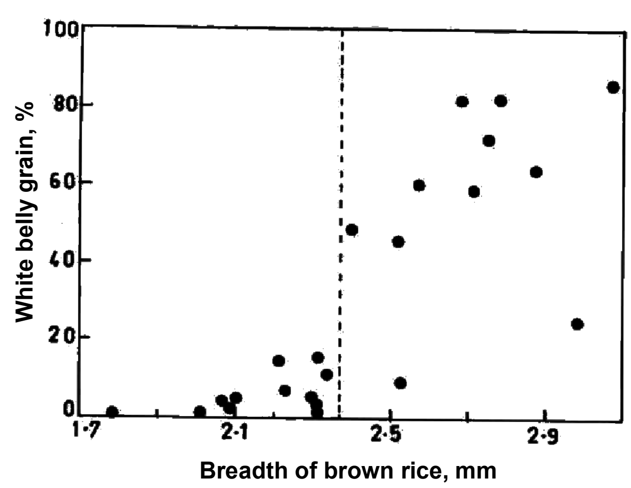

Fig. 5. Dependence of white belly in rice on its grain width (from Murugesan and Bhattacharya 1994)

Table 3. Data showing how cracked grains in a given lot of rice (in ten varieties) were associated with grain chalkiness

Variety	Chalkiness score of grains having cracks numbering		
	0	1	> 1
Basmati 370	2.0	5.3	8.0
S 705	0.3	2.3	4.7
Intan	1.6	7.0	7.0
Jenugudu	2.1	2.4	–
S 749	1.4	3.1	1.0
Mahsuri	2.5	2.8	2.5
Pankaj	2.2	3.6	4.0
Ch2	3.0	4.0	4.0
Bala	2.3	2.9	3.6
C 435	1.6	3.8	3.8
Mean	*1.9*	*3.7*	*4.3*

From Indudhara Swamy and Bhattacharya 1982.

leads to greater breakage during milling. Chalkiness has also been shown to make the grains less hard (Table 4), which is undesirable in the sense that harder grains are better able to resist grain breakage as well as insect infestation. It is therefore always preferable to reject lines showing over about 2.5 mm brown rice width so that white belly is eliminated.

Table 4. Decrease in rice grain hardness with increase in grain chalkiness index in ten varieties

Variety	Hardness[2] of grain having chalky area		
	0%	<20%	>20%
GEB 24	8.5	6.7	5.0
Bengwan	8.8	5.5	3.9
Blue bonnet	8.4	6.6	5.4
Syntha	9.6	7.1	4.8
Madhu	7.7	5.4	4.4
T 141	8.1	5.8	4.6
Intan	9.0	6.8	4.5
Jaya	7.1	5.8	4.9
SR 26B	8.5	6.2	5.5
Br 9	6.6	4.5	3.2

From Murugesan and Bhattacharya 1994. [2]kg/kernel.

Surface ridges: Brown rice has four longitudinal ridges, as well as corresponding grooves, on its surface. It is clear that more prominent the ridges/grooves, the more is likely to be the loss of edible matter during milling to make the milled product free from bran streaks and so more pleasing to look at (Bhashyam and Srinivas, 1984).

Grain hardness: Apart from chalky grains, even translucent vitreous grains do differ in their hardness from variety to variety. Indudhara Swamy and Bhattacharya (1982) observed that the mean Kiya hardness value of brown rice grains with no chalky area varied among ten varieties from 6.6-9.0 kg/grain (Table 4). Obviously, other things being equal, breeders would do well to breed varieties that have harder grains rather than those which have softer grains. This will help not only in milling but more so to resist insect infestation during storage.

Lemma-palea interlocking : Murugesan and Bhattacharya (1991) observed that the tightness of interlocking of the lemma and palea differed greatly from variety to variety. They found this tightness was the most important factor affecting the popping ability of paddy. It also affected the grain's proneness to cracking and therefore, its potential breakage during milling. This tightness is also very likely to affect the insect and disease resistance of a variety. Loose husk covering is likely to facilitate entry of insects and pathogens and vice versa. It is therefore always desirable to select for varieties that have relatively tight lemma-palea interlocking. This can be easily tested by a standard dehusking test (Murugesan and Bhattacharya, 1991, 1994).

Crack susceptibility

Rice grain is susceptible to moisture stress. It is liable to undergo cracking whenever it is subjected to fast hydration (wetting) or fast dehydration (drying). That cracking occurs to paddy grains in stalk in the field if harvesting is delayed. Similarly cracking also occurs during handling and processing, most importantly when the paddy is being dried after harvest before storage. This cracking is of serious concern to the miller because cracked grains are more apt to break during milling.

Rice varieties differ in their susceptibility to cracking. Srinivas *et al.,* (1977) as well as Juliano *et al.,* (1993) clearly observed that rice varieties did show substantial varietal difference in their susceptibility to cracking under a given adverse situation. Data of Srinivas *et al.*, 1977 with respect to the number of cracked grains found in harvested paddy among several varieties in a field at different stages of harvest are shown in Table 5. The wide variation in the percentage

Table 5. Varietal difference in rice grain cracking at harvest

Variety	Cracked grains (%) at harvest moisture			
	26%	22%	18%	16%
Halubbulu	0.0	1.0	5.5	7.0
MR 297	3.0	7.5	12.5	18.0
MR 44	3.5	7.5	20.0	23.0
MR 298	–	13.0	18.0	24.0
IET 2254	2.0	3.5	16.5	30.0
MR 36	–	15.5	28.0	36.5
IET 2501	5.0	21.0	31.0	37.5
GMR 2	5.5	13.0	30.0	38.0
Sona	6.5	15.0	32.0	41.0
MR 62	4.0	23.0	35.0	41.0
MR 301	–	28.0	40.0	44.0
Madhu	–	22.0	45.0	50.8
Jaya	11.0	24.0	41.0	53.0
Satya	–	30.0	52.0	59.0
IET 2246	12.5	36.0	52.0	64.0
IR 20	15.0	35.0	55.0	67.0
IET 2295	10.0	44.5	58.0	68.0
Suhasini	–	–	58.0	70.0
Surya	–	–	63.0	72.0
MR 272	–	29.0	73.0	89.0

From Srinivas *et al* 1977.

of cracked grains among the varieties is striking and easily shows the difference in crack susceptibility of rice varieties. The two sets of authors have suggested various grain parameters (amylose content, gelatinization temperature, grain hardness, protein content, pentosans, as well as plant height, panicle length, etc.) which they thought might have contributed to the above varietal difference. Murugesan and Bhattacharya (1994) too suggested a few contributing factors. However, these hypotheses remain to be confirmed. Yet, the fact of varietal difference in crack susceptibility is obvious. Since rice cracking is a matter of serious concern in milling and mill outturn, this is a subject which deserves urgent attention of breeders to select for resistance to cracking.

End-use quality

Rice is ultimately for consumption. Therefore consumers' choice and/or the quantitative output or quality of a given product meant for consumption should be of paramount importance to its value.

Cooking quality: A matter of great importance with respect to consumers' choice is the cooking-eating quality of rice, viz., hardness, stickiness and other quality parameters of cooked rice. Rice varieties of the world differ widely in these respects. What factors determine these differences were not precisely known until recently and have been a subject of intense research for the last three quarters of a century. It is too elaborate a subject for us to go into its details here. We can just note for our purpose here that after intensive research, chemists have now concluded that the branch-chain structure of amylopectin starch of rice is the preponderant determinant of its eating quality (Bergman *et al.,* 2004). Since about 90% of the dry weight of milled rice is starch, and the lion's share of starch in rice is the amylopectin molecule, the significance of the above should be quite obvious. The above index used to be previously expressed in terms of amylose content or apparent amylose or amylose-equivalent. But such nomenclature is not of much relevance here. The main point is that preference for eating quality of rice shows wide regional divergence based on its starch characteristic and this should be a central point of concern for any selection during breeding.

Product-making quality: There are three main rice products popular in India, viz., flaked rice (*chewda, aval*), puffed rice (*puri, murhi*), popped rice (*kheel, aralu*). Of these there is a wide varietal difference in the suitability of production for the latter two products. Chinnaswamy and Bhattacharya (1983) showed that varieties having 27.5% total amylose-equivalent (AE) and 13.5% soluble AE produced the best *puri* (Fig 6). Similarly Murugesan and Bhattacharya (1991) showed that a high husk interlocking score, absence of white belly and high grain hardness together gave the best

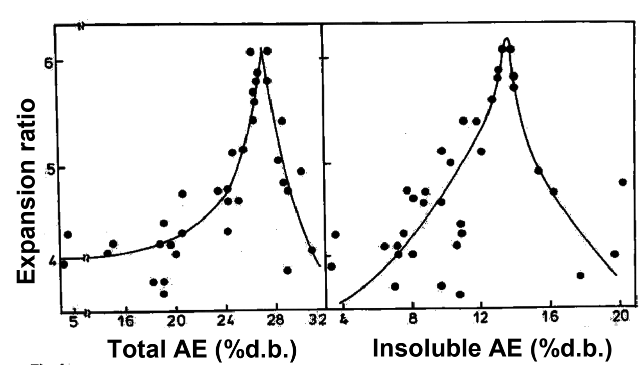

Fig 6. Variation of puffing power with total and hot-water-insoluble amylose-equivalent (AE) content in rice for making puffed rice (puri) (from Chinnaswamy and Bhattacharya 1983)

popped rice (these three parameters accounted for 80% of the varietal variability). Just as maize breeders have produced a special maize variety for making popcorn, it is therefore a task for Indian rice breeders to breed special varieties for the above two products.

To summarise, therefore, it can be said that breeders should pay attention to the following grain properties so as to add maximum value to their produce of paddy- the plants should have as uniform flowering and grain maturity in the field and as short panicles as feasible, the paddy grain should have the least content of husk, lines showing brown rice grains of over about 2.3 mm width should be eliminated to avoid white belly, chalky grains *per se* are to be avoided as far as possible, ridges and grooves on the brown rice surface should be kept as shallow as possible, varieties should be selected for tight lemma-palea interlocking to promote resistance to pests, pathogens and cracking, varieties should be selected for crack resistance, hard kernels should be selected over soft kernels, selection for small and slender grains would promote faster cooking, specific amylose-amylopectin starch type should be selected to cater to difference in preference for table rice texture and flavour in different regions, and specific physical and chemical grain properties should be selected for specific rice products.

Attention to above factors and selection for above properties will certainly enhance the use-value and hence the ultimate value of a given amount of produce.

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