Perspectives Towards Designing Rice Grain Quality

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Abstract

Quality improvement is becoming an integral part of cultivar improvement program in rice as the demand for good quality rice is being increased day by day. Consumers exhibit a varied preference for rice quality depending on their geographical location, culture and nature of culinary use. Therefore, achieving good grain quality in varieties has become a supremely important activity for the breeders. Many groups are engaged in research aimed to understand the grain quality. Rice grain quality is decided by physical traits, amylose content, fragrance, viscosity, gelatinization temperature, alkali spread value, grain types, chalk and sensory evaluation. New technologies like metabolomics are used to gain insights into complex traits like taste, fragrance and nutritional value, genetic and environmental factors that influence these quality related traits. It is important to develop quality grains suitable for varied rice based products with desirable preferences of the consumer to exploit the vast potential in domestic and export markets. An international network research has aimed to unravel critical information on rice quality along with the development of robust molecular markers to transfer chosen quality traits into various genetic backgrounds.

Keywords: Quality, QTLs, marker, amylose, Basmati

Introduction

Rapid change in consumer demand for quality rice is a visible result of better living conditions and concomitant preferences for taste in various rice consuming countries. Since the mid-1960s, plant type based high yielding varieties have been developed and released which brought a quantum jump in production and productivity. It has now become imperative to incorporate quality features in a desirable range into the conventionally bred varieties and hybrids. Consumers base their concept of quality on the grain appearance, size and shape of the grain, behaviour upon cooking, taste, tenderness and flavour of cooked rice. The quality preferences vary within the country, within ethnic groups and from one country to another within different geographical regions (Juliano et al 1964). Further, different countries have their own measures of quality and systems of control and there is a lack of uniformity among rice producing countries. Thus, what constitutes good grain quality to the breeder is different from the perception of the farmer to trader. Consumers also classify rice into long, medium or short, husked, milled, and rough and parboiled or white rices. To bring uniformity into the procedures, FAO and IRRI made early efforts and a global initiative has commenced recently with the launch of international network on quality rice (INQR) to have a common forum for collaborators to compile, share and develop knowledge and materials and to develop universal methods for the characterization and quantification of the traits of rice quality. It has seven task forces viz, physical traits, amylose, fragrance (Basmati - Jasmine), rapid-viscosity analysis (RVA) – gelatinization temperature (GT) - alkali spread value (ASV), grain types, chalk and sensory evaluation. New technologies like metabolomics are also being used to get more insights into complex traits like taste, fragrance, nutritional value, genetic and environmental factors that influence these quality related traits. In India not only the ICAR institutes but also other agricultural universities are involved in the breeding progams for improving the rice grain quality. DRR, Hyderabad, Indian Agricultural Research Institute, New Delhi, Punjab Agricultural University, Ludiana and Central Rice Research Institute, Cuttack and a few other centres analyze 14-16 important grain quality parameters. Extensive quality testing is also undertaken by DRR, Hyderabad for the elite materials included in the All India Co-ordinated Rice Improvement Project (AICRIP) (Rani et al 2009).

Review of recent advances in research

Milling quality

Milling recovery is one of the most important criteria of rice quality especially from the standpoint of marketing.

Milling recovery of rough rice is an estimation of the quantity of whole grain (head) rice and total milled rice that can be produced from a unit of rough rice. It is generally expressed as percentage. A variety should posses a high turnout of head rice as high as 65% or more of the total milled rice. Milling recovery depends on grain shape and appearance, which has direct effect on the percentage of hulling, milling and head rice recovery and also on several factors (Bhattacharya 1980).

Grain size and shape

The appearance of milled rice is important to the consumer, which in turn makes it important to the producer and the miller. In general, medium to long grains are preferred in the Indian subcontinent while the country is also replete with hundreds of short grain aromatic types and long and extra long grain Basmati types, the latter command the highest premium in both domestic and international markets. In temperate areas short grain varieties of *japonica* type are prevalent. Extra long grain types are preferred in Thailand. There is a strong demand for long-grain rice in the international market.

Grain appearance

Consumers prefer white, translucent grains and pay a premium for it. Grain appearance is largely determined by endosperm opacity and the amount of chalkiness. Based on endosperm opacity, rice is classified as waxy or non-waxy. Waxy rices are devoid of or have only traces of amylose content and are opaque. Non-waxy rices have varying amylose level (2.1 to 32%) and are dull, hazy or translucent. Chalky white spots which often appear in the starchy endosperm lower the market value of the variety. The heritability of this character seems to be low, because various agronomic practices and pre-harvest handling, together with other maturity factors are found to influence its expression to some extent (Kaul 1970).

Cooking and eating characteristics

Cooking and eating quality of rice is one of the most important components of grain quality (Juliano 1985). The cooking quality is usually evaluated by major physico-chemical characteristics of the starch as indirect indices: amylose content (AC) (Juliano 1979), gel consistency (GC) (Cagampang et al 1973) and gelatinization temperature (GT) as measured by alkali spreading value (ASV) (Little et al 1958) are the important starch properties, which influence cooking and eating characteristics. A complex relationship however exists, between chemical characteristics of starch and quality. Rice starch is composed of amylose and amylopectin. Many of the cooking and eating characteristics of milled rice are influenced by the ratio of two kinds of starches -amylose and amylopectin in the rice grain (Juliano et al 1964). Amylose is the linear fraction of starch whereas amylopectin, the branched fraction, makes up the reminder of the starch. Studies on the inheritance of AC have shown involvement of one major gene and several modifiers with high AC incompletely dominant over low AC (Somrith 1974; Chang and Li 1981; Chauhan and Nanda 1983). In addition to the waxy gene, involvement of two complimentary genes was also reported (Stansel et al 1966).

Amylose content correlates negatively with taste panel scores for cohesiveness, tenderness, colour and gloss of rice. Amylose is almost absent from the waxy (glutinous) rices. Such rices do not expand in volume, are glossy and sticky and remain firm when cooked (Juliano 1979). High amylose rices show high volume expansion and high degree of flakiness. They cook dry, are less tender and become hard upon cooling. All of the japonica varieties of temperate regions have low AC. Both intermediate and high amylose types are commonly grown in Indian sub-continent. Intermediate amylose rices cook moist and tender and do not become hard upon cooling. Rice varieties are grouped on the basis of AC into waxy (0-2%); very low (3-9%), low (10-19%), intermediate (20-25%) and high (>25%). Intermediate amylose rices are the preferred types in most of the rice growing areas of the world except where low-amylose *japonicas* are grown.

Gelatinization temperature (GT) refers to the range of temperature within which starch granules start swelling irreversibly in hot water. GT determines the time taken to cook the rice and it affects the water uptake, volume expansion and linear kernel elongation (Tomar and Nanda 1985). The pasting temperature provides an indication of the minimum temperature required to cook for a given rice sample. GT ranges from 55 to 79^{o}C. Environmental conditions such as high ambient temperature during grain ripening often lead to starch with higher GT (Dela Cruz et al 1989). The GT of rice varieties may be classified as low (55 to 69^{o}C), intermediate (70 to 74^{o}C) and high (> 74^{0}C). Estimate of the GT is indexed by the alkali digestibility test (Little et al 1958). It is measured by the alkali spreading value (ASV). The degree of spreading value of individual milled rice kernels in a weak alkali solution (1.7% KOH) is very closely correlated with GT. Reports on involvement of dominant and additive (Hseih and Wong 1988), digenic (Stansel 1966) and polygenic (Puri and Siddiq 1980) mode of inheritance for this trait are available.

Gel consistency (GC) is a good index for assessing the texture of cooked rice. The cohesiveness, tenderness, colour and gloss differ greatly based on GC, when the

AC is high. Varietal differences in GC exist among varieties of similar AC (Cagampang et al 1973). The GC test is based on the consistency of the rice paste and differentiates among varieties with high AC. The test separates high amylose rices into three GC categories: very flaky with hard GC (gel length, 40 mm or less), flaky with medium GC (gel length, 41 to 60) and soft GC (gel length > 61 mm).Varieties with soft GC are preferred as the rice cooked would be tender. GC of rice is normally soft, when the AC is less than 25%. Earlier genetic studies revealed that this trait follows the monogenic inheritance (Chang and Li 1981). One major gene in addition to several minor genes, have been reported to be involved in GC (Tang et al 1989). It has also been observed that AC is highly and negatively correlated with GC, and hence the improvement of both quality traits simultaneously becomes difficult (Chang and Lee 1981).

The aroma of rice plays an important role in its consumer acceptability and it draws a premium price in certain specialty markets. Rice grain with fragrance has widespread popularity among consumers worldwide (Rani 1992).The aroma of Basmati is appreciated by many consumers world over and it represents a high value trait. The aromatic character of Basmati rice has been largely attributed to 2-acetyl-1-pyrroline (2-AP) even though more than 100 volatile aroma compounds have been identified in cooked rice (Buttery et al 1988). Inheritance of scent was studied by several investigators and they had reported contradictory results. Most of the earlier studies reported the involvement of a single recessive gene for aroma (Sood and Siddiq1978; Bollich et al 1992; Ali et al 1993; Katare and Jambhale 1995; Li and Gu 1997). Apart from monogenic recessive, digenic recessive inheritance (Vivekanandan and Giridharan 1994), monogenic dominant (Nayak and Acharya 2004; Sarawgi and Bisne 2004); monogenic recessive with an inhibitor (Tsuzuki and Shimokava 1990) and digenic or trigenic dominant (Nagaraju et al 1975) inheritance of aroma have been reported.

Aromatic long grain Basmati rices are known for their pleasant aroma and extra elongation on cooking with least breadth-wise swelling. Lengthwise expansion without increase in girth is considered as a highly desirable trait in some high quality rices such as Basmati rices of India and Pakistan, Bahra of Afghanistan, Domsiah of Iran, Bashful of Bangladesh and D 25-4 from Myanmar which elongate 100% upon cooking. This length-wise elongation characteristic that is unique for Basmati types has been incorporated into improved germplasm through conventional methods to develop several high yielding Basmati varieties (Rani and Singh 2003).Genetic studies revealed the involvement of both non-additive and additive types of gene effects with the former exerting a major role in controlling this trait (Sood et al 1983). But, reports on quantitative nature of this trait and influence of environmental factors especially at the time of ripening are also available (Dela Cruz et a l1989). Even in normal varieties and hybrids those with desirable grain quality features are favoured and widely adopted. Typical example is the case of Samba Mahsuri (BPT 5204). It is a medium slender grained variety with excellent grain, milling and cooking qualities most sought after cultivar occupying about 5 to 10% of the rice growing area in India and 40 to 50% of area in the state of Andhra Pradesh during kharif (wet season). What makes Samba Mahsuri finest quality rice? This needs to be studied. Detailed metabolic profiling possibly can answer how Samba Mahsuri acquires such a soft flaky texture, exquisite taste and good keeping quality.

Specialty Rices

Varieties identified by certain unique quality features for special preparations and product use may be termed as specialty rices. Prominent among the specialty rices include the unique quality aromatic rice – the Basmati of northwestern India, Joha rices of Assam; Kalanamak and Badshahbhog of Uttar Pradesh; Dubraj, Vishnubhog etc., of Chhattisgarh; black rices of Manipur and hundreds of others. Although they are poor yielders they command a higher price in the market. Njavara rices of Kerala have medicinal properties while there are some special rices like the instant cooking Bora and Chakua rices of Assam.

Basmati

Basmati is an epicurean delight and is a nature's gift to the Indian sub-continent. These rices are bestowed with unique quality features – exquisite aroma, silky texture, with remarkable linear elongation with excellent flaky and soft texture on cooking. India has long held the reputation of being one of the major countries producing and exporting best quality Basmati rice in the world. Systematic convergent breeding approaches followed by rice breeders in India, disassociated the jinx of undesirable genetic blocks between yield and the much valued Basmati quality features and 15 semi-dwarf, high productive varieties with exceedingly good quality were released besides four traditional Basmati land races, one MAS derived product of Pusa Basmati 1 with bacterial blight resistance and one aromatic hybrid. These accomplishments in the realm of varietal development led to doubling in rice area under Basmati in India that increased the export quantum of 1990-1991 and the foreign exchange earnings from Rs 280 crores to Rs 10,578 crores (US $ 2205 millions) in 2010-11 (Singh et al 2011; Rani 2011a).

Bora and Chakua are soft rices of Assam. Bora rice is glutinous having mainly amylopectin and only traces of amylose. The amylose content of bora rice varies from 2-9%. Chakowa (Chakua) referred to as Komal Sawl is another class of rice possessing 15-20% amylose and used for instant rice preparation. Navara rices have esteemed attributes making them suitable to the traditional Ayurvedic medicinal systems of Kerala. Grains of this traditional rice strain are used in several Ayurvedic treatments. The oil prepared out of Navara rice is used for a wide range of aches and painful conditions like the cervical spondylosis, low back ache, paralysis, rheumatoid arthritis etc (Rani and Balachandran 2006). The black and white glutinous aromatic rices (Chakhao amubi, Chakhao poireiton, Chakhao angouba) of Manipur with good quality and cooking characteristics are in demand in the domestic market. They are glutinous or sticky rices and used for the community feast as delicacy.

Aromatic short grain rices

India abounds with scores of indigenous aromatic short grain cultivars and land races, grown in pockets in various states (Singh and Singh 2003). Notable among these are the black hulled Kalanamak accessions highly popular in Uttar Pradesh marketed by some export houses as "Black Scented Pearl". Badshahbhog and host of other varieties too enjoy good consumer preference but lack export value as large quantum of rice is not available due to their low yields. Similar is the case with Dubraj, Vishnubhog, Javaphool etc., in Chhattisgarh. In the recent years several aromatic rices have also received special attention as they have high iron and zinc content (Jasmine and Basmati 370) and also many coloured rices. In food processing industry coloured rices have a good market in China as it is used in rice based products like cakes, porridges, noodle, rice wine etc. Research and development for export of short grain aromatic rices from India deserve due attention.

Innovative studies underway

As already enumerated above among the grain quality traits, cooking and eating qualities are most important in many rice growing areas world-wide including India. Several recent developments have increased our understanding of the genes, pathways and molecular mechanisms determining overall quality traits in rice (Fitzgerald et al 2009). But in most of the studies the molecular markers were developed involving *japonica* rice varieties. It will be worthwhile to validate these markers with other rice varieties with unique quality features. Further, many of the quality related traits are controlled by QTLs for which identification of candidate genes and development of candidate gene specific markers have been initiated.

Chalkiness

The research work on "QTL analysis for chalk components in rice grain across nine environments" has been initiated at IRRI, Philippines. To develop markers for chalkiness, two sets of introgression lines (IL) in BC_2F_1 Lemont/Teqing//Lemont///Lemont (L/T) and Teqing/Lemont//Teqing///Teqing (T/L), were evaluated for chalk components in seven countries China, Colombia, Iran, Malaysia, Taiwan, Thailand and Uruguay) and two controlled environments in phytotrons at IRRI. QTLs were detected in both populations. Based on joint analysis across all environments these QTLs were located at overlapping regions on chromosomes 2, 4, 5 and 10. These chromosomal regions could be the targets for MAS, fine mapping and map based cloning for low chalkiness breeding.

Amylose content

Amylose content is considered to be the key determinant of the processing, cooking and eating characteristics of rice and it correlates directly with the volume expansion, water absorption and ultimate firmness of cooked rice (Juliano 1985). Generally, the amylose content of milled rice is categorized into five classes: waxy (0–2%), very low amylose (3–9%), low amylose (10–19%), intermediate amylose (20–24%) and high amylose (above 24%). Low amylose content is associated with cohesive, tender and glossy cooked rice. In contrast, high amylose content is associated with dry, firm, fluffy and well separated grains of cooked rice (Juliano 1971). Lower amylose rice is preferable to higher amylose rice (above 20%) because it does not become hard and dry when cooked. Genetic and molecular marker based analyses have revealed that AC is mainly controlled by a major locus *Wx* encoding granule bound starch synthase (GBSS) and multi minor loci (Okuno et al 1983; Lanceras et al 2000; Bao et al 2002; Septiningsih et al 2003; Aluko et al 2004; Hirano and Sano 1991). *Waxy* (*Wx*) gene locus encodes for GBSS that plays a role in amylose synthesis in plants. Waxy (or glutinous) rices lack amylase, which represents up to 30% of the total starch in non-waxy endosperm. Based on GBSS enzyme quantity accumulated during the process of grain filling, three alleles, viz., *wx, Wxa* and *Wxb* have been identified in sticky rice, *indica* and *japonica* subspecies, respectively. The SSR marker, targeting (CT)n repeats present upstream of *Wx*was reported to be highly correlated with the variation in AC (Bligh et al 1995). Further, five alleles of the *Wx* (*Wxa, Wxin , Wxb , Wxop* and *wx*) which associate with the five classes of amylose were identified (Mikami et al 2008). However, there was no significant association of *Wx* SSR with AC in *indica* genotypes (Rani et al 2011b).

Table 1. Reported QTLs for starch properties traits in rice

Locus	Chromsome	Marker interval/marker	Phenotypic variability (%)	References
Amylose content				
Wx	6	Wx	91.1	He et al 1999
qAC5	5	RG 573-C624	11.8	
-	6	Waxy-RM 204	58.69	Lanceras et al 2000
	4	G177A-GA7-2	15.99	
	3	RM81-C158	11.28	
	7	OSR22-RM 10	9.18	
qAC-6	6	R 2869-R 1962	80.7	Li et al 2003
qAC-5	4	C 1100-R 1783	2.35	
qAC-4	5	C 624- C 128	1.45	
qAC-3	3	R 1927-R 3226	1.6	
wx	6	RM 170	28.2	Septiningsih et al 2003
amy 6	6	RM190-RM253	73.3	Aluko et al 2004
amy 3	3	RM 7RM 251	-	
amy 8	8	RM230-RM264	-	
qAC-8	8	G1149-R727	16.5	Wan et al 2004
qAC-9B	9	C609-C506	12.3	
qAC-12	12	XNpb189-2-XNpb24-2	14.7	
qAC-2	2	R1843-G132	5.83	Sun et al 2006
qAC-6	6	S1084-R1952	74.67	
amy6-1	6	RM3-RM217	39.6	Amarawathi et al 2007
qAC-1-1	1	R753-G359	-	Zheng et al 2008
qAC-1-2	1	C904-R2632	-	
qAC-4-3	4	C56-C820	-	
qAC-6-4	6	C952-waxy	55.8	
qAC-6	6	RM204-RM276	9.0	Rani et al 2011b
Gelatinization temperature (GT)				
alk	6	CT506-C235	82.4	He et al1999
qASS-6	6	CT201-RZ450	24.6	
	6	C1478-RZ667	60.3	Lanceras et al 2000
	2	RG73-RM6	12.2	
	6	RM3-RM238	8.57	
qASS-6a	6	G200-C1478	69.44	Li et al 2003
qASS-6b	6	R2869-R1962	8.10	
qASS-3	3	C25-C515	2.32	
alk	6	RM50-RM527	-	Gao et al 2003
alk6-1	6	RM190-RM253	50.1	Aluko et al 2004
alk6-2	6	RM253-RM162	44.0	
qGT-1	1	C955-C970	13.8	Wan et al 2004
qGT-3	3	C1677-R3156	20.9	
qGT 3-1	3	R2856-R3226	8.31	Sun et al 2006
qGT-6	6	G200-R2171	64.42	
asv6-1	6	RM3-RM217	6.9	Amaravathi et al 2007
qGC-3	3	R2856-R3226	12.74	
qASV-6-1	6	Waxy-C1496	11.3	Zheng et al 2008
qGT-2	2	RG256-RZ213	14.41	Govindraj et al 2009
qGT-5	5	RZ70-RZ225	15.39	
qGT-6	6	RM276-Rm217	30.7	Rani et al 2011b

The other markers, two SNPs in the exons of *Wx* gene were also reported to explain the variation in AC of US cultivars (Ayres et al 1997; Larkin and Park 2003).In non-waxy genotypes collected mainly from China, the different markers (SSR, SNP and STS) developed targeting various genes in the starch biosynthesis showed association with physicochemical properties like AC, pasting viscosity characteristics and gel textural properties (He et al 2006).

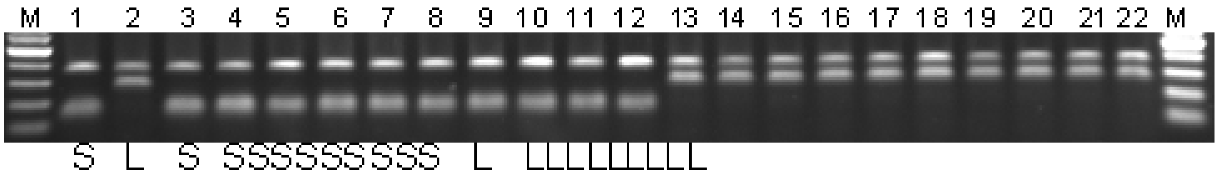

Figure 1. Amplification pattern of DRR-GL in Basmati and non-Basmati samples (M – 100bp ladder; 1= Jeeraga samba; 2 = Basmati 370; 3 to 12 = short grain non-Basmati samples; 13 to 22 = long grain Basmati samples; S = short grain; L = long grain

Recently, three allele-specific co-dominant markers targeting *Wx* were developed for use in MAS. Hence, efforts have to be strengthened in developing perfect markers for identification of each of the amylose classes, which will provide the breeder with better tools to develop rice varieties with preferred amylose content.

Gelatinization temperature

Through QTL mapping studies, it was reported that GT is mainly controlled either by the alkali degeneration gene (*alk*) which codes for starch synthase IIa (*SSIIa*) (He et al 1999, Bao et al 2004, Fan et al 2005) or by the Wx gene (Tan et al 1999).

Further, the nucleotide substitutions in the coding sequence of SSIIa are reported to cause the alteration in GT (Gao et al 2003). The association of amino acid substitution in the SSIIa with GT was determined (Nakamura et al 2005) and using this polymorphism, CAPS markers were developed to detect these SNPs (Lu et al 2010). Further GC/TT polymorphism was also reported in the *SSIIa* and its association in differentiating the genotypes based on GT (Bao et al 2006). Other than the *alk,* QTLs for GT were also reported on chromosome 6 explaining 44 to 87% phenotypic variation in a population derived from *japonica* crosses (Yan et al 2001); in *indica* genotypes, a major QTL (*qGT-6*), which explains 30% phenotypic variation was identified (Rani et al 2011b). Hence, efforts on detecting genes controlling GT in *indica* genotypes for identification of each class will help breeder to develop varieties with preferred GT values.

Gel consistency

Gel consistency is a good index for assessing the texture of cooked rice. QTL mapping confirmed the presence of locus controlling gel consistency on chromosome 6 (Septiningsih et al 2003; Li et al 2003; Huang 2000). But perfect markers have not been reported for this trait so far. Therefore, identification of tightly linked markers for GC will help the breeder in tracking the flow of soft GC locus in the breeding material which in turn will be helpful in precision breeding for this trait.

Kernel elongation on cooking

A positive correlation between kernel elongation on cooking and kernel length has been reported (Rani et al 2008). Mapping studies identified a QTLs on chromosomes 8, 2, 6, and 11 (Ahn et al 2001; Ge et al 2005). PCR based markers viz, RM44 and RZ323 were also identified (Bergman et al 2002). However, these markers were not efficient enough in varied genotypes. Recently, Ramkumar et al (2010) developed a simple marker system (DRR GL-1) targeting the functional nucleotide polymorphism at *GS3,* a major gene controlling kernel length (Fan et al 2006). This marker system showed effective genotyping of kernel elongation in Basmati and non-Basmati genotypes (Fig 1).

Aroma

Basmati aroma is appreciated by many people world over and it represents a high value trait. Initially Ahn et al 1992 mapped fragrance gene (*fgr*) on chromosome 8 and identified marker in a genetic distance of 4.5 cM. Bradbury et al (2005a) identified eight base pair deletion and three SNPs in exon 7 of betaine aldehyde dehydrogenase 2 (*badh2*) was the likely cause of fragrance in Jasmine and Basmati type of rice. Using, this polymorphism, a multiplex marker system was also developed (Bradbury et al 2005b).

Using RNAi technique, Niu et al (2008) explained the importance of *Osbadh2* gene in aroma production. Considering the problems associated with functional multiplex PCR reported by Bradbury et al (2005b), Sakthivel et al (2008) developed a simple functional marker (BADEX 7-5)targeting the candidate gene for fragrance (Fig. 2).

Apart from *badh2,* three other QTLs for were mapped on seven different chromosomes (Amrawathi et al 2007) indicating the presence of other genes. To know the presence of other alleles, other than the reported polymorphism in *badh2* and also to know the compounds determining aroma in various aromatic rices of India, an Indian Aroma Network Research Program has been initiated.

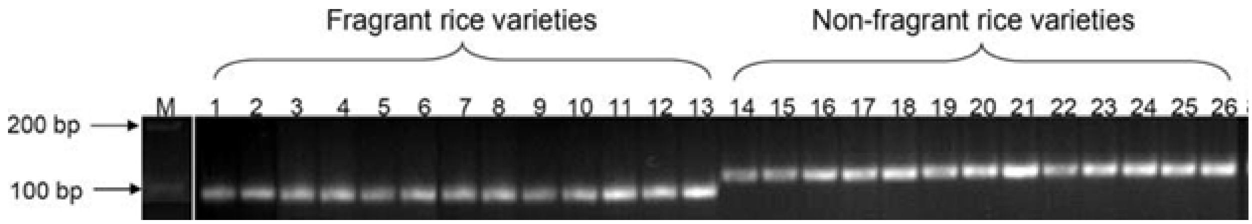

Figure 2. Amplification pattern of the marker BADEX7-5 in fragrant and non-fragrant rice varieties. Fragrant rice varieties amplified a 95 bp fragment, while the non-fragrant varieties amplified a 103 bp fragment

Introgression of bacterial blight resistance into Samba Mahsuri (BPT 5204), a very popular medium slender grain variety with excellent cooking quality has been successful leading its release as Improved Samba Mahsuri in India (Sundaram et al 2008). Likewise, Improved Pusa Basmati 1 has been released as MAS product possessing BLB resistance for the traditional Basmati growing regions. Introgression of bacterial blight and blast into Basmati genetic background through marker assisted backcross breeding (MABB) has been initiated at DRR and NILs of the same were developed at IARI, New Delhi are under evaluation tests.

Future prospects for designing rice grain quality

Although good progress has been made in understanding and dissecting the quality traits through conventional and molecular tools, many issues are yet to be addressed because of the complex polygenic mode of inheritance of these traits. To accomplish product development with desirable quality preferred by the consumer, to exploit the export markets, and to tap the vast potential by creating varied rice based products, it is vital to further understand rice quality and develop tools to ease transfer of such traits into various genetic backgrounds. Therefore, for designing rice grain quality, the future thrust must include the following: precision breeding approach to generate high yielding export quality specialty rices (Basmati, aromatic, instant, pigmented or waxy); develop and utilize gene linked molecular markers for each of the desirable class of quality traits; pyramid QTLs governing grain quality traits through advanced backcross breeding approaches; improve quality of parental lines of hybrids; determine factors responsible for uniqueness of specialty and medicinal rices; develop new tools to measure quality traits and standardization of procedures or protocols; study interrelationships among AC, GC and GT with reference to specific quality type; elucidate genetics and molecular basis of grain chalkiness and its relationship with physical and cooking quality to address the climate change; unravel the enigma of aroma (fragrance) in rice; understand and focus on the potential application of metabolomics to describe nutrition within the definition of quality and investigate on the suitability of rice varieties and specialty rices to generate new and novel rice based products for niche markets.

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