Aromatic Rices

Editors

R.K. Singh • U.S. Singh
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Preface

Aromatic rices constitute a small but an important sub-group of rice. These are rated best in quality and fetch much higher price than high quality non-aromatic rice in international market. In spite of their importance, pace of improvement of this group of rice has been rather slow. In addition to other problems related with their cross-compatibility with high yielding non-aromatic rices and high dependence of expression of quality traits on environmental factors, lack of information on various aspects of these rices too have contributed towards the slow pace of improvement of these rices. Unfortunately no publication is available which deals exclusively with these rices. Most of the information on this group of rice is scattered widely in literature. Considering these facts, the current publication is intended to present in depth the critical information available on various aspects of aromatic rices like taxonomy and origin, methods for estimation of quality traits, chemistry and biochemistry of aroma, genetics and molecular biology of quality traits, breeding for quality traits, factors affecting aroma and other quality traits, plant protection and trade. A few chapters have also been devoted to review the current status of cultivation and improvement of aromatic rice in important aromatic rice growing countries.

Chapters in the book have been contributed by the eminent scientists who are actively involved in research on aromatic rices. Our attempt has been to not merely review but present a comprehensive, analytical and thought-provoking article giving due weightage to the authors' own perceptions and views on the present status as well as future outlook including problems requiring immediate attention of scientists, policy makers and/or traders. The publication is intended to serve not only the rice scientists but also the traders, advanced students and teachers of Botany and Agriculture. How far we have succeeded in our attempt is up to the readers to decide. Whatever we do, there is always scope for further improvement. In this direction we will wholeheartedly welcome the suggestions and criticism from readers which would be a guiding force for us to carry this publication towards perfection in future.

We are thankful to our respective institutions—International Rice Research Institute, Los Baños, Philippines and G.B. Pant University of Agriculture and Technology, Patnagar, India—for permitting us to undertake this project. Our thanks are due to all those authors who accepted our request for contributing chapters to this book. Consistent cooperation and encouragement received from our wives Mrs. Madhuri Singh, Mrs. Namita Singh and Mrs. Harvant Kaur, respectively, are greatly acknowledged. We also appreciate the cooperation offered by the staffs of IRRI Liaison Office, New Delhi particularly Mr. J.P. Noor, Mr. Chander Mohan, Mr. Tara Chand Dhoundiyal and Mrs. Ruchita Bahuguna during the preparation of manuscript. Thanks are also due to Ms. Gemma Belarmino of IRRI (APPA Division) for her support in literature search.

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Chapter 1

Prologue

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Aromatic rices constitute a small but special group of rices which are considered best in quality. These rices have long been popular in the orient, and are now becoming more popular in middle east, Europe and the United States. Most of the trade in aromatic rice is from India, Pakistan and Thailand. Non-aromatic long and medium grained *indicas* and short grained *japonicas* constitute the bulk (79%) of world trade, mainly dominated by Thailand, USA, Vietnam and Australia. Yet it is the aromatic Basmati rice of the Indian sub-continent which clinches a premium and gets three-times higher price (US $ 800-1000 BMT) than high quality non-Basmati types (US $ 200-300 BMT). Bulk of aromatic rice from India and Pakistan consists of Basmati types, while Thailand is the supplier of Jasmine rice. Other important aromatic varieties in the world market are Khao Dawk Mali 105, Siamati (Thailand), Bahra (Afganistan), Sadri (Iran), Della, Texamati and Kasmati (USA).

Although aromatic rices which are popular in world market are long grained, majority of the Indian indigenous aromatic rices are small and medium-grained. A large number of land races of these rices are found in Himalayan Tarai region of the state of UP and Bihar of India, indicating that this region is probably the origin of aromatic rices. Based on isozymes pattern, different rices have been characterized into 6 distinct groups. Of these group V includes aromatic rices of Indian subcontinent including Basmati. Taxonomy and origin of aromatic rices have been discussed in detail in Chapter 2 by G. S. Khush.

Quality rices are characterized by not only aroma but several other traits like grain length and width, elongation after cooking, amylose content, gelatinization temperature etc. Standard procedures for the assessment of rice quality traits are described in Chapter 3 by N. Dela Cruz and G.S. Khush.

Among different quality traits aroma is considered most important. A 'popcorn' like aroma component 2-acetyle-l-pyrroline, has been reported as an important flavour component of several aromatic varieties. However, pleasant aroma what we smell from cooked or un-cooked aromatic rices or in field at the time of flowering is a result of a large number of compounds present in specific proportion. We have little idea, how these compounds differ from one variety to other. Chapter 4 of the book by D.J. Weber, Rashmi Rohilla and U.S. Singh deals with the chemistry and biochemistry of aroma in scented rices.

Most of the traditional aromatic rice varieties are low yielding. In spite of high value and demand of aromatic rices, there has not been much progress in development of aromatic varieties so far. It is partly because of the incompatibility of group V aromatic varieties with improved *indicus* belonging to group I resulting in high infertility in crosses. Polygenic characteristics of some of the quality traits have also complicated the issue. Recently rapid progress was made in standardizing the methodology for transformation in rice and also a number of genes determining different traits have been cloned. These developments in field of biotechnology are expected to give momentum to the improvement of aromatic rice varieties. Genetics and biotechnology of aroma and quality traits have been discussed by R.K. Singh, U.S. Singh, G.S. Khush and Rashmi Rohilla in Chapter 5, whereas Chapter 6 by R.K. Singh and co-authors deals with the breeding of aromatic rice for high yield, improved aroma and grain quality.

Low-yielding aromatic rices have been the major casualty of green revolution where the main emphasis was on yield rather than quality. A large number of aromatic rices have already been lost and many are at the verge of extinction. It is more true for the small and medium-grained aromatic rices which are mostly cultivated for home consumption than the long-grained Basmati types which form the bulk of rice export. Some of the small and medium-grained aromatic rices possess excellent aroma and other quality traits like kernel elongation after cooking, taste etc. These could be excellent sources for improving quality in high yielding varieties. Therefore, there is a strong need to conserve whatever aromatic rice germplasm is left. In Chapter 7, R.K. Singh, P.L. Gautam, S. Saxena and S. Singh discuss the conservation, evaluation and utilization aspects of scented rice germplasm.

Chapters 8 to 10 have been devoted to discussion on the present status of aromatic rice cultivation and the on-going improvement programmes in major aromatic rice growing countries. These chapters are written by the scientists from respective countries who are actively involved in aromatic rice research.

An aromatic rice variety may grow and yield satisfactorily in a wide area but its quality traits are expressed best in its native area of cultivation. Expression of aroma and other quality traits is quite dependent upon environmental factors, which are yet to be properly defined. Understanding of these factors is must for producing finest quality aromatic rices. All these aspects are discussed in detail in Chapter 11 by Rashmi Rohilla, V.P. Singh, U.S. Singh, R.K. Singh and G.S. Khush.

Because of long duration, dense crop canopy and little breeding efforts in past to transfer diseases and pest resistance gene(s), aromatic rice varieties are prone to attack by a number of diseases and insect pests. U.S. Singh and co-authors have discussed plant protection in aromatic rices in detail in Chapter 12.

Aromatic rice is now an important commodity in international trade. Various aspects of global rice trade are described by V.K. Bhasin in Chapter 13. Chapter 14 contains the concluding remarks and discusses some of the important issues that would need our attention for the improvement and promotion of aromatic rice cultivation in future.

Chapter 2

Taxonomy and Origin of Rice

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INTRODUCTION

Rice, like wheat, corn, rye, oats and barley belongs to Gramineae or grass family. The genus *Oryza* to which cultivated rice belongs, has twenty-one wild and two cultivated species (Table 1). Nine of the wild species are tetraploid and the remaining are diploid. Harlan and De Wet (1971) proposed classifying the wild relatives of a crop species into three categories on the basis of isolation barriers and the ease of gene transfer to the cultivated species. This is a useful concept for breeders. In *Oryza,* however, F_1 fertility and other dysfunctions of hybrids occur irrespective of genetic distance, and the distinction between the three categories is not always clear. The pattern of variation among species examined through methods of numerical taxonomy, however, is helpful. A variation study of 16 species based on 42 morphological traits, reported by Morishima and Oka (1960) suggested that *Oryza* species can be divided into three main groups: (1) *O. sativa* and its relatives, (2) *O. officinalis* and its relatives, and (3) other more distantly related species.

In recent years efforts have been made to introgress useful genes from wild species to cultivated rice through interspecific hybridization (Brar *et al.* 1996; Jena and Khush 1990; Multani *et al.* 1994). On the basis of ease of gene transfer, the primary gene pool comprises the wild species — *O. rufipogon, O. nivara, O. glamapatula, O. meridionalis, O. breviligulata, O. longistaminata*— and the cultivated species— *O. sativa* and *O. glaberrima.*

Table 1. Chromosome number, genomic composition, distribution and potential useful traits of *Oryza* species.

Species	2n	Genome	Distribution	Useful or potentially useful traits[a]
***O. sativa* complex**				
O. sativa L.	24	AA	Worldwide	Cultigen
O. nivara Sharma et Shastry	24	AA	Tropical and sub-tropical Asia	Resistance to grassy stunt virus, blast, drought avoidance
O. rufipogon Griff.	24	AA	Tropical and sub-tropical Asia, tropical Australia	Elongation ability, resistance to BB, source of CMS
O. breviligulata A. Chev. et Roehr.	24	A^gA^g	Africa	Resistance to GLH, BB, drought avoidance
O. glaberrima Steud.	24	A^gA^g	West Africa	Cultigen
O. longistaminata A. Chev. et Roehr.	24	A^gA^g	Africa	Resistance to BB, drought avoidance
O. meridionalis Ng	24	A^mA^m	Tropical Australia	Elongation ability, drought avoidance
O. glumaepatula Steud.	24	$A^{gp}A^{gp}$	South and Central America	Elongation ability, source of CMS
***O. officinalis* complex**				
O. punctata Kotschy *ex* Steud.	24 48	BB BBCC	Africa	Resistance to BPH, zigzag leafhopper
O. minuta J. S. Pesl. *ex* C. B. Presl.	48	BBCC	Philippines and Papua New Guinea	Resistance to sheath blight, BB, BPH, GLH
O. officinalis Wall ex Watt	24	CC	Tropical and sub-tropical Asia, tropical Australia	Resistance to thrips, BFW, GLH, WBPH
O. rhizomatis Vaughan	24	CC	Sri Lanka	Drought avoidance, rhizomatous
O. eichingeri A. Peter	24	CC	South Asia and East Africa	Resistance to yellow mottle virus, BPW, WBPH, GLH
O. latifolia Desv.	48	CCDD	South and Central America	Resistance to BPH, high biomass production
O. alta Swallen	48	CCDD	South and Central America	Resistance to striped stemborer, high biomass production
O. grandiglumis (Doell) Prod.	48	CCDD	South and Central America	High biomass production
O. australiensis Domin.	24	EE	Tropical Australia	Drought avoidance, resistance to BPH
O. brachyantha A. Chev. et Roehr.	24	FF	Africa	Resistance to yellow stem-borer, leaf-folder, whorl maggot, tolerance to laterite soil

(Contd.)

Table 1 *(Contd.)*

Species	2n	Genome	Distribution	Useful or potentially useful traits[a]
***O. meyeriana* complex**				
O. granulata Nees et Am. ex Watt	24	GG	South and Southeast Asia	Shade tolerance, adaptation to aerobic soil
O. meyeriana (Zoll. et *Mor.* ex Steud.) Bad.	24	GG	Southeast Asia	Shade tolerance, adaptation to aerobic soil
***O. ridleyi* complex**				
O. logiglumis Jansen	48	HHJJ	Irian Jaya, Indonesia and Papua New Guinea	Resistance to blast, BB
O. ridleyi Hook. f.	48	HHJJ	South Asia	Resistance to stemborer, whorl maggot, blast, BB
Unknown genome				
O. shlechteri Pilger	48	unknown	Papua New Guinea	Stoloniferous

[a] BPH = brown planthopper; GLH = green leafhopper; WBPH = white-backed planthopper; BB = bacterial blight; CMS = cytoplasmic male sterility

They share the AA genome and gene transfer can be accomplished through conventional hybridization and selection procedures. Species belonging to the *O. officinalis* complex constitute the secondary gene pool. Cross between *O. sativa* and species of this complex can be accomplished through embryo rescue techniques. Since there is limited homology between the AA genome of *O. sativa* and BB, CC, CCDD, EE and FF genomes of wild species, only limited gene transfer is possible. Species belonging to *O. meyerianu, O. ridleyi* and *O. schlechteri* complexes constitute the tertiary gene pool. Crosses between *O. sativa* and species belonging to these complexes are extremely difficult to accomplish and the gene transfer is rare if at all.

WILD PROGENITORS OF CULTIVATED RICE

The common rice, *O. sativa* and the African rice, *O. glaberrima* are thought to be an example of parallel evolution in crop plants. The wild progenitor of *O. sativa* is the Asian common wild rice, *O. rufipogon,* which shows a range of variation from perennial to annual types. Annual types, also given a specific name of *O. nivara,* were domesticated to become *O. sativa.* In a parallel evolutionary path, *O. glaberrima* was domesticated from annual *O. breviligulata,* which in turn evolved from perennial *O. longistaminata* (Figure 1).

O. rufipogon is distributed from Pakistan to China and Indonesia and its populations vary between perennial and annual types, which differ markedly in life history traits (Okra, 1988). In short, the perennial types

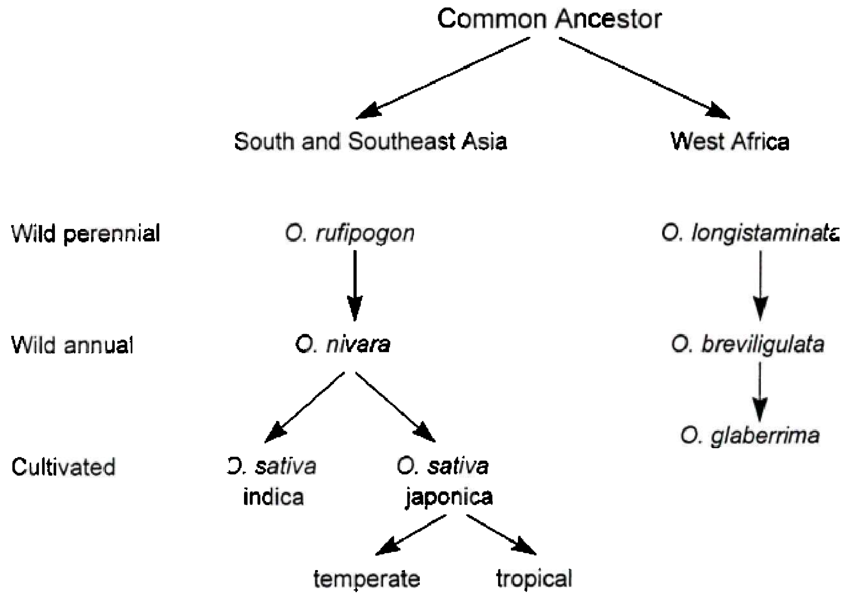

Fig. 1. Evolutionary pathway of two cultivated species of rice.

have higher outcrossing rates and lower seed productivity than annual types. In monsoonal Asia, the perennial types grow in deep swamps, which retain moisture throughout the year while annual types occur in temporary marshes, which are parched in dry season. All these wild rices cross with cultivated rice under natural conditions producing hybrid swarms in the field.

Domestication of wild rices probably started about 9000 years ago. Development of annuals at different elevations in eastern India, northern southeast Asia and southwest China was enhanced by alternating periods of drought and variations in temperature during Neothermal age about 10,000 to 15,000 years ago (Whyte, 1972). Domestication in Asia could have occurred independently and concurrently at several sites within or bordering a broad belt that extends from the plains below the eastern foothills of the Himalayas in India through Upper Myanmar, northern Thailand, Laos, and Vietnam to southwest or south China (Chang, 1976; Ramiah, 1937; Roschevitz, 1931). In this Asian arc, rice was grown in forest clearings, under a system of shifting cultivation. The crop was probably grown by direct seeding and without standing water. It was probably in China that the process of soil puddling and transplanting seedlings was refined. With the development of puddling and transplanting, rice became truly domesticated. In southeast Asia, by contrast, rice was originally produced under dryland conditions in the uplands and only recently did it come to occupy vast river deltas. Linguistic evidence also points to the early origin of cultivated rice in the Asian arc. In several regional languages, the general term for rice and food or for rice and agriculture are synonymous.

Solheim (1972) discovered the earliest and most convincing archaeological evidence for domestication of rice in Southeast Asia. Pottery shreds bearing the imprints of grain and husk of *O. sativa* were discovered at Non Nok Tha in the Korat area of Thailand. These remains have been dated by C^{14} and thermoluminescence testing to at least 4000 B.C.

Ancient India is undoubtedly one of the oldest regions where cultivation of *O. sativa* began. The oldest grain samples excavated at Mohanjodaro, now in Pakistan date back to about 2500 B.C. (Andrus and Mohammed, 1958). The oldest carbonized grains found in India date back to about 6750 BC (Sharma and Manda, 1980). The antiquity of rice cultivation in China has long been a subject of debate (Chang, 1976). The oldest remains of cultivated rice date to five centuries before Christ. Carbonized rice grains from Tongxieng county of Zhejiang province were identified as 7040 years old. The second earliest, 6960 years old is from Hemdu relic in Yuyao county of Zhejiang province.

The African cultivated rice, *O. glaberrima,* originated in Niger river delta. The primary centre of diversity for *O. glaberrima* is the swampy basin of the upper Niger river and two secondary centres to the southwest near the Guinea Coast. The primary centre was probably formed around 1500 BC while the secondary centres were formed 500 years later (Porteres, 1956).

POLYPHYLETIC ORIGIN OF *O. SATIVA*

Oryza sativa is a tremendously variable species and has worldwide distribution. The Chinese have recognized two rice varietal groups, Hsein and Keng, since the Han dynasty. These correspond to *indica* and *japonica* classification introduced by Kato et al. (1928). *Indica* and *japonica* cultivars differ in many characters when typical varieties are compared but show overlapping variations. The *indica* and *japonica* types are each characterized by an association of certain diagnostic characters, such as $KClO_3$ resistance, cold tolerance, apiculus hair length and phenol reaction (Oka, 1958). Classification based on scores given by a discriminant function combining measurements of these characters have low probability of misplacement into varietal groups. Even then a few varieties remain unclassified as atypical.

Morinaga (1954) proposed a third group to include bulu and gundil varieties of Indonesia under the name *javanicas* but gave no description and did not use this name in his later publications. Several authors have ranked *javanicas* at the same taxonomic level as *indicas* and *japonicas.*

However, they cannot be considered to have the same level of differentiation as *indicas* and *japonicas* (Glaszmann and Arraudeau, 1986). As shown by Glaszmann (1987) on the basis of genetic affinity using isozyme analysis, *javanica* varieties fall within the *japonica* group and are now referred to as tropical japonicas and the so-called typical *japonicas* are referred to as temperate *japonicas* (Figure 1).

Glaszmann (1987) examined 1,688 rice cultivars from different countries for allelic variation at 15 isozyme loci and analyzed the data by a multivariate analysis. The results showed that 95 per cent of the cultivars fell into six distinct groups, the remaining 5 per cent being scattered over intermediate positions. This classification involved no morphological criteria. When the six groups were compared with the varietal groups classified by morphological characters, Group I corresponded to the *indica* and Group VI to the *japonica.* Group VI also included the *bulu* and *gundil* varieties formerly classified into so called *javanicas.* Groups II, III, IV and V were atypical but were also classified as *indicas* in the conventional classification. Group II corresponds to very early maturing and drought tolerant upland rices called *Aus* varieties grown in Bangladesh and West Bengal State of India during so called *Aus* season (March-June). Floating rices of Bangladesh and India called *Ashinas* and *Rayadas* belong to Groups III and IV, respectively. Group V includes aromatic rices of Indian subcontinent including basmati. Various levels of sterility are observed in the F_1 hybrids of intergroup crosses but not in the intragroup crosses. For example, F_1 hybrids between cultivars belonging to Group I and cultivars belonging to other groups show sterility. No sterility is observed in the F_1 hybrids between tropical *japonicas* and temperate *japonicas.*

Various opinions have been forwarded about the origin of indica and japonica rices. Kato et al. (1928) expressed the opinion that *indica* and *japonica* rices originated independently from a wild ancestor. Ting (1957) on the other hand proposed that *japonicas* were derived from the *indicas.* Earlier studies primarily focused on indica–japonica differentiation. However, so called *indicas* are such a diverse group that several morphological types can be recognized which correspond to Glaszmann's classification based on isozymes. Thus, the information from isolation barriers (F_1 sterility) genetic affinity (isozyme analysis) and morphological grouping suggests that the six groups may have been domesticated from different populations of *O. nivara* at different locations and on different time scales. Ryada rices (Group IV) of Bangladesh adapted the deepwater conditions and having very strong photoperiod sensitivity may have been domesticated in only recent times as very deepwater areas were brought under cultivation. These rices still share several traits with wild rices.

TAXONOMIC STATUS OF AROMATIC RICES

Aromatic cultivars belong to Groups I, V and VI (Table 2). Only a few of

Table 2. Some aromatic rice cultivars belonging to different varietal groups

Group	Cultivar Name	Country of Origin
I	Zhao Xing 17	China
	Khao Dawk Mali	Thailand
	Khao Mali	Thailand
	Som Hong	Thailand
	Nahng Nuan	Thailand
	Jao Mali	Thailand
	Tam Xuan	Vietnam
	Tam Xuan Hai Hau	Vietnam
	Somali	Cambodia
	Hawm Mali	Thailand
V	Kamod	India
	Kalimunch	India
	Nama Tha Lay	Myanmar
	Ram Tulsi	India
	Kala Nimak	Bangladesh
	Basmati 370	India
	Basmati 5853	India
	Basmati 5877	India
	Dom Siah	Iran
	Badshahbhog	Bangladesh
	Moosa Tarum	Iran
	Barah	Afghanistan
	Lawangin	Afghanistan
	Anbarboo	Iraq
	Bindli	India
	Dubraj	India
	Taungpyan Hmwe	Myanmar
	Balugyun	Myanmar
	Boke Hmwe	Myanmar
	Tulsi Majri	India
	Kalijira	Bangladesh
	Jeeraga Samba	India
	Xiang Keng 3	China
	Xiang Nuo 4	China
	Kamini Bhog	India
	Ngakywe	Myanmar
	Pawsan Hmwe	Myanmar
VI	Rojolele	Indonesia
	Mentik Wangi	Indonesia
	Xiang Keng 3	China
	Sukanandi	Indonesia
	Milfore (6)2	Philippines
	Azucena	Philippines
	Milagrosa	Philippines

the cultivars belonging to Group I (*indica*) and Group VI (*japonica*) are aromatic. However, most of the cultivars belonging to Group V are aromatic. Group V includes world famous high quality Basmati rices of India and Pakistan. Included in this group are long and medium grain aromatic rices such as Basmati, Pankhari 203, Ambemohar, Kataribhog, Hansraj, Barah, Lawangin, and Sadri rices of Iran, as well as cultivars with very small grains such as Badshahbhog, Prasadbhog, Tulsimanjri, Bindli, Nama Tha Lay. Many of the rices belonging to this group have excellent lengthwise elongation.

The centre of diversity of aromatic rice of Group V are the foothills of Himalayas in the Indian states of Uttar Pradesh (UP) and Bihar, and Tarai region of Nepal (Figure 2). Many aromatic cultivars are still grown in this centre of diversity. From here aromatic rices spread northwestward to Punjab in India and Pakistan, Afghanistan, Iran and Iraq, north eastward to Bangladesh and Myanmar and the Indian states of Orissa, Bengal, Assam and Manipur. The westward distribution occurred to other states of India such as Rajasthan, Madhya Pradesh, Maharastra and Gujarat. Numerous aromatic varieties belonging to Group V are now grown under different names (Table 2). It is interesting to note that the eastern most limits of rice of Group V is Myanmar. Rices belonging to this group have not been found in Southeast and East Asia.

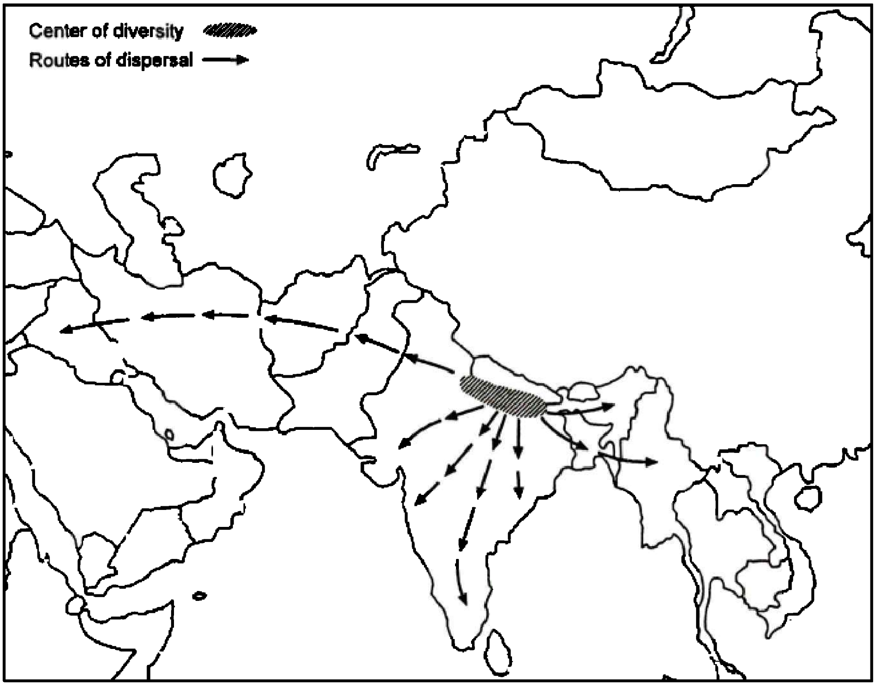

Fig. 2. Centre of diversity and dispersal routes of aromatic rices of Group V.

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Chapter 3

Rice Grain Quality Evaluation Procedures

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INTRODUCTION

Grain quality in rice is very difficult to define with precision as preferences for quality vary from country to country. Few people realize its complexity and various quality components involved. The concept of quality varies according to the preparations for which grains are to be used. Although some of the quality characteristics desired by grower, miller and consumer may be the same, yet each may place different emphasis on various quality characteristics. For instance, the miller's basis of quality is dependent upon total recovery and the proportion of head and broken rice on milling. Consumers base their concept of quality on the grain appearance, size and shape of the grain, the behavior upon cooking, the taste, tenderness and flavor of cooked rice.

The cooking quality preferences vary in different countries (Azeez and Shafi, 1966). Rice is one cereal that is consumed mainly as whole milled and boiled grain. The desired properties may vary from one ethnic group or geographical region to another and may vary from country to country (Juliano et al., 1964). The quality in rice may, therefore, be considered from viewpoint of milling quality, grain size, shape and appearance and cooking characteristics.

RICE GRAIN QUALITY

Milling Quality

Milling yield is one of the most important criteria of rice quality especially from a marketing standpoint. A variety should possess a high turnout of whole grain (head) rice and total milled rice (Webb, 1985).

Milling yield of rough rice is the estimate of the quantity of head rice and total milled rice that can be produced from a unit of rough rice. It is generally expressed as percentage (Khush et al., 1979). Thus the milling quality of rice may be defined as the ability of rice grain to stand milling and polishing without undue breakage so as to yield the greatest amount of total recovery and the highest proportion of head rice to brokens.

The milling process generally consists of five fundamental operations:

1. Cleaning the rough rice to remove leaves, rice stems and other foreign matter
2. Shelling or dehulling the cleaned rice to remove the hulls
3. Cleaning the brown rice to remove hulls not totally removed by dehulling
4. Milling or polishing the brown rice
5. Separating whole grains from broken kernels

Determination of Milling Yields

Duplicate 125 g rough rice samples are used for milling determinations. Moisture content for these samples should be in the range of 12–14%.The moisture content is determined usually by a Motomco or Steinlite moisture meter.

Rough rice samples are dehulled with a Satake laboratory sheller. The sample is poured into the hopper. Samples with many partially filled grains of reduced thickness, usually require two passes. The resulting brown rice is weighed to get the percentage of hulls.

The brown rice is milled in a McGill mill number 2 (Adair, 1952) for 30 seconds with the prescribed added weight (680 g) on the pressure cover; followed by a second milling for another 30 seconds without the weight. The fraction removed may be considered bran in the first milling and that after the second milling, polish. The milled rice sample is collected in a jar or thick paper bag and sealed immediately. The rice is allowed to cool before weighing. This procedure minimizes grain cracking during cooling. The weight of the total milled rice is recorded.

Whole grains (head rice) are separated from the total milled rice with a rice sizing device. The indentation size of the device depends on the grain size. Two plates of the same size are used for each run. The resulting head rice is weighed. Samples should be at least 3 to 4 months old after harvest to obtain reliable head-rice yields.

Calculations

The percentage of hulls of rough rice is calculated as follows:

$$\text{Hull (\%)} = \frac{\text{Weight of hull}}{\text{Weight of rough rice}} \times 100$$

$$\text{Head rice (\%)} = \frac{\text{Weight of total milled rice}}{\text{Weight of rough rice}} \times 100$$

$$\text{Degree of milling (\%)} = \frac{\text{Weight of total milled rice}}{\text{Weight of brown rice}} \times 100$$

The proportions of the various components vary according to the method of milling used and the variety of rice. Generally, the hulls form 20 to 22 percent of the rough rice, although variation of 18 to 26 per cent has been recorded. Bran and embryos constitute another 8 to 10 per cent. Thus, from a given sample of rough rice about 70 per cent milled rice is obtained. The proportion of whole grains is known as head rice recovery and is expressed as percentage of rough rice. Thus, if from a sample of 100 g of rough rice, 70 g of milled rice is obtained and 20 g of this is broken, head-rice recovery is 50 per cent. The head-rice recovery may vary from as low as 25 per cent to as high as 65 per cent (Khush et al., 1979)

Grain Size, Shape and Appearance

The appearance of milled rice is important to the consumer. Thus grain size and shape are the first criteria of rice quality that breeders consider in developing new varieties for release for commercial production (Adair et al., 1966). The length:breadth ratio (L/B) falling between 2.5 and 3.0 has been considered widely acceptable as long as the length is more than 6 mm (Kaul, 1970). The consumer prefer rice with a translucent endosperm and pay a premium price for it, even though opacity disappears during cooking and does not alter eating quality.

Preference for grain size and shape vary from one group of consumers to the other. Some ethnic groups prefer short bold grains, some have a preference for medium long grains, and long slender grains are highly prized by others. In general, long grains are preferred in the Indian subcontinent, but in Southeast Asia the demand is for medium to medium long rice. In temperate areas short grain varieties are prevalent. There is a strong demand for long grain rice on the international market.

Grain appearance depends upon the size and shape of the kernel, translucency and chalkiness of the grain. The physical dimensions of rice kernels are of vital interest to those engaged in the many facets of the rice industry. Rice varieties may be objectively classified into grain-type categories based upon two physical parameters: length and shape. Length (Figure 1) is a measure of the rice kernel in its greatest dimension. The shape (Figure 2) is determined by the length:width ratio. While grain size and shape can be visually classified, more exact measurements are needed for classification and for critical comparison of varieties.

Standards for evaluation of grain length and shape of breeding materials vary among countries and marketing areas. Below is a useful classification for routine breeding evaluation.

Size classification:

Scale	Size category	Length in mm
1	Very long	More than 7.50
3	Long	6.61 to 7.50
5	Medium or intermediate	5.51 to 6.60
7	Short	Less than or equal to 5.50

Shape classification:

Scale	Shape	Lengt/width ratio
1	Slender	Over 3.0
5	Medium	2.1 to 3.0
9	Bold	2.0 or less than 2.0

Grain appearance is also largely determined by endosperm opacity, the amount of chalkiness (Figure 3) either on the dorsal side of the grain (white belly), ventral side (white back) or in the center (white centre), and the condition of the "eye". In some varieties the grain tends to break more frequently at the "eye" or pit left by the embryo when it is milled. Rice samples with damaged eyes have poor appearance and low market value. Similarly, the greater the chalkiness, the lower the market acceptability. The starch granules in the chalky areas are less densely packed as compared to translucent areas. Therefore, the chalky areas are not as hard as the translucent areas and the grains with chalkiness are more prone to breakage during milling.

Milled grains are visually scored for the presence or absence of white belly, white back, white centre, degree of translucency and breakage at the basal-ventral end of the grain referred to as the condition of the eye. These determinations are scored on a 0 to 9 scale according to increasing intensity.

The following scale is used for classifying endosperm chalkiness of milled rice:

Scale	% Area with chalkiness
0	None
1	Less than 10%
5	10 to 20%
9	More than 20%

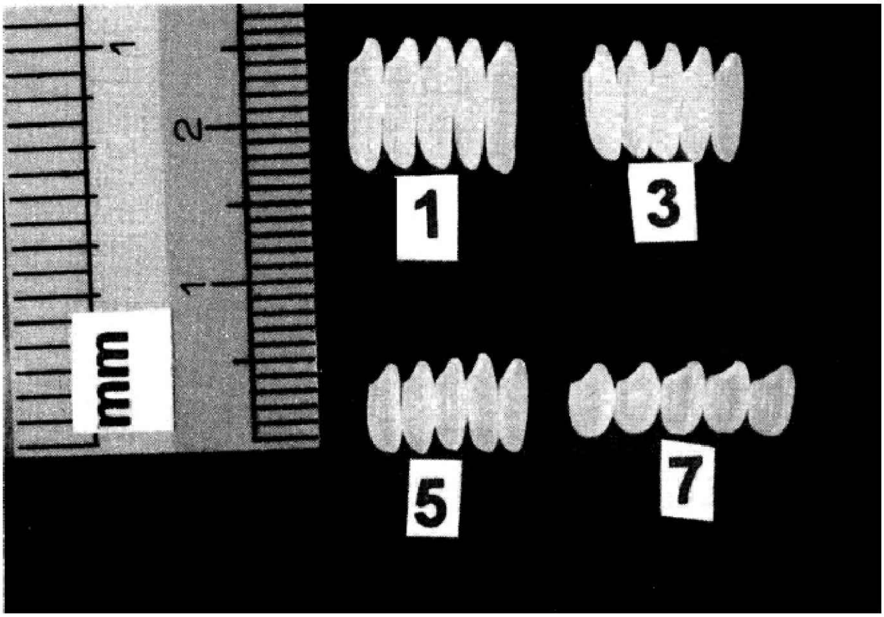

Fig. 1. Varieties differing in grain size (length).

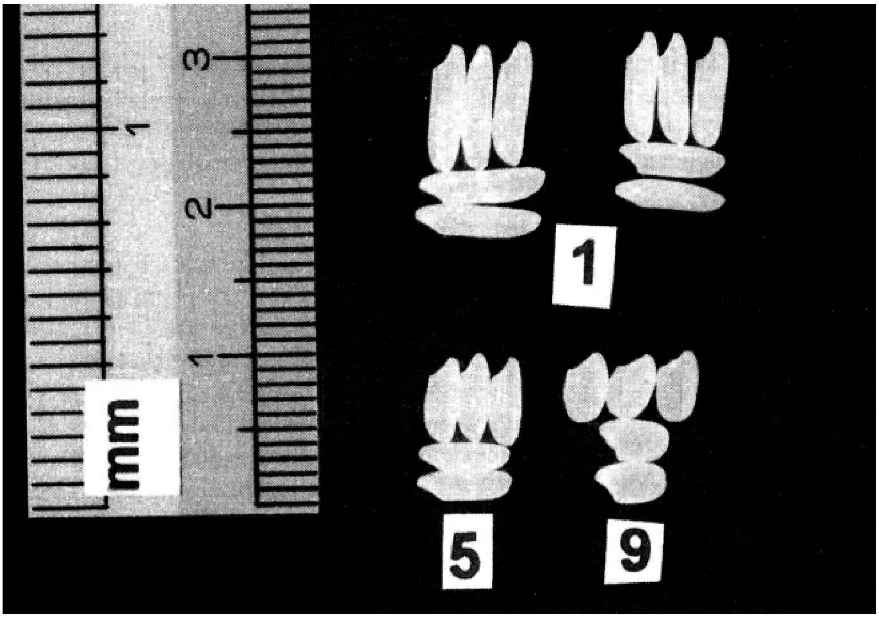

Fig. 2. Types of shape classification.

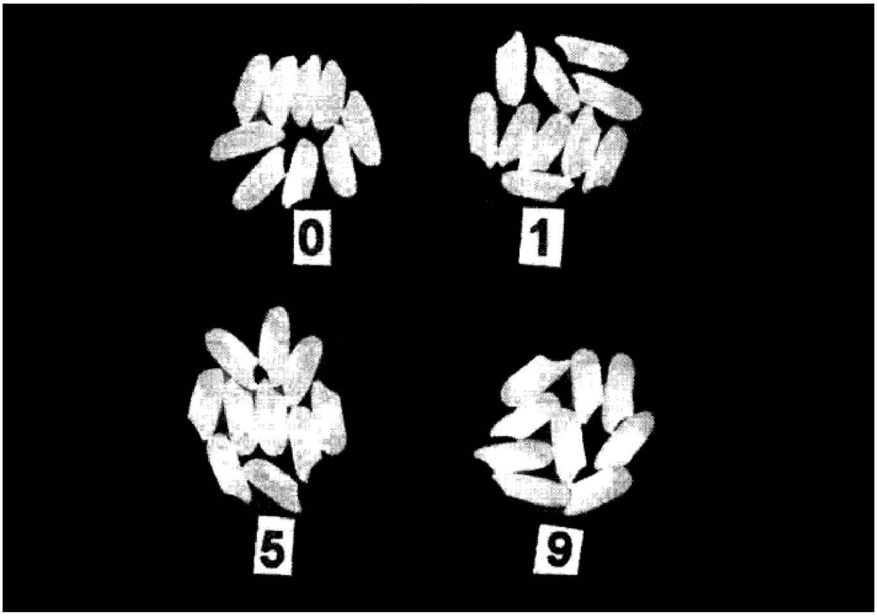

Fig. 3. Scale for the degree of chalkiness.

Cooking and Eating Characteristics

Cooking and eating characteristics are largely determined by the properties of the starch that makes up 90 percent of milled rice. Gelatinization temperature, amylose content and gel consistency are the important starch properties which influence cooking and eating characteristics

Gelatinization Temperature

Time required for cooking is determined by the gelatinization temperature of starch. Gelatinization temperature, a physical property of starch, is the range of temperature wherein at least 90% of the starch granules swell irreversibly in hot water with loss of crystallinity and birefringence. Final gelatinization temperature ranges from 55 to 79°C. Environmental conditions such as temperature during grain development influence gelatinization temperature. A high ambient temperature during grain ripening results in starch with higher gelatinization temperature (dela Cruz et al., 1989). The gelatinization temperature of rice varieties, may be classified as low (55 to 69°C), intermediate (70 to 74°C), and high (>74°C)

An estimate of the gelatinization temperature is indexed by the alkali digestibility test (Little et al., 1958). It is measured by the alkali spreading value. The degree of spreading value of individual milled rice kernels in a weak alkali solution (1.7% KOH) is very closely correlated with gelatinization temperature. Rices with low gelatinization temperature disintegrate completely, whereas rices with intermediate gelatinization temperature show only partial disintegration. Rices with high gelatinization temperature remain largely unaffected in the alkali solution (Figure 4). In a breeding program the alkali digestion technique is used extensively for estimating gelatinization temperature.

Although the gelatinization temperature and cooking time of milled rice are positively correlated (Juliano, 1967), gelatinization temperature does not correlate with the texture of cooked rice (IRRI, 1968). Gelatinization temperature is not associated with other important plant or grain traits except for certain useful correlations with amylose content (Jennings et al., 1979). Varieties with high gelatinization temperature generally have low amylose content. No varieties are known with high gelatinization temperature and high amylose content.

A second correlation concerns intermediate gelatinization temperature which apparently has never been combined with low amylose content. All varieties that have intermediate gelatinization temperature are either intermediate or high in amylose content.

The low gelatinizing class has no strict association with low, intermediate and high amylose contents. Low gelatinization temperature is readily recombined with the three amylose levels.

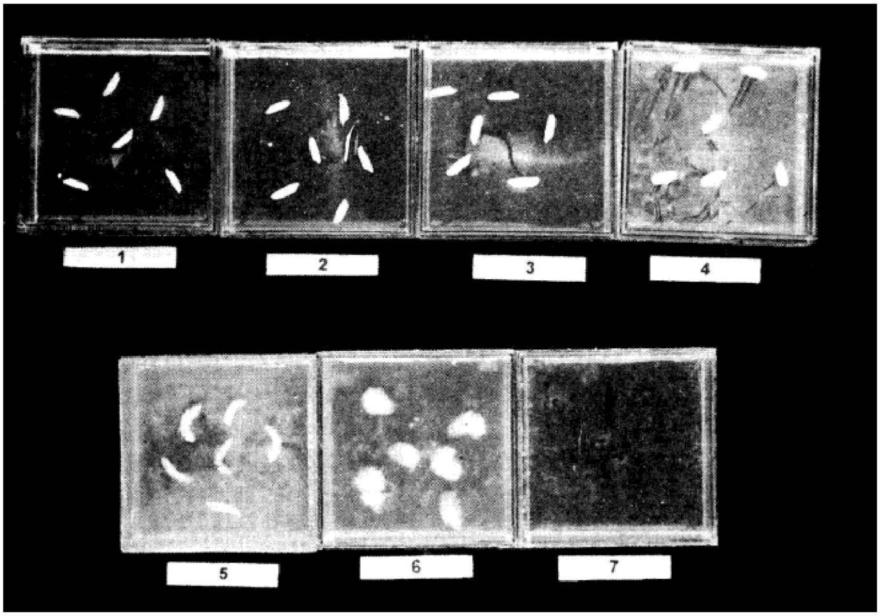

Fig. 4. Alkali digestion of rice kernels. The numbers represent the scales of alkali spreading.

STEPS IN DETERMINING THE RICE GELATINIZATION TEMPERATURE (ALKALI-DIGESTION TEST):

Duplicate sets of six whole milled kernels without cracks are selected and placed in plastic boxes (2” × 2” × 1”). Half kernels can be used in the absence of whole kernels. 10 ml (cc) of 1.7% (0.3035 N) potassium hydroxide (KOH) solution is added. The samples are arranged to provide enough space between kernels to allow for spreading. The boxes are covered and incubated for 23 hours at 30°C in an oven or by use of ambient temperature. Starchy endosperm is rated visually based on a 7-point numerical spreading scale (Table 1). Standard check varieties of high, intermediate and low gelatinization types of rice are included for every test.

Table 1. Numerical scale for scoring gelatinization temperature.

Score	Spreading	Alkali digestion	Gelatinization temperature
1	Kernel not affected	Low	High
2	Kernel swollen	Low	High
3	Kernel swollen; collar complete or narrow	Low or intermediate	High-intermediate
4	Kernel swollen; collar complete and wide	Intermediate	Intermediate
5	Kernel split or segregated; collar complete and wide	Intermediate	Intermediate
6	Kernel dispersed; merging with collar	High	Low
7	Kernel completely dispersed and intermingled	High	Low

Amylose Content

Many of the cooking and eating characteristics of milled rice are influenced by the ratio of two kinds of starchs; amylose and amylopectin in the rice grain (Sanjiva Rao et al., 1952). Amylose is the linear fraction of starch in the non-glutinous varieties, whereas amylopectin, the branched fraction, makes up the remainder of the starch. Amylose content correlates negatively with taste panel scores for cohesiveness, tenderness, color and gloss of the boiled 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. These rices are the staple food of people in Northern and Northeastern Thailand and Laos.

A great majority of rices from Vietnam, Thailand, Myanmar and the Indian subcontinent have high amylose content. These rices show high volume expansion (not necessarily elongation) and a high degree of flakiness. They cook dry, are less tender and become hard upon cooling.

Low amylose rices cook moist and sticky. All of the *japonica* varieties of temperate regions have low amylose content. Varieties grown in the Philippines, Malaysia and Indonesia have intermediate amylose content. Intermediate-amylose rices cook moist and tender and do not become hard upon cooling. Survey conducted by IRRI shows that the most preferred varieties in the areas where high-amylose rices are generally grown have intermediate amylose.

Rice varieties are grouped on the basis of their amylose content into waxy (0-2%), very low (3-9%), low (10-19%), intermediate (20-25%) and high (>25%) (Kumar and Khush, 1986).

Intermediate amylose rices are the preferred types in most of the rice-growing areas of the world, except where low-amylose japonicas are grown. Therefore, development of improved germplasm with intermediate amylose content should be taken into consideration in the grain quality improvement program.

The simplified procedures (autoanalyzer and manual method) of Juliano (1971) is used for the amylose content analysis.

Manual Method

Twenty whole-grain milled rice is ground in a UDY cyclone mill (sieve mesh size 60). 100 mg of rice powder is put into a 100 ml volumetric flask and 1 ml of 95% ethanol and 9 ml of 1N sodium hydroxide are added. The contents are heated on a boiling water bath to gelatinize the starch. After cooling for one hour, distilled water is added and contents are mixed well. For each set of samples run, low, intermediate and high amylose standard varieties are included to serve as checks.

Five ml of the starch solution is put in a 100-ml volumetric flask with a pipette. One ml of 1N acetic acid, 2 ml of iodine solution (0.2 g iodine and 2.0 g potassium iodide in 100 ml of aqueous solution) are added and volume is made up with distilled water. Contents are shaken well and let stand for 20 minutes. Absorbance of the solution is measured at 620 mu with a spectrophotometer such as Baush and Lomb Spectronic 20. Amylose content is determined by using a conversion factor and the results are expressed on a dry weight basis. The moisture content of the samples is essentially constant and need not be determined if the relative humidity and temperature of the laboratory is controlled.

For the standard curve, 40 mg of potato amylose (Sigma Chemical Co. or Stein Hall and Co. Inc. of known moisture content) are wet with 1 ml ethanol and 9 ml 1N sodium hydroxide. Heated for 5-10 minutes in a boiling water bath, cooled and made up to volume. 1, 2, 3, 4, 5 ml of solution are placed with a pipette in 100 ml volumetric flasks. The solution is acidified with 1N acetic acid (0.2, 0.4, 0.6, 0.8, and 1.0 ml, respectively and treated as above. The absorbance values is plotted at 620 mu, against the concentration of anhydrous amylose (mg) and the conversion factor is determined. The dilution factor of 20 for the samples is included in the conversion factor.

Starch solutions (100 mg/100 ml) prepared by the manual method may be automatically analyzed with an AutoAnalyzer. Portions of the starch solutions are transferred into the sample cups of the AutoAnalyzer and run at 70 samples/hour. A standard curve is made using rice samples of predetermined amylose content by the simplified manual method at 620 mu. A fresh working iodine solution (1.0 ml 1N acetic acid and 3.0 ml stock iodine solution diluted to 100 ml) is prepared daily. Results are expressed as per cent apparent amylose content in milled rice weight. Apparent amylose content is used since at amylose concentration of more than 25%, amylopectin shows increased iodine binding instead of amylose (Perez and Juliano 1978). They proposed a constant factor of 2.0% to convert apparent amylose content to absolute amylose content based on methanol defatting.

Gel Consistency Test

A rapid, simple test, complementary to the test for amylose content, was developed based on the consistency of a cold 4.4% milled rice paste in 0.2N KOH (Cagampang et al., 1973). Consistency is measured by the length in a culture tube of the cold gel held horizontally for 0.5 to 1 hour.

Varietal differences in gel consistency exist among varieties of similar amylose content (>25%). The gel consistency test is based on the consistency of the rice paste and differentiates among varieties with high amylose content. The test separates high-amylose-rices into three categories:

1. Very flaky rices with hard gel consistency (length of gel, 40 mm or less);
2. Flaky rices with medium gel consistency (length of gel, 41 to 60 mm); and
3. Soft rices with soft gel consistency (length of gel, more than 61 mm). Typical gel consistency ratings are shown in Figure 5.

STEPS FOR THE GEL CONSISTENCY TEST

Make certain that all the samples are stored in the same room for at least 2 days so that the moisture content is similar. Place 10 whole milled rice grains in the Wig-L-Bug amalgamator and grind for 40 seconds to give a fine flour (100 mesh).

One hundred mg (±1 mg at 12% moisture) of powder is weighed in duplicate into the culture tubes (13 × 100 mm). Hard, medium and soft gel rice varieties are included as checks. 0.2 ml of 95% ethyl alcohol containing 0.025% thymol blue (alcohol prevents clumping of the powder during alkali gelatinization, while thymol blue imparts color to the alkali paste to make the gel front easier to read) are added. 2.0 ml of 0.2N

KOH is added. Contents are mixed using a Vortex Genie mixer with speed set at 6. The test tubes are covered with glass marbles (to prevent steam loss, and to reflux the samples). The samples are cooked in a vigorously boiling water bath for 8 minutes, making sure that the tube contents reach 2/3 the height of the tube. The test tubes are removed from the water bath and let stand at room temperature for 5 minutes. The tubes are cooled in an ice-water bath for 20 minutes and laid horizontally on a laboratory table lined with millimeter graphing paper. The total length of the gel is measured in mm from the bottom of the tube to the gel front.

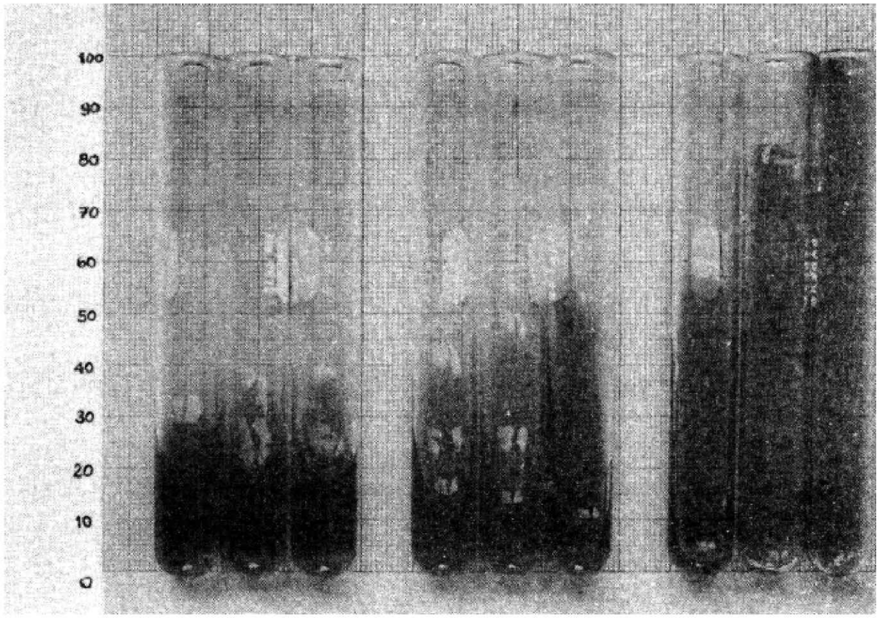

Fig. 5. Typical gel consistency values of milled rice. Left to right: hard, medium and soft.

Grain Elongation

Some varieties expand more in size than others upon cooking. Lengthwise expansion (Figure 6) without increase in girth is considered a highly desirable trait in some high-quality rices. Basmati rices of India and Pakistan, Bahra of Afghanistan, Domsiah of Iran, Bashful of Bangladesh, and D25-4 from Myanmar elongate 100% upon cooking.

This characteristic is being incorporated into improved germplasm. Evaluation for this characteristic commences with the F3 generation. Only the lines originating from crosses involving the parents having this trait are evaluated. Grain elongation appears to be a quantitative trait. Preliminary experience indicates that only a few hybrid lines approach the parents in degree of elongation. The method of Azeez and Shafi (1966) is used for evaluating the degree of elongation.

Procedure

The elongation test consists of measuring 25 whole milled kernels which are soaked in 20 ml of distilled water for 30 minutes. The samples are placed in a water bath and the temperature is maintained at 98°C for 10 minutes. The cooked rice is transferred to a petri dish lined with filter paper. Ten cooked whole grains are selected and measured in a photographic enlarger. The proportionate elongation is the ratio of the average length of cooked rice grains to the average length of raw rice grains.

Aroma

Scented or aromatic rice is preferred in some areas of Asia and draws a premium price in certain specialty markets. The Middle East consumers prefer rices with strong aroma. They feel that rice without a distinctive aroma is like food without salt. For consumers in Europe, a trace of aroma is an objectionable trait, because for them any scent signals spoilage and contamination (Efferson, 1985).

Most of the high-quality preferred varieties in major rice growing countries are aromatic. Examples are the Basmati rices of India and Pakistan,

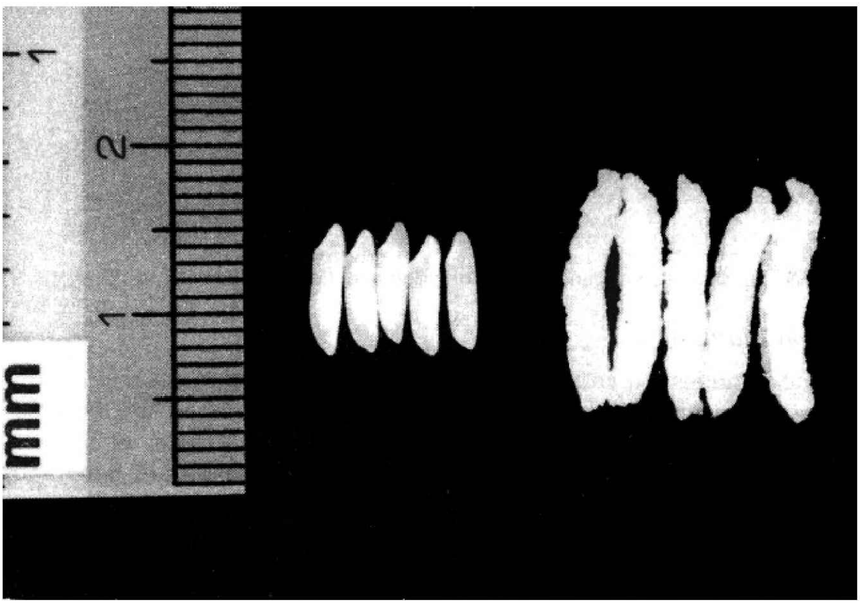

Fig. 6. Grain elongation of Basmati 370. Left: raw rice; right: cooked rice

Dulhabhog of Bangladesh, Khao Dawk Mali and Leuang Hawn of Thailand, Azucena and Milfor of the Philippines, Rojolele of Indonesia, Sadri varieties of Iran, Barah of Afghanistan and Della of the United States. These are characterized by long slender grains, intermediate amylose, intermediate gelatinization temperature, high elongation ratio and strong aroma.

A simple laboratory technique to evaluate rices for presence of aroma was developed at IRRI (1971).

One gram of freshly harvested milled rice is placed into centrifuge tube (50 ml round bottom). About 20 ml distilled water is added. The tubes are then covered with aluminum foil. The samples are placed in a boiling water bath for 10 minutes. The cooked samples are allowed to cool and the presence of aroma is determined for every sample. Brown rice may also be used with the cooking time increased to 30 minutes. The samples are scored as strongly aromatic, moderately aromatic, slightly aromatic and non aromatic. A strongly scented variety is used as check for comparison.

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Chapter 4

Chemistry and Biochemistry of Aroma in Scented Rice

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INTRODUCTION

Rice is a major food commodity throughout the world. Different cultures have preference for different types of rice. Scented rice or aromatic rice is popular in Asia and has gained wider acceptance in Europe and the United States. Because of their aroma, flavour and texture, aromatic varieties command a higher price in the rice market than do the non-aromatic rice varieties. The major far-eastern aromatic rice variety is ‘Basmati’, while the major American aromatic rice variety is ’Della’. It is estimated that there are over 300 aromatic rice varieties that have been recognized, although the use and production of these varieties are limited. Plant breeders are concerned that many of the minor scented varieties will be lost because of low productivity and poor market support (Singh et al., 1997). Because of the economic and culture impact of aromatic rice and need to enhance their productivity without sacrificing their quality traits, plant breeders and food chemists have been interested in determining the volatile compounds associated with aromatic rice.

VOLATILE COMPOUNDS PRESENT IN RICE

The volatiles in rice are normally determined by collecting the volatiles, separating the compounds by gas chromatography and then identifying the compounds by gas chromatography mass spectrometry (GC MS). Bullard and Holguin (1977) ground raw rice (California Brown Pearl Rice) to 40-mesh and then the ground rice was heated at 50°C for 4 h during which time the volatiles were collected. They identified 70 compounds and detected another 30 compounds (Table 1). However, from an odour point of view, they found that no individual compound had the characteristic aroma of uncooked rice.

Table 1. Compounds associated with volatile aroma of unprocessed (raw) rice[a]

acetaldehyde	o-xylene	2-nonanone
acetone	2-acetylfuran	nonanal
ethanol	*a*-pinene	2,4-octadienal
2-methylpropanal	2-heptenal	1,2-dimethyl-3-ethylbenzene
1-propanol	*n* -propylbenzene	1,2,4,5-tetramethylbenzene
2-butanone	1-ethyl-4-methylbenzene	1,2,3,5-tetramethylbenzene
butanal	benzaldehyde	2-nonenal
3-methylbutanol	1,3,5-trimethylbenzene	1,2,3,4-tetramethylbenzene
2-methylbutanal	6-methyl-5-hepten-2-one	decanone
benzene	2-octanone	naphthalene
3-penten-2-one	2-n-pentylfuran	decanal
2-pentanone	octanal	2,4-nonadienal
pentanal	1,2,4-trimethylbenzene	2-decenal
2,5-dimethylfuran	2,4-heptadienal	2-undecanone
2-methylpentanal	d ^{3} carene	2-methylnaphthalene
toluene	1,2,3-trimethylbenzene	2,4-decadienal
2-hexanone	*p* -cymene	1 -methylnaphthalene
hexanal	*trans* - b -methylstyrene	phenylacetaldehyde
2-hexenal	*p* -diethylbenzene	2-dodecanone
ethylbenzene	2-octenal	2-ethylnaphthalene
p-xylene	*m* -diethylbenzene	2-dodecenal
m-xylene	1,3-dimethyl-5-ethylbenzene	18 unidentified ketones
2-heptanone	*o* -diethylbenzene	8 unidentified alkylbenzenes
heptanal	*p* -methylbenzaldehyde	3 unidentified aldehydes
2-butylfuran	1,3-dimethyl-4-ethylbenzene	2 unidentified furans
2,4-hexadienal	1,4-dimethyl-2-ethylbenzene	

[a] Bullard and Holguin (1977).

The volatile compounds from cooked rice were analyzed by Yajima et al., (1978). They found the isolated volatile fraction represented 4.8 ppm by weight of the cooked rice. Of the volatile weight, 66 per cent was in the acid fraction, 33 per cent in the neutral fraction and 1 per cent in the basic fraction. They identified over 100 compounds, which included 13 hydrocarbons, 13 alcohols, 16 aldehydes, 14 ketones, 14 acids, 8 esters, 5 phenols, 3 pyridines, 6 pyrazines and 8 other compounds (Table 2). Obata and Tanaka (1965) identified hydrogen sulfide, ammonia and carbon dioxide in the volatiles of cooked rice. Yasumatsu et al. (1966a) and Ayano and Furuhashi (1970) detected acetaldehyde, propanal, 2 butanone, pentanal and hexanol in their analysis of rice volatiles (Table 2). Kato et al. (1983) evaluated the influence of parboiling on volatiles of cooked rice with *japonica* and *indica* rice varieties. Parboiling of rice resulted in a decrease of unbound lipid and free fatty acids in milled rice. It increased the free phenolic levels from 300-400 to 900-1200 μg/100 g. Using headspace analysis, they identified 29 volatiles (Table 2), however they did not find any distinguishing differences between the two rice varieties. Tsuzuki et al. (1980) evaluated the effect of milling on cooked rice aroma. A total of 40 compounds were identified. The highest volatile content was in the 92 per cent milled rice. They concluded that the outer surface layers of rice play an important role in the formation of cooked rice odour. Maga (1984) and Tsugita (1985-1986) indicated that more than 100 aroma components have been identified in cooked non-aromatic rice. The total analysis of raw and cooked rice volatiles suggested a number of aromatic compounds were involved in the aroma of rice. However, none of the identified individual compound has been found to have the characteristic aroma of raw or cooked rice. Therefore, it can be concluded that aroma in rice is formed by a blend of various volatiles.

VOLATILE COMPOUNDS IN SCENTED RICE

Tsuzuki et al. (1981) and Buttery et al. (1983b) analysed volatiles of cooked scented rice. Over 114 compounds were reported (Table 3). Traditional rice had higher amounts of 4-vinylphenol, 1-hexanol and 1-hexanal but lower amounts of indole as compared to scented rice. Scented rice had an unidentified compound and *a*-pyrrolidone, which was not present in traditional rice (Table 3). However, none of the individual compound identified had the characteristic odour of cooked scented rice. Buttery et al. (1988) determined that the major contributors to the rice odour in California long grain rice (non-aromatic rice) were 2-acetyl-1-pyrroline, (*E,E*)-2,4-decandienal, nonanal, hexanal, (*E*)-2-nonenal, octanal, decanal, 4-vinyl-guaiacol and 4-vinylphenol. Buttery et al. (1983a) analysed 2-acetyl-1-pyrroline in the atmospheric steam volatile concentrate of different varieties of rice. The detection of this compound was only in cooked rice and not in raw rice; therefore, Tsugita (1995-96) suspected that this compound was generated during the cooking process. Yajima et al. (1979) analyzed cooked Kaorimai (scented rice) and found 105 compounds (Table 4). Suvamalatha et al. (1984) developed callus tissue from Basmati rice and compared the volatile compounds from regularly cooked Basmati

Table 2. Volatiles Associated with Cooked Rice

xylene [e]	2-decanone [f]
o -xylene [b]	6-methyl-5-hepten-2-one [e-g]
m -xylene [b]	6-methyl-3,5-heptadien-2-one [e]
p-xylene [b]	2-undecanone [e]
limonene [e]	2-pentadecanone [e]
p-cymene [e]	2-heptadecanone [e]
cumene [e]	2-nonadecanone [e]
pentadecane [e]	6,10,14-trimethylpentadecan-2-one [e]
hexadecane [e]	isophorone [e]
heptadecane [e]	acetophenone [e]
octadecane [e]	ethyl acetate [f]
nonadecane [e]	ethyl benzoate [e]
dodecane [d]	geranyl acetate [e]
naphthalene [e,f]	ethyl myristate [e]
methylnaphthalene [e]	methyl palmitate [e]
eicosane [e]	ethyl palmitate [e]
heneicosane [e]	ethyl stearate [e]
methanol [d]	ethyl oleate [e]
ethanol [d]	ethyl linoleate [e]
butanol [e]	pyridine [e]
3-methyl-l-butanol [e]	2-methylpyridine [e]
pentanol [e-h]	3-methylpyridine [e]
hexanol [d-h]	2-ethylfuran [f]
2-ethyl-4-methylpentan-1-ol [e]	2-pentylfuran [f-h]
heptanol [f-h]	pyrazine [e]
octanol [e,g,h]	2-methylpyrazine [e]
1-octen-3-ol [e-h]	2,3-dimethylpyrazine [e]
2-ethylhexanol [e]	2,5-dimethylpyrazine [e]
I-nonano [g,h]	2,6-dimethylpyrazine [e]
benzyl alcohol [e,g,h]	2,3,5-trimethylpyrazine [e]
linalool [e]	guaiacol [e]
2-phenylethyl alcohol [e]	phenol [e]
nerolidol [e]	*p*-cresol [e]
pentadecanol [e]	4virtylguiacol [e]
ethanal [a,d,f]	4-vinylphenol [e,g,h]
propanal [a,b,f]	caproic acid [e]
butanal [c,f,h]	caprylic acid [e]
2-methylpropanal [c,f]	nonanoic acid [e]
pentanal [a,b,d-h]	capric acid [e]
3-methylbutanal [e]	lauric acid [e]
hexanal [a,b,d-h]	tridecanoic acid [e]
heptanal [e-h]	myristic acid [e]
trans-2-hexenal [e-h]	pentadecanoic acid [e]
octanal [e-h]	palmitic acid [e]
trans-2-heptenal [e-h]	hexadecanoic acid [e]
nonanal [e-h]	stearic acid [e]
trans-2-octenal [e-h]	oleic acid
decanal [e-h]	linoleic acid [e]
trans-2-nonenal [e-h]	linolenic acide

(Contd.)

Table 2. *(Contd.)*

trans-2-decanal[e]	aniline [e]
trans-2-*cis*-4-decadienal[e]	BHT [e]
trans-2-*trans*–4deca-dienal[e-h]	quinoline[e]
2-nonanone[e-h]	benzothiazole[e]
furfural[e]	2,3-dimethyl-2-nonen-4-olide [f]
benzaldehyde[e-h]	indole[e]
phenylacetaldehyde[e-h]	diethyl phthalate[e]
2-propanone [a,b,d,f,g]	dibutyl phthalate[e]
trans-3-penten-2-one[e]	benzene [f]
2-heptanone[e-h]	toluene [f]
2-octanone[e-h]	ethylbenzene[f,h]
3-octanone[e]	6-methyl-5-hepten-2-one[h]

[a] Yasumatsu et al. (1966a). [b] Yasumatsu et al. (1966b). [c] Endo et al. (1977). [d] Legendre et al. (1978). [e] Yajima et al. (1978). [f] Tsugita et al. (1980). [g] Tsugita et al. (1983). [h] Kato et al. (1983).

Table 3. Compounds associated with the volatile aroma from scented rice

methanal[a]	2,4-nonadienal [c]
ethylene[a]	naphthalene [c]
ethanal [a,b]	carvone [c]
ethyl acetate [c]	n-heptadecane [c]
ethanol[c]	citral[c]
hydrogen sulfide [d]	benzyl acetate [c]
dimethyl sulfide[d]	*trans*-2-*cis*-4-decadienal[c]
dimethyl disulfide[d]	nicotine [c]
methyl mercaptan [d]	*n*-octadecane [c]
n-butyl mercaptan [d]	*trans*-2-*trans*-edecadienal[c]
propanal[a,b,e,f]	2-tridecanone [c]
2-propanone[a-b]	geranyl acetone [c]
1-butanal[a]	b -phenylethyl alcohol [c]
2-butanone [a]	quinoline [c]
1-pentanal[a,c,e,f]	*n*-nonadecane[c]
1-hexanal[a,b,c,e,f]	benzothiazole [c]
n-nonane[c]	1-dodecanol[c]
n- decane[c]	*y*-nonalactone [c]
n-butyl acetate [c]	phenol [c]
1-butanol[c]	2-pentadecanone[c]
2-heptanone[c]	*n*-eicosane[c]
xylene[c]	a -pyrrolidone[c]
1-heptanal[c]	*y*-decalactone[c]
d-limonene[c]	*n* -heneicosane[c]
pyridine[c]	6,10,14-trimethyl-
2-methylpyridine [c]	pentadecan-2-one[c]
n-dodecane[c]	*y*-undecalactone [c]
ethyl caproate[c]	*n* -docosane [c]
2-pentylfuran[c]	methyl palmitate [c]
n-pentanal[c]	ethyl palmitate[c]
4-methylpyridme[c]	farnesol[c]
cyclohexanone[c]	tricosane[c]
1-octanal [c]	a-hexylcinnamic aldehyde[c]

(Contd.)

Table 3. *(Contd.)*

3-methylpyridine [c]	diethyl phthalate [c]
trans-2-heptenal [c]	4-vinylphenol [c]
methylheptenone [c]	farnesyl acetone [c]
I-hexanol [c]	*n*-tetracosane [c]
I-nonanal [c]	indole [c]
trans-2-hexenol [c]	methyl stearate [c]
n-tetradecane [c]	methyl oleate [c]
trans-2-octenal	ethyl oleate [c]
benzyl alcohol [c]	*n*-pentacosane [c]
trans-finalool oxide [c]	methyl linoleate [c]
I-octen-3-ol [c]	ethyl linoleate [c]
2-heptanol [c]	dibutyl phthalate [c]
cis-linalool oxide [c]	myristic acid [c]
menthone [c]	palmitic acid [c]
2,4-heptadienal [c]	caproic acid [c]
3-vinylpyridine [c]	2-ethylcaproic acid [c]
2-ethylhexanol [c]	heptanoic acid [c]
l-decanal [c]	capryric acid [c]
n-pentadecane [c]	nonanoic acid [c]
benzaldehyde [c]	furoic acid [c]
trans-2-nonenal [c]	succinic acid [c]
linalool [c]	capric acid [c]
I-octanol [c]	lauric acid [c]
2-undecanone [c]	tridecanoic acid [c]
n-hexadecane [c]	pentadecanoic acid [c]
n-undecanal [c]	stearic acid [c]
methyl benzoate [c]	oleic acid [c]
phenylacetaldehyde [c]	linoleic acid [c]
trans-2-decenal [c]	nonadecanoic acid [c]
menthol [c]	eicosanoic acid [c]
α-terpineol [c]	2-acetyl-l-pyrroline [g,h]

[a] Tsuzuki et al. (1975b). [b] Tsuzuki et al. (1977). [c] Yajima et al. (1979). [d] Tsuzuki et al. (1978). [e] Tsuzuki et al. (1981). [f] Tsuzuki and Tanaka (1981). [g] Buttery et al. (1982). [h] Buttery et al. (1983b).

rice and found the compounds to be very similar (Table 5). However, they did not detect 2-acetyl-1-pyrroline in the callus or in the cooked rice. Perhaps their detection method was not sensitive enough.

Widjaja et al. (1996) did a comparative study on volatile components of non-fragrant and fragrant rice. They identified 70 compounds (Table 6) and gave odour description for most of them. The major components were alkanals, alk-2-enals, alka(E)-2,4-dienals, 2-pentylfuran, 2-acetyl-l-pyrroline and 2-phenylethanol, but they felt that other compounds contributed to the total aroma profile. Non-fragrant rice contained more n-hexanal, (E)-2-heptanal, 1-octen-3-ol, n-nonanal, (E)-2-octenal, (E)-2-(E)-4-decadienal, 2-pentylfuran, 4-vinylguaiacol and 4-vinylphenol than the fragrant rice (Table 7). Basmati had the highest amount of 2-phenylethanol

Table 4. Volatile flavor components from cooked Kaorimai (scented rice, *O. sativa japonica*)

Rt. MS Peak No.	Compound	GC Rt.	GC MS	Rt. MS Peak No.	Compound	GC Rt.	GC MS
4	Ethyl acetate		+	79	*trans*-2-Decenal	+	+
5	Ethanol		+	80	Menthol	+	+
6	*n*-Nonane		+	80'	2-Acetylthiazole [b]		+
7	*n*-Pentanal		+	84	*a*-Terpineol	+	+
11	*n*-Decane		+	84'	2,4-Nonadienal		+
13	*n*-Butyl acetate		+	87	Naphthalene	+	
14	*n*-Hexanal		+	89	Carvone	+	+
19	*n*-Butanol		+	89'	*n*-Heptadecane		+
21	n-Heptanone		+	91	Citral	+	+
21'	Xylene		+	91'	Benzyl acetate	+	+
22	*n*-Heptanal		+	92	2-Undecena [b]	+	
22'	*d*-Limonene		+	93	*trans*-2, *cis*-4-Decadienal	+	+
24	Pyridine		+	93'	Nicotine	+	+
27	2-Methylpyridine	+	+	98	*n*-Octadecane	+	
27	*n*-Dodecane		+	99	*trans*-2,tran-4-Decadienal	+	+
28	Ethyl caproate		+	100	2-Tridecanone	+	
28'	2-Pentylfuran	+	+	102	Geranyl acetone	+	+
30	*n*-Pentanal		+	109	b-Phenylethyl alcohol	+	+
32	Cyclohexanone		+	110	Quinoline	+	+
33	*n*-Octanal		+	111	*n*-Nonadecane	+	
35	3-Methylpyridine	+	+	112	Benzothiazole	+	+
38	*trans*-2-Heptenal	+	+	118	*n*-Dodecanol		+
40	Methylheptenone		+	119	Phenol	+	
42	*n*-Hexanol		+	120	2-Pentadecanone		+
46	*n*-Nonanal		+	120'	*n*-Eicosane		+
48	*trans*-2-Hexenol	+	+	121	*n*-Pentadecanal[b]		+
48'	n-Tetradecane	+		123	a-Pyrrolidone	+	+
50	*trans*-2-Octenal	+	+	126	*y*-Decalactone	+	+
52	Benzyl alcohol	+	+	129	*n*-Heneicosane	+	
52'	*trans*-Linalool oxide	+	+	131	6, 10, 14-Trimethylpenta-		
53	I-Octen-3-ol	+	+		decan-2-one	+	+
54	2-Heptanol		+	137	*y*-Undecalactone	+	+
55	*cis*-Linalool oxide	+	+	142	*n*-Docosane		+
56	Menthone	+	+	143	Methyl palmitate		+
57	2,4-Heptadienal		+	144	2-Heptadecanone[b]		+
57'	3-Vinylpyridine	+	+	148	Ethyl palmitate		+
59	2-Ethylhexanol	+	+	149	Farnesol	+	+
61	*n* Decanal		+	150	Tricosane		+
63	*n*-Pentadecane		+	152	a-Hexylcinnamic		
65	Benzaldehyde	+	+		aldehyde	+	+
66	*trans*-2-Nonenal	+	+	153	Diethyl phthalate		+
68	Linalool	+	+	155	4-Vinylphenol	+	+
69	*n*-Octanol		+	156	Farnesyl acetone	+	+
71	Methylheptadienone[b]	+		156'	*n*-Tetracosane		+
73	2-Undecanone		+	157	Indole	+	+
74	*n*-Hexadecane		+	158	Methyl stearate	+	
75	*n*-Undecanal		+	159	2-Nonadecanone[b]	+	
75'	Methyl benzoate	+	+	159'	Methyl oleate	+	
76	Phenylacetaldehyde	+	+	161	Ethyl oleate	+	

(Contd.)

(Contd.)

Rt. MS Peak No.	Compound	GC Rt	GC MS	Rt. MS Peak No.	Compound	GC Rt.	GC MS
161'	*n*-Pentacosane		+	165	Myristic acid	+	
161''	Methyl linoleate	+		166	Palmitic acid	+	
162	Ethyl linoleate	+		167	Caproic acid	+	
164	Dibutyl phthalate	+					

[a] In cases where two peaks are overlapped, peak numbers are marked with primes(').
[b] Tentatively identified
Data from Yajima et al., 1979

Table 5. Volatile flavour components in Basmati rice and callus

Sample	RT	Callus	Rice	Kovat's index [a]
Hydrocarbons				
1	5 . 15	Decane	Decane	1262
2	5 . 58	Dodecane	Dodecane	1200
3	6 . 52	Tridecane	Tridecane	1300
4	7 . 14	Tetradecane	Tetradecane	1400
5	9 . 36	Pentadecane	Pentadecane	1500
6	12 . 57	Hexadecane	Hexadecane	1600
7	14 . 03	Undecane	Undecane	1100
8	14 . 37	–	Naphthalein	–
9	16 . 03	Octadecane	Octadecane	1800
10	18 . 40	–	Methyl naphthalein	–
11	19 . 59	Nonadecane	Nonadecane	1900
12	20 . 23	Eicosane	Eicosane	2000
13	26 . 35	Heneicosane	Heneicosane	–
14	30 . 15	Docosane	Docosane	–
15	36 . 43	Pentacosane	Pentacosane	–
16	40 . 52	Hexacosane	Hexacosane	–
17	45 . 28	Heptacosane	Heptacosane	–
18	51 . 09	Octacosane	Octacosane	–
19	58 . 46	Nonacosane	Nonacosane	–
Ketones				
20	6 . 16	–	2-Octanone	–
21	21 . 52	–	2-Pentadecanone	–
Alcohols				
22	10 . 50	Decanol	Decanol	1186
23	12 . 10	–	2-Nonenol	1157
24	32 . 35	Hexadecanol	Hexadecanol	–
25	37 . 45	Octadecanol	Octadecanol	–
Aldehydes				
26	23 . 23	Pentadecanol	Pentadecanol	1373
27	17 . 00	–	Decadienal	–
28	5 . 23	–	Hexanal	780
Esters				
29	79 . 54	–	Di-iso-octyl phthalate	–

[a] Because of the non-availability of the high-molecular-weight hydrocarbon the KI of other compounds could not be calculated.
Data from Suvarnalatha et al., 1994.

Table 6. Identify and odour description of volatile components of cooked rice.

Compound	Odour Description
n -Decane	
Toluene	Ethereal
2-Methyl-2-pentanol [a]	
n-Hexanal	Green, grass like
2-Hexanone	Fruity
Pyridine	Pungent
2-Hexanol[a]	
n-Pentanol	Fusel oil-like
d-Limonene	Fresh, sweet
Methyl caproate	Fruity
2-Pentylfuran	Nutty, bean
2,6-Dimethylpyridine [a]	
n -Heptanal	Fruity, fatty
2-Heptanone	Fruity, floral
(*E*)-2-Hexenal	Green
n -Hexanol	Herbaceous
Methyl heptanoate	Green, fruity
Dodecamethyl-cyclohexasiloxane [a]	
2-Acetyl-l-pyrroline[b]	Sweet, pleasant
Collidine	
n-Octanal	Slightly fruity
6-Methyl-5-hepten-2-one	Banana-like
(*E*)-2-Heptenal	Herbaceous
1-Octen-3-ol	Raw mushroom
n -Heptanol	Woody, sweet
(E)-2,(E)-4-Hexadienal[a]	Green, floral
n-Tetradecane	
n-Nonanal	Floral, fruity
2-Nonanone	Fruity, herbaceous
(E)-3-octen-2-onea	Green, fruity
Benzaldehyde	Nutty, bitter
(E)-2-Octenal	Green, fatty
n -Octanol	Fruity, floral
(*E*)2,(E)-4-Heptadienal	Hay-like
n -Pentadecane	
2,5-Cyclohexadiene-1,4-dione[a]	
1-Ethylcyclohexene [a]	
n -Decanal	Sweet, waxy, floral
2-Decanone	Orange-like
Camphor [a]	Slightly minty
(*E*)-2-Nonenal	Fatty, woody
2-Methylbenzaldehyde [a]	Mild floral, sweet
n -Nonenal	Floral, citrus
Methyl caprate	
n -Hexadecane	
Acetophenone	Sweet, floral
Phenylacetaldehyde	Sweet (dilute)

(Contd.)

Table 6. *(Contd.)*

Compound	Odour Description
Undecanal	Fresh, lemon-like
2-Undecanone	Fruity, floral
Naphthalene	
(*E*)-2-Decenal	Waxy
(*E*)-2,(*E*)-4-Nonadienal	Waxy
Benzyl alcohol	Slightly sweet
2-Phenylethanol	Sweet, floral
(*E*)-2-Undecenal	Fatty, sweet
Butyl benzoate[a]	Mild floral
(*E*)-2,(*E*)-4-Decadienal	Fatty, waxy
2-Tridecanone	Oily, nutty
Dodecanol	
n-Eicosane	
2-Pentadecanone	
4-Vinylguaiacol [b]	Unpleasant
6,10,14-Trimethylpentadecan-2-one	
4-Vinylphenol[b]	Unpleasant
n -Docosane	
Indole	Floral
Methyl stearate	
Diethyl phthalate	
Methyl oleate	
Methyl linoleic	
1,2-benzenediol [a]	

[a] Not previously reported in cooked rice.
[b] Tentatively identified.
Data based on a review by Tsugita (1985-1986).

and the lowest content of n-hexanal (Table 7). The major volatile components for the scented cultivars were: Goolarah (indole, 2 acetyl-l-pyrroline), YRF9 (2-acetyl-l-pyrroline), Jasmine (indole, 2-acetyl-l-pyrroline) and Basmati (2-phenylethanol, 2-acetyl-1-pyrroline). The non-fragrant rice (Pelde) contained much more n-hexanal, (E)-2-heptenal, 1-octen-3-01, (E)-2-octenal, n-nonanal, (E)-2,(E)-4-decadienal, 2-pentylfuran, 4-vinylguaiacal and 4-vinylphenol than fragrant rice (Table 7). Kim (1991) identified 16 hydrocarbons, 15 alcohols, 16 aldehydes, and ketones, 4 acids and 10 other miscellaneous compounds in aromatic rices. The most common hydrocarbon is paraffin, whereas most common aromatic (alcohols) compounds included n-pentanol, n-heptanol and n-nonanal. The n-butanol and n-hexanol were detected in aromatic rices only after cooking.

Table 7. Concentration of major volatile compounds in various types of cooked rice [a]

Compound	Jasmine	Basmati	Goolarah	YRF9	Pelde
n-Hexanal	1818	829	1498	1396	2038
2-Hexanone	7	13	7	18	7
Pyridine	tr	tr	11	9	28
n-Pentanol	152	130	82	104	160
2-Pentylfuran	98	65	118	121	274
n-Heptanal	78	111	94	102	132
2-Heptanone	94	204	70	92	117
(*E*)-2-Hexenal	161	598	193	233	294
n-Hexanol	78	41	23	60	48
Methyl heptanoate	tr	tr	18	21	26
2-Acetyl-l-pyrroline[b]	c	c	691	670	15
n-Octanol	c	c	58	83	105
6-Methyl-5-hepten-2-one	28	10	32	34	58
(*E*)-2-Heptenal	99	58	108	97	208
l-Octen-3-ol	87	46	57	75	111
n-Heptanol	32	54	17	30	32
n-Nonanal	158	125	210	244	429
2-Nonanone	6	11	4	tr	5
Benzaldehyde	136	142	78	52	126
(*E*)-2-Octenal	113	55	91	98	192
n-Octanol	49	41	33	52	56
(*E*)-2,(*E*)-4-Heptadienal	c	c	13	14	26
n-Decanal	26	16	24	36	45
(*E*)-2-Nonenal	40	24	36	41	67
n-Nonanol	19	c	14	16	20
Acetophenone	33	20[d]	24	48	44
Phenylacetaldehyde	76	25	17	23	21
n-Undecanal	20	23	5	6	6
2-Undecanone	11	c	8	9	14
(*E*)-2-Decenal	20	19	20	30	34
(*E*)-2,(*E*)-4-Nonadienal	18	8	9	6	21
2-Phenylethanol	195	703	316	217	353
(*E*)-2,(*E*)-4-Decadienal	50	16	77	97	150
2-Tridecanone	tr	tr	tr	tr	2
2-Pentadecanone	67	67	58	95	99
4-Vinylguaiacol [b]	29	109	81	84	119
4-Vinylphenol [b]	67	47	99	72	108
Indole [b]	253	91	168	88	102

Data from Widjaja et al. 1996.
[a] Calculations have been divided by the compound's relative recovery factor
[b] Tentatively identified
[c] Coeluted peaks
tr = trace amount

MAJOR VOLATILE COMPOUND ASSOCIATED WITH AROMATIC ODOUR

Buttery et al. (1982) isolated and identified 2-acetyl-l-pyrroline as an important compound contributing to the aromatic odour. They suggested that 2-acetyl-l-pyrroline was a major contributor to the popcorn-like aroma in several of the Asian aromatic rice varieties. Odour quality evaluation of 2-acetyl-l-pyrroline was described as popcorn-like, and the evaluation order of the amount of popcorn-like odour in 10 different rice varieties ranked them in general order of the concentration of this compound (Tsugita, 1995-96). Orientals normally describe the aroma of the aromatic rice as being pandan-like. Paule and Powers (1989) reported 2-acetyl-l-pyrroline in Basmati 370, an aromatic rice from Pakistan, and positively correlated the 2-acetyl-l-pyrroline concentration with the characteristic aroma of aromatic rice. Lin et al. (1990), Ahmed et al. (1995), and Tanchotikul and Hsieh (1991) confirmed the reports of Buttery et al. (1983a) and Paule and Powers (1989) that 2-acetyl-1-pyrroline was the characteristic odour of aromatic rice varieties. It is a common practice in Asia to include Pandan (*Pandanus amaryllifolius*) leaves in cooking non-aromatic rice to give it an aroma. Buttery et al. (1983b) analysed Pandan leaves and found that the major volatile component was 2-acetyl-1-pyrroline. They found a high correlation between the 2-acetyl-l-pyrroline in Pandan leaves and aromatic rice. The concentration of 2-acetyl-1-pyrroline in Pandan leaves was 10 times greater than aromatic rice and 100 times greater than non-aromatic rice. The concentration of 2-acetyl-1-pyrroline was lower in aged aromatic rice. Kim (1999) reported that hydrocarbon compounds were not significantly different between aromatic and non-aromatic rices but aromatic rice had higher levels of alcohol (mainly n-pentanol, l-octen-3-ol, menthol and estragol), aldehydes and ketones (e.g. n-pentanal, n-heptanal and n-nonanal), acids and other compounds. Aromatic rice had 15 times more 2-acetyl-1-pyrroline than non-aromatic rice.

SYNTHESIS OF 2-ACETYL-1-PYRROLINE

Laksanlamal and Ilangantileke (1993) identified 2-acetyl-l-pyrroline by GC-MS and NMR and by comparison of the spectra of synthesised 2-acetyl-l-pyrroline. Hofmann and Schieberle (1998) developed a method for synthesizing 2-acetyl-lpyrroline and 2-acetyltetrahydropyridine. The four step reaction sequence starts with the N-shielded cyclic a -amino acids, L-proline and pipecolinic acid. They are converted into the N-shielded 2-acetyl derivatives. The shielding groups are removed and the compounds oxidised to yield 2-acetyl-l-pyrroline and 2-acetyltetrahydropyridine.

CONCENTRATION OF 2-ACETYL-1-PYRROLINE IN AROMATIC RICE

Tanchotkul and Hsieh (1991) quantified the concentration of 2-acetyl-1-pyrroline in several aromatic rice varieties Della (76.2 ppb), Basmati 370

(87.4 ppb) and Jasmine (156.1 ppb). A normal reaction to this data is to conclude that the concentration in the ppb ranges would be too low to be the major aroma compound of aromatic rice. Buttery et al. (1983a) determined the concentration for 10 varieties of rices (Table 8). The range of concentration was from 6 ppb to 90 ppb with the milled rice. The unmilled rice (brown rice) had concentrations of 2-acetyl-pyrroline from 100 ppb to 200 ppb. It could be possible that the surface layer constituents of rice grain play an important role in the formation of cooked rice aroma. A difference of almost 10 fold existed between the Texas long grain variety and Basmati 379. An odour threshold of 2-acetyl-1 pyrroline was determined using a trained panel of 16 judges. The panel could consistently detect 7 ppb. The threshold level appeared to be 0.1 ppb (Table 9). It is

Table 8. Concentration of 2-acetyl-1-pyrroline found in cooked rice varieties in terms of dry weight of rice.

	2-acetyl-1-pyrroline concn, ppm [a]	
Variety	nulled rice	brown nce
Malagkit Sungsong	0.09	0.2
IR841-76-1		0.070.2
Khao Dawk Mali 105	0.07	0.2
Milagross	0.07	
Basmati	0.06	0.17
Seratus Malam	0.06	
Azucena	0.04	0.16
Hieri	0.04	0.1
Texas Long Grain	<0.008	
Calrose	<0.006	

[a] ppm = parts (weight) of compound per million (10^6) parts of rice (dry weight).
Data from Buttery et al., 1983.

Table 9. Odor threshold determination of 2-acetyl-1-pyrroline

Concn parts/10^9 parts of water	% Correct judgements	Total no judgments
7	100	16
3.5	94	16
0.9	94	16
0.35	95	19
0.18	86	52
0.09	75	81
0.045	65	113
0.023	53	94

Data from Buttery et al., 1983.

amazing that the human nose can detect such low levels. The result would suggest that it takes very little 2-acetyl-1-pyrroline to contribute to the odour of aromatic rice. Paule and Powers (1989) used panels to distinguish four aromatic rice, two non-aromatic rice varieties. It was interesting that the non-volatile characteristic of stickiness (amylose) was the dominant distinguishing trait to distinguish the different rice varieties. To evaluate the odour of the volatiles, the panel members sniffed the effluent of peaks separated by gas chromatography. The peak containing 2-acetyl-l-pyrroline was highly correlated with the odour of aromatic rice. Hexanal was negatively correlated with the odour of rice.

GENETICS OF RICE AROMATIC AROMA

Plant breeders (Bollich, 1989) in the US developed a Jasmine type of aromatic rice (Jasmine 85) and the variety Della (Jodon and Sonnier, 1973). When Thai taste panels evaluated Jasmine 85, it was criticised for its dull off-white colour and less pronounced aroma (Rister et al., 1992). However, Lin et al. (1990) determined that the aromatic variety, Della, contained a higher level of 2-acetyl-l-pyrroline than the imported Thai Jasmine variety. This suggested that the aroma is more complex than one compound.

The genetics of the aroma characteristic is somewhat complex. Berner and Hoff (1986) concluded that a single recessive gene controlled the aromatic nature of Della. This gene was located on chromosome 8 as determined by RFLP technology (Ahn et al., 1992). Several others (Ghose and Butany, 1952; Sood and Siddiq, 1978; Reddy and Reddy, 1987) suggested the aroma characteristic was a single recessive gene. In contrast, Kadam and Patankar (1983) results suggested a single dominant gene. Dhulappanavar and Mensinkai (1969) interpreted their result to indicate two dominant aroma genes that interacted in a duplicate or complimentary manner. Reddy and Sathyanarayanaiah (1980) concluded that there were three complementary recessive aroma genes. Dhulappanavar (1976) suggested there were four complementary recessive aroma genes. Pinson (1994) suggested that one of the reasons for the confusion over the aroma gene was that different rice cultivars were analysed. He looked at six cultivars to evaluate the type of aroma genes involved. Pinson (1994) found that Jasmine 85, A-301, Della-X and PI45917 each contained a single gene for aroma and that they were allelic. Amber and Dragon Eyeball 100 each contained two aroma genes, a novel gene plus one allelic to the gene in A-301, Della-Z, Jasmine 85 and PI 457917. Buttery et al. (1986) suggested that the difference between aromatic and non-aromatic rice was not the presence or absence of 2-acetyl-l-pyrroline but to a difference in the quantity of the chemical in the grain. Multiple alleles of a single aroma gene could produce slightly different alteration in the same enzyme that resulted in rice with different aromatic intensities.

MARKERS FOR AROMA GENE

Any breeding program needs an easy assay to follow the inheritance. Sood and Siddiq (1978) developed an assay for determining the scent from plant material by adding KOH to the plant sample, which released the aroma. Jin et al. (1996) used the RAPD technique to find a marker associated with the aroma gene. Ahn et al. (1992) used RFLP methods to tag the aroma gene. Mittal et al. (1995) evaluated 322 races and Basmati cultivar for aroma. They found 177 stocks had strong aroma and 28 had mild aroma. The characteristic for aroma was heterogeneous for 117 lines.

Because of the role of 2-acetyl-1-pyrroline in the aroma of aromatic rice, a patent has been taken out to use 2-acetyl-1-pyrroline to non-aromatic rice much like you would add a spice or flavouring to other foods to give the odour of aromatic rice (Buttery et al., 1985), although the aroma is probably due to a combination of different compounds. In addition, taste, texture, stickiness, whiteness, grain size and grain elongation after cooking are also factors in consumers acceptance.

CONCLUSION

There is no individual compound, which imparts pleasant odour to raw or cooked non-aromatic or aromatic rice. Probably it is a blend of various volatiles. Most volatiles recorded so far from cooked non-aromatic and aromatic rice are the same except for their relative proportion. Even 2-acetyl-1-pyrroline is present in both types of rice. Therefore, there is need to find out optimum proportions of volatile compounds forming the pleasant smell of aromatic rice.

In aromatic varieties pleasant aroma is not only associated with cooked rice. Quite often these varieties emit aroma in the field at the time of flowering. Chewing of immature grains is one of the method quite often used for the rapid identification of aromatic rice varieties in field. Aroma can be determined from leaves (Mittal et al., 1995). Whether volatile aromatic compounds released in field at the time of flowering differ from those released after cooking is an important question to be answered.

In addition to field factors (Singh et al., 1997; also see Chapter 11 of this volume) there are other factors like storage conditions, milling and processing methods, cooking methods, parboiling etc. which might influence the aroma. These factors must be standardised to harness maximum aroma from rice.

One of the major limitation in improvement of aromatic rice through breeding is the lack of a quantitative assay for the aroma. There is an urgent need to develop the method either based on relative concentration of different compounds or activity of some critical enzyme. More than

300 aromatic rices have been documented so far. However, chemical characterisation of aromatic compounds were attempted only in few popular long-grain varieties. There are a number of small grain varieties and land races like Bindli (Indian variety) which are far more aromatic than popular varieties. There is need to analyse these varieties for the chemical nature of aromatic volatiles and their relative proportion.

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Chapter 5

Genetics and Biotechnology of Quality Traits in Aromatic Rices

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INTRODUCTION

Grain quality has always been an important consideration in rice variety selection and development. Based on the survey of 11 major rice growing countries, Juliano and Duff (1991) concluded that grain quality is second only to yield as the major breeding objective. In the future, grain quality will be even more important once the very poor—many of whom depend largely on rice for their staple food—become better off and begin to demand higher quality rice (Juliano and Villareal, 1993). Aroma is an important quality characteristic of high-quality rices. In most countries aromatic rices command higher prices in the domestic market. In the international market, the aromatic Basmati and Jasmine rices command premium prices. However, the quality of rice demanded by one community may be completely unacceptable to another. For instance, the Middle East consumer prefers a long grain, well-milled rice with strong aroma; he feels that rice without a distinctive aroma is like food without salt. In contrast, the European community generally prefers a long grain rice with no scent; to them, any scent signals spoilage and contamination

(Efferson, 1985). However, even there the consumer's perception about aromatic rice is now fast changing.

Quality means much more than aroma alone, and depends on features such as amylose content (AC), gelatinization temperature (GT), gel consistency (GC), kernel length (L), breadth (B) and L/B ratio, kernel elongation after cooking (KLAC), etc. For planning a systematic breeding program for improvement of quality rices, an understanding of the nature of the inheritance of the quality attributes mentioned above is a pre-requisite. In this chapter, attempt has been made to review the current status of our understanding of the genetics and biotechnology of the aroma and other grain quality traits and to identify the gaps, for further study.

GENETICS OF QUALITY TRAITS

Aroma

Aromatic rices emit specific aroma in fields, at harvesting, in storage, during milling, cooking and eating (Gibson, 1976; Efferson, 1985). Aroma development is influenced by both genetic factors and environment. It is known that aroma is best developed when aromatic rices are grown in areas where temperature is cooler during maturity. Aroma is due to certain chemicals present in the endosperm. The biochemical basis of aroma was identified as 2-acetyl-l-pyrroline. The compound is known to be present in raw grain as well in plant. In addition to 2-acetyl-l-pyrroline, there are about 100 other volatile compounds, including 13 hydrocarbons, 14 acids, 13 alcohols, 16 aldehydes, 14 ketones, 8 esters, 5 phenols and some other compounds, which are associated with the aroma development in rice (see Chapter 4 of this volume).

Rice breeders have used various techniques to detect and evaluate scent in order to study the inheritance of scent in rice. These techniques have included chewing a few seeds from individual plants and noting the aroma (Dhulappanavar, 1976; Dhulappanavar et al., 1975), and cooking a sample of seeds from individual plant and noting aroma (Chowdhary and Ghosh, 1978; Ghose and Butany 1952; Kadam and Patankar 1938). The leaf tissue of scented plants has also been reported to contain the characteristic scent (Nagaraju et al., 1975; Sood and Siddiq 1978,1980).

It has been shown by Goodwin et al. (1994) that cultural, harvest, and post-harvest practices can affect the amount of 2-acetyl-l-pyrroline in a sample of aromatic rice. Further, the difference between aromatic and non-aromatic rice is not due to absence or presence of 2-acetyl-l-pyrroline but to a different quantity of the chemical in grain (Buttery et al., 1983, 1986). Thus, conversion of a non-aromatic rice to an aromatic one would require a modification of an existing metabolic pathway rather than the development of a new one. It could be hypothesized that aromatic rices have an altered enzyme that more effectively catalyzes a step in the biosynthesis of 2-acetyl-l-pyrroline. Multiple alleles of a single aroma gene, then, could produce slightly different alterations in the same enzyme resulting in rices with different aromatic intensities. Alteration at additional steps within the metabolic pathway could account for the presence of multiple aroma gene in rice. Since the component is known to be formed from a reaction of the amino acids, proline and ornithine with 2-oxopropanol, the release of the 2-acetyl-l-pyrroline from rice during the heating or cooking process, may also depend on the quantity or composition of protein or starch in the rice grain.

Inheritance of aroma has been reported to vary depending upon the materials used in the study. However, one thing is sure that scent is a highly heritable character as some of the lines derived from T142 (scented) x IR 20 (non-scented) cross, and some of the released high yielding aromatic rice varieties show strong scent.

A single dominant gene was reported to control aroma in rice by Jodon (1944), di or trigenic by Kadam and Patankar (1938), Nagaraju et al. (1975) and Reddy and Sathyanarayanaiah (1980). Dhulappanavar (1976) reported the involvement of four complimentary genes in control of scent, one of them showing linkage with a complimentary gene for red pigmentation in apiculus. Tripathi and Rao (1979) reported that scent was controlled by two dominant complimentary genes, *SK1* and *SK2,* and either of the two also produces moderate aroma. Further, these genes were independent of other genes controlling leaf sheath colour, ripening hull colour etc. Nagaraju et al. (1975) found the scent to be controlled by the simultaneous action of three dominant complimentary genes. They also suggested leaf analysis as the simplest and best method to analyze aroma. Polygenic inheritance has also been suggested for aroma in rice by Richharia et al. (1965).

However, most studies indicated involvement of a single recessive gene in the inheritance of aroma in rice (Sood and Siddiq, 1980; Shekhar and Reddy, 1981; Berner and Hoff, 1986; Bollich et al., 1992; Ali et al., 1993; Li et al., 1996; Li and Gu, 1997; Sadhukhan et al., 1997). Berner and Hoff (1986) reported monogenic recessive inheritance of scented character and suggested that the scent could be detected in half of a single seed by chewing the distal portion, while saving the portion of the seed with the embryo. Li et al., (1995) also found that the scented character of leaf tissue or seed was controlled by a single recessive gene. Of the 37 marker genes that they studied, 36 segregated independently of scented gene, the only linked gene was *V-8* (Virscent-8). The study confirmed that the gene for aroma was located on chromosome 8 of rice genome. Li and Gu (1997) also studied the inheritance and location of the aroma gene in rice cv.

Shenxiangjing, and found that the scent was controlled by a single nuclear recessive gene. Reciprocal crosses between scented varieties indicated that their genes were allelic. That the gene for aroma was located on chromosome 8 of rice was confirmed by the result of crossing WX (a scented variety) with trisomic lines derived from IR36, and WJ (also a scented variety) with translocation lines. Later, using RFLP technique, Ahn et al. (1992) mapped this gene to chromosome 8.

Reddy and Reddy (1987) also reported the control of aroma by a single recessive gene. Further, they found that the absence of a specific esterase isozyme was associated with the development of the scent character in rice. In scented F_2 segregants, and in the scented parental strain, a fast moving esterase isozyme (Rf-0.9) was missing whereas it was present in all the non-scented F_2 segregants. Huang and Zou (1992) found F_1 plants from all the reciprocal crosses to be non-aromatic indicating a recessive nuclear gene controlling aroma. The F_2 plants scent evaluation gave 3:1 (non-aromatic : aromatic) segregation confirming single recessive gene control of aroma in rice. Katare and Jambhale (1995) studied inheritance of aroma in four crosses involving Kasturi and Ambemohar-197 as scented and Jaya and Mahsuri as non-scented parents. In all the crosses, they found inheritance to be governed by a single recessive gene. Song et al. (1989) crossed four diploid aromatic varieties with three non-aromatic, and two similar cross combinations were made at autotetraploid level. All the F_1 plants of four autotetraploid reciprocal crosses and five diploid ones were non-scented, with the ratios of non-aromatic to aromatic 35:1 and 3:1, respectively. These results conclude that the inheritance of aroma is controlled by a recessive nuclear gene. In his study, on the inheritance of aroma in six rice cultivars, Pinson (1994) found lack of leaf aroma in aromatic x non-aromatic F_1 hybrids indicating the recessive nature of aroma in all studied cultivars. F_2 segregation ratios revealed that two varieties, Jasmine 85 and PI 457917, each contained a single gene for aroma, and the aromatic nature of the F_1 leaves from crosses with each other and with A-301 and Delta-X, revealed that the aroma genes in all four cultivars are allelic. However, Amber and Dragon Eyeball 100 each contain two aroma genes, and a novel gene plus one allelic to the gene in A-301, Delta—X_2, Jasmine 85 and PI 457917. The reduced aroma and off white color of milled rice of Jasmine 85 limit its marketability. Pinson (1994) argued that incoporation of the novel aroma gene from Amber/Dragon Eyeball 100 into a Jasmine 85 may potentially increase its marketability. Sadhukhan et al. (1997) reported that aroma in scented varieties Govindobhog and Kataribhog were allelic and controlled by a nuclear recessive gene.

Some other studies have shown involvement of more than one recessive gene in control of aroma. Siddiq (1983) reported three recessive genes, two of which were essential for the expression of aroma. Tsuzuki and Shimokava (1970) observed 13 : 3 (non-aromatic : aromatic) ratio in F_2 thereby indicating one gene for aroma and one inhibitor gene to be responsible for aroma development. These results were also confirmed on the basis of segregation in F_3 generation. Vivekanandan and Giridharan (1994) reported both monogenic and digenic recessive genes for the control of aroma depending on the genotypes used in the crossing for study. Geetha (1994) also reported two recessive genes, instead of one, controlling aroma in rice.

Based on a study of 50 recombinants F_8 inbred lines developed by single-seed-descent from the cross BG1 × Koshihikari, the genetics of scent and its association with several agronomic traits were worked out by Kato and Itani (1996). Sensory tests for grain scent segregation suggested that the difference in scent between BG1 and Koshihikari is controlled by a single recessive gene, which originated from a Chinese scented indica rice cultivar, Chang Hsian Tao, a parent of BG1. For every pair of characters, the correlation coefficient in the scented group was not different significantly from that in the non-scented group. They observed that since there was a wide overlap between the ranges of every trait in the scented and non-scented groups, no serious difficulty due to pleotropy or linked deleterious genes should be encountered when the rice scent gene is used in the breeding programs.

Bollich et al. (1992) tried to offer a scientific explanation to the contradictory reports on inheritance of aroma in rice as observed by various workers. They stated that aroma is generally recessive but it has been also reported to be dominant in inheritance, which is possibly because of the failure to recognize the effect of xenia, and the fact that aroma is a character specific to endosperm. Therefore, genetic ratios calculated from evaluation of multi-seed samples from F_1 and F_2 plants would be expected to vary depending upon the number of seeds in the sample. Since the endosperm is a product of sexual fertilization, it is one generation advanced from that of the plant on which it develops. Therefore, in case of a cross between aromatic and a non-aromatic rice genotype, the F_1 plant will be heterozygous for aroma, but the seed produced on F_1 panicles will segregate for aroma. In their study, Bemer and Hoff (1986) reported that when the individual seeds from F_1 plant were chewed and rated as scented or non-scented, the results showed that the seeds of F_1 plants were also segregating in a 3:1 (non-scented : scented) ratio. Aroma is expressed in the leaves as well as in the grains, but where aroma is recessive, only the plant that are homozygous recessive will be aromatic. In plant populations that are segregating for aroma, it is not possible to identify which plants are segregating and which are homozygous for aroma on the basis of grain samples, unless individual grains on a panicle are classified for aroma. Detection of aroma in individual grains is generally unreliable because of small size and because current methods of aroma detection are error-prone. Berner and Hoff (1986) stressed the importance of using blind controls as well as selecting plant materials and sample sizes that are appropriate for endosperm character like aroma where heterozygous plants are expected to produce both aromatic and non-aromatic seeds. Khush and Dela Cruz (1998) proposed that aroma is a quantitative trait as segregants with varying levels of aroma are observed in crosses between aromatic and non-aromatic rices. There is also possibility of one major gene for aroma with several modifiers or QTLs. However, there is a major G $\times$ E component in the expression of aroma. There are defined pockets for the cultivation of major aromatic rices where their quality traits are expressed best (see Chapter 11 of this volume). At the same time, although organoleptic test is quite sensitive to characterize presence or absence of aroma, it may not be suitable enough to differentiate different levels of aroma. There is no quantitative method for the estimation of aroma. Probably because of impact of environment on expression of aroma and lack of a quantitative method to differentiate the different levels of aroma there have been so much variation in different reports concerning genetics of aroma.

Kernel Elongation

Lengthwise elongation upon cooking without increase in girth is considered most desirable in high quality rices. During cooking rice grains absorb water and increase in length, breadth and volume (Sood, 1978). The increase may be accompanied by both lengthwise or breadthwise splitting of grains which is not a desired character. The mechanism of grain elongation is not well understood, but it is thought to be both physical and chemical phenomena. Anatomical features such as endosperm cells affect kernel elongation upon cooking. Sood et al. (1983) reported penta or hexagonal cells arranged in a honey-comb fashion in Basmati rices, in contrast to long and rectangular cells radially arranged in columns of 10-12 cells in other varieties.

Like aroma, kernel elongation is also influenced both by genetic factors and environment, especially temperature at the time of ripening (Dela Cruz et al., 1989). The ambient temperature of about 25°C during day time, and 21°C during night at ripening has been found to have favourable effect. Maximum elongation was reported in grains matured at these temperatures. This explains the differences in quality of rice, especially in kernel elongation between the Basmati rices grown in Punjab (India) and Dokri (Sindh, Pakistan) (Khush et al., 1979). The Basmati grown in Punjab elongates more than the one grown in Dokri due to high temperature in Sindh area. Besides, aging and pre-soaking before cooking add to grain elongation. During storage, grain hardness and gelatinization temperature (GT) increase which allow more swelling and elongation during cooking.

Only limited reports are available on the genetics of kernel elongation upon cooking. Based on their study, using a 5 × 5 diallelic cross involving parents differing distinctly in the degree of kernel elongation, Sood et al. (1983) reported the involvement of both non-additive and additive types of gene effects, with the former playing predominant role. Among the varieties studied, Bindli and Type-3, the parents with high kernel elongation, were found to be the best general combiners. Further, crosses involving parents of high and low or high and medium combining abilities, exhibited significant and positive specific combining ability effects.

Kernel Length (L), Breadth (B)—L/B Ratio

Kernel length, breadth and L/B ratio are considered important traits especially in quality rices. For commercial purposes, the rices are classified according to the kernel length as short-grain, medium-grain, long-grain and long-slender-grain. The scented rice varieties fall in all the four categories, but the long-slender-grain type scented rice varieties fetch the maximum premium in the world market.

Despite variable reports, most studies indicate that grain length and breadth are due to the action of multiple factors. However, there are reports of monogenic (Chau, 1928; Ramiah et al., 1931), digenic (Bollich, 1957), trigenic (Ramiah and Parthasarthi, 1933) to polygenic (Jones et al., 1935; Moringa et al., 1943; Chakravarty, 1948; Mitra, 1962; Nakata and Jackson, 1973; Chang, 1974; Somrith, 1974) control of grain length. For kernel breadth also Jones et al. (1935) suggested the involvement of multiple factors. Further, Jones et al. (1935) also found that in the F_2 population in all the three crosses that they studied, the kernel length and breadth showed the same segregation patterns, irrespective of the testing locations where the experiments were conducted, indicating that the nature of the segregation of hybrid material was primarily determined by genotypic consideration of the varieties used rather than by the climatic conditions under which the material was grown. Rao and Sang (1989) observed that the inheritance of grain length and breadth were independent of each other and are governed by different set of genes. Hsieh and Wang (1986) observed that the grain length was controlled by polygenes or by 3 alleles in the order of dominance G11 > G12 > gl. Slender grain shape was dominant over bold grain shape and the concerned 3 alleles are in the order of Gs1 > Gs2 > gs. Dave (1939) obtained the order of dominance as long > medium > short > very short, although in some other cases short was reported to be dominant over long grain. Somrith (1974) reported involvement of both additive and dominance effects in the control of grain length, although the direction of dominance varied from cross to cross (Jones et al., 1935; Poonai, 1966; Somrith, 1974). Murthy and Govindaswami (1967) found that the grain size is under polygenic control, like grain length and grain width. L/B ratio also showed polygenic inheritance (Nakata and Jackson, 1973; Somrith, 1974).

Vivekanandan and Giridharan (1994) reported the inheritance of breadthwise expansion in Basmati and non-Basmati varieties. They found that the mean value of F_1 was more toward minimum breadthwise expansion, indicating its dominance over maximum expansion. BC_1, with better parent produced less breadthwise expansion than BC_2 with the other parent. Additive, dominance and dominance × dominance effects were significant. Further, comparison of the gene effects indicated the involvement of duplicate gene action in the control of the breadthwise expansion.

Amylose

Amylose content of rice is considered to be one of the most important constitutional indices of rice cooking and processing behavior (Rao et al., 1952; Williams et al., 1958), as it determines the hardness of cooked rice, gloss of the final product and rice-water ratio. Waxy or glutinous rice which lacks in amylose, does not expand in volume, is sticky and remains firm when cooked. In contrast, the non-waxy or non-glutinous rice characterized by intermediate amylose, cooks moist and tender and does not become hard upon cooking, and hence preferred. Most of the aromatic rices, both Basmati or non-Basmati, possess intermediate amylose (Sood et al., 1983). Rices with high amylose content cook dry and hard. These differences clearly indicate the importance of amylose content as a selection criterion. However, little published information is available regarding its mode of inheritance.

Studies on the inheritance of amylose content have shown involvement of one major gene and several modifiers with high amylose content incompletely dominant over low content (Seetharaman, 1959; Kahlon, 1965; Bollich and Webb, 1973; Somrith, 1974; Chang and Li, 1981; Chauhan and Nanda, 1983). However, Kumar and Khush (1987) reported the complete dominance of high amylose content over those for low and intermediate amylose content. Influence of genes of minor effects or modifiers was also noted. Beachell and Halick (1957) found that the amylose content measured by starch-iodine blue test was governed by a single gene in one cross, while two or more genetic factors appeared to be governing the iodine value in the other cross. The role of at least two complementary genes in addition to the waxy gene was indicated by Stansel (1966). Bollich and Webb (1973) observed a different pattern of inheritance in the crosses, depending upon the differences in amylose contents of the parents involved in the crosses. In the crosses with significant parental differences in amylose content, the amylose was found to be controlled by one pair of genes of major effect and a few modifying genes of minor effects. The major gene for high amylose was dominant to its allele. However, in the crosses with low mean parental differences for amylose content, the amylose was controlled by only a few pairs of modifying genes of small and approximately equal effects. The result of this study shows that selection for amylose would be effective in populations derived from crosses in which the parents differ to any practical extent in amylose content.

Heda and Reddy (1986) reported bimodal segregation in F_2 population with a large number of progeny exhibiting high amylose content. They concluded that amylose content is governed by two pairs of genes with partial dominance of high amylose over the low amylose. Chang and Li (1981) did a very comprehensive study of the inheritance of amylose content using F1, F2, F3 , BCFl and BCF2 populations from the crosses between high and low amylose parents. The results clearly showed the monogenic control of amylose content and the gene for high amylose was incompletely dominant. In addition, there was evidence of modifiers involved in the inheritance of amylose in one of the crosses, as also reported by others.

In these studies, the amylose content analyses were done on bulk F_2 seeds borne on F_1 plants, and dosage effects were not considered (Puri et al., 1980). Based on single seed analysis of direct and reciprocal crosses, Kumar and Khush (1986) reported significant differences in amylose content due to differences in doses of amylose genes in the endosperm. The dosage effects for amylose content in rice in waxy/non-waxy and among non-waxy crosses have been observed in some earlier studies (IRRI, 1976; Heu and Park, 1976; Okuno, 1978; Chang and Li, 1981; Okuno et al., 1983; Okuno and Yano, 1984). Because the endosperm is a triploid tissue, differences in amylose content are due to varying dosages of the wx alleles known to control amylose or glutinous condition in rice (Sugawara, 1953; IRRI, 1976). Kumar and Kush (1986) observed that a single dose of very low or low amylose gene was not capable of producing amylose to the level of non-waxy parents in waxy/non-waxy crosses. The effect of one dose of a gene for intermediate or high amylose was easily detectable with relatively less dose effect. Using isogenic lines for glutinous endosperm, Heu and Park (1976) developed different endosperm genotypes, WXWXWX, wxwxWx, wxWxWx and WxWxWx, to study the dosage effect. They found the dosage effect of Wx allele to be additive in its action on the amylose content, though the amylose content was not directly proportional to the number of Wx dose. Thus, amylose content in the endosperm starch increases with the increase in number of non-waxy alleles, though not in linear fashion (Okuno, 1978).

Okuno et al. (1983) identified and investigated the starch properties and inheritance of a newly induced mutant of rice, called dull mutant. They found that the amylose content of the dull mutant is controlled by a single gene (du) which is non-allelic to the wx alleles. The amylose content of the dull mutant was half as low as that of the non-waxy counterpart, but it did not decrease proportionally with the du alleles, in contrast to the proportional reduction in amylose content with the number of wx alleles. These findings confirm the existence of genes which control the proportion of amylose and amylopectin molecules in starch granules of rice in addition to the waxy alleles. Okuno and Yano (1984) further substantiated that there was no proportional change in the amylose production with the dose of du alleles and that the wx alleles were epistatic to du alleles on the amylose production in the endosperm cell.

Kumar and Khush (1986) emphasized the need for single grain analysis and study of dosage effect for precise understanding of the inheritance pattern of amylose content, as in absence of such information, the apparent continuous variation may lead to erroneous conclusions such as polygenic inheritance. Based on their data, they suggested that selection for higher and lower amylose content in the crosses involving intermediate amylose content parents may not be useful to develop cultivars with low or high amylose content due to the limits imposed by the presence or absence of modifiers.

Gelatinization Temperature

Gelatinization temperature (GT) is the physical property of the starch. It refers to the range of temperature within which starch granules start swelling irreversibly in hot water. Thus, GT determines the time taken to cook the rice. The GT of the rice varieties is known to vary between 50°C and 79°C, and classified as low 55-69°C, intermediate 70-74°C and high 75-79°C (Juliano, 1972). The quality and quantity of starch and the GT strongly influence the cooking quality of rice (Ghosh and Govindaswamy, 1972). The GT affects the water uptake, volume expansion and linear kernel elongation (Tomar and Nanda, 1985). The rice varieties with intermediate GT are preferred all over the world, as the high GT rice becomes excessively soft when overcooked, elongate less and remains undercooked under standard cooking procedure, and hence least preferred. Scented rices especially Basmati types exhibit intermediate GT. In laboratory, GT is measured by the extent of alkali spreading score of milled rice soaked in 1.7% KOH for 23 hours at 30°C. Rice with low GT disintegrates completely, the one with intermediate GT are slow in disintegration while those with high GT are unaffected. Reports on genetics of GT are available both in terms of GT and alkali digestibility.

Conflicting reports are available on the genetic nature of the GT. Stansel (1966) reported involvement of two loci in the control of this trait in medium × high GT cross, while Puri and Siddiq (1980) found a bimodal curve in crosses with medium × high GT, but a unimodal curve in cross with medium × medium and high × high alkali value. Heda and Reddy (1986) observed that the segregation pattern for GT differed from cross to cross, depending upon the parental value. The crosses with low × intermediate and intermediate × intermediate GT showed a bimodal curve, whereas crosses involving high GT parents exhibited a unimodal curve. Study of F_3 generation population showed polygenic nature of inheritance in the cross showing unimodal curve in F_2 generation. Tomar and Nanda (1984) concluded from their study on F_1, F_2, back crosses and parents involved in six crosses that gelatinization temperature was governed by the interaction of two pairs of major genes showing duplicate gene action with cumulative effect. Heu and Choe (1973) investigated the inheritance of GT in terms of alkali digestibility of milled rice in *indica* × *japonica* crosses, and their *indica* and *japonica* parents. Their results indicated dominance of low digestibility over high digestibility. Further, the distribution of alkali digestibility grades of F_2 seeds, was not continuous and showed 3 low : 1 high segregation ratio, indicating control of alkali digestibility by a single gene. They did not observe any reciprocal effects for alkali digestibility in F_1 or F_2 seeds. Hsieh and Wang (1988) observed inheritance of GT varying from cross to cross. However, they concluded that GT was controlled by dominant and additive genes. Somrith (1974) also reported the role of additive gene effects in some of the crosses he studied.

Gel Consistency

Gel consistency is a good index of cooked rice texture. Varieties having same amylose content may differ in tenderness and therefore, the cooked rices may be differentiated by the gel consistency test (Cagampang et al., 1973). Within the same amylose group varieties with softer gel consistency are generally preferred by the most rice consumers e. g. IR5 and IR8 had similar amylose content but IR5 always scored higher than IR8 for acceptability in panel test because IR5 had soft gel consistency (Khush et al., 1979).

Chang and Li (1981) studied the inheritance of gel consistency in locally developed *indica* rices using F_1, F_2, F_3, BCF_1, BCF_2 populations from the crosses between the hard and soft gel consistency parents. The results clearly showed that the inheritance of gel consistency was controlled by one gene and the short and hard gel consistency was dominant over long and soft gel consistency. Further the difference due to reciprocal crosses also provided the evidence of cytoplasmic effect on gel consistency. Chang and Lee (1981) also reported that the amylose content was highly significantly negatively correlated with gel consistency, indicating that simultaneous improvement of these two quality traits can be made with selection of either one but not both of them.

Using diallel cross analysis, both graphic and combining ability, Tang et al. (1989) reported the involvement of one major gene plus several minor genes and/or modifiers in governing the expression of gel consistency and the average dominance within the range of incomplete dominance. Combining ability showed both additive and non-additive gene effects to be important. The results suggested the importance of choosing appropriate donor parents in the crosses, as the selection for intermediary segregants from the crossed hard/soft gel consistency parents would be ineffective because of the major gene control of the traits.

BIOTECHNOLOGY AND RICE GRAIN-QUALITY

New tools and techniques in biotechnology and genetic engineering have now become available which offer great promise to solve some of the critical issues in grain quality inheritance and improvement. The important among them are : standardization of methods for the transformation and regeneration; marker aided selection (MAS) and tagging of genes using restriction fragment length polymorphisms (RFLPs), random polymorphic DNA (RAPD), amplified fragment length polymorphisms (AFLPs), simple sequence length polymorphisms (SSLPs) micro-satellites, transposon tagging, antisense RNA etc. and chimeric genes. Following are the examples of using some of these tools to tag genes responsible for aroma and other grain quality traits, and this is opening up the ways for their use in breeding aromatic cultivars.

Methods for the Regeneration and Transformation

Methods have been standardized for the establishment of calli, embryonic calli/cell suspensions and plant regeneration in aromatic rice cultivars (Zafar et al., 1992; Singh and Minocha, 1993; Siripichitt and Cheewasestatham, 1994; Suhaimi and Abdullah, 1995; Jain et al., 1996a; Jain, 1997, 1998; Jain et al., 1997). Jain et al. (1996b) reported that use of maltose as carbon source and higher agarose concentration in culture media, significantly promoted both the proliferation of embryonic cells and shoot regeneration frequencies in aromatic rice cultivars like Pusa Basmati 1, Basmati 385 and Taraori Basmati. The embryonic potential of cell cultures was greatly enhanced following cryopreservation. Shoot regeneration in cv. Khao Dawk Mali 105 (KDML-105) was increased by dehydration prior to transfer to regeneration medium (Sripichitt and Cheewasestatham, 1994). Dehydration and higher level of micronutrient in culture medium were reported to have synergistic effect on regeneration from callus of cv. Qubao 3 (Yang and Jian, 1995). Suvarnalatha et al. (1994) obtained perceptible Basmati flavour from Basmati calli raised on Murashige and Skoog medium with 2,4-dichlorophenoxyacetic acid and kinetin. Soontari (1993) standardized the methodology for the anther culture of three aromatic rice varieties. Raina et al. (1996) generated double haploids from hybrids involving fine-grained aromatic rices.

Biolistic procedure was developed for the transformation of embryonic suspension cells and calli of Pusa Basmati 1 gain et al., 1996c; Minhas et al., 1996; Balasubramanian et al., 1997) and KDML-105 (Nimlek et al., 1997). Khanna et al. (1996) transformed mature embryos of Basmati rice cv. Karnal local, via microprojectile bombardment, using plasmid pAHC25 carrying *GUS* and *bar* (for resistance to phosphinothricin (glufosinate) (PPT)) gene coding regions. A liquid medium based selection system was successfully utilized for recovering transformed sectors and regenerants (Khanna et al., 1997). Gosal et al. (1996) regenerated plants from cell suspension derived protoplasts of Pusa Basmati 1. Protoplast derived plants were fertile. Genetic transformation of Basmati rices were obtained using *Agrobacterium,* electroporation and protoplast transformation systems (Chowdhury et al., 1997). Burikam and Attathom (1997) transformed rice cv. KDML-105 with D^1 pyrroline-karboxylate synthetase *(P5CS)* gene using particle bombardment mediated transformation system. Inez et al. (1997) transformed aromatic rice cv. Rajalele by *Agrobacterium tumifaciens* containing a versatile binary vector (pCAMBIA 1301). Some selectable marker and reporter genes used were *bur, npt II/hpt II* and *GUS.* Some genes of interest like chitinase, *Bt,* bacterial blight resistance *(Xa-21),* rice tungro resistance *(RTBV CP gene, RTSV polymerase* in sense and antisense orientation), drought tolerance *(P5CS)* and submerged tolerance *(adh and pdc)* have been introduced into non-aromatic and aromatic rices (Abrigo and Datta 1996; Burikam and Attathom, 1997; Datta et al., 1997; Fauquet et al., 1997; Gill et al., 1997; Li et al., 1997).

Molecular Tagging and MAS for Quality Traits

Aroma

In recent years, marker aided selection has received attention as a powerful method for the improvement of breeding efficiency in various crops.

Ahn et al. (1992) reported that a single-copy marker, *RG-28,* on chromosome 8, at a distance of 4.5 cM, is closely linked to scent gene (*fgr1*). They suggested that this marker can be used to facilitate early selections for the presence or absence of scent, and to identify the heterozygous or homozygous condition at the locus in a reliable manner. It may also be useful for the rapid incorporation of the scent character into breeding lines. Search for additional probe-enzyme combinations showing polymorphism between NILs would help in identifying more closely linked marker(s) to scent gene. Such tightly linked markers can be used to begin chromosome walking or to isolate very large DNA fragment-containing the gene. Identifying *RG* 28, a RFLP marker located on chromosome 8 linked with scent gene is also supported by the report of Li et al. (1996) that aroma is under control of single recessive gene located on chromosome 8 of rice genome. The linkage between RFLP marker RG *28* and *fgr* has been confirmed in a different segregating population obtained from cross Pusa 751 (aromatic) x IR 72 (non-aromatic) (Pandey, 1994; Pandey et al., 1994,1995). However, the map distance between the marker and the gene in this study was larger (10 cM) compared to that observed (4.5 cM) by Ahn et al. (1992), probably due to small mapping population. Pandey et al. (1994) using same F_2 population, based on bulked segregant analysis also identified a RAPD marker amplifylng a 1.2 kg band in non-aromatic parent and non-aromatic bulk but not in aromatic parent and aromatic bulk. Jin et al. (1995) and Tragoonrung et al. (1996), using RAPD technology, identified one primer (5'-GAACGGACTC-3') which amplified 1.5 kb polymorphic fragment only in non-aromatic lines/cultivars. It was shown to be closely linked to aromatic locus (Jin et al., 1996). This 1.5 kb fragment was in a coupling phase with the dominant non-aromatic allele. Results from linkage analysis revealed that the cloned fragment (named Jasmine marker) and aromatic locus was located on rice chromosome 8. The Jasmine marker was 13.9 cM from the aromatic locus. This marker clearly distinguished between the aromatic and non-aromatic varieties, suggesting usefulness of this marker in breeding program. RAPD marker closely linked to the aromatic locus can be used not only for the identification of the gene, but also for detecting the size of linkage-block found during the introgression of the locus by backcrossing. Moreover, they can be used to efficiently select plants with the aromatic gene in early generation and in early stages of plant development. However, tightly linked markers are needed for the marker aided breeding to ensure higher selection accuracy and efficiency.

Having mapped *fgr* to chromosome 8 will allow a point of comparison for other studies of aroma inheritance and may lead to a better understanding of the genetics and molecular biology of aroma in rice varieties throughout the world. Efforts should also be made to use other genetic stocks for molecular tagging particularly in those cases where aroma has been reported to be controlled by dominant gene(s). This would provide additional scent gene(s) for molecular manipulation.

Cooked kernel elongation

Ahn et al. (1993) identified RFLP loci that were potentially associated with loci affecting kernel elongation in rice. According to this report a segment of chromosome 8 introgressed from Basmati 370, contains a gene(s) affecting kernel elongation. Having mapped a QTL with relatively large effect, markers could be used to facilitate early generation selection for this character and to transfer the chromosome segment containing the QTL into breeding lines or varieties with a high degree of certainty. Importance in selection for kernel elongation could be expected by the identification of markers with tighter linkages to the QTL reported, and by identifying additional QTLs. Having mapped a QTL for grain elongation alongwith *fgr* to chromosome 8 allows a point of comparison for other studies of inheritance of kernel elongation and may lead to better understanding of genetic basis of polymorphism in Basmati type rices throughout the world. In another study Ram et al. (1998) reported two RAPD markers (H4.1& H4.2) co-segregating with kernel elongation. These markers were mapped on linkage group 5. This clearly shows that the QTLs for kernel elongation may be present on other linkage groups too. Therefore, mapping and localization of QTLs for kernel elongation could ultimately lead to isolation of a gene(s) for this character through map based cloning.

Amylose content, length/breadth ratio and gelatinization temperature

The two co-segregating RAPD markers (H4.1 and H4.2) on linkage group 5 which showed association with kernel elongation, were also found associated with amylose content and length/breadth ratio (Ram et al., 1998). On same linkage group, two other markers (F5.5 and E9.1) located 7.1 cM apart, showing association with length/breadth ratio were also reported. They also observed a second locus affecting amylose content on linkage Group 6 and three markers associated with gelatinization temperature.

CONCLUSION

One of the most interesting observations that came out of the studies on molecular mapping is that the genes for various quality traits are concentrated in certain genomic regions. It is evident from the report of Ahn et al. (1993) where *'fgr'* the gene for aroma and a QTL for kernel elongation were mapped in the same genomic region of linkage group 8 derived from Basmati 370. Similarly the report of Ram et al. (1998) indicated

Table 1. Inheritance of quality traits in aromatic rices

AROMA	
1. Monogenic dominant	Jodon (1944)
2. Monogenic recessive	Ghose & Butany (1952); Sood & Siddiq (1980); Shekhar & Reddy (1981); Burner & Hoff (1986); Reddy & Reddy (1987); Bollich et al. (1992); Huang & Zou (1992); Ali et al., (1993); Vivekanandan & Giridharan (1994); Wu et al. (1994); Kato & Itani (1996); Katare & Jambhale (1995); Song et al. (1989); Li et al. (1996); Li & Gu (1997); Sadhukhan et al. (1997)
3. Monogenic recessive with an inhibitor	Ghose & Butany (1952); Tsuzuki & Shimokava (1990)
4. Digenic or trigenic dominant	Kadam and Patankar (1938); Nagaraju et al. (1975) Reddy & Satyanarayana (1980)
5. Two dominant complimentary genes	Tripathi & Rao (1979)
6. Digenic recessive	Vivekanandan & Giridharan (1994); Geetha (1994)
7. Four complimentary genes	Dhulappanavar (1976)
8. Polygenic	Richharia (1965)
KERNELELONGATION	
1. Polygenic, predominant, non-additive	Sood et al. (1983)
KERNELLENGTH	
1. Monogenic	Chau (1928)
2. Digenic	Bollich(1957)
3. Trigenic	Ramaiya & Parthasarthy (1933)
4. Polygenic	Jones et al. (1935); Moringa et al. (1943); Chakravarty (1948); Mitra (1962); Nakata & Jackson (1973); Chang (1974); Somrith (1974); Moorthy & Govindaswami (1967)
5. Triallelic	Hsieh & Wang (1988)
6. Polygenic additive & dominant	Jones etal (1935); Poonai (1966); Somrith (1974)
AMYLOSE CONTENT	
1. Monogenic with modifiers (incompletely dominant)	Seetharaman (1959); Kahlon(1965); Bollich & Webb (1973); Somrith (1974); Chang & Li (1981); Chauhan & Nanda (1983)
2. Two Complimentary genes	Stansel (1966)
3. Digenic with partial dominance of high over low	Heda & Reddy (1986)
4. Dosage effect of genes	Kumar & Khush (1986); Heu & Park (1976) Okuno (1983): Okuno & Yano (1984)

(Contd.)

Table 1 *(Contd.)*

GELATINIZATION TEMPERATURE	
1. Two pairs of major genes (with duplicate action cumulative effect)	Tomar & Nanda (1984)
2. Monogenic recessive	Heu & Choe (1973)
3. Dominant and additive effect	Hsieh & Wang (1988)
4. Additive gene effect	Somrith (1974)
5. Trigenic	Stansel (1966)
6. Polygenic, additive and non-additive	Puri & Siddiq (1980)
GEL CONSISTENCY	
1. Monogenic; hard gel consistency dominant; cytoplasmic effect	Chang & Li (1981)
2. Monogenic with several minor genes and/or modifiers	Tang et al. (1989)

concentration of genes for kernel elongation, amylose content and length/breadth ratio in the same genomic region of linkage Group 5. At the same time identifying independent loci for kernel elongation on linkage group 8 by Ahn et al. (1993) and linkage group 5 by Ram et al. (1998), for amylose content on linkage group 5 and linkage group 6 by Ram et al. (1998) clearly indicates that there are possibly many loci governing traits like kernel elongation, length/breadth ratio and amylose content. It appears therefore, that the earlier reports on polygenic mode of inheritance of these traits were in the right direction. Marker aided selection (MAS) for these traits would help in the introgression of independently inherited/linked desirable QTLs into breeding lines and breeding for a complex trait like "Basmati Quality Rice" would become much easier.

Mostly single recessive gene control of aroma has been reported. But there are also the reports of dominant gene(s), multiple factors/polygenes, controlling aroma. Molecular tagging of these genes would not only enhance our knowledge about clear understanding of aroma inheritance, but might also provide additional gene(s) for molecular manipulation in the breeding work. Dosage effects of waxy alleles on the amylose content has now been well understood. Similar studies are needed to clarify the xenia effect of endosperm on aroma development.

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Chapter 6

Breeding Aromatic Rice for High Yield, Improved Aroma and Grain Quality

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INTRODUCTION

With the introduction of dwarfing genes in the early sixties, the rice variety development programme made spectacular gains in productivity. Rice production increased many-fold, and several countries in South and Southeast Asia that were once net rice importers became major exporters. Although during this period, emphasis was on increased yield and resistance to diseases, insects and pests, some efforts were also made in the area of breeding resistant varieties against physical stresses, related mainly to soil and water. However, there was not much emphasis on improving aroma and rice grain qualities. Since most countries which produced and exported aromatic rices, were facing deficit in rice self-sufficiency, they were more concerned with increasing their rice production than dealing with complex issues such as aroma and grain quality improvement. Therefore, mostly local cultivars of aromatic rices are grown. These cultivars, although tall lodging-susceptible and low yielders, are preferred for their pleasant aroma, excellent grain qualities and taste. Of these, the long grain types are also exported. As an aftermath of the green revolution, when yield increases were the main consideration, most of the once well-known aromatic rice cultivars are now fast disappearing. In fact, many of them are already lost. If some of them are still surviving, it is purely because of the personal preferences of the farmers; some grow these aromatic varieties for their own consumption. Some farmers grow certain specific varieties like Basmati 370, Taraori Basmati in India, Pak Basmati in Pakistan and Jasmine rices in Thailand mainly for export purposes.

Earlier attempts to improve aromatic rices were mainly through pure-line breeding. The land races being grown by farmers provided ample variability and scope for improvement. Attempts to introduce dwarfing genes into the aromatic rice background met with limited success. This is attributed to the inter-group incompatibility resulting into hybrid sterility and restricted recombination. Khush and Juliano (1991) identified three main hurdles in the grain quality and aroma improvement programmes, which are: multiplicity of breeding objectives, lack of infrastructures for grain quality evaluation, and lack of well-defined selection criteria. Some of the newly developed varieties have higher yields, even improved grain qualities, but they are no match for some of the well established aromatic rice varieties like Basmati 370 in cooking qualities and taste.

Following Glaszmann's (1985) revelation that the aromatic rice varieties fall into a separate group from that of the typical *indicas,* and that the two groups are incompatible causing inter-group hybrid sterility, efforts are being made to look for compatible parents to avoid hybrid sterility and inter-group barriers to recombination. Available wide-compatibility genes and new tools and techniques of molecular biology offer great scope for simultaneous improvement of yield as well as grain quality and aroma of these rices.

In this chapter, breeding of aromatic rices for improved yield, grain quality and aroma are reviewed. Besides breeding methods and practices, future concerns and prospects are also discussed. The review also includes some recent developments in rice biotechnology that are likely to make significant dents in varietal improvement of aromatic rices in future.

PAST EFFORTS AND ACHIEVEMENTS

Pure-line Breeding

In the past, farmers in the different regions of India and elsewhere have been growing locally adapted aromatic rices with different names and qualities. Pure-line breeding was adopted by breeders and in some cases by farmers to improve the locally adapted land races and to purify and maintain their specific features. The landraces and even some old varieties seem to preserve lot of variability and, thus, provide scope for improvement through selection. The breeders at the rice research station in Phrae, Thailand, isolated six different plant types in Basmati 385 for awn type, height, grain shape and maturity. These selections were tested for their comparative superiority in the intra-station trials (IRRI 1996). Another example is the Jeerakasala, a tall scented rice variety, grown in Kerala (India) at 976 m above the sea level. Its white, fine grain gives off a pleasing aroma when cooking—a trait that makes Jeerakasala popular for the preparation of the delicacy *biriyani.* Jeerakasala is, therefore, also known as *biriyani* rice. Further improvement of Jeerakasala by pure line selection at the Kerala Agricultural University led to the identification of three cultures having varying degrees of awning and yield potentials (Ramankutti and Bhaskaran, 1979). The cultures yields ranged from 2.9 to 3.6 t/ha compared to its parental yield of 2.2 to 2.4 t/ha. Similarly, through selection and purification, 14 distinct types were identified from the local Kalanamak variety (Table l), which differed in a number of traits—flowering and maturity duration, plant height, panicle length, total effective tillers, disease score and intensity of aroma—indicatinglarge variation within the same genotype providing scope of further improvement (Anonymous 1996a). Within culture variation was also reported in the collections of Kanakjeera, Badshahpasand, Shamjira, and Adamchini by Singh and Srivastava (1996).

Table 1. Yield and other ancillary characters of some selections from Kalanamak*.

Selections	Yield [1] (Q/ha)	50% Flowering (days)	Maturity (days)	Total tilled m^2	Panicle bearing tillers/m^2	Plant height (cm)	Panicle length (cm)
KB -7	23.87(1)	127	158	277	264	173	26.0
KB - 10	22.13(4)	131	161	280	247	152	26.6
KB - 13	19.09(6)	130	160	260	240	161	25.4
KB - 100	12.15	127	157	277	257	156	24.8
KB - 123	23.43(2)	129	161	287	270	150	23.6
KB - 136	17.79	127	156	327	297	153	24.6
KN - 45	15.19	127	158	284	267	174	25.4
KN -54	13.02	130	157	310	287	172	27.0
KN - 65	23.00(2)	132	162	290	253	157	26.8
KN - 123	19.53(5)	132	162	294	267	159	26.4
K. Basti A - 8	23.87(1)	120	155	304	263	166	25.7
K. Basti B - 20	19.09	118	148	344	317	158	26.4
Kalanamak A	17.79	116	146	287	254	162	27.4
Kalanamak B	17.36	117	145	334	320	155	26.2
Kalanamak (Local)	06.07	120	152	337	314	146	26.2

*All selections are medium slender and scented.
[1] Numbers in parenthesis indicate ranks.

Single plant selection from the local cultivars/land races led to the release of a large number of scented rice varieties. Some of them are still quite popular especially because of their pleasant aroma, excellent cooking and eating qualities. Mahadevappa et al. (1977) reported about improvement of some local scented rices of Karnataka (India) through single plant selection. Most important among them are C435, a selection from Jeerige Sanna, K44-1 from Kakasali and DP33 from Krishna Pasangi. Richharia (1979) identified and reported a local selection, Kadam Phool, from the farmers' field, which was early maturing and aromatic. Kadam Phool yielded 2.7 t/ha and was significantly superior to the check, Madhuri (2.1 t/ha), a popular early maturing scented variety of the Chhatisgarh region in Madhya Pradesh (Sharma, 1981). Kadam Phool was also drought tolerant and was found promising under rainfed conditions. Besides, another selection from Madhuri 9, Madhuri selection A9 was reported to be doing well even under delayed planting conditions (Paliwal et al. 1996).

Probably the first and the most successful example of a pure-line selection from a locally adapted land race was Basmati 370 by the Late Sardar Mohammad Khan in 1933 at Kala Shah Kaku, now in Pakistan. The release of this variety opened the door to an economic revolution in the rice producing areas of the Indian sub-continent (Mann, 1987). This variety has been grown very widely in both India and Pakistan, and is considered to be the best in eating qualities. Another important pure-line selection from Kala Shah Kaku was the Pakistan Basmati released in 1968 (Shafi and Ahmad, 1971). It is still grown to a limited extent in Pakistan as well in Punjab (India). Beginning 1932, research work at Nagina (India), emphasized development of better quality, high yielding rice varieties. Selections made from the local cultivars resulted in the release of several improved strains of variable maturity group including fine grain aromatic rice varieties such as N-10B (selection from Hansraj–Pilibhit), N12 (selection from Safeda–Punjab), Type 3 (selection from Basmati–Dehradun), Type 9 (selection from Dimnepet–Basti), Type 1 (selection from Ramjeevan–Saharanpur) and Type 23 (selection from Kalasukhdas–Banda). Varieties Type 3, N-10B and Type 9 are still popular and widely grown in some regions. Kamal Local, considered being the best export quality rice, has been further purified and released as Taraori Basmati. It is widely grown in Haryana, Punjab and western UP. Its grain is longer than other traditional Basmati rices, as a result its share in India's basmati export is the largest. Most other high yielding semi-dwarf aromatic varieties are cross products of these and the short and high yielding IRRI lines.

Quality Basmati rices of India and Pakistan, characterized by photo-thermosensivity and late maturity, are difficult to fit into multiple cropping systems. In 1987, Bijral et al. (1989) isolated an early maturing plant from farmers' field. The strain (IET 11348) later named Ranbir Basmati, was evaluated against Basmati 370 for two years at a research station and on the farmers' fields for performance, stability and adaptability, and then released in Jammu and Kashmir. It matures in 115–120 days, 30-35 days earlier than Basmati 370 with comparable yield, and grain quality. It is also resistant to gall midge and WBPH, and fits well into the prevailing cropping patterns of the region.

Selections from local types have also been reported in other countries. BR5, an aromatic short bold grain type rice variety was developed in 1976 in Bangladesh. It was a selection from the land race Badshahbhog (Dr. M.A. Salam, personal communication). Nang Huong is a local aromatic rice variety popularly cultivated in South Vietnam. By pure-line selection, several promising lines were selected with improved characters as shorter duration, tolerance to acid-sulphate soil and higher grain yields (23–25%), with stability of aroma and other cooking qualities (Thinh et al. 1995).

Like Basmati 370, another most prominent selection from the locally adapted germplasm is Khao Dawk Mali 105 (KDML105) of Thailand. The original selection was made by a farmer in 1945. Subsequently, a district agricultural officer selected 199 panicles from this material in 1950. Following a panicle–row method, pure line selection was initiated at Kok Samrong Rice Research Station. The outstanding line, Khao Dawk Mali 4-2-105 was then identified and further evaluated for yield potential and adaptability. Later, it was released as Khao Dawk Mali 105 (Somrith, 1996). (Khao means white, Dawk Mali means jasmine flower). In a short span of time, this variety has occupied a key position in Thai rice export. In 1997, of total 5.24 million tons of paddy exported, more than 2.2 millions tons came from KDML 105, accounting for 42 per cent of the total export (Anonymous, 1997).

KDML 105 was introduced and tested at 14 locations in five districts of Assam (India) between 1995 and 1997 in semi-deep water situation (Sarma et al., 1999). The variety recorded a pooled average yield of 4.2 t/ha with 33 per cent more yield than the local Panikekoa and 51 per cent more than the best joha (aromatic) variety—Kolajoha (Table 2). KDML 105 was recommended for cultivation in semi-deep ecosystem of the North Bank Plain Zone of Assam in 1998.

Hybridization and Selection in Segregating Generations

On account of tall and weak straw and poor response to fertilizers, local scented rices could not compete and remain remunerative against the high yielding dwarf rice varieties that became available during mid-sixties. This led to a sharp decline in their area of cultivation; today most of

Table 2. Yield of KDML 105, Kolajoha, and Panikekoa in Assam, India, 1995-97.

Year	Location	District	Yield (t/ha $^{-1}$)		
			KDML 105	Kolajoha	Panikekoa
1995	Garumuria	Lakhimpur	3.4	2.4	1.8
	Gharmora	Lakhimpur	6.0	3.0	–
1996	Garumuria 1	Lakhimpur	3.0	2.2	2.8
	Garumuria 2	Lakhimpur	4.4	2.6	2.5
	Garumuria 3	Lakhimpur	1.9	–	0.9
	Gharmora	Lakhimpur	3.5	2.7	–
	Kuwari-Pukhuri	Jorhat	5.4	3.1	–
	Borigaon	Jorhat	5.8	3.0	–
1997	Dhemaji	Dhemaji	4.4	–	4.3
	Dhakuakhana	Lakhimpur	4.8	–	4.0
	Garumuria	Lakhimpur	2.8	–	2.4
	Gohpur	Sonitpur	5.4	–	6.0
	Mangaldol	Darrang	2.0	–	3.2
	Gharmora	Lakhimpur	5.2	3.0	-
Pooled av			4.2	2.8	3.1

(Adopted from Sarma et al. 1999)

them are at the verge of extinction (Singh and Singh, 1998). In view of this, breeders in different countries started working on developing semi-dwarf varieties in the background of the famous and preferred scented rices. Pedigree selection, backcross and convergent improvement methods are among the most commonly used breeding methods.

In India, research was undertaken by several research organizations such as Directorate of Rice Research (DRR), Hyderabad; Indian Agricultural Research Institute (IARI), New Delhi; Punjab Agricultural University (PAU), Rice Research Station, Kapurthala; Haryana Agricultural University (HAU), Rice Research Station Kaul, and G.B. Pant University of Agril. & Tech. (GBPUAT), Pantnagar. Mostly direct crosses were attempted and subsequent generations handled by pedigree method of selection. The efforts have met with some successes. Kusuma, one of the first dwarf scented varieties, was released in Kamataka in 1969 (Mahadevappa et al., 1977). The variety was developed by crossing TN1 and Basmati 370 followed by thorough testing in the All India Coordinated Rice Improvement Programme. It has long slender grain with mild aroma and better yield than local scented varieties. PAU 29-295, a superfine scented rice variety was developed from a cross between Basmati 370 and Hamsa, the latter is a semi-dwarf variety with fine grain, grown in Andhra Pradesh (India) (Saini and Gagneja, 1973). The process involved growing of large F_2 population after selecting out the dwarfs in nursery stage in all crosses involving Basmati 370. The technique not only reduced competition between talk and dwarfs but also permitted dwarfs to express better (Saini and Kumar, 1978). In F_2 and onward generations, plants with improved plant type and long slender grains were selected and tested for aroma by the chewing test. PAU 29-295 is shorter in height and matures 21 days earlier than Basmati 370. It gives 62 per cent more yield, had longer grains (7.58 mm) with higher L/B ratio (3.64), and is strongly aromatic.

Following pedigree method of selection, a line was selected from segregating material of IR8 and Pankhali 203 cross and released as GR 101 in 1986. Its average yield is about 4.1 t/ha, 83.6 per cent higher than Pankhali 203. GR 101 has long (9.52 mm), slender, fine grains with oily translucent kernel and mild aroma. It is also resistant to neck blast. The milled rice recovery is also high (69.63 per cent) (Desai et al., 1987).

Haryana Basmati-1 (HKR228), a semi-dwarf aromatic rice variety for Haryana (India) was developed by Panwar et al. (1991) from a cross between Sona and Basmati 370. HKR228 has 143-day duration. Its grain is long and slender with higher hulling and milling recovery than Basmati 370. Kernel elongation after cooking is 1.76 with 25.41 per cent amylose content. It is resistant to blast, stem rot and WBPH.

As most traditional varieties are poor combiners, breeding/selection methodologies especially convergent and backcross approaches seem to be useful in breaking undesirable linkages and to increase the frequency of useful recombinants. Following a strategy of stepwise convergent breeding, dwarf basmati type breeding lines that possess high yield potentials and atleast one or two quality traits, were developed and inter-crossed. Through this approach, scientists at IARI (India) recovered Pusa 615, and in 1989, a sister selection of this was later named and released as Pusa Basmati-1 (Siddiq, 1990). Pusa Basmati-1 was the first ever dwarf, photo-insensitive, input responsive high yielding variety. Notable in its ancestry are the Basmati 370 and Karnal local for aroma and grain quality characteristics, while TKM6, IR8, Ratna and IR72 for yield and resistance (Fig. 1). On par with traditional basmati varieties in its quality features, Pusa Basmati-1 has 1 to 1.5 t/ha yield advantages over them (Table3). Similarly, by following the same technique at DRR (India), a semi-dwarf variety, Kasturi, was released in 1989 (Shobha Rani, 1992). Kasturi had high yield potential and several quality features of the traditional basmati varieties, besides high head rice recovery and resistance to blast, but it is inferior in cooking qualities and aroma (Arumugachamy et al., 1992).

In Pakistan, systematic work on developing high yielding aromatic rice varieties was started at Rice Research Institute, Kala Shah Kaku in 1968. Several varieties were released through selection from crosses involving mostly high yielding IRRI lines. Earlier releases include Pakistan Basmati, Basmati 198, KS282 and Lateefy. Lateefy, an aromatic semi-dwarf rice was released in 1983 for general cultivation (Bhatti and Soomro 1985), to replace the local tall scented Sugdasi and other Basmati rices. It was developed from a cross between IRRI line IR 760-A1-22-2-3 and

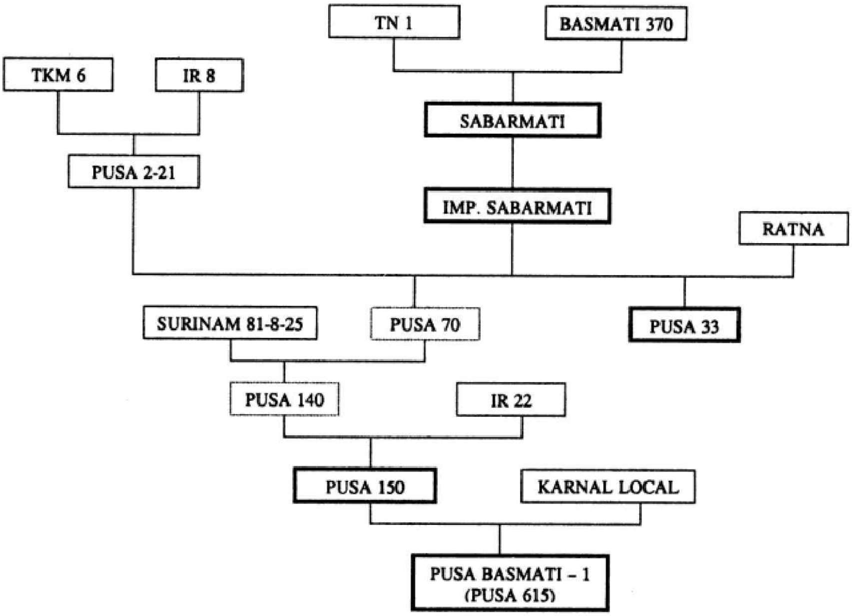

Fig. 1. Genetic ancestry of Pusa Basmati-1

Basmati 370. Selection emphasized semi-dwarf plant types, grain characters, aroma and early maturity in a pedigree method. Lateefy yields twice more than Jajai 77 and Basmati 370, and has stemborer resistance and matures 3 weeks earlier. Subsequently, Basmati 385 and most recently Super Basmati were released.

As shown in Table 4, several short statured aromatic varieties have been released. However, except Pusa Basmati-1, none of these varieties released in India and Pakistan have found favour with growers and millers because their grain quality does not match that of the traditional basmati varieties. Thus farmers continue to grow traditional Basmati varieties. In Pakistan, however, improved basmati varieties have almost entirely replaced traditional ones. Basmati 385 and Super Basmati are grown in traditional Basmati areas of central Punjab and Basmati 198 in southern districts. These three varieties are non-dwarf and have intermediate height. The cultivated area of Basmati 385 is the largest. These varieties have yield advantage of 20 per cent over the traditional Basmati (Chaudhry and Rahman, 1986). However, their level of aroma does not match that of traditional varieties and are also susceptible to lodging. This has affected Pakistan's Basmati export.

Tainung Sen 20 was released by Taiwan Agricultural Research Institute, with an average grain yield of 6.1t/ha and 5.4t/ha in the first and second crop season, respectively (Yang et al., 1988). It was a selection

Table 3. Important quality and yield traits of Pusa Basmati–1 vis-a-vis other varieties

Quality trait	Taraori Basmati	Basmati 370	Haryana Basmati -1	Pusa Basmati -1
Kernel:				
Length (mm)	7.10	6.76	6.74	6.82
Breadth (mm)	1.78	1.76	1.65	1.73
L/B ratio	4.03	3.84	4.08	3.94
Colour	White	White	White	White
Abdominal white	A/OP	A/OP	A	A
Milling:				
Hulling (%)	75.5	76.8	78.3	76.3
Milling (%)	68.5	69.0	71.3	67.7
Head rice (%)	45.5	46.0	44.7	44.2
Cooking:				
Kernel length (mm)	13.30	12.72	11.46	13.23
Elongation ratio	1.87	1.88	1.70	1.89
Aroma	SS	SS	MS	MS
Amylase content (%)	20.11	19.10	21.77	27.14
Alkali value	5.27	4.45	6.57	5.81
Water uptake	205.00	221.00	338.00	228.00
Volume expansion	3.70	3.92	3.80	3.81
Yield & related traits:				
Duration	150	145	140	150
Pl. height (cm)	148	145	116	106
1000-grain wt. (g)	24.4	22.9	19.0	21.5
Av. Yield (t/ha)	2.5	2.8	4.0	3.8
Potential yield (t/ha)	3.5	4.0	5.0	4.8

A = Absent, OP = Occasionally present, SS = Strongly scented, MS = Moderately scented, L/B = Length/breadth ratio

Table 4. Improved Basmati type varieties released in Pakistan and India.

Name of Variety	Year of Release	Breeding Organization
Pakistan		
Basmati 198	1978	Rice Research Institute Kala Shah Kaku
Basmati 385	1986	Rice Research Institute Kala Shah Kaku
Super Basmati	1996	Rice Research Institute Kala Shah Kaku
India		
Punjab Basmati 1	1981	Rice Research Station, Kapurthala, Punjab
Guarav	1985	Rice Research Station Kaul, Harayana
Sabarmati	1970	IARI, New Delhi
Improved Sabannati	1971	IARI, New Delhi
Pusa Basmati 1	1989	IARI, New Delhi
Kasturi	1989	DRR, Hyderabad
Haryana Basmati–1	1991	Rice Research Station, Kaul, Haryana

from cross between Chianung Shi-pi 671178 and an F4 line, having strong aromatic flavour, excellent rice quality and resistance to blast and brown plant hopper. The variety is less cold tolerant and hence not recommended for early planting.

A *japonica* type scented rice variety, Tainung 72, was derived from a cross between Chianung J662007 and Taishousen (a Japanese local scented rice variety). Tainung 72 possesses the scent of plant and grain, and has good grain and eating quality. Being resistant to brown plant hopper it is recommended for cultivation in BPH-prone regions of Taiwan. It yielded about 6.3 t/ha, slightly lower than the check variety Tainung 68 (Yang et al., 1990).

Hyangmibyeo 1, the first aromatic variety in Korea, was derived from a cross between IR841-76-1, an aromatic line, and Snweon 334, a semi-dwarf high yield line (Choi et al., 1994). Hyangmibyeo 1 has non-glutinous scented endosperm with high amylose content, and a mean length/breadth ratio of 2.46. It is resistant to blast, bacterial blight and stripe virus, and possesses larger number of grains/panicle. On an average, it yields around 4.95 t/ha and is adaptable to central and southern lowland areas of Korea.

Following pedigree selection from a cross between IR661 and Khao Dawk Mali 105, Panichapat et al., (1974) identified only one line (WP 153) which was promising to be a new variety, but later on they found that its aromatic quality was not successive, although other characters were better than those of RD1, a popular variety in Thailand (Panichapat et al., 1974).

One of the objectives of rice breeding in Thailand has been to breed photoperiod non-sensitive varieties. The efforts led to release of two varieties, Hawn Klong Luang and Hawn Supanburi in 1997. The former was derived from a cross between a Thai traditional cultivar Nahng Mon 64 and IR 841-1-1-2, a KDML-105 derivative. This is a semi-dwarf type, moderately resistant to blast, bacterial blight and white-backed plant hopper. Hawn Supanburi is a product of a multiple cross (SPR 84177-8-2-2-1 and SPB85091-13-1-1-4 and KDML105). It is moderately resistant to bacterial blight and white-backed leaf hopper. The cooking and eating qualities of both these varieties are quite similar to KDML-105, but these are photo-period non-sensitive and can be grown at any time of the year.

In China, breeding for new scented rice in semi-dwarf background started in 1985. Many aromatic rices including IR841, Bas 370, and KDML 105 were selected for use in crosses with the objective of developing semi-dwarf, high quality rice with slender grain and at least 5 per cent higher yield than Shuang-Zhu-Zhan, a high quality rice variety widely planted in south China (Chuanyuang and Shuzhan, 1994). Through pedigree selection, two lines were finally selected. Gan-wan-xian 22, released in 1994, has intermediate amylose content (AC) and gelatinization temperature (GT), soft gel consistency (GC) and promising agronomic characteristics.

SR 5041 has low AC (16.1 per cent), and GT and soft GC with strong fragrance. Its kernel length is 7.2 mm compared to 6.9 mm of the former. Both scented rices are very popular in the local markets and are being exported to Southeast Asia. Another scented variety, Zhe 9248, was reported to be developed in China by a team led by Associate Professor QIU Baigin of Crop Breeding and Cultivation Institute, Zhejiang Academy of Agricultural Sciences (Anon., 1994). It has high degree of resistance to blast, early maturity and high yield. Being soft, smooth and glossy, the cooked rice of Zhe 9248 has excellent eating quality.

B7136e-Mr-22-1-5, released as Bengawan Solo, in Indonesia, is another example of the selection from a direct cross (Partoatmodjo, 1994). The variety was derived from the cross $IR56^2$ and IR841. It is resistant to BPH biotype 1 and similar to IR64 in maturity, and yield potential. Bengawan Solo has good grain quality and strong aroma. Its aroma is maintained across regions and, thus, could be grown widely.

Aromatic rice varieties have been cultivated in many regions throughout Japan for over a thousand years although on small scale for religious purposes, festivals, entertaining guests or daily use. However, with the spread of the modern varieties, the number of aromatic rice varieties has fast declined. Miyakaori, the first improved cultivar of aromatic rice in Japan was developed from the cross between a native aromatic rice variety called Iwaga and On 282, a semi-dwarf high yielding variety. A promising line selected in F_{10} generation was tested for its local adaptability for three years and released as Miyakaori in 1983 (Oikawa et al., 1991). It is early to medium in maturity, semi-dwarf with moderate lodging resistance. It has *pi*-a gene for true resistance to blast disease. The hulled rice of Myakaori is intermediate in size and the grain appearance is slightly inferior to that of Iwaga. Miyakaori yields about 90 per cent of Sasaminori, the most popular variety of early medium maturity. Beside Miyakaori, the other two recently released varieties are Haginokaori (traditional improved) and Sari Queen (Japanese/Indian—Basmati product) (Itani, 1993).

Following selection from a cross between a high yielding line Iri 389 and an aromatic line Dohoku 144, an aromatic and good grain quality *japonica* rice variety Hyanguanbyeo, was developed by National Honan Agricultural Experiment Station, RDA in 1996 (Ha et al., 1996). Milled rice of Hyanguanbyeo has good grain appearance, and no white centre and white belly. Cooked rice had good palatability with preferable aroma when mixed with 5-10 per cent of ordinary non-aromatic rice.

The Iranian market is dominated by aromatic rices that are flaky and soft when cooked. Due to such preferences, despite high yields, the newly developed non-aromatic varieties fetch lower price than the traditional local types (Shobha Rani, 1998). However, Nemat, a newly released variety with high yield potential (greater than 7t/ha) with mild aroma and good grain quality, coupled with resistance to blast and tolerance to stem borer, is believed to be spreading fast and may replace the traditional local types. Nemat is a selection from the cross between Sang Tarom, a local aromatic high cooking and eating quality cultivar, and Amol3, an improved high yielding variety (Nematzadeh et al. 1995). It has intermediate AC, medium GC and low GT and the kernel elongation is 4.8 mm compared to 2.5 mm of Sang Tarom and 2.3 mm of Amol 3. Neda and Dast are the other promising cultures. Two IRRI basmati lines, IR 62871-264-3-4 and IR 62871-75-1-10 have been extensively tested and are likely to be released on account of their high yield (6.5 to 7.5 t/ha) and desirable quality characters.

Bollich et al. (1992) believed that breeding aromatic varieties of rices is relatively simple to accomplish by use of back cross method. The aromatic character is relatively simply inherited, most reports indicating only one or two pairs of genes. Because the endosperm is a product of sexual fertilization, it is one generation advanced from that of the plant on which it develops. Therefore, in case of a cross of an aromatic and a non-aromatic rice, the F_1 plant will be heterozygous for aroma, but the seed produced on F_1 panicles will segregate for aroma. Aroma is expressed both in leaves and in grains, but where aroma is recessive, only plants that are homozygous recessive will be aromatic. In plant populations segregating for aroma it is not possible to identify which plants are segregating (heterozygous) and which are homozygous for aroma on the basis of grain samples unless individual grains on a panicle are classified for aroma. In Texas, a simple back cross technique was used in developing the aromatic variety, Dellmont, which was derived from a cross of Della-X2 and Lemont following four back crosses with Lemont, the recurrent parent. In each back cross, aromatic plants were identified and crossed with Lemont. Identification of aroma was on the basis of leaf tissue rather than grain, in order to identify homozygous plant. After four back crosses, panicles for head rows to produce seeds were selected from individual plant with verified aroma.

The back cross technique used in the development of Dellmont, could be readily used in any established rice breeding program. However, if aroma in the donor parent should be dominant, some changes in procedure might be necessary, but the general methodology would still be valid.

Reinke and Lewin (1988) followed panicle-row selection approach in the segregating population to be assessed for scent. A number of selections of semi-dwarf plants with the scent character have been made. Scent assessment is done by chewing the distal portion of the seed to evaluate the presence or absence of scent, and growing the germ end, should the test prove positive (Reinke et al., 1991). The method, although laborious, is an important step in selecting and controlling the expression of scent and in the stability of future varieties.

Welsh et al. (1991) made a number of crosses involving fragrant lines and locally adapted non-fragrant lines. Testing procedure involved assessment of breeding lines for aroma and flavour characteristics by experienced taste panels. From F_2 onwards, single panicle selections are taken in subsequent generations. These selections advanced to replicated trial when seed increase was initiated. Testing of individual seeds allows single panicles to be screened for the process and intensity of aroma, as well as proportion of flavoured seeds per panicle. To obtain pure seeds of fragrant selection, half individual seeds are taste-tested and the remaining embryo half of seeds found to be positive for aroma, grown into a plant using a sterile agar-culture technique prior to planting out in the glass house. All selections are also tested for amylose, gelatinization temperature, cooked-grain elongation and, in later generations, cooked-grain texture. Welsh et al. (1991) emphasized that by adopting a pure seed scheme based on single-seed-descent of taste-tested grains, it is possible to develop pure fragrant varieties. Incorporating the taste-testing of individual grains into breeding programme for fragrant rices achieves two aims. In early generations it ensures that populations segregating for fragrance are retained and non-fragrant lines discarded. In later generations, the use of half-seed regeneration technique guarantees that the resulting cultivar is homozygous for fragrance character.

Using this approach, Goolarah, a fragrant variety, was developed and Reinke et al. (1991) reported release of this first fragrant New South Wales cultivar in 1991. It is a tall long grained rice cultivar which has a fragrance or aroma which is released during cooking, and has similar grain quality to that of aromatic cultivars of Thailand, good milling quality and excellent appearance. Extra selection criteria for fragrance and flavour were included into the breeding programme in which individual grains from each panicle were selected throughout early generations to ensure that fragrance was maintained in the population, and at later generations to confirm that new cultivar was homozygous for the character (Reinke et al., 1993).

Tseng et al. (1997) reported release of A-201, an aromatic long grain rice, developed by California Cooperative Rice Research Foundation from a cross L-202 and PI457920 followed by back-crossing with L-202 and selection. L-202 is an early mating semi-dwarf, long-grain cultivar, while PI457920 is an introduction from Pakistan, and a semi-dwarf mutant of Basmati 370. A 201 is high yielding (9889 kg/ha) and has good grain quality.

Breeding for cooked kernel elongation does not seem to be so easy and it needs several cycles of crossing and back-crossing, besides involving many parental input to derive an ideal basmati variety in which case kernel elongation after cooking is a unique quality. Genetics of the cooked-kernel elongation is not quite understood. Bollich et al. (1992) selected some trangressive segregates for greater elongation than Basmati 370 from a cross between Basmati 370 and RU 7803075, the latter a non-aromatic variety with long grain cooking quality. There was no correlation between elongation and aroma. However, none of the lines in this cross were ergonomically acceptable. Therefore, one of the lines with superior cooked-kernel elongation was crossed with the semi-dwarf variety Rexmont and F_1 anthers were subjected to anther culture. One of the regenerated plants had a good semi-dwarf plant type but with a high level of sterility. This plant also possessed superior cooked-kernel elongation but no aroma. So, it was further crossed with the aromatic variety Dellmont that resulted into selection of lines having superior cooked-kernel elongation of Basmati 370 and translucent long grains. But none of the grains were as long and slender as those of Basmati 370. The work is still going on, but the experience clearly shows the difficulties in deriving a plant type superior to Basmati 370.

Mutation Breeding

Mutation breeding has been successfully used for bringing about desirable changes in traits usually controlled by single genes or polygenes with distinct effects. In case of aromatic rices, the approach was tried to induce dwarf stature in otherwise tall basmati rices or to rectify defects such as lack of resistance to diseases and pests. Shobha Rani (1992) reported some cultures, which emerged from gamma ray induced mutants of Basmati 370. Most mutants did not fare well when compared to the parental line. One line, IET 7861 had excellent quality characteristics like aroma, long slender grains, good head rice recovery, intermediate amylose content (21.5 per cent) and gelatinization temperature (5) in organolectic test for two seasons in the Aromatic Slender Grain Variety Trial. Although it was judged as the best culture, but the yield improvement of IET 7861 over the traditional Basmati 370 was only marginal. Similarly, NDR-625, a mutant of well known local variety Badshah Pasand, was only marginally superior to some of the selections of Kalanamak, another local type, and other lines (Anon, 1996). Performance of three mutant selections of Basmati 370, HU Bas H-4 (2550 kg/ha), HU Bas M-21 (2350 kg/ha) and HU Bas M-18 (2170 kg/ha) were found superior to the national check-Pusa Basmati-1 (1820 kg/ha) by 40.1%, 29.1% and 19.2%, respectively. In another trial, three mutant selections of T3, HU T3 M-11 (2870 kg/ha,) HU T3 M-14 (2700 kg/ha) and HU T3 M-18 (2500 kg/ha), gave higher yields than T3 (2150 kg/ha), used as check. These mutants had dwarf stature and long slender grains (Nagar and Mishra, 1996).

There is need for the more systematic mutation breeding program by growing large number of M_2 populations using directed mutagenesis. It is likely to be more successful in slightly reducing the height of the tall traditional varieties like Type-9, NP-49, T412 which have comparatively more sturdy stems. Semi-dwarf induced mutants of Bindli, and Kamal local have been used in hybridization programs, and have helped developing high yielding aromatic lines with better grain quality.

Srivastava and Mishra (1973) reported recovering dwarf mutant lines of Kalimoonch-64, a scented variety of Madhya Pradesh in India, which were superior in certain grain quality attributes to Kalimoonch-64. Having dwarf stature, the mutants also had higher yields especially due to increased number of tillers (from 9.2 to 12.8), panicle length (from 29.4 to 31.4 cm) and number of spikelets per panicle from (117 to 219). Likewise, mutants have been isolated in the scented varieties NP 49, NP 114 with a fair degree of resistance to blast, bacterial leaf blight, and tungro virus but these were found to be inferior to high yielding semi-dwarf varieties (Mahabal Ram, 1973). Gangadharan et al. (1975) identified some mutants in Basmati 370 which were short statured and with no change in grain and cooking qualities. Some mutants had high yields (33-133%) and more ear-bearing tillers than the control. They suggested using these mutants as donors for improvement of basmati varieties.

About 127 mutants are being maintained at the Central Rice Research Institute (CRRI), Cuttack (India). Out of which many mutants of Basmati 370 and Basmati 385 with dwarf-stature and earliness were evaluated for their yield potential. More than 3 t/ha yield potential was recorded in some of these mutants but high sterility is the main problem. Further work is going on to improve this drawback (IRRI 1996).

Bhardwaj et al. (1986) produced and evaluated some mutants of a local cultivar, Muskhan with a view to improve its blast resistance. A few of them had high yield potential and showed good degree of tolerance to cold and brown spot disease. One of the mutants, MM_2 gave high and stable yield over locations, and possessed early maturity, shorter plant height and higher panicles/m2 than Muskhan. These mutants are being used in crosses to improve aromatic rices in Himachal Pradesh (India).

With a view to induce polygenic variation in scented rice, Reddy and Reddy (1987) irradiated Basmati 370 with different doses of gamma rays at different developmental stages. They reported that irradiation at gametic stage will be more suitable for recovery of micro-mutations in basmati rice.

Rao et al. (1990) reported the performance of a 125-day mutant of Basmati-370, IET 8579 (CRMB-5078-388-212) in a plant population trial. The result showed that the mutant had the similar grain quality characters as Basmati 370, but a 46% higher yield potential. Heighest yield (2.9 t/ha) was obtained with 50 hills/m2 and a spacing of 20 × 10 cm.

Traditional aromatic varieties, Kamal local and Bindli, were irradiated to obtain semi-dwarf non-lodging mutants with parental cooking characteristics (Singh and Srivastava, 1996). All short statured mutants selected from Kamal local tended to lodge and were near or inferior to parents in yield. However, KLM-14 and KLM-24 showed longer and finer grains with desirable alkali spreading value and amylose content. Most of the mutants had strong aroma. The mutants selected from Bindli were also strongly aromatic. Short-statured mutants had thick, sturdy stems and relatively upright, dark green leaves. Bindli mutants, BM34, 65 and 68 had desirable cooking quality characteristics. Interestingly, two mutants BM21 and BM24 despite having very short duration, maintained strong aroma and parental level of amylose content and alkali spreading value, even when they flowered and matured in September in North India. A similar study was done by Hasan and Jagadish (1992) in which they treated four scented rice varieties—HF22, HR47, HR59 and Pakistani Basmati to isolate dwarf non-lodging and early mutants. The frequency of dwarf mutants were generally less than one percent. Similarly, the frequency of early flowering mutants was also less. A total of 200 dwarf and 307 non-lodging types were recovered which are being utilized in further breeding program.

One of the dwarf and early mutants from Basmati 370 (BMT-370/87G 1C-Klg-143-2-4-5-2-1) was reported to be doing well in the Inter-Station Trials at two Rice Research Centres, Phitasanulok, Thailand (IRRI, 1996). Similarly, Tseng et al. (1997) reported using PI457920, a mutant of Basmati 370 from Pakistan, in the development of a new aromatic rice variety, A 201 in the United States.

The Rice Research Institute, Rasht, Gilan, Iran is reported to have developed semi-dwarf mutants with lodging resistance and partial resistance to blast. Out of Amol 3, early maturing mutants have been identified. These are being currently evaluated for their performance and adaptability (IRRI, 1996).

Most of the mutants reported here failed to qualify as varieties for release due to one or more weaknesses. However, some of these could be well utilized in further breeding program; in fact, a few of them have already been used and have given good results. Following are the examples of some successful mutant selections.

PNR 546, a promising aromatic rice line in India, is an excellent example of a combined use of nuclear and genetic tool (Chakrabarty, 1996). Desirable mutant selections of Basmati 370 and Pusa 150 were crossed and selection made in the following generations. This led to the identification of PNR 546. Although formally not released PNR 546 has fast become popular with the farmers due to its high yield, resistance to important pest and diseases, adaptability, earliness and attractive long, moderate aromatic grains. On an average, it yields around 4t/ha.

A high yielding mutant line of the popular traditional aromatic rice cultivar, Govindbhog, was tested in the All India Coordinated Rice Improvement Program across all locations (Ghosh and Ganguli, 1994). The line IET 13541 (1243-12-4) yielded an average of 4.6 t/ha, slightly more than the 4.5 t/ha of check Pusa Basmati-1. It has a short, bold, white kernel of 3.7 mm long and 1.9 mm wide with a L/B ratio of 2.0. It has retained the original aroma of Govindbhog. Its high yield potential is due to more number of grains/panicles than its parent had.

Gu and coworkers (1992) reported development of two new rice varieties, FJR 832 and FBGR 861, using radiation of soft-x-ray, after thorough evaluation in fields for 4 years. FJR 832, a mutant of the Fragrant Japonica Rice 832, was characterized by scent, resistance to blast, good quality and highly stable yield. FBGR 861 is the mutant of Fragrant Blood Glutinous Rice 861, and had long purple grains with strong glutinosity and some medicinal properties.

In Thailand, two main aromatic rice varieties are grown, KDML 105 and RD 15. Notably, RD15 is a mutant of KDML 105, and is non-glutinous, similar in grain appearance and quality traits as KDML-105. However, RD15 is approximately 7-10 days earlier than KDML 105 (Somrith, 1996). Breeding of aromatic rice variety KDML-105 for photoperiod insensivity, short culm, high yield, good cooking quality etc. was launched by using *in vitro* multiple shoot induction and gamma-irradiation (Siripichitt et al., 1994). Through sustained selection over generations, four M_5R_5 lines were selected which possessed weakly photoperiod sensitivity, short culm, moderate tillering, erect plant type and good cooking and eating qualities of grains with aroma. These lines are being utilized in further improvement of aromatic variety KDML-105 for strong photoperiod insensivity.

NEW OPTIONS AND APPROACHES

Hybrid Breeding

The potential of hybrid rice in increasing production and productivity was clearly demonstrated by the People's Republic of China. About 55% of the rice area in China is already under hybrid rice, producing 66% of the total rice production (Virmani et al., 1998). China was also the first to develop the aromatic rice hybrids. Using an aromatic male sterile line, Xiangxiang 2A and a non-aromatic restorer line Minghui 63, the first quasi-aromatic hybrid–Xiangyou63, was released in January 1995 (Kunlu, 1995; Kunlu and Fuming, 1995). The hybrid soon became popular with both, the farmers and consumers. On average, it yields around 6.9 t/ha, has good grain quality, disease resistance and wide adaptability.

In 1997, another hybrid—Xiangxiangyou 77—was released. The CMS line used to design this hybrid was Xiangxiang A, an improved version of the aromatic CMS line, Xaiangxiang 2A. It was more stable and had better out - crossing characteristics (Kunlu and Fuming, 1997). The restorer line was the non-aromatic Minghui 77, a popular strong restorer line with good grain quality, developed by Sanming Agricultural Institute, Fujinan, China. In the trials on farmers' fields, Xiangxiangyou 77 yielded about 6.9 t/ha, 5.5% higher than the check variety Weiyou 64.

In China, consumers prefer semi-aromatic rice to pure aromatic rice. Both the above hybrids are considered semi-aromatic rices, as they produce only partially aromatic grains on each plant owing to F_2 segregating for aromatic genes. Therefore, there was a quick acceptance of these hybrids by the farmers and the consumers both.

Convinced of the potential of hybrid rice technology, ICAR (India) initiated a time-based hybrid rice program in collaboration with IRRI in the year 1989. The project Development and use of hybrid rice technology" (Shobha Rani et al., 1996) was further strengthened with the assistance of UNDP/FAO in 1991. Production of Basmati hybrids was also a part of this program and the responsibility for this was assigned to IARI (New Delhi) and PAU (Kapurthala Centre). Development of requisite lines for basmati hybrids was initiated simultaneously at these centres in India and at IRRI. Pusa Basmati-1, a popular semi-dwarf high yielding basmati rice variety developed at IARI, New Delhi, India, was identified as a perfect maintainer and converted into a CMS line by the scientists of this Institute. The CMS line named as Pusa 3A and another basmati CMS line Pusa 4A are being used in combination with several Basmati-like restorer lines developed at the institute, to produce Basmati rice hybrids (Virmani and Zaman, 1998). A few of the hybrids have shown high promise in the All India Coordinated Trials, yielding 20-25% higher than the highest yielding variety Pusa Basmati-1. They also have good plant type as well as grain quality.

At IRRI, a number of elite basmati cultivars bred by IRRI were test-crossed to identify maintainer and restorer lines for CMSWA system. A number of these maintainer lines and Pusa Basmati-1 from India were converted into CMS lines. Grain quality traits of some of the CMS and restorers lines developed at IRRI from the aromatic rices are given in Table 5. The lines have moderate to strong aroma and two of them have equal or more grain elongation ratio than Basmati 370. The other grain quality traits are similar to Basmati 370. One experimental rice hybrid derived from a basmati CMS line and Basmati restorer at IARI showed a higher yielding ability than Basmati 370 with comparable grain quality, and based on multi-location testing, it was identified and released as Pusa RH 10. It has recorded an yield average of 20% over Pusa Basmati–1 that yields about

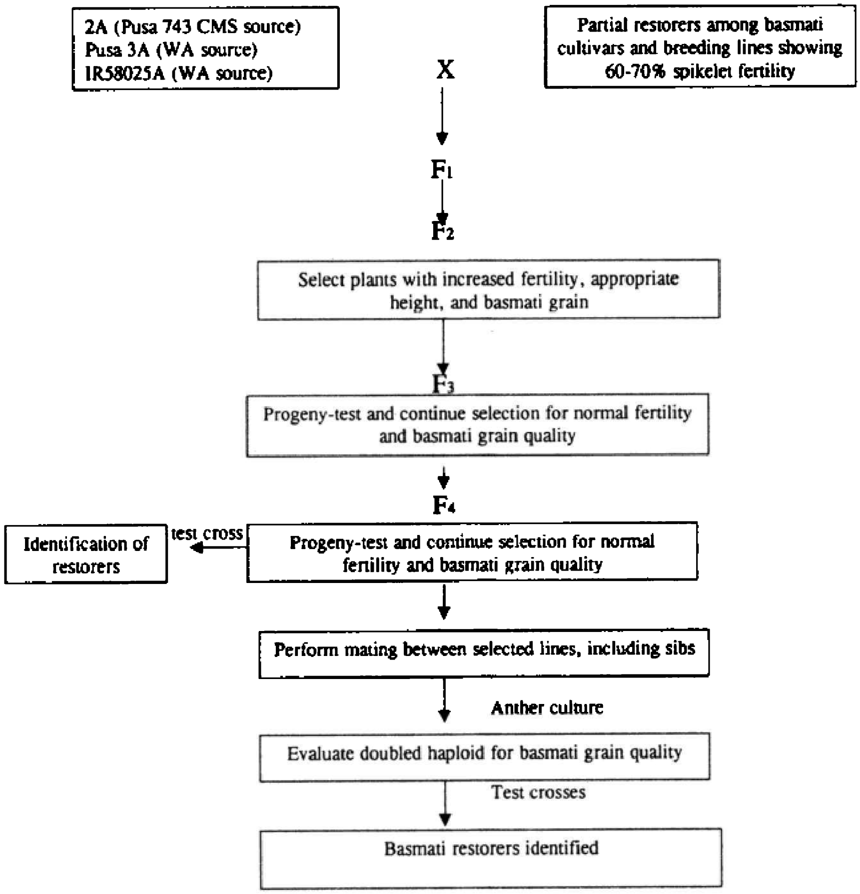

Fig. 2. Breeding strategy followed for developing Basmati-quality restorers at the Indian Agricultural Research Institute, New Delhi (Adopted from Virmani and Zaman, 1998).

5.6 t/ha. Scientists at IARI (India) also developed a breeding strategy to produce Basmati-type restorers (Fig. 2. Virmani and Zaman, 1998).

Besides, the Indo-American Hybrid Seeds (India) has recently tested a Basmati hybrid, IAHS Basmati Hybrid-1, in the market evaluation trials in Rajasthan and Uttar Pradesh. Hybrid recorded an yield ranging from 6001 to 7500 kg/ha compared to Basmati varieties like CB-II (4700 kg/ ha) and Pusa Basmati-1 (3750 k/ha). Thus the hybrid showed an yield advantage of 1300 to 3700 kg/ha over the Basmati rice varieties. The hybrid also performed well at Hyderabad and Bangalore and showed a clear advantage of about 1200 kg/ha over Pusa Basmati-1. In Uttar Pradesh it yielded as high as 8000 kg/ha compared to the best check non-aromatic variety Sarjoo-52 (2500-3800 kg/ha).

Table 5. CMS lines with basmati-type grain developed at IRRI. All have a slender grain shape.

CMS line	Days to flowering	Out-crossing [a]	GE ratio[b]	Aroma	Length	Chalkiness	Gelatinization temperature	Amylose content (%)
IR67684A	87	5	1.71	Strong	Long	None	Low	23.2
IR68280A [c]	88	4	1.92	Strong	Long	None	Intermed. /low	22.3
IR68281A	88	5	1.64	Moderate	Long	None	Intermed.	19.8
IR69617A[c]	78	5	1.66	Strong	Long	Small	Intermed.	19.8
IR70372A[c,d]	96	6	1.90	Strong	Extra long	Small	Low	22.0

[a] On a 1-9 scale, where 1 = excellent and 9 = poor.
[b] GE ratio = grain elongation ratio after cooking.
[c] Grain quality of the maintainer line is indicated.
[d] Derived from Pusa Basmati-1. (Adopted from Virmani and Zaman, 1998)

Further, as per the Company records, the IAHS Basmati Hybrid-1 had higher head rice recovery (66.14%) compared to Pakistan Basmati (63.12%). Also the kernel length was slightly more (7.09 mm) than the Pakistan Basmati (6.79 mm). The grain elongation after cooking was almost the same (12.00 mm) as that of Pusa Basmati-1. In an independent grain analysis also, it was found that the kernel length of the hybrid was more than that of Pusa Basmati-1. However, after cooking the kernel length was less (11.81 mm) than that of Pusa Basmati-1 (12.27 mm), and the elongation ratio was 1.58 for hybrid compared to 1.86 and 1.65 for two different samples of Pusa Basmati-1. After cooking, the hybrid grains showed stickiness, and also there was variation in GT as evident by ASV ranging from 1 to 6.

Only limited reports are available on the basic studies related to hybrid breeding in aromatic rices. Panicle exertion is one of the main breeding considerations in hybrid rice breeding. Vivekanandan and Arumugachany (1996) studied panicle exertion in 27 rice hybrids involving 10 aromatic and 4 non-aromatic rice genotypes. Majority of the hybrids showed dominance. Jeeraga Samba and IET 11345 with good panicle exertion appeared to be the best to be used as donors for improving this trait. Pusa 33 × IET 11345 and Jeerga Samba × IR64 recorded the maximum heterosis of 172.1 and 141.9%, respectively. Selections from these hybrids might throw desirable segregates with improved panicle exertion.

Reaction of some scented rice hybrids to brown spot (BS) diseases was studied by Vivekanandan et al. (1995). They found wide variation among parents for incidence of BS ranging from 1.6 (ADT 39 and Pusa Basmati-1) to 8.6 (ADT 41). The F1 hybrids, in general, were susceptible indicating the dominance of susceptibility over resistance. Pusa Basmati-1 and ADT

39 with least incidence are desirable parents for evolving BS resistant varieties in the scented rice breeding program. ADT39 x Kasturi, Improved White Pooni × Pusa Basmati-1 and Improved White Pooni × Kasturi recorded the least incidence with significant negative heterosis ranging from -77% to -63%.

In a study on heterosis and inbreeding depression in rice, Ram (1992) found that some of the local scented rice cultivars like Adamchini, Kanakjeera, Pawanpeer when involved in crosses, gave high degree of heterosis for yield and other agronomic characters. The range of heterosis for grain yield varied from 20.7% for IET 4140 × Pawanpeer to 160.4% for Kanakjeera × IR50.

Using four CMS lines from Iranian aromatic rice varieties—Khazar A, Domsiah, Gharib A, and IR58025A, —Kyadeh (1998) produced 15 hybrids and studied the heterosis level in local rice varieties. Only three hybrids (IR58025A × IR3441-97-1; IR58025A × IR4491-89-1; IR58025A × Ghil-3) showed superiority over the check—Sapidround. However, the male parents of these hybrids were not the local cultivars. The result showed that the Iranian local cultivars are not the good restorers and did not exhibit heterosis probably because these are genetically similar. There is need to incorporate divergent parents from other sources.

In another study in Iran, Sattari (1998) studied heterosis in six improved high yielding and three local varieties using four CMS lines, V20A, IR 62829A, Krishna A, and PMS1A. Results indicated that standard heterosis for all combinations ranged from 9.3% to 25.5%. Notably, the hybrid combinations with aromatic rices did not show any significant heterosis.

One of the main problems that arises in developing aromatic high grain quality hybrids, is due to the fact that the harvested grains from commercial F1 hybrids are the F_2 seed and show segregation. Therefore, a concern is expressed about consumer preferences because of the possible effect of this segregation on the grain quality. Khush et al. (1988) studied the grain quality of several rice hybrids and compared with their parental lines possessing diverse grain quality characteristics. They observed clear cut differences with respect to certain traits like endosperm appearance, amylose content and aroma, etc. in the bulk seed sample from the hybrid plants while some other traits had little effect on the overall grain quality. They emphasized that to produce hybrids with desirable tenderness, cohesiveness, gloss, and aroma, parents should so carefully be selected that the weighted averages of the grains in the bulk sample match consumer preferences.

Biotechnology and Molecular Breeding

Molecular biology and biotechnology have opened new opportunities for genetic manipulation of crop plants. Rice is one of the two crops where molecular map is nearly saturated with almost 2300 molecular markers mapped on rice genome through the concerted efforts of Rice Genome Project (RGP) in Japan, IRRI, University of Cornell, USA and several NARS (Kurata et al., 1994, Causes et al., 1994, Welsh and McClelland, 1990, and Williams et al., 1990). These markers include RFLPs and PCR-based markers (RAPD, SCAR, CAPS, AFLPs). Several micro-satellites have also been converted into PCR-based markers (Wu and Tannskey, 1993). High density rice map offers an opportunity to tag genes of importance with high probability (Tanksley, 1993; McCouch et al., 1988 and Saghai-Maroof et al., 1996).

Rice cultivars of isozyme Group V include high quality scented rices that are difficult to improve by traditional methods due to loss of quality traits upon sexual hybridization. Molecular techniques offer good alternatives. As a matter of fact, gene(s) for quality traits like aroma (Ahn et al., 1992) and QTL for kernel elongation (Ahn et al., 1993) have already been tagged using RFLP markers, thus, making marker-assisted selection a feasible alternative to hybridization. The aroma gene (*fgr*) has been tagged with RFLP marker, RG 28 on chromosome 8 of rice. Rice germplasm suitable for different ecological conditions may be screened for presence/ absence of this aromatic gene using RG 28 as a molecular probe and the trait can be recombined into a high yielding rice variety. Similarly, Ahn et al. (1993) found that a DNA segment in the region of RFLP marker RZ 323 on chromosome 8 caused a highly significant increase in the kernel elongation of the derived lines for which Basmati 370 was a donor parent. Further the QTL for kernel elongation and the gene for aroma are reported to be linked, indicating the scope for selecting both the traits in early generation of breeding.

Although the RFLP markers can be used for marker-assisted selection, the procedure is expensive and time-consuming. RAPD assay has the advantages that only minimal amounts of DNA use required, non-radioactivity is used, and species-specific probes are not needed. Utilizing this technique, Jin et al. (1996) identified one primer, designated as Jas 1.5, which could amplify a polymorphic band between aromatic and non-aromatic plants. Their results showed that the marker 1.5 kb fragment clearly distinguished between aromatic and non-aromatic varieties, suggesting usefulness of this marker in breeding program. Ram et al. (1998) have identified RAPD markers co-segregating with QTLs for amylose, kernel elongation and L/B ratio. Similarly, molecular characterization of waxy gene (Hirano and Sano, 1991) and characterization of micro-satellite sequence closely linked to waxy gene (Bligh et al., 1995) have opened the possibility of accelerating aromatic rice improvement program. Gene(s) for fertility restoration in F1 hybrids based on CMS line have been tagged (Yao et al., 1997, Ishikaree et al., 1997). Closely linked markers as identified by Yao et al., (1997) could be used for marker-aided selection in rice hybrid breeding programs. Similarly, molecular markers linked to gene(s) for resistance to gall midge, bacterial leaf blight, blast etc. have been developed (Mohan et al., 1998). All this would help in marker aided selection (MAS) for transferring and pyramiding of these genes into a desirable agronomic background to provide for durable resistance.

Identifying closely linked markers flanking gene(s) of interest would finally help in map based cloning of important gene(s) through the approach of chromosome walking. Once cloned, these gene(s) can be used for developing transgenic rice plants. Already beginning has been made in this direction with cloning of first disease resistance gene, *Xa 21,* by Ronald (1997). *Xa 21* is a dominant gene, which was transferred to *O. sativa* from *O. longistaminata* and located on chromosome 11 (Khush et al., 1990). This gene confers wide spectrum resistance against all pathotypes of BLB worldover. When used to transform, indica rice varieties IR64, IR72 and Taipei 309, a *japonica* rice variety (Ronald, 1997) and in a rainfed lowland variety Swarna (Reddy et al., 1997), *Xa 21* has been found quite effective against BLB. Transformation of the elite indica rice variety, IR 72, with a cloned gene *Xa 21* was also reported by Tu et al. (1998). After inoculation with prevalent races 4 and 6 of Xoo, T1 plants positive for the transgene were found to be resistant to bacterial blight. Transforming high yielding Basmati rice variety Pusa Basmati-1 with *Xa 21* would revolutionize Basmati rice production. Since regeneration system for Pusa Basmati-1 is almost established (Jain et al., 1996), its transformation with *Xa 21* will not be difficult. *Xa 21* can also be transferred by conventional back-cross breeding. Similarly, for yield, the quantitative trait loci (QTLs), Yield 1 and Yield 2, have been identified with help of molecular markers among crossing population of *O. rufipogon* × *O. sativa* (Tanksley and Nelson, 1995). Transferring these QTLs to candidate genotype/variety would help enhancing the yield level.

Beside diseases, the aromatic rices are also quite susceptible to insects; stem borer is one of them. Ghareyazie et al. (1997) reported enhancement in the stem borer resistance through transformation by microprojectile bombardment in the aromatic rice cultivar Tarom Molii. Bombardment with gold particles coated with plasmid r C1B4421, carrying a synthetic toxin gene *cry1A(b)* and plasmid r *Hygill,* carrying the selectable markers, produced a T2 line 827-6 homozygous for the *cry1A(b)* gene which showed no dead hearts or white heads after infestation with stem borers. However, the T2 line 827-25 lacking the gene averaged 7 dead hearts and 2.25 white heads per plant. Similarly, Maqbool et al. (1998) reported the generation of transgenic *indica* rice, Basmati 370, by particle bombardment expressing the novel *cry2A (Bt)* insecticidal gene. Most of the plants exhibited Mendelian segregation consistent with transgene integration at a single locus. Insect feeding bio-assays demonstrated that the *cry* 2A protein was effective against the yellow stem borer and leaf folder. Further, they indicated the use of this gene in combination with other insecticidal genes for pyramiding resistance again insect pests. The results establish that transformation of high quality rices of group V is a feasible alternative to sexual hybridization and control of pest through molecular approach is feasible.

A successful case of rice transformation of the Vietnamese aromatic variety, Nang Huong Cho Dao using particle gun was reported by Ho et al. (1995). Regenerable calli and embryogenic suspension cultures of Nang Huong Cho Dao (*indica* rice) were bombarded with *pRQ6* containing hph coding for hygromycin phosphotransferase and *gus A,* both driven by CaMV35S promoter. Regenerated plants were resistant to hygromycin B and express the *gus A* gene. PCR analysis of the transgenic plants confirmed the presence of hph gene. Recently, Chitinase gene has been successfully introduced in Basmati 122 using Agrobacterium transformation (Datta et al., 1999, personal communication).

In rice, the successful transformation with subsequent integration into DNA has been mostly done in *japonica* rice (Raineri et al., 1990, Chan et al., 1992, 1993, Hiei et al., 1994). Recently, Rashid et al. (1996) developed a reproducible system for the production of transgenic plants in indica rice using *Agrobacterium* — mediated gene transfer. Transformation efficiency of Basmati 370 and Basmati 385 was 22%, which was as high as reported in Japonica rice and dicots. A large number of morphologically normal fertile transgenic plants were obtained. Integration of foreign genes into the genome of transgenic plants were confirmed by Southern blot analysis. They are now in the process of transferring some useful genes in the Basmati cultivars by using this approach.

The best quality Basmati varieties are known to be late flowering and have tall weak stem, hence susceptible to lodging. Due to their long duration in the field, second crop after their harvest is generally not feasible. The genes for shortening the height *(pTM 124)* and for early flowering *(pGA 5268)* have been transferred and Basmati plants produced. These plants are being tested for their performance in field (Datta, 1998; personal communication). Among the possible transgenic lines developed at IRRI for testing are stem borer resistant Basmati 370 with *Bt* gene and sheath-blight resistant Basmati 122 with PR-genes.

Gene for balanced amino acids composition and protein quality cloned from *Amaranthus* mobilized to rice through genetic transformation would help in nutritional fortification of the world's most important cereal and solve the problem of malnutrition among rice eaters. Similarly a gene coding for glucose-1-6 pyrophosphorylase cloned from bacteria (Stark et al. 1992) when used to transform potato, has helped increasing starch content by 15-20 percent. Carbohydrate being a major constituent of rice endosperm, glucose-1-6 pyrophorphorylase offers an effective means to enhance yield level in rice. It is now well known that the waxy gene is the key gene in the control of amylose content of rice endosperm starch (Sano et al. 1986). Therefore, genetic manipulation of this gene may facilitate the control of the level of amylose in grain starch. Recently, the effects of antisense RNA have been studied and its use has been extended to the control of gene expression (Krol and Stuitze, 1988). Shimada et al. (1993) constructed an antisense waxy gene utilizing a PCR amplified fragment, and found that some of the seeds from the transgenic rice plants showed a significant reduction in the amylose content of the grain starch. These results suggest that antisense constructs can bring about a reduced level of expression of a target gene.

Developments in biotechnology have also provided for better understanding of heterosis and its utilization in hybrid breeding program. Using SSR molecular marker technique and a half-diallel method, Liu and Jian (1998) found that neither genetic diversity nor heterozygosity is a good indicator for predicting heterosis. They also discovered that four favourble alleles and six favourable heterogenic patterns on parental lines significantly contribute to heterosis of their hybrids in grain yield, whereas six unfavourable alleles and six unfavourable heterogenic patterns significantly reduce heterosis. Thus in the hybrid breeding program, it may be important to remove unfavourable alleles rather than broaden genetic diversity or heterozygosity of parents. These results confirm the earlier observation by Xiao et al. (1995) that dominance complementation is the major genetic basis of heterosis in rice. This was the reason that they found some recombinant inbred lines in the F8 population having phenotypic values superior to F_1, a result not expected if overdominance was a major contributor to heterosis. Similarly, Li et al. (1998) using double-haploid lines derived from *indica* × *japonica* cross showed that parental genotypic divergence had a relatively low impact on heterosis for two yield components, i.e. panicle number and 1000-grain weight. But it had a great bearing on fertility restoration i.e., filled grains/panicle and seedset.

Other significant developments are in the area of apomixis and synthetic seeds of heterotic hybrids. Apomixis will simplify seed production and will be a valuable breeding tool in crops. It will eliminate the need to produce F1 hybrids seeds every year since fertilization of the egg is not involved in embryo development. Attempts are being made to transfer apomictic genes from wild species to rice (Hanna and Bashaw, 1987). Identification, cloning and transfer of apomitic gene(s) from distantly related or unrelated species with the aid of recombinant DNA technology is also in progress. At CSIRO, induction of mutations affecting the specific stage of seed development in the test system like Arabidopsis or yeast is also being tried. In latter the idea is to trigger embryo development before megaspore mother cell enters meiotic cycle. Similarly our ability to develop an economically viable method of mass production of synthetic seeds of heterotic hybrids will go a long way in extending the benefits of hybrid breeding without the need of tedious methods of suppressing self-pollination in female parent. Among other techniques, doubled-haploidy has been effectively used for developing instant pure breeding lines from hybrids for fixing heterosis in F_1 hybrids (Ba Bang and Swaminathan, 1995). Ovary culture can also be used for this purpose (Rongbai and Pandey, 1998). Somaclonal variants of Basmati 370, a tall variety of Basmati rice (Raina et al., 1986) could be recycled in breeding programs or used in cross-breeding for generating additional genetic variation for genetic improvement of Basmati rices.

BREEDING HIGH YIELDING BASMATI RICES AT INTERNATIONAL RICE RESEARCH INSTITUTE (IRRI)

Breeding work to develop high yielding Basmati rices was initiated at IRRI in early 1970s. Original crosses were made between Basmati 370 and improved *indica* lines with intermediate amylose content and intermediate gelatinization temperature. Large segregating populations were grown and a few lines with short stature were selected. These lines had varying levels of sterility and some had poor plant types. From intercrosses of these lines, segregants with less sterility and better plant types were selected. These segregants were evaluated for amylose content, gelatinization temperature, aroma and grain elongation. Intercrosses between selected lines have been made over the year to combine all the quality characteristics. Other aromatic varieties released in India and Pakistan such as Sabarmati, Punjab Basmati, Pusa Basmati-1 and Basmati 385 have also been utilized in crosses. Each year 50-100 crosses are made amd 4000-5000 breeding lines are grown. All these lines are evaluated for Basmati grain quality characteristics every season. Selection is based on short stature, improved plant type, less sterility, shorter growth duration and various components of grain quality. Lines with poor plant type, sterility, poor grains, lack of aroma and poor grain elongation are discarded each generation. After several cycles of hybridization and recurrent selection, improved plant type lines with short stature that match the grain quality characteristics of Basmati rices have been selected (Table 6).

These lines are being evaluated in replicated yield trials at IRRI and in observational nurseries in India and Pakistan. We hope improved Basmati varieties with high yield potential will become available in next 2-3 years.

Table 6. Improved plant type lines with Basmati grain characteristics developed at International Rice Research Institute, Philippines.

Breeding line	Plant height (cm)	Growth duration (days)	Grain length (mm)	Amylose content (%)	Gelatinization *temperature	Aroma	Grain Elongation
IR70416-82-4-3	90	116	7.00	21	I	Strong	1.96
IR70418-78-2-3	92	113	7.22	21	I	Strong	1.88
IR70422-44-3-3	90	115	6.78	18	HI	Strong	2.06
IR70422-95-1-1	93	112	7.26	20	HI	Strong	1.91
IR70422-141-3-3	95	119	8.06	22	I	Moderate	1.91
IR70423-169-2-2	95	116	6.84	21	HI	Strong	2.28
IR70423-170-2-3	93	117	7.14	21	HI	Strong	1.95
IR70446-85-3-2	94	116	6.98	21	HI	Strong	1.97
Basmati 370	161	118	6.98	22	HI	Strong	2.30

* I = Intermediate, HI = High

Another important development at IRRI is the selection of a high-iron and high-zinc high-yielding conventionally bred line with excellent grain quality and aroma. IR 68144 has excellent grain type, is aromatic, yields about 4.2 t/ha, and has an iron content of 20 mg/kg. It produces not quite as much as popular variety IR 72 which has an iron content of only 12 mg/kg when grown under same conditions. It has long grain like IR64 and is suitable for consumers in much of Asia (Anonymous, 1998-1999). Interestingly, it has now been found that if the rice smells good while it is cooking, chances are it is packed with iron and zinc too. Scientists believe that the traits of high zinc and iron are linked to the gene for aroma, making it easy for them to identify.

Under the IRRI-sponsored Rainfed Lowland Rice Research Consortium, germplasm improvement is the most important component. Diverse sets of breeding materials were generated under this program, which are being evaluated in NE Thailand, E India, Laos and Bangladesh (Surapong, 1998). In Thailand where grain quality is the top priority, KDML105 and RD6 have been used as recurrent parents in the crosses to meet this requirement. After several cycles of intense selection, many advanced breeding lines both with glutinous and non-glutinous endosperm that combine good grain quality and aroma with resistance to insects and diseases are now available for testing. The promising advanced breeding lines are being tested in Thailand's national yield testing program. IR68796-27-3-B-5-5-2-Byielded 4750 kg/ha as compared to 2342 kg/ha for KDML105. It is early and has long slender grains with clear endosperm. Another line nominated for less favorable rainfed lowland environment produced 30% higher than KDML105.

Realizing the world-wide importance and popular needs for fine grain aromatic rices, an INGER nursery named as International Fine grain Aromatic Rice Nursery (IRFAON) was initiated in 1996. The first IRFAON had 34 entries, which originated from India, Iran, Mozambique, Pakistan, Philippines and IRRI. The nursery was grown at 23 locations in 12 countries, followed by a monitoring team visit of IRFAON to see the trials on some of the sites. Based on scent and other important quality traits and yield, 9 entries were identified (Table 7). Except IR43450-SKN-506-2-2-1-1, all other entries are the well known aromatic rice varieties of different countries. IR43450-SKN-506-2-2-1-1 had not only excellent aroma and grain quality, but its yield was also highest (Anonymous, 1996b). The team reviewed the work being done at these sites and made some important suggestions. The team felt the need for more and closer collaboration among the scientists, institutions and countries concerned with fine grain aromatic rices. High yield, stem borer, leaf folder, blast, and brown spot were identified to be the key issues. Photoperiod insensitivity may be incorporated to make varieties widely adapted, but date of seeding has to be manipulated to maintain good grain quality. To increase further yield potential, Basmati-based hybrid rice should be encouraged. Breeding approaches could involve step-wise convergent method, population improvement through utilization of genetic male sterility, mutation breeding, biotechnological approach of gene tagging, developing quantitative trait loci and marker-aided selection. With wide compatibility gene (*WC*) available in many backgrounds, crossing and germplasm development should be encouraged.

Table 7. Aromatic rice entries with overall best scores for aroma under IRFAON test site.

Entry No.	Designation	Origin	Across location means for[a]				
			SCT	LEN (mm)	BrW (mm)	Grain yield (t/ha)	Plant height (cm)
16	IR43450-SKN-506-2-2-1-1	IRRI	2.5	8.0	2.1	4.9	135
1	Agulha (Nampula)	Mozambique	2.4	8.5	2.6	2.4	152
19	Khao Dawk Mali 105	Thailand	2.4	8.3	2.2	2.9	136
2	Ambemohar	India	2.3	5.5	2.2	1.9	143
33	Basmati 370	Pakistan	2.3	7.4	1.8	3.7	128
6	Binam	Iran	2.1	7.5	2.3	3.3	142
10	Dom Siah	Iran	2.1	7.5	2.0	2.6	136
7	DM 16-5-1	Pakistan	2.0	7.2	1.8	3.2	123
5	Basmati 385	Pakistan	2.0	7.7	2.0	3.7	127

[a]SCT: Scent (1-Moderate, 2-lightly scented, 3-Scented); LEN: Brown rice length; BrW: Brown rice width.

FUTURE PROSPECTS

Low yield and susceptibility to pests and diseases are the main concerns of the currently grown aromatic rice varieties. Attempts to improve yield in the dwarf background met with limited successes; as the newly developed varieties lacked aroma and taste of the well established varieties. Several factors are responsible for this lack of progress. Basmati rices are generally differentiated from high yielding short-statured *indica* varieties and belong to a distinct group (Glaszmann, 1985). In rice, inter-group crosses between Basmati and short-statured *indica* varieties do not produce full spectrum of recombinants. Perhaps a gamete eliminator located close to the sd-1 locus for short stature is responsible for such distortion. Possibly, in specific, challenge like unraveling the gene blocks responsible for sterility and reduced recombination in inter-group crosses between dwarf *indica* and typical Basmati rices through tagged molecular markers would help in selecting against these gene blocks in early segregating generations and accelerating the efforts to develop high yielding dwarf Basmati rices. Similarly, the new developments in molecular biology like tagging of genes for aroma, kernel elongation and other grain quality traits and the QTLs for yield, now provide opportunities for improving both the yield and the grain quality. Similar developments are also taking place in the area of disease resistance. Resistance to sheath blight, for example, has been transferred to Basmati 122, and stem borer resistance to Basmati 370.

Increasing yields of aromatic rice through hybrid breeding has several problems. In case of hybrids what is consumed commercially is F_2 grain produced on F_1 plants, hence, due to segregation, the quality of the commercial product is likely to be impaired. This is more so in case of rice hybrids where the appearance, aroma, kernel elongation etc. of individual grains is important as against wheat where after making flour, the end-product becomes uniform. Low genetic diversity is another problem especially in Indian subcontinent where only a few common local materials and Basmati 370 have been mostly used in hybridization program. Extensive use of small and medium-grained aromatic rice germplasm may be a viable alternative to diversify the basmati gene pool. Identifying heterotic QTLs for yield from aromatic, non-aromatic and wild species using molecular markers and their transfer to potential lines through MAS is likely to enhance the level of heterosis in basmati hybrids. Similarly, the molecular divergence as a tool, could be helpful in identifying heterotic cross combinations. Diversification of CMS sources is another area that needs attention. At the moment all the released hybrids in China, India and other countries are based on a single source of sterile cytoplasm, WA, causing a fear of genetic vulnerability. Further, most of the Basmati restorer lines bred in India are isocyto-plasmic, and hence have a narrow genetic base. It is important to develop a Basmati restorer breeding population using diverse cyto-plasmic and genetic bases. Composite populations using genetic male sterility are being developed for that purpose in India as well as at IRRI. Somatic hybridization can be effectively used to develop alternative CMS lines. Wide hybridization also offers the scope of diversifying CMS sources. Low frequency of restorers lines among basmati rice cultivars is another serious handicap in Basmati hybrid breeding program. However, this problem can be overcome by using a TG MS system that does not require restorer lines.

The continuation of research on quality measurements and the economic value of quality characteristics need to be promoted. Standardization of methodologies for measuring rice quality criteria for specific end uses and markets for rice should be developed.

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Chapter 7

Scented Rice Germplasm: Conservation, Evaluation and Utilization

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INTRODUCTION

The diversity of the aromatic rices crop evolved over thousands of years, as Asian and African peasant farmers—mostly women—selected different types to suit local cultivation practices and needs. This process of selection has resulted in aromatic rice varieties adapted to a wide range of agro-ecological conditions.

Major advances in the productivity of aromatic rices, achieved in both developed and developing countries, have largely depended on access to a wide range of diverse types available. The diversity in crop varieties is essential for agricultural development: for increasing food production; poverty alleviation; and promoting economic growth. These are not only important to farmers using particular variety, but they also have a major significance in that they provide important characteristics for use in developing modern varieties. In addition, the available diversity in the germplasm also serves as an insurance against unknown future needs/ conditions, thereby contributing to the stability of farming systems at local, national and global level.

There is growing realization, that plant biodiversity is a fundamental basis of agricultural production and food security, as well as valuable ingredient of ecological stability. However, biodiversity associated with agriculture and food production is being rapidly eroded and disappearing throughout the world, and aromatic rices are no exception. The genetic diversity in aromatic rices, like the biodiversity in general, is being lost mainly due to genetic erosion, vulnerability and wipe-out. These processes are not mutually exclusive, but are in fact, braided together by the demand of an increasing population and rising expectations.

Since the dawn of civilization, thousands of locally adapted genotypes of aromatic rices have evolved because of natural and human selection. These land races or folk varieties have the genetic reservoir of useful genes. Although, the small number of varieties bred for higher yield are contributing to increasing food production, the technical bind of improved varieties is that they eliminate the resource on which they are based and lead to their genetic erosion. In addition, scarcity of land is forcing change in land use pattern with phenomenon like deforestation and loss of the habitat of these species. In Taiwan, the number of land races of rice dropped from 1200 in 1910 to approximately 400 in 1920, and the numbers have reduced dramatically since then (Juma, 1989, cited in Clevelen et al., 1994 and Thrupp, 1998). In Bangladesh, the promotion of HYV rice mono-culture has led to loss of diversity including 7000 traditional rice varieties. Itani (1993) also reported decline in the number of local aromatic rice varieties due to spread of the high yielding non-aromatic varieties in Japan. In Japan cultivation of aromatic rices for household use is now confined to the inner mountainous areas in Kyushu district, Kii peninsula, Tohhuku district, etc. This large scale spread of modern, high yielding varieties and the replacement of traditional varieties, particularly in the irrigated rice ecosystem, is leading to reduced genetic base and increased genetic vulnerability of these varieties. In addition, rapid destruction of the habitat of aromatic rices as a result of natural calamities, social disruptions or war also pose a constant threat of genetic wipe-out of such promising diversity in no time.

NEED FOR CONSERVATION

The loss in the genetic diversity is taking place at a time when new tools of biological research enable scientists to focus as much on the diversity of genes as on the diversity of genotypes. Future progress in the improvement of aromatic rices largely depends on immediate conservation of gene resources and their effective utilization.

There are many centres in the world which are engaged in the conservation of rice germplasm. Although most of these gene banks have considerable representation of aromatic rices, but nowhere the efforts are exclusively devoted for these rices. The oldest rice gene bank reported was established in Mahistsy, Madagascar in 1932. The first modern gene bank is the USDA-ARS National Seed Storage Laboratory, in Fort Collins, USA. Recently constructed gene bank facilities in Bangladesh, China (at CNRRI), Malaysia, Myanmar, and Thailand are primarily designed to conserve rice germplasm. The newly commissioned National Gene Bank (NGB), with state of the art facilities, at the National Bureau of Plant Genetic Resources (NBPGR), New Delhi, India is one of the most modern gene-banks in the region. It has a mandate to maintain the base collection of all agri-horticulture crops and has more than 45,000 rice accessions including the aromatic rices.

Not much research has been done for developing strategies and protocols specifically for aromatic rices probably because the general protocols followed for rice conservation are suitable for conservation of aromatic rices as well.

The essentials of genetic resources conservation is storage *per se,* the term 'conservation' covers entire process from collecting through access for evaluation and utilization. Different strategies followed for genetic resource conservation are: *in situ, ex-situ,* and *in vitro* conservation.

ASSESSMENT OF GERMPLASM HOLDINGS

Explorations and collection activities for indigenous rice cultivars were initiated around the turn of the century. While no special emphasis was given exclusively for aromatic rices, the grain characteristics including aroma has always been an important character explorers have looked for.

In India systematic explorations were initiated during the period 1955 - 60 by the Jeypore Botanical Survey which led to collection of 1,745 cultivars from south Orissa and adjoining areas of Madhya Pradesh. About 900 cultivars of Manipur were collected during 1965-67. During 1965–72, 6630 accessions were collected by Indian Agriculture Research Institute which came to be known as the Assam Rice Collection. Cultivars grown in the Madhya Pradesh region were collected and the 19,116 accessions collected formed the Raipur Collection. A special drive for upland paddy varieties under cultivation in Andhra Pradesh, Kamataka, Maharashtra, Madhya Pradesh, Uttar Pradesh, Orissa and West Bengal resulted in collection of 1,938 cultivars. NBPGR augmented the collections during 1983–89 by about 4,862 accessions. In addition, joint explorations by NBPGR in collaboration with state agriculture universities during 1978-80 and Central Rice Research Institute, Cuttack during 1985 resulted in collection of about 7000 and 447 accessions (from Sikkim, south Bihar, and parts of Orissa) respectively. The germplasm of the hilly region of Uttar Pradesh was explored by VPKAS Almora and 1,247 cultivar were collected. Many joint explorations with other countries have also been undertaken. Japanese exploration teams led by H. Kihara in the early 1960s and T. Watabe in the late 1960s and early 1970s made systematic collections in western Uttar Pradesh, Bihar, Andhra Pradesh, and parts of Maharashtra. H. I. Oka travelled extensively on collection trips in different parts of India. The French team from IRAT and ORSTOM collaborated with ICAR for collecting *O. nivara, O. rufipogon,* and *O. officinalis* from Goa, Karnataka, Maharashtra, and Gujrat in 1986. During 1987-89, ICAR and IRRI scientists undertook intensive collection for wild rice in south India and West Bengal (Rana and Sharma, 1991; Paroda and Malik, 1990; Singh, 1997). Similar explorations have also been undertaken in other countries. All these explorations have resulted in a large assembly of aromatic rices maintained as working/active collections/base collections at various gene banks.

Collections made in Madhya Pradesh and maintained at IGAU, Raipur, need special mention. The late Dr. Richharia while collecting rice germplasm from Madhya Pradesh found that rice varieties belonged to different groups and the local farmers have given different names to varieties in each group depending upon colour, look, taste, etc. He classified them into 8 major groups of which three groups-Phul, Chattri and Scented—have mainly aromatic rice cultivars. He observed wide variation within Phul and Scented group, this was not the case with the Chattri group. The dominant varieties in Phul group included Ajwain Phul, Badal Phul, Kendhu Phul, Sewanti Phul, Tulsi Phul while Tulsi Manjari, Kali Moonch, Chinnor, Vishnu Bhog, Badshah Bhog, Dubraj are famous among the Scented group of cultivars (Anonymous, 1998).

CLASSIFICATION OF SCENTED RICE GERMPLASM

The scented rice germplasm is characterized by mild to strong aroma. However, the overall eating quality of these rices is determined by not only the degree of aroma present, but also by presence or absence of some other important attributes such as length and breadth of kernel, elongation of kernel after cooking, amylose content (AC), gelatinization temperature (GT), and gel consistency (GC) and taste. Broadly, the scented rice germplasm are grouped into three categories i.e. the Basmati, jasmine, and non-basmati/jasmine scented rice group. As evident from Table 1, the Basmati type of rice cultivars, which have their origin in India and Pakistan, are characterized by intermediate AC, low to intermediate GT and medium gel consistency (GC) as against Thai Jasmine rices which have low AC and GT and soft gel consistency (Jualiano and Villareal, 1993). The jasmine rices have slightly larger kernel length than the basmati, however the latter due to being more slender, look longer. The L/B ratio is almost the same in the both types of rices. However, the

Table 1. Some important scented rice cultivars grown in different countries

Country/Cultivars	Some major quality features				
	Amylose (%)	Alkali spreading value	Gel-consistency	Length	Breadth
USA					
Della	21.8	4.5	36	–	–
A 301	26.8	5.8	34	7.5	2.0
Australia					
VRF6	16.3	6.8	77	6.6	1.9
India/Pakistan					
Basmati 370	22.4	3.7	39	6.9	1.9
Basmati 385	24.6	6.9	42	6.7	1.8
Bas Pak	23.6	7.0	48	6.8	1.7
KS 282 (Bas 370 x IR 98)	26.3	7.0	28	7.0	2.0
Philippines					
Malagkit Sungsong	2.9	5.9	–	4.8	2.7
2nd Sample	4.4	6.4	100	4.6	2.8
Iran					
Domsiah	18.2	4.8	–	6.8	1.9
Thailand					
KDML 105	14.5	7.0	60	7.5	2.0
RD 15	15.6	7.0	66	7.4	2.0
Nahg Mort S4	25.0	7.0	36	6.7	2.2
Vietnam					
Lua Thom	30.4	6.8	61	6.8	2.0
Huyet Rong	26.4	5.0	57	6.5	2.0
Tau Huong	22.2	5.1	74	6.7	2.0

most characteristic feature of the Basmati group of rices is their ability to elongate, almost double their original length, after cooking (Table 2). No other scented rice has this feature and even if a few of them do elongate, their elongation is not as pronounced as that of Basmati rices. Sadri varieties of Iran have an elongation more or less similar to that of basmati and also look very much alike, but are not as aromatic as the basmati (Juliano and Villareal, 1993). Nga Kywe (D25-4) from Burma, is another variety, which has the ability to elongate upon cooking (Khush and Juliano, 1985).

Table 2. Some distinguishing cooking qualities of milled Basmati, Jasmine and Della rites*.

Sample	Kernel width (mm)	Length of cooked kernel (mm)	Expansion ratio	Water uptake at 77°C (ml)	Amylose (%)
Basmati 1	1.80	13.67	1.95	119.1	22.76
Basmati 2	1.78	14.05	1.97	119.1	22.76
Della AR	2.08	9.68	1.36	80.0	22.70
Della LA	2.03	10.03	1.42	73.8	23.16
Jasmine	1.98	9.91	1.39	330.4	18.20

(* Adopted from Sharp, 1986)

The third category—non-Basmati/jasmine scented rices—consists of scented rice germplasm which besides being aromatic, have one or more of the other attributes of the Basmati or Jasmine rices, but not all of them. The non-basmati scented rices of India and Pakistan, in particular are characterized by small to medium kernel length. Malagkit Sungsong, a *japonica* variety, of Philippines has been reported to have the highest amount of 2-acetyl-1-pyrroline which has been attributed to aroma development in the aromatic rices (Buttery et al., 1983, Table 3). It has however, very low amylose content (3-4%) and has bold grains. Della, a scented long grain variety of USA, is a specialty rice, produced in limited quantity (Jodon and Sonnier, 1993). Its aroma is like that of roasted popcorn or nuts and its nutty taste resembles that of the much sought-after Basmati rices of India and Pakistan. Della, however, does not possess the extreme cooked kernel elongation of true Basmati (Webb et al., 1985). Further, Thai Jasmine was preferred in every respect over all US grown rices that were tested. The main points of difference were in color, texture and aroma (Coley, 1996).

Table 3. Ranking of cooked rice samples in terms of those having the greatest popcorn-like aroma (at the top of the table) to those having the least (at the bottom of the table) and the concentration of 2-Acetyl-1-pyrroline found in terms of dry weight of rice.

Variety	Aroma	Concentration (ppm)
Malagkit Sungsong		0.09
Milagrosa		0.07
Khao Dawk Mali 105	Greatest popcorn aroma	0.07
IR841-76-1		0.07
Basmati 370		0.06
Seratus Malam		0.06
Azucena		0.04
Hieri	Least popcorn aroma	0.04
Calrose		<0.008
Texas Long Grain		<0.006

(Adopted from Buttery et al., 1983)

Glaszmann (1985, 1987) classified rice germplasm into six categories on the basis of allelic composites at 15 isozyme loci. Accordingly, Group I consists of typical *indica* rices, while Basmati and other aromatic rices of India, Bangladesh, Pakistan, Afghanistan, and Iran fall into Group V (see Chapter 2 of this volume). Whereas normal *indicas* belong to Group I and VI and *japonicas* belong to Group VI. This understanding led to realize why the inter-group rice hybrids had varying degrees of sterility and did not yield full spectrum of recombinants in the segregating generations. Due to this very reason, progress in combining grain quality characteristics of Basmati and high yields of *indicas* has been difficult. Study made by Singh, 1998 (personal communication) also recognized that collections from India, Bangladesh and Nepal belong to Groups I, II, V and VI, while majority of the accessions that could be classified as Basmati fall in Group V, notwithstanding a few which are not classified into any of the identified isozymic groups. Nematzadeh et al. (1993) analyzed a total of 178 local varieties of Iran and classified them using isozyme markers. Most of the cultivars (61.10 per cent) were categorised in Group V and about 6.8 per cent each in Group I and VI, but the remaining 25 per cent could not be placed into any of the identified groups

GERMPLASM EVALUATION AND SCREENING

Itani et al. (1991) studied 94 local scented rice varieties of Japan and observed that, as a rule, scented rices were tall, had fewer panicle number, higher stem weight, lower yields, and were susceptible to lodging and awned more frequently than the leading varieties. About 60 per cent of the collections had such names related to scent as Kohtoh, Kabashiko, Jakahtob (Jakoh means musk), Nioimai, etc. Sixty-three varieties (77 per cent) had the characteristic scent like Hieri, a major variety in Kochi Prefecture. There were examples of the same variety having different names, as has been reported by Singh and Singh (1997) in India as well.

Tsuzuki et al. (1979) reported significant differences in the protein and amino acid contents among 41 Japanese native and two foreign scented rice varieties. The scented rice variety, Brimful showed the highest protein (12.14%) and amino acids, especially lysine (569 mg/100g of dry weight). Sabarmati, another variety screened, was reported to have 10 per cent protein, while for rest of the materials the protein content ranged from 7.19 to 9.62 per cent. Shima-mochi and Henrogoti had the highest methionine content (121 and 116 mg/100g of dry weight). Varietal differences in lipid and fatty acid contents were also reported by Tsuzuki et al. (1979,1986). They observed higher oleic acid content in scented rice varieties than in non-scented ones. However, the former had lower amount of linoleic acid than the latter. A positive correlation between the degree of flavour and oleic acid content ($r=0.605$) and negative correlation with linoleic acid content ($r = -0.792$) was also reported.

Miyagawa and Nakamura (1984) classified 85 scented rice cultivars based on the regional differences in varietal characterstics. Using principle component analysis they divided the material into four major groups and found that the cultivars from Tohoku and Kanto area showed early maturity having shorter culms, longer awn, larger angle of flag leaf, less straw weight and yield. In Kinkind and Kyushu, the cultivars showed late maturity, and had longer culms, more straw height and yield.

Cultivars from Shikoku differed from those of the warm areas of Kinkind and Kyushu. Similarly, the cultivars from Hokuriku area were different from that of the other regions.

Using Mahalanobis' D^2 statistic, Ratho (1984) analyzed the genetic diversity among 39 Indian and 40 Afghanistan scented rice collections. All the 43 scented rice cultures were grouped into 5 clusters (Table 4). The 4 varieties of Afghanistan were distributed in 3 clusters. Similarly varieties from Maharashtra and U.P. (India) were also distributed in 3 different clusters. Thus, the clustering pattern did not follow the geographical origin of the variety. Kernel length, volume expansion ratio and alkali value were the main contributors to genetic divergence.

Table 4. Grouping of 43 scented rice varieties into different clusters

Cluster	Number of Varieties	Varieties
I	12	Domsiah, Domzad, Prasadbhog, Sitasail, Ghamsali, Ambemohar 157, T-9, M-112, AC 1711, AC 5225, Chandanchurad and P40-40-7.
II	10	Randhunipagal, Moosatarum, Jammu Basmati, Kaminibhog, Badshabhog (Chinsurah), M 146, AC 118, Kalazira, Kamodkeri and AC 5095.
III	8	Mehar, Basmati 370, Basmati Purple, S 38, S 39, Badshahbhog, Latai and Ambemohar 159.
IV	4	Gopalbhog, Badshahbhog Sel., MNP 115, and Zuhi Bengal.
V	9	Tulsimanjari, Pimpudibasa, NP 114, NP 49, MNP 49, Lilabati, Kalanamak, Ramjawain, and Krishna Sadhabi.

Chang (1985) reported occurrence of land races of aromatic rice in Hualien district of Taiwan grown by the Aimei aboriginal tribe. These rices are mostly tall and leafy with large panicles and long awned grains. There are large intra and inter-varietal differences which offer vast genetic diversity for breeding program.

Hung and Ro (1995) studied the combining ability of aromatic rice varieties in combination with some early and high yielding rice varieties. The results showed that Jasmine 85 possessed good general combining ability. The crosses of Jasmine 85 and IR64, Jasmine 85 and Om 1300-6, and Jasmine 85 and Om987-1 were promising for further selection, because both the parents in these crosses had high gca.

Sarma et al. (1990) studied the grain characteristics of 43 traditional aromatic rice varieties of Assam and reported wide variation in grain length (566–994 mm), breadth (180–296 mm), L/B ratio (2.44-4.33) and 1000-grain weight (8.44–25.48 g). Obviously, some of the collections had extraordinarily high grain length and could be used as donors in breeding programmes.

Twenty-six scented rice germplasm collected from different parts of Orissa were evaluated for seed protein variability by Dikshit et al. (1992). Highly significant differences were reported for protein content, grain weight and L/B ratio. Some of the land races (Kalajira, Kanakpura, etc.) were found to have a protein content in the range of 9–10 per cent and more. The L/B ratio varied from 1.6 to 3.5 with six collections characterized as long slender grain type; most notable among them were Gidhanpakshi Barhampuri, Badshahbhog and Durgabhog showing kernel length of 7, 7 and 6.6 mm, respectively.

Rani et al. (1992) screened about 400 scented quality rices to identify Basmati types resistant to whitebacked plant hopper (WBPH). HBC5 was the only one variety found resistant to WBPH. HBC5 had extra-long slender grains (7.42 mm), strong scent and also a high KLAC of 13 mm. Another variety, Basmati Kota, with moderate resistance to WBPH, also had extra long grain and showed the highest KLAC of 15 mm. Besides, Basmati 397 and HBC 95 were also moderately resistant with good KLAC. These varieties can be well utilized in breeding programmes to develop high yielding dwarf basmati rices. Kushwaha et al. (1992) also evaluated about 35 entries of tall and dwarf groups of scented rices against resistance to stemborers. None of the tall entries showed any resistance. However, three new entries — IET 12609,12603, and 12608 showed promise in their resistance to stem borer, where the whitehead incidence ranged between 6–12 per cent.

Reddy et al. (1989) evaluated some scented varieties for their reaction to bacterial leaf streak (BLS) and bacterial blight (BB) under different doses of nitrogen application. BLS incidence during early crop growth stages was severe in Basmati 370, IET 8580, and Badshahbhog with 10 to 35 per cent damage to leaf area, depending on the nitrogen level, BLS was only 0.5 per cent in Pakistan Basmati, IET 8579, and T412. In contrast, BB disease caused 15-42 per cent leaf area damage in Pakistan Basmati, T412, IET 8580 and IET 8579. Basmati 370 and Badshahbhog suffered least damage at all N levels.

In a study on germplasm evaluation against stem rot and bacterial blight, Chand and Singh (1986) screened 150 scented rice genotypes during the kharif season in 1983. Only three entries HKR 213, HBC 19 and Pakistani Basmati were found to be resistant to all the three *sclerotium* species in laboratory and field tests. Such entries can best be utilized in multiple resistance breeding programme.

Tolerance of 18 scented rice varieties was tested against stem borer by Manjunath et al. (1977). The highest incidence of 116 white-ears/plot was observed for Basmati 370, followed by 103.6 white-ears for Guruvadisanna and 79.6 white-ears for Sabarmati. A local variety, Gamanasanna showed the least incidence (1.7 white-ear/plot), indicating its suitability as a donor for breeding resistant scented rice varieties.

Singh and Srivastava (1997) collected and purified 19 aromatic rice germplasm at Varanasi (UP) for evaluation. They identified a number of local germplasm which were resistant to various pests and diseases. They reported a large intra-varietal variation and accordingly selected 9 different types of variant in a locally well known cultivar — Kalanamak. These are being further evaluated. Similarly, at GBPUAT, 235 lines were obtained from the 827 working germplasm accessions available at the Directorate of Rice Research (DRR) for testing against bacterial leaf blight (BLB) (100) and stem borer (135). None of them exhibited any resistance to BLB. However, lines such as Basmati Aman, Chok-jye-be-chal, ARC 7057, Batia Bora 613, Dubraj, Abor Bora, Uki Bora, Boka Chakara and Haru Chokura showed varying degrees of resistance to stem borer in replicated field testing (Nagar and Mishra, 1996).

Kumar et al. (1996) reported on evaluation of 1010 accessions of aromatic germplasm for quality traits as well as for their reaction to key pests and diseases. Several donors possessing resistance to moderate resistance coupled with excellent quality characteristics were identified in Basmati background. Some of them with multiple resistance such as Karnal local and Basmati 6129 (tolerant to bacterial blight, WBPH and neck blast), HBC 5 and Basmati 405 (tolerant to leaf blast, WBPH), Domsiah (tolerant to BB and neck blast) are being used in breeding programmes to incorporate resistance in the high yielding Basmati varieties.

Reddy and Reddy (1986) studied ten morpho-physiological and genetic parameters using 76 aromatic rice varieties. High genotypic variations were observed for number of panicles, panicle weight and grains per panicle. Strong positive correlation with seed yield/plant were exhibited by panicle length, panicle weight and grains per panicle. Path coefficient analysis revealed large positive direct effects of days to flower, panicle length, panicle weight and grains per panicle on grain yield. These attributes should be given greater weight age while formulating selection indices in scented rices.

Grain quality characteristics of 15 aromatic slender-grain rice varieties were studied by Verma and Srivastava (1993). HKB-228 showed the maximum L/B ratio of 3.76; T-3 had the highest hulling (76.65 per cent), milling (73.50 per cent) and head rice recovery (68.98 per cent). The water uptake by grains was the highest in BK 7763, and it also had a higher (1.77) kernel elongation after cooking. Saket 4, a non-scented variety, was reported to have the highest protein content (8.74 per cent).

Patra and Dhua (1996) collected 88 long slender grain scented basmati rice germplasm from north India and studied their morpho-agronomic characteristics. Significant variation was observed for the traits like leaf length, culm length, culm number and panicle length. Among the non-Basmati scented rices, Bindli and Tilakchandan, though bold in look, produced a fine aroma when cooked. The elongation of cooked kernels of Tilakchandan was also very good. Most Basmati types were susceptible to bacterial leaf blight and did not have dormancy as the lodged panicles start germinating in the field itself.

Amino acid profiles of 12 traditional Basmati and non-Basmati scented rice cultivars were studied by Sekhar and Reddy (1982) and compared with the FAO standards. It was observed that most of the scented rice cultivars had comparable or superior values, while cultivars such as Type 3, Basmati Sufaid 100, Likitimachi, Randhuni Pagal, and Basmati 370 showed superior lysine, phenylalanine, leucine and methionine content. The results clearly indicate that the scented rice cultivars possess better amino acid profile and exhibit superior nutritional qualities which could be utilized in breeding varieties with improved amino acid composition. Type 3 and Basmati 370, for example, were reported to have very high protein content (11.36 and 11.22, respectively).

Histological variation among aromatic rices have been reported by Awasthi et al. (1997). Large to medium size metaxylem, and phloem were observed in mild to medium scented and non-scented rice varieties. On the contrary, the strongly scented varieties like Basmati 370, Kalanamak, Phoolchandi and Pusa Basmati-1, had smaller size of metaxylem and phloem. In this group of varieties, normal phloem and xylem elements were replaced by a largely undifferentiated parenchymetous cell mass. However, the mildly aromatic and non-aromatic rice varieties were free from such histological peculiarities.

Singh (1997) evaluated 356 traditional aromatic rice varieties of India, Pakistan, Thailand, etc. for grain and cooking characteristics and observed wide variation for all the traits, maximum being for gel consistency (GC), 1000-grain weight (WT), and amylose content (AC) (Table 5).

Table 5. Some typical Basmati varieties of different countries and their grain and cooking quality characteristics

Variety	Origin	AC	GT	GC	KL	KB	L/B	KE
Barah	Afghanistan	17.6	4.58	70	7.55	1.88	4.02	2.18
Mussa Tarom	Iran	19.2	4.20	40	7.62	1.88	4.05	1.83
Mulai	Iran	19.5	3.58	55	7.76	1.96	3.96	1.93
Sadri	Iran	18.2	4.54	35	7.66	1.94	3.45	2.10
Pakistani fine	Pakistan	20.4	5.40	50	6.96	1.96	3.55	1.93
Sathi Basmati	India	18.4	3.83	58	7.24	1.92	3.78	1.95
Basmati 370	India	21.0	3.83	57	6.84	1.84	3.72	2.10
Kamal local	India	21.2	3.66	60	7.06	1.90	3.72	1.85
Hansraj	India	18.1	4.50	60	6.88	1.94	3.55	2.17

AC = Amylose content (%); GT = Gelatinization temperature; GC = Gel consistency;
KL = Kernel length; KB = Kernel breadth; L/B = Length/Breadth ratio;
KE = Kernel elongation after cooking.

Barah (Afghanistan), Mesa Tarom, Mulai and Sadri (Iran), Sathi Basmati and Karnal Local (India) had kernel length of more than 7 mm while Mulai from Iran had the longest kernel length of 7.66 mm. However, Barah and Hansraj were found to have the highest kernel elongation after cooking (2.18 and 2.17 per cent, respectively), followed by Sadri of Iran and Bas 370 of India, both having kernel elongation of 2.10 per cent. Barah from Afghanistan and Mesa Tarom form Iran had the L/B ratio of 4.02 and 4.05, respectively. Based on grain shape and elongation, 39 of the 356 accessions were classified as Basmati types and the rest as non-Basmati scented rice.

Sood and Siddiq (1980) screened 94 diverse Basmati types collected from all over the world and reported considerable variation in their quality attributes. Volume expansion, amylose content and water uptake showed relatively more genetic variation than other traits. High heritabilities were observed for amylose content, gelatinization temperature, length, breadth and L/B ratio of kernels. The aroma varied from mild to strong. A few types were found to possess a smell altogether different from that of the typical Basmati aroma. Thereby, warranting a detailed study on the chemical nature of aroma in these varieties. The 94 diverse genotypes were grouped according to varied constellation of attributes and found that accessions — 27810 and 27825 — possessed the maximum number of desirable traits to be used as donors in breeding programmes. In another study, Sood et al. (1983) found that the two local varieties — Bindli and Type 3 — not only possessed high kernel elongation, but were also better general combiners, showing their suitability as donors in breeding programmes.

Vivekanandan and Arumugachamy (1996) examined the panicle exsertion in 10 aromatic and 4 non-aromatic rice genotypes, to judge their suitability in hybrid breeding programmes. Jeeraga Samba and IET 11345 with good panicle exsertion may be used as donors for improvement of this trait in hybrids. These two genotypes when crossed with IR64 and Pusa 33 gave high degree of heterosis as well.

Seventeen newly developed scented rice cultivars were analyzed for their physio-chemical and cooking quality characterstics by Padmavathi et al. (1992). The Basmati parent involved in the development of these cultivars was Basmati 370. There was some reduction in the overall palatability/acceptability rating of these cultures, but IET 12013, 11341, and 11350 were found to possess palatability score comparable to that of Karnal local. They were superior in yield by 29.4 per cent to the checks.

In a study on grain characteristics and cooking quality of scented and non-scented long, slender-grain varieties of rice, Sarkar et al. (1994) found that Basmati 385 and Gaurav among scented and Hatipanjari among non-scented group, were superior to others, and could be used as donors for quality-breeding programmes. Hatipanjari had the longest kernel of 7.07 mm compared to 6.98 of Gaurav and 6.74 of Basmati 385. Dehradun Basmati had the highest hulling, milling and head-rice recovery percentage after Hatipanjari. Further, they concluded that to increase head-rice recovery with long and slender grains, greater attention is necessary to completely filled grains, especially high-density grains.

Twenty-three promising aromatic rice genotypes were evaluated for milling, and physio-chemical characteristics by Chikkalingaiah et al. (1997), who observed that HP-32 (Pusa 150 x Basmati 370) ranked first both in brown and head-rice recovery. Most of the lines had long, slender grains with low amylose content, except HP-31, MFL-18 and PBH which had long, slender grains and intermediate amylose.

Vaidehi et al. (1984) studied some new scented rice varieties along with Basmati for grain size before and after cooking, protein content and organoleptic value. T-5735 scored higher for appearance, aroma and flavour over market samples of Basmati and yielded much higher. One of the locally grown scented varieties, Jeerige Sanna, had the highest elongation after local Mandya Basmati.

Singh et al. (1988) compared the grain characteristics of 23 traditional Basmati varieties from northwest India and found them falling into two groups. Group A consisting of varieties such as HBC-5, HBC 85, Pakistani Basmati, Basmati Kota and Karnal local having growth duration of 140–150 days and characterized by higher kernel length and L/B ratio and similar to Karnal local. Group B varieties had 135–140 days growth duration. These varieties (HBC 30, 40, 45, 46, 98, and 136, Mohabawali, Konwali, Chandbani I and 11, Niranjanpur) were phenotypically similar to Basmati 370 whereas Hansraj and NB 10B resembled Type 3.

Using ten local aromatic rice germplasm from Orissa and Bihar, Malik et al. (1994), determined their agro-morphological and some physio-chemical characteristics (Table 6). Results indicated that the collections from eastern India had mostly medium slender grain, but had high recovery with around 20 per cent of amylose content and excellent elongation ratio and pleasant aroma on cooking. Jubraj was observed to have the highest kernel length after cooking (9.5 mm), and Makarkanda and Badshahbhog the highest elongation ratio (1.86). Pimpli-basa had the longest panicle length, Durgabhog maximum grains/panicle and Baiganbija the highest fertility, indicating their suitability as donors. All the ten varieties studied had high head rice recovery, milling and hulling percentage. There is need to study their combing ability to incorporate these traits into long slender-grain scented varieties.

Chowdhary and Ghosh (1978) evaluated 62 fine grain and scented varieties of rice for their agronomic and physio-chemical characteristics (Table 7). Seetabhog, Badshahbhog, JBS 742 and JBS 802 gave higher

Table 6. Quality characters of some traditional scented rices of Orissa and Bihar (India)

IC No.	Local Name	Hulling (%)	Milling (%)	Head rice (%)	Kernel length after cooking (mm)	Alkali spreading and clearing value	Water uptake (ml)	Volume expansion ratio	Elongation ratio	Amylose (%)	Desirable trait
86053	Jubraj [a]	76.1	70.4	64.2	9.8	3.0,2.0	160	3.7	1.71	23.40	Kernel elong.
86061	Durgabhog [a]	76.4	70.2	65.6	9.4	3.5,2.5	195	3.7	1.65	22.05	Head rice
86137	Pimplibasa [a]	75.5	70.2	64.0	6.0	3.0,2.0	185	3.7	1.52	22.05	Head rice
98904	Mugajai [b]	73.5	67.3	68.0	7.0	3.0,2.0	110	3.7	1.58	17.10	Head rice
98906	Durgabhog [b]	76.0	70.4	65.0	7.0	3.0,2.0	135	3.7	1.73	15.97	Head rice recovery
98920	Rangsuri [b]	75.6	70.4	66.0	9.0	3.0,2.0	175	4.0	1.54	17.69	Vol. expansion
98984	Makarakanda [b]	78.2	72.4	69.0	6.2	3.0,2.0	185	3.7	1.86	17.69	Kernel elong.
99016	Badshabhog [c]	77.0	72.0	67.0	7.4	3.5,2.5	200	3.7	1.86	20.11	Kernel elong.
92710	Basmata [d]	77.1	71.2	65.5	8.0	3.0,2.0	160	3.7	1.79	20.74	Kernel elong.
9211	Baiganbija [d]	76.2	70.0	65.0	8.4	3.0,2.0	205	4.0	1.76	16.53	Kernel elong.
Range		73 to 5	67 to 3	64 to 0	6 to 0	3 to 0, 2 to 0	1 to 10	3 to 7	1 to 52	15 to 97	
		78.2	72.4	69.0	9.8	3.5,2.5	205	4.0	1.86	23.40	
Mean		76.16	70.45	65.93	7.82	3.1,2.1	171	3.76	1.70	19.33	
SEM±		0.23	0.149	0.22	0.23	0.06,0.05	5.29	0.02	0.02	0.35	
CV(%)		16.68	1.13	1.72	16.21	6.45,9.52	16.81	3.72	7.10	2.10	

Place of collection : [a]Keonjhar, [b]Phulbani, [c] Bolangir, [d] Santhal Parganas of Bihar.

Table 7. Grain yield and cooking characteristics of some important scented rice varieties

Variety	Grain yield (kg/ha)	Flow. Duration (days)	Kernel size (mm) Length	Kernel size (mm) Ratio	Hulling recovery (%)	Head rice (%)	Alkali value	Amylose (%)	Kernel elong. (mm)	Kernel-elong. Ratio	Protein content (%)
Basmati 370	1,018	96	6.64	3.92	73.0	35.0	4.0,3.0	21.2	12.8	1.9	7.4
Basmati (Kurnool)	1,022	98	7.10	3.94	74.5	47.0	3.0,2.0	20.0	15.1	2.1	8.3
Basmati (Kota Rajasthan)	1,069	90	6.26	3.00	76.0	52.6	3.5,2.5	18.6	14.1	2.2	8.3
Basmati (Ahtsar)	1,100	97	6.76	3.50	76.0	55.0	6.6,5.6	21.0	13.6	2.0	6.5
Kalanamak	1,478	105	5.47	2.66	75.0	64.0	4.6,3.6	19.0	11.3	2.0	7.5
Rajanam	1,718	115	4.67	2.32	79.6	57.2	6.0,5.0	26.0	10.0	2.1	7.5
Gopalbhog	1,785	110	5.20	1.81	78.9	69.0	7.0,6.0	19.2	10.6	2.0	6.1
Badshahbhog (WB)	2,054	111	4.53	2.61	78.1	62.0	4.0,3.0	20.4	9.1	2.0	6.0
NC 324	1,863	111	5.33	3.05	78.6	71.3	3.6,2.6	20.4	11.0	2.1	7.9
Seetabhog	2,160	115	4.11	2.12	77.4	72.0	4.6,3.6	18.8	10.0	2.4	7.6
Seetasail	1,481	115	3.87	1.92	77.7	57.8	5.8,4.8	18.6	9.7	2.5	8.0
JBS 742	2,284	110	4.34	2.15	79.6	72.0	5.0,4.0	18.6	9.6	2.2	8.0
JBS 802	2,096	111	4.58	2.36	78.8	67.0	6.5,5.5	18.9	10.3	2.2	7.0
T 412 (local check)	1,690	115	4.24	2.09	79.0	70.0	4.0,3.0	19.0	9.6	2.3	8.0

yield and greater kernel elongation ratio than Basmati types. Although, the highest linear elongation of kernel during cooking was recorded for Basmati Kurnool (15.1 mm), the highest elongation ratio was exhibited by a very small grained variety — Seetasail (2.5 mm). Further, the linear elongation during cooking was shown not only by long grain Basmati types, but also by very small grain types. Some of the short grained types — Seetasail (2.5) Seetabhog (2.4) and T412 (2.3) had higher elongation ratio than the Basmati types (1.9 – 2.0). Thus, the cultivar like Seetasail could be a good source for elongation after cooking.

Chaube et al. (1988) studied 9 scented and 11 non-scented rice varieties for their quality attributes. SG8, SG22 and Dulhania had strong scent, and high elongation ratio, of these SG 8 has short-bold grain, while SG 22 and Dulhania are medium slender-grain types. Madhuri, a mild scented variety had the highest L/B ratio of 4.0, followed by Vishnuparag (3.80) and Dulhania (3.24). The varieties can be utilized as donors in the breeding program.

Raju et al. (1990) compared the performance of a few scented rice cultivars under different levels of nitrogen and found that Jeeragasambha, a well known local variety of Andhra Pradesh ((India), had higher number of productive tillers/m2 and filled grains/panicle than IET 8580 and Basmati 217. However, the weight of the cooked rice was more in IET 8580, and it also absorbed more water during soaking as well as upon cooking. Jeeragasambha took less time for cooking than the other two varieties.

Singh and Nagar (1996) reported evaluation of 111 germplasm of scented rices. Some of the genotypes had as high as 240 (Jeerabatti), 257 (Dhania B2) and 267 (Kaminibhog) spikelets per panicles, whereas the grain number per panicle were 118 for Tulsipasand, 119 for Basmati-B and 127 for Jeerabatti. The sterility was as low as 4 per cent in Lalsar and 25 per cent in Bindli, while test weight was the lowest (6 g) in Kaminibhog, 7.1 g in Sitabhog and 7.6 g in Kanakjira-B and Dhania-B2. There were a number of lines with grain length of more than 7.5 mm and L/B ratio more than 4.05. Large variation was reported in some of the local traditional varieties like Kalanamak, Badshahpasand, Shamjira, and Kanakjira, etc.

To identify the varieties with Basmati background to be used as donors, Rani et al. (1998) studied the first International Fine Grain Aromatic Rice Observation Nursery consisting of 33 entries including Basmati 370 and Pusa Basmati-1 as checks. In the long slender group, DR 28 (7.88 mm), DR 29 (7.37 mm) and Shahpasand (7.35 mm) recorded high kernel length. Basmati 385 and Shahpasand exhibited high KLAC and ER. They observed that with the emphasis now shifting to the development of dwarf short grained aromatic rice for domestic and export purposes, Azucena (Philippines), ARC 11554 and Tulsimanjari 14-2 (India) may be used as donors depending upon the objectives. These two cultivars also had the maximum head rice recovery of 64.7 and 67.5 per cent respectively.

Dwivedi (1997) studied the response of some scented rice cultivars to nitrogen application and found that Kamini and Sugandha had significantly higher number of tillers/m2 and grains/panicle than rest of the cultivars-RP615, Harbans, and Kasturi. Kamini and Sugandha also had higher harvest index i.e. 42.79 and 45 per cent, respectively.

In a review of rice situation in Iran, Rani (1998) remarked that the quality of cooked rice overweighed all other considerations for Iranian consumers. Therefore, despite low yields, but because of their excellent quality traits, more than 86 per cent of the total rice area in Iran is still under local varieties which are similar to basmati and are characterized by tall stature (125–135 cm), a weak stem and droopy leaves. They have long slender grains and a high head rice recovery of 60-63 per cent, an intermediate amylose content, aroma and elongation qualities. The most popularly known local varieties are Hasan Sarai, Domsiah, Binam, Hasani, Salari, Ambabor and Sang Tarom (Table 8). As evident some of the varieties have very high kernel length, the highest being for Shahpasand (8.68 mm) followed by Domsefid (7.69 mm), Salari (7.61mm) and Domsiah (7.51 mm). Of these, Domsiah also has very strong aroma.

Table 8. Quality characteristics of traditional local cultivars of Iran

Variety	Aroma	Kernel length (mm)	Gel. temperature	Gel. consistency	Amylose content (%)
Hasani	Strong	6.49	6.5	57	22.0
Domsefid	Slight	7.69	5.0	100	23.0
Gharib	Slight	5.89	4.7	100	22.8
Domzard	Moderate	7.48	4.7	95	24.8
Shahpasand	Moderate	8.68	5.0	100	23.2
Binam	Strong	6.66	4.6	100	23.2
Domsiah	Strong	7.51	6.0	77	22.2
Salari	Slight	7.61	4.6	75	25.0
Domsorkh	Slight	6.9	4.7	47	22.7
Dylamani	Strong	6.4	4.9	35	22.0
Hasan Sarai	Moderate	6.7	3.0	29	22.8
Mosa Tarom	Strong	6.4	4.5	45	23.0
Ramzanaei Tarom	Moderate	6.7	4.0	49	22.5
Dylamani Taron	Moderate	6.6	4.8	45	23.8
Tarom Mahali	Strong	6.6	4.6	41	24.0
Sang Tarom	Strong	6.6	4.5	53	22.5
Zayandesh rood	Moderate	Medium	Intermediate	Soft	22.0
Sazandegy	Moderate	Medium	Intermediate	Soft	24.0
Ghasraldashti (P)	Strong	Medium	Low	Soft	24.0
Rahamatabadi (P)	Slight	Medium	Low	Soft	23.4
Kotsiah (P)	Moderate	Medium	Low	Soft	24.0
Gardeh Mianeh	Slight	Short	Intermediate	Soft	23.0
Champa Iordegan	Strong	Low	Intermediate	Medium	23.6

UTILIZATION OF AROMATIC RICE GERMPLASM

Although large number of germplasm collections are known to exist at various collection centres and in gene banks, not all of them have been fully and properly characterized and documented. Still few have been actually used in breeding programmes, despite the fact that several of them have been reported to have one or more excellent features to be used as donors. Inter-group incompatibility has been assigned as the main reason for this. Moreover, in the past little priority was given to breeding of high yielding aromatic rices as increasing yield was the main emphasis in the most rice breeding programs.

In India, the research work on aromatic rice was strengthened with the initiation of a network programme on 'Improvement of Basmati rice for increased productivity and export purposes' (1990–93)by the Indian Council of Agricultural Research ((ICAR). After the expiry of this programme, a new project 'Genetic enhancement of quality rice for higher productivity and export' was launched. A number of donors from India and other countries for various traits such as grain yield/plant, 1000-grain weight, panicle length, quality traits including kernel elongation after cooking and resistance to stem borer and white backed plant hopper and blast were identified under this programme (Ahuja et al., 1995, Table 9).

Table 9. Donors for traits in scented rice identified at Rice Research Station, Kaul (India)

Trait	Donor
Grain yield (11 - 15.36 g/plant)	Bala King, Pae woltu, HBC29, HBC169, RPSC26, Azucena, Her-Xiang-Jing
1000-grain weight (20 - 24 g)	HBC5, HBC28, HBC29, HBC31, HBC70, HBC96, HBC143, Basmati 370
Panicle weight (14 - 17.5 g/plant)	Bala King, Pae woltu, Azucena-2, Her-Xiang-Jing, HBC5, HBC29, RPSC26
Effective panicles/plant (10 - 14)	Her-Xiang-Jing, HBC5, HBC62, HBC96, HKR229
Grains/panicle (110 - 134)	Basmati Surkh, Basmati-4, Zeera, Azucena-2, Basmati 136, Yi-Lu-Hisang, HBC145, HBC159, Ramja Vana
Panicle length (28 - 30 cm)	Azucena-2, Pankhari203, Basmati-4, HBC94
Quality traits	Basmati 370, Basmati 397, Basmati 405, Type-3, HBC5, HBC19, HBC28, HBC98, HBC135, HBC143
Grain elongation	Muskan-41, Domsiah, Basmati 213, Basmati Maher 381, T-3, HR59, HBC5, HBC45

HBC = Haryana Basmati Collection

As regards utilization of scented rice germplasm as donors in the hybridization programs, Rani et al. (1996) have listed out more than 40 lines from India, Iran and Afghanistan (Table 10). However, a critical review

Table 10. Scented donors from different countries used in Basmati programs

Basmati 370	Pusa Basmati 1	Type 3	Basmati 385
Sonali	Basmati 1A	Pakistan Basmati	Basmati 386
Pusa 167	Pusa 44-33A	Domsiah	Basmati 5853
Karnal local	Basmati 1	Gr 101	Basmati 213-C
Bahra	Basmati 150	Govindbhog	Basmati Sunderpur
Sadri	Kasturi	Dwarf Basmati	Basmati 5888
Muskon 41	Bindli Sd mutant 28	HBC 143	Basmati 410
Pankhari 203	JJ92	Patnai 23	Basmati 378
Local Basmati	Basmati 372	Taraori Basmati	Indrayani
Madhuri	Basmati 6311, HBC 5	HBC 19, HBC 85	

(Adopted from Ahuja et al., 1995)

of the pedigrees of the varieties released in India since 1965, both by Central and States' Varietal Release Committees, shows that only a few of them have been used in crossing as parents more frequently than others. From a total of about 19 crossbred varieties released until 1996 in India, as many as 12 had Basmati 370 as one of the parents. (Kumar et al., 1996, Table 11).

In Pakistan, out of 7 scented rice varieties currently under cultivation, 4 had Basmati 370 as one of the parents. Beside, Basmati 370 is still a most popular variety (Khan, 1996, Table 12). From Iran, Nematzadeh and Ilahinia (1996) reported that out of 253 local collections, 27 cultivars had extra long grains, more than 7.50 mm; 78 between 6.61 to 7.50 mm; 152 of them had excellent kernel elongation after cooking (>2 times), a characteristic only Basmati varieties are reported to possess, and 134 cultivars had strong to very strong aroma. However, Domsiah and Sadri varieties have been most frequently used as parents in the crossing program (Table 13). Khao Dawk Mali 105 of Thailand is another most popular and also most frequently used variety in the breeding programs. RD6, a selection from irradiated KDML105, has grain texture close to Nia Sanpatong, an old traditional variety of Thailand, and has exceptional aromatic grains, and is the most popular variety in North and Northeast Thailand (Somrith 1996). Similarly, RD15 is another mutant selection of KDML 105. It is similar in grain appearance and quality traits of RD6, the only difference is the maturity. RD15 is approximately 7-10 days earlier than RD6. In the IRRI sponsored Rainfed lowland rice consortium, a large number crosses were made using KDML 105 and RD 6 as the recurrent parents. After several years of intense selection, many advanced breeding lines both with glutinous and non-glutinous endosperm that combine good grain quality and aroma with resistance to insects and diseases are now available for testing (Surapong et al., 1998).

Table 11. The parentages of finegrain aromatic rice varieties released in India since 1965

Variety	Parentage	Year of Release	Released in	Duration (days)
Kusuma	Basmati 370/T(N)1	1969	Karnataka	120
Jamuna	T(N)1/Basmati 370^2	1970	CVRC	120
Sabarmati	T(N)1/Basmati 370^2	1970	CVRC	125
Kolhapur	Local selection	1971	Gujrat	110
Impr. Sabarmati	T(N)11 /Basmati 370^{222}	1972	CVRC	135
Pusa 33	Impr. Sabarmati/Ratna	1975	Tamil Nadu	110
ADT 32	IR22/Pusa 33	1978	Tamil Nadu	120
Madhuri	Jaya/R 11 (Dubraj)	1980	Madhya Pradesh	150
BK 79	T(N)l/NP 130/Basmati 370	1981	Rajasthan	130
Punjab Basmati 1	Sona/Basmati 370	1982	Punjab	150
Himalaya 2	Impr. Sabannati/Ratna	1982	Himachal Pradesh	125
Sugandha	PLS from Basmati (Orissa)	1983	Bihar	150
SYE2	-	1985	Maharashtra	135
Indrayani	Ambemohar 157/IR8	1987	Maharashtra	132
Pawana	IRS/Pusa 33	1988	Maharashtra	125
Sakoli 7	T(N)1/Basmati 370	1988	Maharashtra	135
Pusa Basmati 1	Pusa 167/Karnal Local	1989	CVRC	150
Kasturi	Basmati 370/CR88-17-1-5	1989	CVRC	125
Haryana Basmati 1	Sona/Basmati 370	1991	CVRC	140
Kamini	PLS from Kataribhog	1991	Bihar	130
Ambica	Resection from SKL47-8	1991	Maharasthra	120
Basmati 385	T(N)l/Basmati 370'	1992	Punjab	135
JJ 92	Selection from Basmati 370	1993	Tamil Nadu	80
Ranbir Basmati	Selection from Basmati 370	1994	Jammu	120
Basmati 386	Local selection	1995	Punjab	155
Taraori Basmati	Pure line selection	1995	Haryana	150
Mahi Sugandha	BK 79/Basmati 370	1995	Rajasthan	140
Khushboo	Baran Basmati/Pusa 150	1995	Raiasthan	123

Table 12. Varieties developed and released by the Rice Research Institute, Kala Shah Kaku (Pakistan)

Variety	Parentage	Year of release	Varietal status
Basmati 370	Selection	1933	Cultivated
Basmati Pak	CM7/Basmati 370	1968	Cultivated
Basmati 198	Bas.370^3/T(N)1	1972	Cultivated
KS282	Bas.370/IR95	1982	Cultivated
Basmati 385	Bas.370^4/T(N)1	1985	Cultivated
Super Basmati	Bas.320/IR661	1996	Cultivated

IR 841-67-1, a selection from the cross IR262-43-8-11 × KDh4L105, was released as Jasmine 85 in the USA (Bollich,1989). Although it is similar to KDML105 in most physical characteristics, it was found to be inferior to KDML105 especially in taste.

Table 13. Parentages of the high-yielding varieties of Iran

Variety	Cross combination	Year of release
Amol 1	IR8/Domsiah	1979
Gill	Mosa tarom/Ancitco	1979
Gil3	IR498/Salari	1979
Khazar	IR36 sister sel./TNAU 7456	1982
Sepeed rood	Domsiah/IRB/Garm Sadri	1987
Ekjar	Domsiah/IR8/IR28	1995

At IRRI, the breeding work for developing high yielding basmati rice varieties was started in early 1970s. Original crosses were made between basmati 370 and improved indica lines. Subsequently, many other aromatic rice varieties grown in different countries and known for their special quality characteristics were also involved in the crosses (Table 14). Beside Basmati rice varieties of India and Pakistan, Khao Dawk Mali and Leung Hawn of Thailand, Rodjolele of Indonesia, Mehr of Iran and Anbarboo of Iraq were the important varieties used in different cross combinations. Selections for short stature, improved plant types, less sterility, shorter growth duration and various components of grain quality have led to identification of several improved lines with short stature and desirable grain quality traits. These lines are being evaluated at IRRI and other countries.

Demand for quality rice is fast increasing and with the improvement of living standard, it is likely to rise further. Breeding for rice varieties with improved grain qualities and aroma is, therefore, now on the priority list of breeding programs in most countries. Further, with the availability of wide compatibility genes and new tools and techniques in molecular biology, it seems now easy to transfer genes even among incompatible groups.

CONCERNS AND OPPORTUNITIES

Genetic erosion seems to have been more intense for scented rices than for any other types. Since in the past emphasis has been mostly on increasing yield, the release and spread of high yielding varieties have fast replaced the low yielding locally grown scented rice cultivars not only in India (Singh et al., 1997), but also in other countries (Itani 1993, Juma 1989, etc.). There is a need to protect whatever scented rice material has been left in the field or available in the collection centres/gene banks and utilize them in breeding high yielding and high quality aromatic rices.

Glaszmann's (1987) classification of rice germplasm into six groups, based on allelic composites at 15 isozyme loci, opened up the mystery of sterility in the inter-group rice hybrids and low frequencies of recombinants

Table 14. Scented rice varieties of different countries used in crossing program at IRRI.

Country	Variety
India	Basmati 370
	Basmati 5888
	Basmati 6311
	Basmati 3708
	Basmati 5875
	Basmati 107
	Basmati 123
	Basmati 93
	Basmati 208
	Pankhari 203
	Kalimunch
	Kalimunch dwarf
	New Sabarmati
	Kala namak
	Dehraduni Basmati
Indonesia	Rodjolele
Myanmar	Ngakywe
	Paw San Hmye
	Nama Thi Lai
Bangladesh	Tulsi Prasad
	Basmoti
	Kalijira Aman
Thailand	Khao Dawk Mali
	Leung Hawn
Philippines	Milfore 6-2
	Wagwag
	Azucena
Afghanistan	Lwangin
	Bahara
	Maien Garma
	Sadri Heart
	Sherkati
	Behsudi
Iran	Mehr
	Musa Tarom
	Dom Sofaid
	Dom Surkh
	Dom Zard
	Dom Siah
Iraq	Anbarboo

in the segregating populations. Khush and Juliano (1991) emphasized that due to the problems of inter-group incompatibility and low priority given to breeding for high yielding aromatic rices, there has been little success in breeding high yielding aromatic rice varieties. As a first step, such an analysis of the large number of scented rice germplasm available in India, Pakistan, Iran, Thailand and elsewhere will be helpful in identifying their inter-group compatibility for hybridization and release of desirable recombinants. Efforts should be made to identify aromatic rices that belong to Group I to use as donors for aroma. Khao Dawk Mali from Thailand is one such variety with potential as parent (Khush and Juliano, 1991).

Review of the earlier information on evaluation and screening of scented rice germplasm indicated availability of several local cultivars as well as improved varieties having potential to be used as donors for aroma and various other quality traits. Among the local aromatic rices in India, Bindli, Kalanamak, and Randhuni Pagal are known to have strong aroma. Malagkit Sungsong of Philippines was found to have the highest amount of 2-acetyl-l-pyrroline, the chemical responsible for aroma in scented rices. The kernel elongation after cooking is 200 per cent for Bindli, a tall low yielding scented rice cultivar of Eastern India. Kernel elongation after cooking is also very high for Dhania and Jeerabatti (153 per cent and 142 per cent, respectively). Phool Patas, a local scented rice cultivar from Himachal Pradesh (India) bears more than 300 grains/panicle, an attribute very much required for increasing yield potential. No doubt, the materials with distinct specific characteristics, could also be the excellent candidates for molecular breeding. Using appropriate molecular techniques, the genes for these features could be introduced into the high yielding genetic background, thus improving both the yield and the quality.

Improving locally preferred small and medium—grain scented rices could be a major goal in it self. Singh et al. (1997), for example, identified a few of the local scented rice cultivars which are in great demand in the domestic markets. Due to some reasons, they did not receive the due attention that they deserved in the past. As a result, they are fast disappearing, and a few of them are already lost. Breeding efforts coupled with appropriate public policies will go a long way in not only preserving these valuable materials, but also helping improve the conditions of the farmers. Singh et al. (1997) suggested an on-farm conservation policy to achieve both these objectives.

The rapid advancement in the molecular genetics has now opened a new era of technologies employed by the gene-banks as additional variation can be revealed through analysis of DNA (Tanskley and McCouch, 1997). DNA data as revealed by restriction fragment length polymorphism (RFLP) are becoming routinely used and widely accepted as providing taxonomic, genetic and phylogenetic information. Probe DNA molecules which map at sites covering all the chromosomes are being accumulated for the fundamental research or genetic engineering and probe markers will be available for all small regions of the rice genomes including the aromatic types. The development of the ploymerase chain reaction (PCR) has provided methods for detecting DNA polymorphisms by amplifying specific DNA fragments and separating the fragments by gel electrophoresis to visualize polymorphism. Amplification of DNA using arbitrary 10-base oligonucleotides as primers has been described as a way to detect random amplified polymorphic DNAs (RAPDs). These DNA markers are very simple to detect because they do not require DNA sequence information or synthesis of specific primers. The ease of detecting RAPD markers makes them an attractive choice for determining genetic relationships. These techniques, obviously, offer great opportunity as tools for genotype identification, and assessment of genetic diversity and relationships and selection of parents for heterotic hybrid combinations.

There is a need for stronger and closer collaboration among the scientists, institutions and countries concerned with production and export of aromatic rices. Preferences for quality rices has expanded from South and South-east Asia to Europe, Africa and America (Blakeney 1979; Webb et al. 1985). This added interest requires more effort and research support. There is a need to establish a special network for aromatic rices enjoining these regions. Germplasm acquisition of all the aromatic rices available from every country should be initiated and tested for their similarities and differences. Most importantly, international agreement on sharing of germplasm and information would be the key issue for scented rice improvement in future.

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Chapter 8

The Basmati Rice of India

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HISTORICAL PERSPECTIVE

The late Dr. R.C. Hazra, professor of history and philosophy at the University of Calcutta stated to Dr. H.I. Oka, in a personal discussion on 28 October 1979 that the inhabitants of Punjab had a high level of civilization - social life and communication — before the invasion of Aryans (2000-1500 BC) and that they were rice eaters. The oldest sacred book in Sanskrit Rig Veda (4000–1500BC) does not mention rice, although it describes wheat and barley, while the *Atharva-Veda* (1500 BC) mentions rice. The earliest archaeological evidence of rice was obtained from excavations at Mohenjodaro and Harappa in Sind and Punjab (now part of Pakistan) together with remains of a cotton culture which dated to the 3rd millennium BC (Oka, 1988). Remains of early neolithic culture have been discovered at Mahagara in Uttar Pradesh, where rice grains have been found in earthenwares in all layers. Carbon dating indicates these to be 8000 years old (Sharma & Manda, 1980).

The word 'Basmati' has been derived from two Sanskrit roots (*vas* = aroma) and (*mayup* = ingrained or present from the beginning). While combining mayup changes to *mati* making *vasmati.* Generally people pronounce it as Basmati. Earliest mention of Basmati has been made in the epic *Heer and Ranjha* composed by the Punjabi poet Varish Shah in 1766 (Thakral & Ahuja, 1993). In a compilation of *Races ofRice in India,* Basmati has been differently spelled (Bansmatti, Bansmutty, Bansmati, Bansmuttee and Basmatee) and described as a race of rice cultivated throughout the Punjab said to be the best'; 'A rice grown in small areas in the Sirsa district for luxury (Anonymous, 1910).

In trade circles, Dehraduni Basmati has been famous since generations. The rice research station at Doiwala, Dehradun, established in 1921 maintained a local germplasm collection of 1265 which included Basmati (Anonymous, 1923). The most widely used rice variety Basmati 370 selected from local collections and released for commercial cultivation in 1933 at the Rice Research Station Kalashah Kaku (now in Pakistan) is known in the trade as Dehradun or Amritsari Basmati (Ramiah & Rao, 1953). Another important variety selected at the rice research station Nagina, district Bijnor (UP) from the local collection was Type 3. Varieties with such a combination of morphological and quality attributes are not present in traditional rice growing areas anywhere in the world. From these archaeological and historical findings, it may be inferred that Basmati rice seems to have evolved through human and natural selection over a long period of time in northern India.

WHAT IS BASMATI RICE?

Of the largest aromatic germplasm maintained in the International Rice Germplasm Centre at IRRI, about 86 are described by the name Basmati irrespective of grain dimensions and intensity of aroma: Pakistan (67), India (9), Nepal (7), Bangladesh (2) and Srilanka (1). Comparing these with Basmati standards, only 18 qualify as Basmati. There is a general notion that any aromatic rice is Basmati, however, this is not the case (Mani et al., 1993). No single criterion can distinguish Basmati rice from other rices. A harmonious combination of minimum kernel dimension, intensity of aroma, texture of cooked rice, high volume expansion during cooking made up by linear kernel elongation with minimum breadthwise swelling, fluffiness, palatability, easy digestibility and longer shelf life qualify a rice to be Basmati in consumers' and traders' view (Singh et al., 1988).

Milled rice/brown rice kernel appearance and dimensions determine the price in the market. Full rice (unbroken) of uniform colour with superfine appearance fetches the highest premium. Kernel size variation in the panicles of even genetically pure seed of long grain varieties is enough to make different grades during the processing in modem rice mills. Based on key quality characteristics and popularity with farmers and traders, Taraori Basmati (also known as Basmati 386, Karnal local, HBC-19, and Amritsari), Basmati 370, Type-3 (both known as Dehra Dun Basmati), Hansraj, and Pusa Basmati-1 are the major Basmati varieties. Among these Taraori Basmati and Pusa Basmati-1 command higher premium, as more than 80 per cent of the milled rice is longer than 7 mm compared to Basmati 370 and Type3 (Table 1). Based on these observations, the minimum Basmati standards were fiexed for the purpose of providing guidelines for traders and evaluating breeding lines (Table 2). The varieties that meet these criteria are considered Basmati varieties.

AREA OF CULTIVATION AND PRODUCTION

Basmati rices have been in cultivation for generations in northern India, confined mainly to Punjab, Ilaryana, western UP and adjoining districts of Rajasthan (Table 3). Following partition in 1947 a sizeable portion of this area is part of Pakistan. The area under Basmati rice cultivation in Pakistan is around 0.75 million ha. Introduction of high yielding varieties further contributed to the reduction in acreage during the early seventies. However, with the establishment of modern mills in the early eighties and an increase in the export demand, there has been continuous increase in the area under Basmati cultivation. At present, India produces about 0.7 to 0.8 million tons of milled Basmati rice. About 60 to 70 per cent of the produce is exported every year mainly to Saudi Arabia, UAE, Kuwait, Oman, Russia, UK and USA. During 1997-98, India exported around 581791 metric tons of Basmati rice.

CLIMATIC REQUIREMENTS

Assured irrigation, drainage and normal soil help in quality production of Basmati. During vegetative growth period high humidity (70–80 per cent) and a temperature range of 25 to 35°C are favourable. From flowering onwards bright and clear sunny days with a temperature range of 25°C to 32°C, comparatively cooler nights (20–25°C) moderate humidity and gentle wind velocity at the time of flowering and maturity are considered necessary for proper grain and aroma development.

VARIETAL IMPROVEMENT PROGRAMME

Breeding Research Before 1965

Punjab was relatively of minor importance among the rice growing states in the beginning of twentieth century. However, the state produced rice of good quality like Peshawari, Dehra Dun and Amritsari, which were in great demand in north Indian markets. This class of rice often fetched double the price of ordinary rice even in the early 1900s. These varieties represented two groups. The aromatic muskan group, was grown over particular areas only by big landlords. Another group, Basmati had a

Table 1. Morphological, Agronomic and Quality features of export quality Basmati varieties

Features	Basmati-370	Type-3	Karnal local	Pusa Basmati-1
1. Morphological characters				
a. Foliage	Normal green	Normal green	Normal green	Dark green
b. Leaf orientation	Droopy	Droopy	Droopy	Relatively erect.
c. Leaf breadth	Medium	Medium	Medium	Medium
d. Apiculli	Pointed, lemmal apiculus longer	Pointed, dull yellow in colour	Pointed, lemmal apiculus longer	Pointed, lemmal apiculus longer
e. Awn	Partial tip awning, with straw colour	Partial tip awning, with straw colour	Partial tip awning, with straw colour	Complete, with straw colour
f. Panicle	Long and lax	Long and lax	Long and lax	Long and compact
g. Glume colour	straw white	straw white	straw white	straw white
h. Grain shape	Long slender, distal end slightly curved towards palea and tapered	Long slender slightly broader & shorter than Bas370, Karnal local & Pusa Bas-I, distal end slightly curved towards palea and tapered	Extra long slender, distal end very slightly curved towards palea tapered	Extra long slender, compara-tively narrow distal end tapered
i. Brown rice colour	Tan with occasional white belly	Tan with occasional white belly	Tan with occasional white belly	Light tan with occasional white belly
2. Agronomic characters				
a. Plant height (cm)	160-175	160-175	160-175	90-110
b. Total Duration (days)	145-150	140-150	155-160	130-135
c. Average yield (t/ha)	3.0	3.0	2.5	4.5
3. Kernel characters				
a. Milled rice kernel length (mm)	6.89	6.87	7.35	7.30
b. Milled rice kernel breadth (mm)	1.85	1.93	1.78	1.70
c. Length/Breadth	3.72	3.55	4.13	4.29
d. Classification	Long slender	Long slender	Extra long slender	Extra long slender
e. Colour	Translucent creamy white	Translucent creamy white		Translucent creamy white

(Contd.)

Table 1. *(Contd.)*

Features	Basmati-370	Type-3	Karnal local	Pusa Basmati-1
4. Milling characters				
a. Hulling (%)	77.0	80.0	78.9	78.0
b. Milling (%)	72.5	75.0	67.7	66.5
c. Head rice (%)	53.0	59.0	49.9	48.06
5. Cooking characters				
a. Alkali spreading value	4 or 5	4 or 5	4 or 5	5 or 7
b. Amylose content (%)	24	23	22	25
c. Water uptake (at 77°C)	230	230	240	230
d. Volume expansion	3.7	3.5	3.8	3.7
e. Kernel length after cooking (mm)	13.40	12.5	13.89	14.75
f. Kernel breadth after cooking(mm)	2.40	2.40	2.35	2.30
g. Kernel elongation ratio	1.94	1.82	1.89	2.02
h. Aroma	Strong	Strong	Strong	Mild
i. Rating on cooking	very good	very good	very good	very good

Table 2. Minimum acceptable standards for Basmati breeding

Quality components	Minimum acceptable standards
A. Kernel	
Milled rice length	> 6.6 mm
Milled rice breadth	< 2.0 mm
Length/breadth Ratio	> 3.0
Appearance	Translucent, creamy white
Classification	Long-slender
B. Milling	
Hulling (%)	>78.0
Milling (%)	>70.0
Head rice (%)	>40.0
C. Cooking	
Amylose (%)	20-22
Alkali spreading value	4 or 5
Volume expansion	> 4 times
Cooked kernel	
Elongation ratio	>1.80
Breadth of cooked rice	< 2.4 mm
Texture of cooked rice	Firm and tender without splitting and bursting; non-sticky
Colour	Bright white
Aroma	Appetizing and strong
Taste	Sweet and appealing

Table 3. Basmati growing districts in India

State	Estimated area (Million hectare)	Districts
Punjab	0.10	Amritsar, Gurdaspur, Pathankot, Kapurthala, Jallandhur, Ludhiana, Patiala, Ropar and Sangrur.
Uttar Pradesh	0.50	Saharanpur, Dehradun, Haridwar, Muzaffarnagar, Bijnor, Moradabad, Rampur, Udham Singh Nagar, Bareilly, Pilibhit, Nainitai, and Kheri.
Himachal Pradesh	0.05	
Haryana	0.25	Karnal, Panipat, Kaithal, Kurukshetra, Jind, Ambala, Sonipat and Sirsa
Jammu	0.05	Randhir Singh Pura
Rajasthan	0.05	Sri Ganganagar

special place, due to its great demand in northern India. The special characteristics that were preferred in the polished grain of Basmati rice were: (1) a 'greasy' look without any abdominal white, (2) an entire rice grain, (3) fully developed and uniform kernel, and (4) neither too soft nor too hard when crushed under the teeth. The characeristics of the cooked rice for which it was valued were: (1) maximum elongation, nearly double that of the uncooked grain, (2) individuality of the cooked grain without bursting, and (3) sweetness and a special fragrance of the cooked product. Rice being the crop of minor importance for the state, it did not receive due attention in earlier years of the twentieth century. However, in 1926 a rice research station was established at Kala Shah Kaku under the immediate charge of Late Sardar Mohammed Khan, who had special training in rice breeding in Madras. Local rice collection was made. After selection and extensive comparative trials, seven most promising strains were fixed. Among these Basmati 370 became more popular in the trade (Ramiah and Rao, 1953).

In the United Provinces (now Uttar Pradesh) local rice collections were made in 1921, at a rice research station in Cawnpur (now Kanpur). Since Kanpur was not suitable for rice growing, the collection was evaluated at the rice research station in Doiwala district Dehra Dun. In 1932, with financial assistance from the Indian Council of Agricultural Research a separate rice research station was established in Nagina in district Bijnor. Dr. R.L. Sethi, was the first economic botanist (sugarcane and rice). The selection and evaluation work resulted in the development of several useful strains. One of these was Type 3, which became very popular in the trade due to its better cooking and eating quality (Ramiah & Rao, 1953).

Breeding Research After 1965

After the introduction and popularity of the semi-dwarf high yielding varieties in mid-sixties, Dr. M.S. Swaminathan (then, Director, Indian Agricultural Research Institute), initiated in the late-sixties a systematic Basmati varietal improvement programme at IARI, New Delhi. Later on other state agricultural universities in northern India also started work on all the basic and applied aspects of this rice.

Basic aspects

INHERITANCE OF AROMA

Aroma is one of the important factors which distinguishes Basmati from non-Basmati. Inheritance of aroma has been studied in great details. Rice breeders have used different techniques to detect and evaluate aroma in order to study the inheritance of aroma and improve the selection response. In the beginning, aroma was evaluated by chewing a few grains (Dhulappanawar, 1976), cooking the bulk, individual grain or plant part in hot water (Ramiah 1937; Ghose and Butany, 1952; Kadam and Patankar, 1938, and Nagaraju et al., 1975) and by smelling the samples. These methods have their limitations. After chewing a few grains the chances of misevaluation increases as part of first chewed grain remain sticking inside the mouth and a feeling of aroma prevails. In the hot water method, the smell of chlorophyll interferes with aroma. To overcome this problem a new and efficient method has been developed (Sood and Siddiq, 1978). Rice varieties differ in intensity and kind of aroma (Sood and Siddiq 1978). Aroma can be detected at any growth stage and in all plant parts including calli and roots (Mohanty et al., 1991).

Based on the segregation of F_2 populations and F_1 behaviour of aromatic and non-aromatic parents, inheritance has been differently reported. Ghose and Butany (1952), Sood and Siddiq (1978), Berner and Hoff (1986) observed aroma as recessive and monogenic. Kadam and Patankar (1938) reported it to be monogenic dominant. The digenic segregation of 9 non-aromatic and 7 aromatic (Tripathi and Rao, 1979), 13:3 (Chakravarti, 1948) and trigenic ratio of 37 non-aromatic and 27 aromatic (Kadam and Patankar, 1938; Nagaraju et al., 1975) have also been reported. The present disagreement on mode of inheritance of aroma appear to be related to the genetic differences among the aromatic germplasm and also the method of evaluation. But transfer of aroma is relatively simple, though a problem arises when expression of other quality characteristics is not up to the desirable level, along with resistance to diseases and grain yield.

INHERITANCE AND MECHANISM OF LINEAR KERNEL ELONGATION

Linear cooked rice kernel elongation with minimum breadth-wise swelling on cooking is yet another important key quality index. Large variations have been observed for this trait (Singh et al., 1997). Linear kernel elongation has significant positive association with amylose content. Transfer of this character has been found to be difficult as it is controlled by polygones (Sood et al., 1983). Water uptake during cooking show positive and significant influence on kernel elongation (Sood and Siddiq, 1986). Anatomical studies show nearly penta or hexagonal cells arranged in a honeycomb fashion in elogating types (Sood et al., 1979). It has also been observed that the cell wall is more compact in Basmati 370 and holds the pressure until maximum linear expansion of cooked rice has taken place. In non-elongating types (IR8 and PR 106) the pressure leaks out before the expansion is complete due to loose cell walls (Beerch and Srinivas, 1991).

Variability for quality indices

Majority of the varieties described as Basmati possess intermediate amylose content (AC) and gelatinization temperature (expressed as alkali spreading value) and medium gel consistancy (GC). Season to season variation for amylose has been observed. In some crop seasons even Basmati 370 show an AC of 17%. Based on minimum Basmati standards, quality characters of 17 Basmati varieties have been given in Table 4. AC

Table 4. Varieties described as Basmati and qualify for minimum Basmati standards

IRRI Acc. No.	Varieties name	AC	ASV	GC	MRKL	MRKB	UB	ER
27809	Basmati-134	18.3	4.33	65	6.75	1.86	3.62	2.21
	Basmati-136	17.6	3.91	60	6.85	1.90	3.60	2.09
27792	Basmati-Sufaid-106	19.1	3.58	70	6.64	1.86	3.57	1.82
27802	Basmati-106-12	18.1	4.66	42	6.64	1.94	3.42	1.83
27791	Basmati-Sufaid-100	18.7	4.83	50	6.72	1.96	3.43	1.84
	Basmati-217	18.8	4.50	66	6.96	1.80	3.87	1.84
10332	Basmati 6141	18.8	4.56	62	6.96	1.82	3.82	1.86
10330	Basmati 6311	17.8	4.83	48	7.18	1.92	3.73	1.87
27830	Basmati 388	18.8	3.75	50	6.98	1.96	3.58	1.89
10331	Basmati 6813	18.8	5.00	99	7.62	1.88	4.05	1.96
	Early Basmati	19.0	3.50	40	7.14	1.84	3.88	2.01
9034	Basmati-5875	20.7	3.84	80	6.70	1.86	3.60	1.81
9030	Basmati-5836	20.0	4.75	85	6.84	1.84	3.72	1.81
	Kamal local	21.2	3.66	60	7.06	1.90	3.72	1.85
10629	Basmati-370	18.4	3.83	95	6.44	1.84	3.50	1.91
	Type-3	17.9	3.91	52	6.68	1.90	3.51	1.89
	Hansraj	18.1	4.50	60	6.88	1.94	3.55	2.17
	Basmati tall	19.1	6.50	40	6.68	1.88	3.55	2.05

AC = Apparent amylose content; ASV = Alkali spreading value; GC = Gel consistancy; MRKL = Milled rice kernel length; MRKB = Milled rice kernel breadth; L/B = Ratio of length and breadth; ER = Elongation ratio.

and GT, two major determinents of texture, cohesiveness, tenderness, colour and gloss of cooked rice do not show apparent variation. Same is the level of AC and GT in other varieties described as Basmati in the germplasm. But inspite of similar starch characteristics, degree of polishing, ageing, method of coaking and growing location, these varieties show easily perceptable variation with respect to taste and texture of cooked rice. The factors responsible for such differences are still unclear.

Isozyme polymorphism

Complete set of aromatic germplasm maintained at IRRI, representing twenty major rice growing countries was analysed for isozyme polymorphism. Maximum variation was observed in Nepal, followed by India and Bangladesh. After deleting duplicates, based on familiarity with the collection, morphological features and names, 425 were considered for classification (Table 5). Pakistan represented 65 accessions. All are described as Basmati except Jajai-77, Sunehri, Sugadasi and Pakistani fine. Sixty have almost similar isozyme pattern as of Basmati 370 and Type-3 and fall in Group V. Pakistani fine, Basmati 113, Basmati 6113 and Basmati 6129 do not come in any isozyme group. Basmati 138 belongs to Group II. Basmati 6113 is identical to Karnal local.

India represented nine. All are identical to Basmati 370 and Type-3, except Karnal local, indicating that the collections have the same origin. Varieties described as Basmati

Table 5. Distribution of aromatic rices in isozyme groups (Singh et al., 989)

Country	I	II	V	VI		Total
India	11	7	62	21	32	133
Pakistan	–	1	60	–	4	65
Indonesia	19	–	1	24	4	48
Thailand	29	–	–	4	1	34
Bangladesh	3	3	17	7	3	33
Malaysia	9	–	1	9	2	21
Iran	–	–	17	–	1	18
Nepal	1	2	6	1	6	16
Vietnam	6	–	–	2	7	15
Philippines	1	–	–	11	–	12
China	3	–	–	8	–	11
Myanmar	4	–	4	–	–	8
Laos	–	–	1	2	–	3
Sri Lanka	–	2	1	–	–	3
Korea	–	–	–	2	–	2
USA	–	–	–	1	–	1
Japan	–	–	–	1	–	1
Afghanistan	–	–	1	–	–	1
Total	86	15	171	93	60	425

* = Do not belong to any isozyme group

in Nepal, Bangladesh and Srilanka do not qualify to be Basmati due to shorter grain length. Karnal local and Basmati 370 differ at Pgi-2, Amp 3 and Adh (Table 6).

Applied aspects

BREEDING METHODS

In most of the varietal improvement programmes, variability was generated by direct and back-cross programmes. Segregating populations were managed through pedigree method. In some programmes mutation breeding and pure line selections have also been used. Somaclonal variation, doubled haploid technology and development of transgenics have also been taken up in selected centres since early nineties. Using WA cytoplasm, cytoplasmic male-sterile lines have been developed in the background of Pusa Basmati-1. Basmati hybrids are under evaluation.

METHODS OF EVALUATION

To evaluate the agronomic performance of newly developed promising lines an All India coordinated Rice Improvement Project (AICRIP) was established in 1965 at Rajender Nagar, Hyderabad. A special trial was constituted to evaluate the newly developed aromatic progenies in name of Slender Grain Varietal Trial in 1969.

These trials are conducted every year from June to November at 30-40 locations, throughout the country. Data on 50% flowering, plant height, tiller number, grains per panicle, yield per plot, lodging, diseases and pest incidence are recorded. Grain samples from one of the main Basmati growing locations (Rice Research Station, Kaul, Haryana) is sent each year to three national rice quality testing laboratories (I.A.R.I., New Delhi, Directorate of Rice Research, Rajender Nagar, Hyderabad, and Central Rice Research institute, Cuttack). Entries are evaluated for more than twelve grain cooking and eating quality parameters. Promising enteries are identified for on-farm testing and further considered for notification and release by the Central Sub-committe for Release and Notification of Crop Varieties. The promising lines developed and varieties released are given in Table 7.

IMPROVED AROMATIC GERMPLASM

Since 1969 with the constitution of Aromatic Slender Grain Varietal Trial (ASGVT), every year 5-10 new nominations are entered in the Basmati trials possessing specific characters of economic importance. Some of these promising lines have been recycled in the breeding programmes (Table 8). Pusa 167-120-3-2 has helped in the development of IR 58025A, a popular CMS line, being used in the development of rice hybrids.

Table 6. Isozyme polymorphism among Basmati culivars (Glaszmann et al., 1988)

IRRI Acc.No.	Varieties	CAT	SDH	ICD	PGI-2	PGI-1	AMP-1	AMP-3	AMP-2	AMP-4	ADH	EST-2	EST-1	EST-15	EST-9	ISO
27809	Basmati-134	1	2	1	1	2	2	0	1	1	1	0	1	1	1	5
	Basmati-136	1	2	1	1	2	2	0	1	1	1	0	1	1	1	5
27792	Basmati-Sufaid-106	1	2	1	1	2	2	0	1	1	1	0	1	1	1	5
27802	Basmati-106-12	1	2	1	1	2	2	0	1	1	1	0	1	1	1	5
27791	Basmati-Sufaid-100	2	2	1	1	2	2	0	1	1	1	0	1	1	1	5
	Basmati-217	1	2	1	1	2	2	0	1	1	1	0	1	1	1	5
10332	Basmati 6141	1	2	1	1	2	2	0	1	1	1	0	1	1	1	5
10330	Basmati 6311	1	2	1	1	2	2	0	1	1	1	0	1	1	1	5
27830	Basmati 388	1	2	1	1	2	2	0	1	1	1	0	1	1	1	5
10331	Basmati 6813	1	2	1	1	2	2	0	1	1	1	0	1	1	1	5
	Early Basmati	1	1	1	1	2	2	0	1	1	1	0	1	1	1	5
9034	Basmati-5875	1	2	1	1	2	2	0	1	1	3	0	1	1	1	5
9030	Basmati-5836	1	2	1	1	2	2	0	1	1	1	0	1	1	1	5
	Basmati-tall	1	2	1	1	1	2	1	1	1	1	0	1	1	1	0
10629	Basmati-370	1	2	1	1	2	2	0	1	1	1	0	1	1	1	5
	Kamal local	1	2	1	3	2	2	4	1	1	3	0	1	1	1	0
	Type-3	1	2	1	1	2	2	0	1	1	1	0	1	1	1	5
	Hansraj	1	2	1	1	2	2	0	1	1	1	0	1	1	1	5
	Pusa Basmati-1	1	2	1	1	1	1	2	2	1	1	1	1	1	1	1

CAT = Catalase; SDH = *Sikimate* -dehydrogenase; ICD = Isocitric -dehydrogenase; PGI = Phoshpho-gluco-isomerase; AMP = Aminopeptidases, ADH = Alcohal-dehydrogenase, EST = Esterase; ISO = Isozyme group.

Table 7. Prominent aromatic rice varieties of India

Strain/ variety	Parentage	Year of release/remarks	Developed at
Sabarmati	T(N)-1/Basmati 3702	1970	IARI, NewDelhi
Improved Sabarmati	do-	1972	-do-
Pusa-33	Improved Sabarmati/Ratna	1975	-do-
Punjab Basmati-l	Sona/Basmati 370	1982	P.A.U., Ludhiana
Pusa Basmati-1	Pusa 167/Karnal local	1989	IARI, New Delhi
Kasturi	Basmati 370/CR88-17-1-5	1989	D.R.R., Hyderabad
Haryana Basmati-1	Sona/Basmati 370	1991	H.A.U., R.R.S., Kaul
Mahi Sugandha	BK79/Basmati 370		R.A.U.,R.R.S., Banswara
Ranbir Basmati	Pureline Selection from Basmati 370		R.R.S., R.S. Pura
Taraori Basmati	Pure line selection from Karnal local	1995	H.A.U., R.R.S., Kaul
Basmati 386	do-	1996	P.A.U., R.R.S., Kapurthala
B.K. 843-7	Pusa Basmati-1/ local Basmati	Identified (1995)	R.A.U., R.R.S., Banswara
RP 3238-33-15-7-1	Pusa Basmati-l/Ajay (IET8585)	Identified (1995)	D.R.R., Hyderabad

Table 8. Improved aromatic germplasm (Singh, 1997)

IET No.	Designation	Yield(t/ha)	Special features
7307	Puss 150-21-1	5.5	Superfine strongly aromatic grain, medium early duration and maintainer
	Puss 167-120-3-2	6.0	Superfine strongly aromatic grain, medium early duration and maintainer
12021	HKR240	3.4	Intermediate GT and AC, and moderately resistant to neck blast
12601	RRB94	4.6	Strong aroma, high head rice recovery and intermediate AC
12603	UPR 908-11-1-1-5	3.9	High head rice recovery and intermediate AC
12603	HKR 86-402	4.4	Tolerance to gall midge, high head rice recovery and strong aroma
12609	RP 2144-19-2	4.1	Resistant to gall midge, tolerant to leaf and neck blast
13153	UPR 85-71-81	5.1	Resistant to gall midge and BPH
13162	OYT 1673	5.0	Good kernel elongation, intermediate GT and AC
13548	RP 3238-33-157-1	4.8	Intermediate AC, good kernel elongation, strong aroma, resistant to blast and WBPH

Genetic enhancement of Basmati rice is one of the main mandates of Indian Council of Agricultural Research (ICAR). To strengthen the research efforts, a Basmati network "Improvement of Basmati Rice for

Increased Productivity and Export" was sanctioned for a period of three years (1990-1993). After evaluating the progress made, the scheme was further extended from 1994 to 1997, and again from 1997 to 1999.

At present around fifty nominations are under evaluation. While maintaining the quality characters and yield level of newly released varieties, breeding for resistance to major rice diseases is the major thrust area of research.

CULTIVATION PRACTICES

Better crop management ensures higher grain yield and enhanced quality. Timely field operations help in proper utilization of the inputs. Non-monetary inputs like healthy nursery, number of seedlings per hill, proper spacing and depth of transplanting play key role in higher and stable grain yield. Farmers generally either use their own seed or take from the lot brought by other farmers to the grain market, which is offered maximum price in the grain market. However, the seed must be from authentic sources, genetically pure, healthy and free from weed seeds.

Seed Rate

In case of Basmati varieties 20 kg seed per hectare is recommended.

Seed Treatment

Prepare the fungicide solution by dissolving 5.0 g of Emissan (methyl ethyl mercuric chloride-MEMS) and 2.5 g of Paushamycin or 10. g of streptocycline in ten liters of water. Soak 20 kg of seed in 25 litres of fungicide solution for 24 hours by thoroughly mixing the seed, before sprouting. This treatment minimises primary inoculum of bacterial blight, blast and other diseases.

Sowing Time

Traditional Basmati varieties are tall growing and highly photosensitive. Therefore, farmers sow the nursery from 10-20th June. Delayed transplanting helps in less vegetative growth.

Nursery

An area of one-tenth of the main field is enough to raise healthy seedlings. Plough the field twice or thrice under dry condition. Arrange to apply 500 kg of well decomposed farm yard manure per 1000 m^2 twenty days before the sowing and irrigate immediately to avoid drying of the manure. Irrigate again after a week. It will allow all the weed seeds to germinate. Start puddling after a week of second irrigation. Puddle twice after a gap of two days. Level the field perfectly during the process of puddling. Divide the field in convenient size of beds to have a better control on irrigation and drainage. Each seed bed must have perfect levelling for uniformly healthy seedlings.

Apply 5 kg N, 2 kg P_2O_5 and 2 kg of K_2O for every 1000 m^2 uniformly before final levelling. Broadcast sprouted seeds uniformly in each bed in slightly turbid 3-4 cm of standing water. It will make a thin film on sprouted seed and protect the young seedlings from extra heat and bird damage. Keep the beds wet. Irrigate preferably in the evening to avoid any damage from the standing water in day time as water gets heated up in noon hours in the month of June. Practise hand weeding after ten days of sowing and apply 5 kg N/1000 m^2 ten days before uprooting the nursery. Chemical weed control is possible by applying butachlor or any other weedicide as per recomendation immediately after complete germination.

Preparation of the Mainfield

Follow the field preparation as recommended for nursery. If any green-manure crop has been grown, trample it ten days before transplanting to allow proper decomposition. Apply N.P.K. and zinc as per Table 9.

Table 9. Recommended doses of nutrients and time of application

Varieties/ Time of application		**Nutrients kg/ha**			
		N	**P_2O_5**	**K_2O**	**Zn**
Tall		60	30	30	25
Semi dwarf (SD)		90	30	30	25
	Tall	SD			
Transplanting	30	15	10	10	25
15 days after transplanting	30	40	10	10	–
Panicle Initiation	10	20	10	10	–
Boot leaf	10	15	–	–	–

Transplanting

Transplant two-three, 25-30-day old seedlings per hill at a spacing of 30 × 30 cm and depth of 2-3 cm in case of traditional tall varieties. In case of semi-dwarf varieties follow a spacing of 20 × 20 cm. If varieties are low tillering types adopt a spacing of 20 × 15 cm. Wherever seedlings have died fill the gaps as early as possible.

Weed Control

Allow 4-5 cm deep standing water continuously after three days of transplanting for a week. Three days time is enough for healthy seedlings to establish. It will not allow the weed seed to germinate. After a gap of few days again maintain the same water level for a week. Some weeds may come, which shall be removed by hand weeding. If possible use butachlor or any other herbicide, as per the written instructions on the container. Do not allow the weeds to produce seed in any case in the rice field.

Disease and Insect-pest Management

Depending on the climatic conditions traditional as well as semi-dwarf high yielding varieties suffer from various pests and diseases. Among the pests yellow stem borer (*Tryporyza incertulas),* leaf folder (*Cnaphalchrosis medinalis*) and brown plant hopper (*Nilaparvata lugens*) affect the crop to varying degrees. In case of diseases bacterial leaf blight, blast, sheath blight and false smut not only reduce the grain yield, but severely impair the grain quality. Necessary prophylectic measures, balanced nutrition and clean cultivation can help reduce losses.

Irrigation and Drainage

Rice in general is a water loving plant. Appropriate moisture level is important for proper vegetative growth. However, starting from panicle initiation to hard dough stage water becomes all the more important. Moisture stress at any stage will affect the grain quality. Therefore, efforts should be made to maintain saturation level for proper grain development. Do not allow crack formation in the field at any crop growth stage. Traditional varieties generally lodge even with light showers and medium wind velocity during grain development period. Damage can be reduced by timely and proper drainage in the lodged crop.

Pruning

Cutting of the upper portion of leaf blades of top 5-6 leaves by 10-20 cm at 45-55 days after transplanting is practised by farmers. It is helpful in reducing lodging without affecting the grain quality and yield (Angrish, 1991).

Harvesting

Ascertaining optimum harvest time is very essential. Delayed harvest leads to grain shedding and fissure formation in rice, resulting in breakage during processing. Before time harvest will also lead to grain yield losses due to higher percentage of under-developed green kernels and low head rice recovery. Maximum grain yield and head rice recovery are assured by harvesting the crop at 35 days after 50% flowering when moisture content ranges from 20 to 22 per cent (Table 10).

Table 10. Effect of harvesting time on Basmati rice (Chaudhry & Iqbal, 1986).

Harvesting time (days after flowering)	Moisture content (%)	Grain yield (t/ha)	Head rice recovery (%)
25	29.9	1.95	38.0
30	26.6	2.17	46.5
35	21.6	2.29	56.6
40	17.2	2.21	49.1
45	14.0	2.06	40.4

MARKETING AND TRADE

At present only three traditional i.e. Taraori Basmati, Basmati 370, Type-3 and one semidwarf Pusa Basmati -1 are accepted as Basmati in the rice trade. Opening price of Pusa Basmati-1, starts with Rs. 650-700/quintal and goes upto Rs. 1500/quintal. Taraori Basmati which starts coming to market by middle of November opens up with Rs. 900-1000/quintal and reaches Rs. 2000/quintal. Traditional varieties give an average yield of 2.5 tonnes per hectare, giving the farmers a gross income of Rs. 17,000 - 50,000 /ha. Pusa Basmati-1 on an average, yields 4.5 tones, and due to stiff stem rarely lodges. Due to this, there has been a steady increase in the spread of this variety during the last five years.

From grain market paddy is purchased by the rice mill owners. Some progressive mill owners also supply good quality seed to farmers and directly purchase paddy from the farmers. In some areas of western U.P., traders directly go to the farmers and purchase the paddy from the temporary markets on day to day basis. In Punjab and Haryana grain markets are well distributed and organized. Farmers get a market with in 20 km distance from their residence. More than 90% of the produce comes to market. In the absence of a well organized grain market and low price offered to Basmati paddy in western U.P. (district Bijnor) farmers take their produce to the neighbouring state of Haryana for sale. During the last two years exporters are processing Dehradun Basmati directly from farmers. In Sola-Majra belt of Dehradun, this local Basmati fetches high price, which is almost double of Pusa Basmati-1.

FUTURE OUTLOOK

For centuries Basmati rice has been the food of choice for rich and enlightened people. With the modern methods of information technology, awareness about its unique palatability and easy digestibility is spreading. Every year domestic as well as international demand is on the increase. In USA, Australia, Philippines, Vietnam, Japan and China varietal improvement work on Basmati rice is now one of the major objectives of their rice breeding programme. Rice Tech in USA claims to have developed a line of Basmati 6187, which has been granted patent.

In India, Basmati cultivation is spreading to neighbouring districts of Basmati growing states. Modern rice mills with complete automation have further improved the physical quality of Basmati rice. Now it is possible to separate well developed, high density kernel of uniform size and colour with desired degree of milling. Scientific packing and transportation make it possible to deliver the best product without any deterioration in quality or colour any where in the world. Since present day varieties require less inputs, there is a wave to grow these varieties organically. Basmati rice grown organically has tremendous potential in domestic and international market. Unique climatic conditions available in north west India for growing best quality Basmati rice are unparallel in the world. If high yielding, disease and pest resistant varieties of identical grain and cooking quality are made available, the area under rice will definitely increase. Quality rice, thus will be available to a larger section of society.

Bacterial leaf blight, rice blast, sheath blight, stem borer and leaf folder are important impediments in successful cultivation of Basmati rice. Over the years twenty-three resistant genes for bacterial blight have been identified. Important ones have been pyramided in the high yielding back ground. With the modem methods of biotechnology it is now possible to transfer them in Basmati varieties without disturbing the gene order and gene combination, keeping the grain cooking quality intact. Similarly the use of *Bacillus thuringiensis* (Bt) genes will help in developing varieties resistant to major pests.

SUMMARY

Archaeological and historical evidence indicate Basmati rice to have evolved in northern India around 8000 years before the present time. By its unique combination of grain, cooking and eating characteristics it can be distinguished from other rices. Long slender, attractive and aromatic translucent grains (length more than 6.60 mm and breadth less than 2 mm), high volume expansion, made up by linear cooked kernel

Chapter 9

Small and Medium Grained Aromatic Rices of India

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INTRODUCTION

Aromatic or scented (fragrant) rices have occupied a prime position in Indian society not only because of their high quality, but also because they had been considered auspicious (Ahuja et al., 1995). The Basmati type among them is accepted as the best scented, longest and slenderest rice in the world and the Indian subcontinent continues to be its home land. Both India and Pakistan have monopoly over its production and marketing in the world markets. Both these countries together export more than five and a half lakh tonnes of good quality of Basmati rice (Mahindru, 1995). However, the aromatic rices are also highly regarded throughout Asia, and are becoming popular in Europe (Berner and Hoff, 1986) and the USA including non-traditional rice growing countries like Australia (Blakeney, 1992). Most of the rice growing countries are now working on scented rices and are using Basmati as one of the base materials. India, one of the major exporters of Basmati rice, is facing stiff competition from Pakistan and in future there are likely to be more competitors.

Earlier, a large number of such rices were collectively known as Basmati (*bas* = aroma). Over the years the definition of Basmati has changed, and it is increasingly restricted to long slender grain type with moderate to strong aroma (Mahindru, 1995). Accordingly, the small and medium grain aromatic rices are being regarded as a separate class of non-Basmati aromatic rice. Although no concrete documentation exists, native areas of cultivation are known for most of the latter types, here referred to as indigenous scented rices. Almost every state of India has its own varieties of aromatic rices, and specific areas of the aroma formation and cultivation of these rices are known. These areas are identified from hundreds of years of experience of the farmers (Nene, 1998). However, so far, importance of this information has not been realized by the scientists.

India has had immense wealth of these rices. But a lot has already been lost as an aftermath of the green revolution where major emphasis was on yield rather than quality (Singh and Singh, 1998). This is despite the fact that some of the non-Basmati scented rices are much superior to Basmati types with respect to traits like aroma, kernel elongation after cooking, fluffiness, taste, etc. Nevertheless, due to the special attachment of the farmers with Basmati rices, a large number of them are still in existence. However, a survey of the Seola–Majra belt of Dehradun, once famous for producing the finest quality Basmati rice in the world, indicated that 80 per cent of the prime Basmati growing area in this belt is now utilized for housing alone (Singh et al., 1997). The story is not different in other tracts of their cultivation.

In view of this scenario, our long term concerns are: how to make Basmati cultivation profitable to farmers and expand the Basmati rice export market, and save these varieties from being extinct.

BASMATI *VS.* NON-BASMATI SCENTED RICES

In the Indian subcontinent, scented rices are categorized as Basmati and non-Basmati scented types (Fig. 1). The Basmati types are characterized by long, slender grains having kernel length of 6 mm and more, length(L) to breadth(8) ratio (L/B ratio) of 3 and above, and high kernel elongation after cooking. The grains of Basmati cultivars are pointed at both ends with gradual tapering at the end opposite to the germination end and has uniform breadth between the taperings (Mahindru, 1995). The non-Basmati aromatic rices also have one or more of the Basmati characteristics, but not all them. Especially, they have small and medium kernel length, although they may have similar L/B ratio or kernel elongation rate as high as Basmati or more. But over all kernel elongation after cooking is much higher in Basmati types than in non-Basmati types. The comparative characteristic features of both groups of cultivars have been worked out by Mahindru (1995) which clearly shows the distinction of Basmati types over the non-Basmati types (Table 1).

Fig 1. Some important indigenous aromatic rices of India. **A.** Hansraj (long grain, Basmati-type); **B.** Tilak Chandan (medium grain, non-Basmati-type); **C.** Kala Namak (medium grain, non-Basmati type); **D.** Bindli (small grain, non-Basmati type).

Table 1. Comparative features of Basmati and non-Basmati scented rice

Characteristic features	Basmati type*	Non-Basmati scented rice**
Kernel Length (L)	6.4–7.6	5.4-5.7
L/B ratio	3.5-4.2	3.3–3.35
Lc-Lu/Bc-Bu	8.8–10.6	2.8-4.6
Lc/Bc	4.9–5.6	2.95–3.8
Lc/Lu	1.70–1.83	1.40-1.57
Bc/Bu	1.26–1.33	1.31–1.61

*Basmati culture: Basmati/Basmati Punjab, Basmati (raw milled)
**Non-Basmati Scented: Vishnoparag, Ram Raj and Rambhog
Lc : Length of kernel after cooking
Lu : Length of kernel before cooking
Bc : Breadth of kernel after cooking
Bu : Breadth of kernel before cooking

Distinctions between the two groups are also found in terms of the specific areas of their adaptation for cultivation. The cultivation of Basmati has been concentrated in Indian states of Uttar Pradesh (Dehradun, Nagina, Haridwar, Bijnore etc), Himachal Pradesh, Kashmir, Haryana and Punjab, and Punjab province of Pakistan. It is said that the Basmati grows best and produces best quality grains under warm, humid, valley-like conditions. Experience has also shown that true Basmati when cultivated outside these specified areas, does not produce the same quality of grains. The small and medium grain non-Basmati scented rices have also adapted to specific localities and conditions, but are widely distributed in different parts of the country. For example, kalanamak is primarily grown by the farmers of Siddharthnagar and Basti districts of UP, while shakkarchini is found mainly around Mirzapur district in the same state. Joha, a group of small and medium grain non-Basmati scented rices are cultivated only in Assam. Table 2 lists out the most important non-Basmati and Basmati scented rice cultivars that were or some of them even now are popular in different regions of the country. Characteristics of some of these small and medium grain aromatic rices, are summarized in (Table 3). All these traditional varieties are tall, photosensitive, with average to very strong aroma, and up to 100 to 200 per cent of kernel elongation after cooking, but have long duration and low yields. These varieties are not well characterized for other kernel characteristics and susceptibility towards diseases and pests and their cultivation is restricted to certain pockets only.

AROMATIC RICES: HISTORICAL

Rice cultivars with pleasant fragrance, white colour and excellent cooking quality have been grown in India about 2500 years (circa 400 BC)

Table 2. Major aromatic rices of diiferent states of India

State	Small grain	Medium grain	Long grain
Andhra Pradesh		Jeeragasambha	
Assam	Bengoli Joha, Bhaboli Joha, Bhugui, Boga Joha, Bogamanikimadhuri, Boga Tulsi, Bogi Joha, Bokul Joha, Borjoha, Borsal, Cheniguti, Chufon, Goalporia Joha-1, Goalporia Joha-2, Govindbhog, Joha Bora, Kaljeera, Kamini Joha, Kataribhog, Khorika Joha, Kola Joha, Koli Joha, Kon Joha-1, Kon Joha-2, Krishna Joha, Kunkuni Joha, Manikimadhuri Joha, Ramphal Joha, Ranga Joha		
Bihar	Badshahbhog, Deobhog, Karia Kamod, Katami, Shyam Jeera, Kanak Jeera, Kanakjeeri, Badshapasand, Mircha, Brahmabhusi, Ramjain, Kamina, Dewta Bhog, Tulsi Pasand, Chenaur, Sona Lari, Sataria, Tulsi Manjari	Gopalbhog, Champaran Basmati (Lal), Champaran Basmati (Kali), Champaran Basmati (Bhuri), Bhilahi Basmati, Amod, Abdul, Bahami, Kalanamak, Kesar, Sonachur	Baikani
Haryana			Basmati 370, Khalsa 7, Taraori Basmati, Pakistani Basmati
Himachal Pradesh		Achhu, Begmi, Panarsa local	Baldhar Basmati, Madhumalti, Chimbal Basmati, Mushkan, Seond Basmati
Kerala	Jeerakasala, Gandhkasala		
Kamataka		Kagasali	
Madhya Pradesh	Chinore, Dubraj, Kalu Mooch, Vishnubhog, Badshabhog, Tulsi Manjari	Chatri, Madhuri, Vishnu Parag	Laloo

Maharastra	Ambemohor, Chinore,	Kagasali, Prabhavati, Sakoli-7	
Manipur		Chahao Amubi (black scented rice), Chahao Angangbi (pink/red scented rice)	
Punjab			Basmati 370, Basmati 385, Pakistani Basmati
Rajasthan			Basmati (local), Basmati 370
Uttar Pradesh	Adamchini, Badshapasand, Bhanta Phool, Bindli, Chhoti Chinnawar, Dhania, Jeerabattis, Kanak Jeeri, Laungchoor, Moongphali, Rambhog, Ramjawain, Sakkarchini, Tinsukhia, Bengal Juhi, Thakurbhog, Yuvraj, Bhantaphool	Karmuhi, Kesar, Parsam, Sonachur, Tilak Chandan, Kesar, Kalanamak, Vishnuparag	Basmati 370, Dehraduni Basmati, Type 3, Hansraj, Nagina 12, Safeda, Vishun Parag, Kala Sukhdas, Lal Mati, Tapovan Basmati, T-9, Dubraj, Duniapat (T9), Ramjinwain (T1)
West Bengal	Badshabhog, Chinisakkar, Danaguri, Gandheshwari, Kalo Nunia, Kataribhog, Radhuni Pagal, Sitabhog, Tulai Panji, Tulsibhog	Kanakchur, Katanbhog	

Table 3. Indigenous aromatic rice cultivars and land-races of India : some specific features

Name	Duration (days)	Yield (t/ha)	Plant height (cm)	Grain Quality Size	Aroma	Elong.	Adaptability (for aroma)
Adamchini	150–155	1.0-3.0	125	small	average	80%	restricted
Ranga Joha-1	150	1.5-2.3	142	small	average	100%	wide
Bindli	135	0.8-1.2	tall	small	v. strong	200%	restricted
Dhania	150	0.8-1.5	tall	small	poor	153%	restricted
Dehradun Basmati	140-145	2.0-3.0	140-145	long	strong	100%	restricted
Hansraj	135-140	2.5-3.0	135-140	long	average	40%	wide
Jeerabatti	150	0.6–1.2	150	small	poor	142%	restricted
Kalanamak	150-160	1.5-3.0	150	medium	strong	80-100%	restricted
Katarni	160	1.0-1.5	130-175	small	strong	80%	wide
Ramjawain	150	2.0-2.5	tall	small	average	75%	restricted
Randhuni Pagal	155-160	2.0-3.5	150	small	v. strong	100%	restricted
T-9	150	1.0-2.5	tall	long	strong	89%	restricted
Type 3	140-150	2.5-3.5	145-175	long	strong	85%	restricted
Basmati370	145-150	2.0-3.0	160	long	v. strong	100%	restricted
Taraori Basmati*	155	2.5-3.0	155	extra long	average	87%	restricted

(*) Also known as Karnal local.
(**) Phool Patas has >300 grains/panicle.
Elong. = Elongation after cooking.

since the time of Susruta, the great Indian pioneer in medicine and surgery (Nene, 1998). The first documented record of both scented rice and short duration rice in India was made by Susruta. Later, circa 100 BC to 100 AD, Charaka and Kashyapiyakrishisukti (circa 800-900 AD) mentioned a large number of rice cultivars with specific quality features including fragrance and their medicinal values (Kumar, 1988; Wojtilla, 1985). Some of these cultivars were also mentioned by Susruta. Records of rice cultivars grown during 15th to 17th century AD are available in Acharya Bhavamisra's Ayurvedic treatise (Indian Material Media) (Chunekar and Pandey, 1986) and in *Ain–I–Akburi* written by Abul Fazl Allami around 1590 AD (Blochman, 1927; Jarret, 1949). *Ain–I–Akburi* also gives the prices of some rice varieties, certain varieties fetching much higher price over other because of their superiority in respect of fragrance and pleasant taste. Mushkin was one such variety, besides sukhdas and shakarchini.

One European traveler, Jean Baptiste Travernier, has made special mention of the musk scented rices of Surat (Gujarat, India) (Watt, 1891). He wrote that "All the rice which grows in this country possesses a particular quality causing it to be much esteemed. Its grains are half as small against as that of common rice, and when it is cooked, snow is not whiter than it is, besides which, it smells like musk and all the nobles of India eat no other. When you wish to make an acceptable present to anyone in Persia, you take him a sack of this rice".

Interestingly, this popular rice cultivar described by Travemur was small-grained, white with musky scent. This description fits with the description of cultivar mushkin, described about 50 years earlier in *Ain-I-Akbari* (Nene, 1998). Sinha (1996) reported that a musk-scented cultivar called gandh-kasturi was also grown in Jessore (now in Bangladesh) towards the end of the nineteenth century. Nene (1998) reported a large number of small grained to long grained scented rice cultivars prevalent in different parts of the country and documented by various workers (Watt, 1891; Padam, 1977; Ahuja et al., 1995; Sinha, 1996; Buchanan, 1807 and CSIR, 1966).

However, the earliest record of Basmati, is found in the famous poem—Heer Ranjha—by the poet Waris Shah (1725–1798). Nene (1998) argues based on this, that it is safe to assume that Basmati mentioned by Waris Shah in Circa 1766 must have been in cultivation for at least 50 to 60 years earlier i.e. around 1700 AD. The cultivar Basmati has been frequently mentioned in the *Dictionary of Economic Products of India* compiled by George Watt. Watt (1891) has covered a period of at least a century because a good deal of information was obtained at the field level from practicing farmers.

Although there are records of scented rices being grown in China, Thailand, Indonesia, and other countries in South Asia, the emphasis both on their cultivation and improvement has been less than in northern India (Nene, 1998). There existed a reference to a red Champa cultivar that was late in maturity, soft, fragrant and sweet on cooking and grew well on saline soil (Needham, 1984). There are also the records showing introduction of this variety from the kingdom of Champa in Central Indo China (now in Vietnam and Cambodia) to Fukien Province of China. It is well known that the kingdom of Champa, which existed between 2nd and 17th century AD, was under strong cultural influence of India indicating the origin of this rice cultivar from India.

Notably, these cultivars were developed by farmers and were maintained under different names. The names of the cultivars were often derived from the main feature, quality or originating locality. Based on available evidence it may be conjectured that the name Basmati also originated at the level of farmers and traders around 16th or 17th century. Nene (1998) argues that the cultivar must have easily found the patronage from the nobility of that time since Persian and Muglai rice preparations such as *biryani* and *pulao,* aromatic, non-sticking, long-grained and easy to cook rice was preferred.

CURRENT SCENARIO

Formation of aroma in aromatic rices is very much dependent on poorly defined climatic, cultural, soil and nutritional factors. Each variety performs best in its own native area of cultivation. An aromatic variety may yield good in a wider area, however, its fine grain traits (like aroma, grain size and shape, elongation during cooking, taste, fluffiness, etc.) are best expressed only in small pocket known as native area. Almost every state of the country has its own set of varieties of aromatic rice, and each variety has a native area for its cultivation. These native areas are identified through tradition and history of experience of farmers. Unfortunately, so far, importance of this information has not been realized by the scientists. In order to get acquainted with the current scenario, an extensive survey of some of the aromatic rice growing areas was conducted in the districts of Dehradun, Bijnore, Pauri, Nainital, Tehri, Sidharthanagar and Basti in UP and east and west Chamaparan districts of Bihar. The main observations are summarized in this chapter.

Story of Seola-Majra Belt

Statistics provided by district administration of the Dehradun shows that area of cultivation of Basmati rices has increased considerably (i.e. from 1000 ha in 1990 to 1500 ha in 1996). However, on visiting Seola-Majra belt that includes villages like Seola Kala, Majra, Pithuwala, Bamanwala, Niranjanpur and Seola Khurd which is famous for producing finest quality Basmati rice in the country, it is found that almost 80 per cent of the prime Basmati growing area of this belt has gone to housing. Many farmers from this area have sold their land to housing projects at higher prices and have purchased land on Dehradun–Delhi road away from the city. There, too, they are growing Basmati but as farmers themselves admit there is no comparison in quality. Some farmers who have sold their land are repenting their decision. In valleys of Dudhai Khadar and Jagatpur Khadar, which are a bit away from city, the situation is not that bad and Dehraduni Basmati is cultivated widely; thanks to the interest taken by Basmati exporters. The exporters come and procure the produce at the village. However, in surrounding villages other fine grain rice varieties like Kasturi, Pusa Basmati-1 and coarse grain varieties like Pant Dhan-4 and China-4 are fast replacing the much better quality native Dehraduni Basmati, because of their superior yields. In Vikas Nagar, Basmati cultivation has been virtually replaced by sugarcane.

Story of Tapovan

Tapovan, a small village, located at the top of the hilly ridge, just above the Lakshman Jhoola in Rishikesh. Agricultural lands of the village are on slopes as terraces. In Dehradun several villagers told us to go to Tapovan if we are looking for the finest quality Basmati. In Rishikesh a shopkeeper from Punjab, from whom we enquired about the village, told us that till 10 years ago when he used to take Basmati rice from Tapovan to his village in Punjab, its scent was so strong that entire village used to know about it the very first day when rice was cooked at his home. However, the story is quite different now. We reached the village with great hope after climbing about a couple of thousands feet from Lakshman Jhoola. When we met the villagers and asked them for the samples of native Basmati rice, we had a real shock. They have nothing to offer except rosy stories of bygone days. The economic condition of the villagers was pathetic. They now grow Basmati only in a small valley and that too, according to farmers, is left with little scent. When we collected a few of these samples they were all found to be mixtures.

Farmers informed that earlier as per decree of King of Tehri, only Basmati rice was cultivated in the entire village for consumption of the royal family. Later ownership of land was shifted to the *mahant* (Head Priest) of Bharat Mandir at Rishikesh. Then the entire Basmati rice of the village was used for *bhog* (offering) at the temple. When farmers of the village became owners of these lands their financial problems forced them to shift from single to multiple cropping resulting in replacement of Basmati cultivars, and drastic reduction in fertility of the land. We observed a wide spread zinc deficiency in crops, which were growing at the time of our visit. Now most of the farmers grow two to three crops but because of poor fertility of land and inability of farmers to use fertilizers, the financial condition of those farmers who are totally dependent on their land, has deteriorated further with time. In our assessment, the loss of purity of Basmati seeds and poor fertility of the soil resulting out of multiple cropping are major factors for near extinction of the famous Lal Basmati of Tapovan.

Story of West Champaran

The Tarai belt adjoining Nepal border and comprising Chanpatia, Narkatia, Ramnagar and Jhumka areas of west Chamaparan in Bihar were once considered as the bowel of aromatic rices. Several varieties of aromatic rices like Champaran Basmati (Lal, Bhuri and Kali), Kanakjeera, Kamod, Baharni, Dewta Bhog, Kesar, Ram Jawain, Tulsi Pasand, Chenaur, Sona Lari, Badshabhog and Marcha were once popular in this area. Till a couple of decades ago, rice was the major kharif crop of this district.

Presently it is left with only 45 per cent of the area. The remaining area (approx. 50 per cent) has been replaced by sugarcane. Scientists at Rajendra Agriculture University, Pusa gave us the impression that many scented rices are still widely cultivated in west Champaran Tarai. However, even after extensive survey of this area we could not get seeds of a number of once popular cultivars. Among aromatic rices only Champaran Basmati (mainly Lal) is being cultivated in small areas and that too by the large farmers primarily for their own consumption. Declining aroma and yield were a major concern of the farmers. They are still cultivating Basmati primarily because they have developed special taste and attachment with this variety. Most other aromatic rices are now part of the past. Kanakjeera and Baharni were popular only about five years ago. During our discussions the farmers showed serious concern for the loss of aromatic varieties. They were very receptive to our suggestions to revive cultivation of some of these varieties at small scale for their personal consumption. When we enquired about the economics of Basmati cultivation we learned that its yield was approx. 2.5 times lower while the prices are 2.5 to 3 times higher than the high yielding non-aromatic varieties that are popular in that area. In spite of this, farmers were not convinced of large-scale cultivation of Basmati and other scented rices. Although they could not explain it, it is assumed that sustainability was the major issue. Although sugarcane has replaced rice in a large area in this district, a reverse trend may emerge soon. The local farmers face a lot of problems in the sale of sugarcane. They also told us that in sugarcane they earn money only once in a year, which they spend fast, and face financial problems most of the year. They want to diversify to other crops so that money is in better circulation. Cultivation of scented rices may offer part of the solution to these problems.

The story was much the same in most of the native aromatic rice growing pockets surveyed in U.P. districts of Pauri, Bijnore, Nainital, Tehri, Basti and Sidharthanagar. Based on our interaction with the farmers in these native areas the following major concerns were identified.

Shrinkage in area

Cultivation of indigenous scented rices in their prime areas is fast declining. Several reasons can be attributed to this trend. Growing population and ever-dividing land holdings have made food security the foremost concern for small and marginal farmers. They have now better technological options like improved high yielding varieties, both non-aromatic and mild aromatic types. Alternate and more profitable cropping systems have also evolved. Sugarcane-based cropping system, for example, has become prevalent in Dehradun and Champaran belts often without rice in the sequence. A lot of area near cities is now used for housing and other non-agricultural uses.

Since late seventies and early eighties, the international rice market has undergone a sea of change. The demand for long grain non-aromatic rice and aromatic rices with mild scent but extra-long slender grain has increased (Bhasin, 1996). Thus, there is now less demand for once well-known Basmati varieties. In northern India, Basmati 370, Type 3 and Hansraj were the most popular and widely grown among Basmati varieties. At present, Karnal local which is known by different names (HBC-19, Taraori Basmati, Amritsari, Pakistani, Basmati 385) has almost replaced Basmati 370 in Punjab and Haryana. It is now slowly replacing Type 3 and Hansraj in UP., especially by virtue of its extra long slender grains, although other quality parameters are almost same or even inferior to Basmati 370, for example, in milling percentage, elongation and volume expansion after cooking. Karnal local has higher percentage of grains, longer than 7.68 mm, whereas Basmati 370 and Type 3 grains are comparatively shorter (Singh et al., 1996). Gradual decline in yield of the local non-Basmati scented rices has been another reason for decrease in their cultivated area. There is need to properly address some of the issues like scarce water resource, land degradation, varietal impurity and indiscriminate use of chemical fertilizers.

Aroma crisis: farmers' perception

Indigenous aromatic rices are gradually loosing their bus (aroma). This was the unanimous opinion of farmers wherever we visited (Singh and Singh, 1997; see also Chapter 11). Some of the factors for decline in aroma, as perceived by the farmers and us, are:

- ***Varietal mixtures:*** Since ages farmers are using their own-saved seeds. There is no seed production/improvement programme for these rices. Some of the farmers are quite aware of the importance of quality seeds and they do select good seeds from their field for planting in the next season. But almost all these farmers give major emphasis to yield rather than quality in their selections.
- ***Use of chemical fertilizers:*** Farmers were of the strong opinion that FYM improves and nitrogenous fertilizers, particularly urea, adversely affect aroma formation. In literature, there are many references dealing with dose optimization for nitrogenous fertilizers for the best yield of scented rices. They hardly give any consideration to the effects of these fertilizers on aroma or other quality traits.
- ***Soil factors:*** Soil factors do affect aroma formation but these are not yet defined. Leaching of minerals may result in decline in aroma. During the survey we could see clear-cut symptoms of the deficiencies of micronutrients like Zn, Fe and sulphur.
- ***Cultivation practices:*** Although there is no experimental evidence, but farmers say that there is better aroma in direct-sown rice crop than in transplanted ones, particularly in the Hansraj variety.

- ***Rising temperatures:*** Both in scientific and farmers' circles it is accepted that comparatively lower temperature (20–27°C) at the time of flowering or grain filling enhances aroma content of the seeds. However, this critical temperature may vary for different varieties. Gradual increase in temperature because of global warming, deforestation and industrialization may have affected aroma content.

Rapid loss of the germplasms

In the absence of any conservation programme, we are fast losing most valuable germplasm of scented rices. While surveying some of the areas, we found that a number of high quality local rice germplasms which were in cultivation a few years ago, are now extinct. In UP., for example, 30 odd such aromatic types were earlier cultivated in different regions, it has now been left with hardly 4 or 5 varieties (Table 4) (Nagar, 1997; Singh et al., 1997). The reasons are not far to seek. For sometime now the emphasis has been more on grain yield than on aroma. Similarly, long-grain Basmati types with mild to strong aroma and higher yields are being preferred over non-Basmati strongly aromatic but low yielding rices. Due to their low yields and limited markets, farmers seem to have little interest to continue growing these cultivars. Also, there is no incentive for them to do so, nor is there any systematic research efforts to ensure better quality seeds and improved yields.

Marketability

Small and medium grain aromatic rices command a very limited market base. Their prices are lower than Basmati types. In a few cases their prices could be equal to or even higher than Basmati types but only in their native areas of cultivation where farmers and consumers are aware of their qualities (Table 5). However, in cities only long grain aromatic rices are in demand. So far no attempt has been made to explore the export market for small and medium grain aromatic rices which are superior than Basmati in all characteristics except grain length.

NEED

Research Support

There is no denying of the fact that India still has immense wealth of aromatic rice germplasms/land races. However, the expression of aroma is very much dependent on environmental and cultural conditions which are not yet defined. Until we are able to do so and are in a position to manipulate them we must try our best to study and improve these varieties in their natural habitats. Since farmers have been using their own

Table 4. Some famous aromatic rice cultivars and land races of Uttar Pradesh

Landraces	Region	District(s)
Kalanamak**	Tarai	Basti, Sidharthanagar, Maharajganj, Gorakhpur, Gonda.
Ramjawain	Tarai	Basti, Sidharthanagar.
Shakkarchini	Tarai	Gonda
	Central Plain	Varanasi
	Vindhyan	Mirzapur, Sonbhadra
Hansraj**	Tarai	Dehradun, Rampur, Pilibhit
Basmati safeda*	Tarai	Bareilly Nainital, Saharanpur Haridwar, Bijnor, Muzaffamagar
Tilakchandan*	Tarai	Nainital, Pilibhit, Rampur
Ram Jawain	Tarai	Saharanpur Rampur, Pilibhit
Dhaniya	Tarai	Basti, Gorakhpur, Gonda
Kanakjeera	Tarai	Basti, Sidharthanagar, Bahraich
	Central Plain	Barabanki
Bhataphool	Tarai	Basti, Sidharthanagar
	Central Plain	Azamgarh, Mau, Sultanpur
Duniapat	Tarai	Basti
Rambhog	Tarai	Bahraich, Gonda
Lalmati*	Central Plain	Barabanki, Faizabad,
Vishnuparag	Central Plain	Barabanki, Bahraich
Selhi; Dulahniya	Central Plain	Mau, Azamgarh
Badshapasand**	Central Plain	Pratapgarh, Allahabad, Raibareilly, Bareilly
Benibhog	Central Plain	Barabanki
	Tarai	Bahariach
Moongphali	Ganga Basin	Ghajipur
Tulsi Manjari	Ganga Basin	Ballia
Tulsi Prasad	Ganga Basin	Ballia
Adamchini**		
Kesar		
Laungchoor		
Phool Chameli	Vindhyan	Mirzapur, Sonbhadra, Varanasi
Jeerabatti		
Dubraj		
Soonachoor		

**Still popular and grown in large areas.
* Popular but grown in small areas only.

produce as seed since ages there is wide variability within each aromatic rice cultivar/germplasm which can be exploited for their improvement by simple selection. Some aspects that need immediate research support are as follows:

Germplasm collection, characterization, maintenance and data base development

Collection, purification, agronomics, morpho-physiological and molecular characterization; evaluation, and maintenance of the indigenous scented

Table 5. Relative market rate of indigenous and developed rices

Market place	Varieties	Rate (Rs per kg rice)
Dehradun (U.P.)	Dehraduni Basmati (Native)	30
	Pusa Basmati-1	18
	Non-scented varieties	6-8
Manipur	Chakhao (Native)	25-30
	Non-scented	10
Gurdaspur, Hoshiarpur, Amritser, Ropar (Punjab)	Pakistani Basmati	20
	Basmati 385	15
	Pusa Basmati-1	12
	Basmati 370	15-20
	Non- scented	6-8
Basti, Siddhartha Nagar (U.P.)	Kalanamak (Native)	25
	Basmati 370	20
	Bhantaphool	15
	Badshahpasand	15
	Duniapat (Native)	20
	Non-scented varieties	8
Mirzapur (U.P)	Shakkarchini (Native)	15-20
	Adamchini	15-20
	Basmati	20
	Duniapat	20
Bijnor	Hansraj (Native)	20
	Nagina-12	20
	Pusa Basmati-1	15
	Tilakchandan	15
	Non-scented varieties	8
Vidarbh Region	Chinoor (Native)	20-25
	Non-scented varieties	10
Belgaon, Dharwad (Karnataka)	Kagasali (Native)	25
	Non-scented varieties	12
Varanasi	Basmati 370	30
	Adamchini	20
	Jeerabattis	20
	Sonachur	18
	Non-scented varieties	8-10
Bhagalpur (Bihar)	Tulsi Manjari (Native)	25-30
	Basmati 370	20
	Katarni (Native)	25-30
	Non-scented varieties	10
Delhi	Taraori Basmati	35-40
	Khalsa 7	25
	Dehraduni Basmati	25
	Non-scented varieties	10
Birbhum (West Bangal)	Radhunipagal (Native)	20-25
	Badshahbhog (Native)	25
	Kataribhog	20
	Non-scented varieties	8

(Contd.)

Table 5. (Contd.)

Market place	Varieties	Rate (Rs per kg rice)
Pune (Maharashtra)	Ambemohor (Native)	20-25
	Indriyani (Developed variety)	15
	Basmati 370	30
	Non-scented varieties	10
Kota (Rajasthan)	Local Basmati	25
	Khusboo	20
	Pusa Basmati	18
	Kasturi	18
	Basmati 370	25
	Non-scented varieties	12
Raipur (M.P.)	Vishnubhog	18
	Dubraj (Native)	20
	Badshahbhog	20
	Chinoor	20
	Non-scented varieties	10-12

rice germplasms should be given top priority. There is an urgent need to develop detailed data-base on all indigenous aromatic rices of India and publish them. It would not only be of immense use for the scientists involved in improvement of aromatic rices but also it should help us to save our precious wealth from being lost to other countries. With the help of Agricultural and Processed Food Products Export Development Authority (APEDA), Government of India, All India Rice Exporters' Association (AIREA) is fighting a legal battle against Rice Tec Inc., USA for protecting the name 'Basmati' in international market (Sharma, 1998). Safeguarding our precious indigenous scented rice germplasms is important for the future.

In situ conservation and improvement of germplasms

Importance of the preservation of germplasms of indigenous scented rices cannot be over emphasized in the changing world scenario where free exchange of these materials would no longer be possible. As far as it is possible these germplasms should be preserved and multiplied in their native areas of cultivation. During our survey of the Pauri district one octogenarian visionary farmer, Rishal Singh of Kishanpur village while describing the characteristics of some scented rices which were in cultivation about a quarter century ago commented that 'what a wealth we inherited from our ancestors and destroyed them by our foolishness and lust for more profit'. Several farmers in west Champaran district showed serious concern for the loss of precious germplasm of aromatic rices. They are showing much interest in our on-farm conservation programme.

Environmental characterization of factors affecting aroma formation

Environmental, cultural, soil and nutritional factors affecting aroma formation in major cultivars of Basmati and non-Basmati type scented rices must be characterized. It will help to produce better quality aromatic rices and identify alternate non-traditional cultivation areas for the major aromatic rices.

Chemical characterization of aromatic compounds

The most commonly present compound in scented rices is 2-acetyl-1-pyrroline. It imparts popcorn-like smell (Tsugita, 1985-86, Widjaja et al., 1996). Among Indian scented rices whatever information is available on the chemical nature of aroma compounds is restricted to Basmati. Even the type of Basmati is not defined. No information is available on the chemical entities responsible for the aroma of different cultivars of non-Basmati scented rices. There is a need to chemically characterize major aroma compounds of Basmati and non-Basmati Indian scented rices and develop a quantitative assay for the rapid estimation of scent.

Alternate aromatic rices

India has a large number of different types and cultivars of aromatic rices, which, if properly exploited, can satisfy taste and aroma preference of people from different regions of the world. Unfortunately, except for the Basmati-types, available diversity is un-exploited. A number of non-Basmati type aromatic rices can surpass Basmati with respect to several quality traits. Beside, they are adapted to local conditions in areas where Basmati cannot be grown.

Validation research

Following observations of the farmers with respect to aroma and other quality traits should be verified by carrying out on-farm trials:

- Nitrogenous fertilizers vs organic manure
- G x E (especially temperature)
- Soil factors including micronutrients.
- Direct sowing vs transplanting

Alternate areas for the production of high qualify scented rices

Till environmental and soil factors affecting aroma formation are characterized, Basmati type rices could be tested in non-Basmati areas like Sidharthanagar (native area of Kalanamak). Similarly performance of Kalanamak could be explored in Dehradun (native area of Dehraduni Basmati).

Standardization of post-harvest technologies

Farmers of Tapovan claim that manual dehulling using *musal* and *okhali* results in better quality (with respect to aroma and taste) rice than mechanical dehulling. Drying, milling and storage technologies affect both texture and preserved aroma of the grains. These should be standardized for the major indigenous scented rices.

Policies

To achieve the above goal we need not only more research but also change in our policies.

There should be price support to the farmers of native aromatic rice growing areas to convince them not to shift to other cultivars of rice or to other crops. Some of the farmers from Dehradun told us that increase in Basmati prices by Rs. 3 per kg may change the situation and make the Basmati cultivation more profitable than sugarcane. Traders and exporters of Basmati rices should realize that their own survival and success depend on cultivation of these varieties in their native areas.

There should be incentives for on-farm conservation of germplasms. There is a need to improve rather than replace these varieties. Government and university extension services ought to be more pragmatic in their outlook and approach. Their aim should be to conserve rather than destroy or replace local varieties/germplasms. So far their major goal has been to increase productivity (with little consideration to quality) and short term profitability of the farmers.

Organize seed production and distribution programs for local scented rice cultivars.

Restricting sale of land for non-agricultural use in prime scented rices growing areas.

Exploring/developing the international market for small/medium-size grain, non-Basmati type high quality scented rices. This should be primarily the job of AIREA and APEDA.

RESEARCH STATUS

Only sporadic attempts were made in the past to improve short and medium grain aromatic rices, mainly through selection or mutation. As a result, varieties like Ambemohar-157, Prabhawati, Indrayni, Pawan, Kamini, Sugandha etc. were released for cultivation in different pockets of the country. Many of these materials are being used as donors in the Basmati improvement program. Some of the locally grown scented rice germplasm have also been evaluated and characterized for their quality and morpho-physiological traits. A few of them are being used as donors by breeders at various centers (Singh, 1997).

A few years back, the Indian Council of Agricultural Research (ICAR) established a research network involving seven centres on 'Improvement of Basmati Rices for Increased Productivity and Export Purposes' (Anonymous, 1990-93). Major thrust of this network is to improve Basmati-type rices with respect to their yield and fine grain parameters. Practically it places little emphasis on aroma and non-Basmati scented types.

Only in 1996, another project with major emphasis on non-Basmati type indigenous scented rices was initiated involving scientists from International Rice Research Institute and G. B. Pant University of Agriculture and Technology, Pantnagar with the following objectives:

Germplasm collection, purification, morpho-physiological, biochemical and molecular characterization.

Chemical characterization of aromatic compounds and development of quantitative assay for the aroma.

Location and documentation of genes for aroma, other fine grain qualities and diseases and pests resistance in the collections.

Structuring of the gene pool in distinct groups based on aroma and further sub-structuring based on other characteristics.

Effect of organic manures, chemical fertilizers and micronutrients on aroma formation in Basmati and Kalanamak.

G × E studies on aroma and other grain quality parameters.

Improvement of the Kalanamak, Bindli, Lal Basmati, Dehraduni Basmati and other indigenous aromatic varieties primarily by selection and purification.

The major emphasis of this project is to study the indigenous scented rices in their native areas of cultivation and give due importance to aroma. Progress made so far is follows:

Database Development

As a first step toward comprehensive data base development on scented rices the authors devised a questionnaire and sent it to all the agricultural universities and institutes with active research program on rice. Most of them responded. In spite of the fact that these information are preliminary in nature and we are still in the process of verification by various means, certain points are worth mentioning.

- cultivars with widely different characteristics are given the same name at different places,
- cultivars/land races with almost similar characteristics are called by different names, and
- even for popular scented cultivars, wide variation is reported in some of the important characteristics like aroma (poor to strong) and grain elongation on cooking apart from duration, yield, and

plant height (Singh and Nagar, 1996). This emphasizes the fact that the area of cultivation has a great impact on aroma formation and other grain characteristics. Full potential of the cultivars would be expressed only in their native areas of cultivation. Therefore, screening for the parameters like aroma away from the native cultivation areas has little significance.

Collection, Purification and Evaluation of Germplasms

In the last two years, more than 300 germplasms of scented rice have been collected mainly from U.P. and Bihar. These have been cultivated at major aromatic rice growing areas of the state like Seola-Majra (Dehradun), Nagina, Sidharthnagar and Mirzapur for their purification and selection of off-types and for the study of different physio-morphological and agronomic characteristics with major emphasis on aroma.

FUTURE STRATEGY

Our objective should not be limited to the maintenance of germplasm of the indigenous scented rice. Instead, what is needed is a well organized research program on germplasm characterization, utilization and enhancement including chemical characterization and quantification of aroma. Selection and purification should be the first step, as lot of variation appears to be present even in the individual varieties. For example, in Kalanamak—a local land race—16 distinct types were identified (a few are given in Table 6), which differed in one or more yield and ancillary characters (Anonymous, 1995). The components responsible for aroma in different aromatic rice cultivars have not been properly identified and quantified (Buttery et al., 1988; Tsugita, 1986; Widjaja et al., 1996). There is need to identify aroma components, their distribution and also to understand which of the synthetic metabolic pathways are involved in aroma development. Genotype × environment study will be helpful in under standing the environmental factors influencing the aroma formation as well as determining the suitability of cultivars for specific growing regions for further promotion. There is also a need to validate some of the observations made by farmers. These include effect of nitrogenous fertilizers versus organic manure on aroma, soil factors (micro-nutrients), same plot versus change in plot and temperature. Identification and manipulation of post-harvest factors would also be quite useful.

The indigenous scented rices are known to have specific adaptation, and their quality is fully expressed only when grown in their specified territories. Characterization of environments of the specified localities will go a long way in understanding the genotypes × environment

Table 6. Yield and other ancillary characters of different Kalanamak selection

Group	Yield (t/ha)	Maturity (days)	Plant height (cm)	Remarks
KB-7	0.5	146	118	MS, Scented
KB-123	0.4	150	106	MS, Scented
KN- 65	1.1	154	112	MS, Strongly scented
Kala Namak Local	0.8	154	121	MS, Scented

(MS) = Medium Slender

inter-action and be helpful in identifying alternate non-traditional areas for long-grain Basmati cultivation thus providing opportunities to the farmers of these regions also to avail export benefits.

A number of non-Basmati scented rices can surpass Basmati in one or more characteristics like aroma, texture, elongation on cooking and taste etc (Table 3). Moreover, many of them can be cultivated under conditions and in areas where Basmati can not be. Small-grain Bindli, for example, is superior to Basmati in aroma, grain elongation, taste and digestibility (as perceived by the farmers) and it performs well under water-logged conditions. We must try to identify and promote cultivation of such varieties for their export. A few such potential candidates could be Kalanamak, Tilakchandan, Sakar-chini and Dhania (U.P.), Ambemohar (Maharastra), Badshahbhog (Bihar and West Bengal), Bindli (waterlogged conditions of U.P.), Chakhao (Manipur), Madhumalti and Mushkan (H.P.), Kon-Joha - 1, Raja Joha and Krishna Joha (Assam), Randhuni Pagal (W.B.), Vishnubhog and Dhubraj (H.P.), Katarani and Sonachur (Bihar) (Singh et al., 1997).

In small and medium grain aromatic rices, there is still a great scope to improve them by selecting short statured, better yielding and early maturing plant types. Since expression of aroma gene is dependent on lower temperature during flowering (Asoaka et al., 1985), comparatively early maturing materials can fit by late sowing which would enable farmers to take on the summer crop before transplanting of rice.

These rices have enough biomass, but week stem makes them lodge. If used with CMS lines of semi-dwarf stem background, it will be possible to develop hybrids of Mahsuri stature and plant type having better quality aroma, high yield and stability. Not many of the local germplasm have been evaluated for restoration ability. Similarly, some of the land races have far greater elongation ability (Bindli 200%, Dhania 153%, Jeerabatti 142%) and stronger aroma (Bindli, Ranga Joha-1, Randhuni Pagal) (Table 3). Some are also the good sources of resistance to pests and diseases. Phool Patas, a local cultivar from Himachal Pradesh, produces as many as 300 grains/panicle which could be utilized to improve rice yields. Genes for such specific traits could be isolated from these cultivars and transferred to high yielding dwarf, long, slender grain background by using molecular techniques (Ahn et al., 1992).

As discussed above, in order to achieve the set goals, not only we need strengthening of research, but also the appropriate changes in public policies.

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Chapter 10

Aromatic Rices of Other Countries

The aromatic rices are mainly grown and consumed in India, Pakistan, Thailand, Bangladesh, Afghanistan, Indonesia, Iran and United States. Of these, India, Pakistan and Thailand export fine grain aromatic rices mostly to Middle East, Europe and USA with the annual export worth millions of dollars.

Pakistan is an important aromatic rice producing country. The total area under rice cultivation in Pakistan is 2.1 million ha, of which 1.1 million ha is in Punjab. Of the total area under rice cultivation in Punjab 80 per cent is under Basmati-type rices. Its total production is 3 million tonnes-44 per cent in Punjab, 44 per cent in Sindh, 3 per cent in NWFP and 9 per cent in Baluchistan. Two-thirds of the production is locally consumed while one-third is exported. Pakistan's Basmati export in 1994-95 was 452,300 tonnes. Basmati rice research in Pakistan is concentrated at the Rice Research Institute (RRI), Kala Shah Kaku (Punjab). RRI has a long history of developing rice varieties with excellent grain quality and aroma. Basmati 370 was developed in 1933, Basmati Pak in 1968 followed by Basmati 185 and Basmati 385. The latest variety released was Super Basmati in 1996. New promising lines under testing include PK 50010, PK 4048-3, PK 50005-3, Basmati 6129 and Basmati 50021-1 (IRRI 1996).

Aromatic rice is grown only on a limited scale in the United States. Della is the predominant and most liked variety. The other known varieties are Dellamont, A201 and Jasmine 85.

The status of aromatic rice in Thailand, Bangladesh, Vietnam and Iran is described in this chapter. Of these, Thailand is a major producer and exporter of fine grain aromatic rices in the world market.

AROMATIC RICES OF THAILAND

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INTRODUCTION

Rice has been in Thailand for more than 5000 years but the aromatic rice locally known as Khao Hawm (fragrant rice) is considered to be the national pride of the Thai people; it was grown in almost every household in Thailand mainly for their own consumption. In each region, farmers grew in their fields several aromatic varieties which suit their requirements; these varieties differ in cooking quality, maturity and responses to day-length, adaptability, etc. Only recently that the diversity of aromatic rice cultivars has been narrowed down to a few varieties in order to conform with domestic and international demands. Aromatic rice includes the glutinous and non-glutinous endosperm types which share similar economic and social importance among Thai consumers. In the north and northeast regions glutinous rice is produced and consumed locally with little surplus for export. By contrast, the aromatic non-glutinous rice, predominantly KDML 105 is produced for both domestic consumption and export; it is considered to be one of the top earners of foreign exchange among agricultural products.

GEOGRAPHICAL DEPENDENCE OF AROMA EXPRESSION

Because of high demand for specific type of aroma in the local and international markets, only a few aromatic varieties are being grown. These varieties, mainly KDML 105, are primarily grown in the north and northeast regions and to a smaller extent in the other parts of the country (Fig. 1). The reason why aromatic cultivars are concentrated in the north and northeast regions is that the growing conditions are more favourable, especially after the flowering periods. Such factors as cool temperature, bright sunshine, and diminishing soil moisture at grain filling stage play very significant roles in the expression and accumulation of aroma. Farmers knew very well about this and prefered to grow the improved traditional cultivars (KDML 105 and RD 6) in the wet season. This practice not only helps them get a higher profit but also they are assured of harvesting some grains even in drought years. The modern varieties, on the other hand, are normally grown in the central part under well-managed irrigated conditions. Production, area planted, and other characteristics of traditional and improved aromatic varieties in Thailand are shown in Table 1.

Table 1. Type of aromatic varieties, areas planted, and production in 1997

Variety	Area planted (ha)	Production	Remarks
Non glutinous			
KDML 105	2,098,308	3,376,002	Photoperiod sensitive improved traditional
RD 15	284,947	466,711	Photoperiod sensitive improved traditional
Hawm Klong Luang	NA	NA	Photoperiod insensitive semi-dwarf, 120 days maturity
Hawm Supanburi	NA	NA	Photoperiod insensitive semi-dwarf, 118 days maturity
Glutinous			
RD 6	2,557,026	4,528,222	Photoperiod sensitive improved traditional

NA = no data available

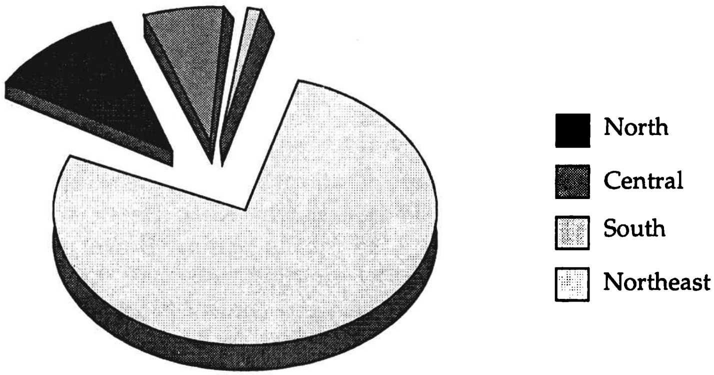

Fig. 1. Distribution of rice area (ha) planted with KDML 105 in 1996-97 season

AROMATIC RICE VARIETIES GROWN IN THAILAND : AREAS PLANTED, PRODUCTION

In 1997, aromatic rice accounted for 5 million ha (60 per cent) of total 9.2 million ha rice area; only three varieties — KDML 105 and RD 15 for non-glutinous, and RD 6 for glutinous rice — were grown. For the non-glutinous rice, approximately 2 million ha (23 per cent of total area) were planted with KDML 105 and 285,000 ha RD 15. The variety RD 6, however, was planted in little more than 2.9 million ha (28 per cent of total area), almost 1 million ha more than KDML 105 (Table 1).

Total rice production in 1997 was 18 million tons of which only 8 million tonnes were of aromatic rice — KDML 105 and RD6 produced 3.3 and 4.5 million tonnes, respectively. Glutinous rice is produced primarily for domestic consumption and only a little is exported. The main component of rice export comes from the non-glutinous type. In 1997, of total 5.24 million tons rice exported, more than 2.2 million tonnes came from KDML 105, accounting for 42 per cent (Anonymous, 1997c). Due to diverse preferences among Thai consumers in cooking quality, the low amylose content (16 per cent) of KDML 105 which gives soft and tender texture after cooking is preferred by the upper income group class. The majority of consumers, however, are more accustomed to the intermediate amylose type that remains in their stomach longer. This is fortunate for the country because larger quantity of KDML 105 is, thus, saved for export.

HISTORY OF KDML 105: ORIGIN, PURE LINE SELECTION

KDML is the abbreviation for Khao Dawk Mali. It is a traditional variety and its origin can be traced to 1945 when it was found by a farmer in Chon Buri province in eastern Thailand. The seed of KDML was later distributed to the neighboring province of Cha Seong Sao where a district agricultural officer collected 199 panicles in 1950 (Somrith, 1996). The panicle-row method was employed and pure line selection initiated at Kok Samrong Rice Research Station in Lop Buri province. The outstanding line, Khao Dawk Mali 4-2-105, then was identified and further evaluated for yield potential and adaptability in the north, northeast, and central regions. It was later released as Khao Dawk Mali 105 in 1995 (Khao means white; Dawk Mali means jasmine flower) (Somrith, 1996). KDML 105 is said to have low yielding potential; the average yield is about 1.7 t/ha. However, in the yield contest plots of the different rice experiment stations of the Rice Research Institute with appropriate technology, it yielded as high as 4.5-5 t/ha indicating the possibility of obtaining higher yields by proper management (Anonymous, 1996).

BREEDING FOR AROMATIC RICE VARIETIES

The photoperiod responses of KDML 105 led to experimentation with non-sensitive types. The efforts have resulted in the release of two new aromatic varieties, Hawm Klong Luang and Hawm Supanburi in 1997. These varieties developed by Rice Research Institute (RRI) have semi-dwarf plant type and are photoperiod insensitive. These varieties can be grown at any time of the year, facilitating the planting in dry season. This is of course a strategy to increase the production of the aromatic rice by planting in the off-season with supplemental irrigation water. This practice helps cope with the increasing demand for non-glutinous aromatic rice.

The variety Hawm Klong Luang was derived from a cross involving a Thai traditional cultivar, Nahng Mon S4 and IR841-85-1-1-2, a KDML 105 derivative. It was named after Klong Luang Rice Research Station where the cross was made in 1983. This variety has semi-dwarf stature and is moderately resistant to blast, bacterial blight, and white-backed plant hoppers (Anonymous, 1997a). On the other hand, Hawm Supanburi was a product of a multiple cross (SPR84177-8-2-2-2-1, SPB85091-13-1-1-4 and KDML 105). The selection was made at Supanburi Rice Research Station after the cross was made in 1989. It has moderate level of resistance to bacterial blight and white-backed plant hoppers (Anonymous, 1997b). It is interesting to note that both varieties derived their aroma from KDML 105. Their cooking and eating qualities are similar to the parents.

FUTURE RESEARCH ON AROMA RICE

In response to high demand of non-glutinous aromatic rice in the international market, Thai government has intended to increase planting areas, particularly in the northeast and north region from 5 to 6 million ha. In the areas where irrigation water is limited, only KDML 105 could be grown. The genetic uniformity of this variety would certainly be a major concern because of its vulnerability to pests. The major pests such as blast disease and brown plant hoppers could be very devastating when favorable conditions prevail. KDML 105 is susceptible to major diseases and insects such as blast, bacterial blight, brown plant hoppers, and green leaf hoppers. Greater research efforts, therefore, are needed to develop aromatic cultivars that have a broad base of resistance to major diseases and insects and to educate farmers on how to handle their crops. The varieties with "built-in" resistance, that combine aroma and non sensitivity to day-length would be ideal for farmers.

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AROMATIC RICES OF BANGLADESH

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INTRODUCTION

Rice is cultivated in 10.1 million ha and produces 95 per cent of the total food-grain of Bangladesh (BBS, 1994). Aromatic rice is generally used to prepare dishes such as *polau* and *biriani* which are served on special occasions. Demand for aromatic rices in recent years has increased to a great extent for both internal consumption and export.

AROMATIC RICE GROWING AREA

Most of the aromatic rice varieties in Bangladesh are of traditional type, photoperiod-sensitive and are grown during Aman season in the rainfed lowland ecosystem. A recent study (Islam et al., 1996) revealed that 12.49% of the study area was cultivated by aromatic rice varieties. Another study (Baqui et al., 1997) revealed that among the aromatic rice varieties, Chinigura is the predominant one that covers more than 70% farms in the northern districts of Naogaon and Dinajpur. In these districts, 30% of rice lands were covered by aromatic rice varieties during Aman season. The other important aromatic varieties are Kalijira (predominant in Mymensingh) and Kataribhog (predominant in Dinajpur). Islam et al. (1996) observed that the yield of aromatic rice was lower (1.5-2.0 t/ha) but its higher price and low cost of cultivation generated higher profit margins compared to other varieties grown in the area.

VARIETAL IMPROVEMENT

To attain self-sufficiency in rice, sustainable high yielding variety was the main consideration for varietal improvement in the past. Gradually grain qualities are assuming importance. Bangladesh Rice Research Institute (BRRI) released two short bold (SB) grain type aromatic rice varieties BR5 and BR34 in 1976 and in 1997, respectively. Varietal improvement for indigenous aromatic rice, Basmati rice and development of modern aromatic rice are outlined below.

LOCAL AROMATIC RICE

Thirty-six indigenous aromatic rice accessions in BRRI germplasm bank belonging to Kalijira, Chinigura, Sakkorkhora, Radhuni Pagal, Modhumala, Tulsi, Mohonbhog, Rajbhog, Badshahbhog, Kataribhog and Khaskani groups were evaluated (BRRI 1993). Among them four entries were selected for further evaluation for variety release (BRRI 1996). Table 1 shows the yield and ancillary characteristics of the selected entries compared to BR5. Among the selected entries Chinigura, Radhuni Pagal and Shakkorkhora are short-bold (SB) grain type. The Kataribhog is medium slender (MS) grain type, and yields 1.0 t/ha more than BR5 (Table 1).

Table 1. Yield and ancillary characteristics of selected traditional rices of Bangladesh (BRRI, 1996).

Designation	Plant height (cm)	Days to maturity	Kernel length (mm)	Kernel breadth (mm)	Mean[a] Yield (t/ha)
Chinigura (Acc 1880)	147	135	4.05	2.0	2.4
Radhuni Pagal (Acc 2502)	156	138	4.04	2.0	2.3
Sakkorkhora (Acc 1605)	162	137	4.04	2.0	2.2
Kataribagh (Acc 2512)	128	132	5.05	1.1	3.2
BR5 (check) (Acc 4343)	124	132	4.05	2.0	2.2

a) averaged over years and locations.

BASMATI RICE

Varietal improvement for Basmati started in early 70's. However, little success was achieved because of poor combining ability and undesirable segregants. During 90's, a total of 70 Indian and Pakistani Basmati rice collections from IRRI were evaluated (BRRI 1996). Table 2 shows yield and ancillary characteristics of the few selected entries (BRRI 1996). Basmati (D), an early selection having black hull color, has been isolated and appeared to be promising (BRRI 1997).

Table 2. Yield and ancillary characteristics of selected Basmati rice (BRRI 1996).

Designation	Plant height (cm)	Days to maturity	Kernel length (mm)	Kernel breadth (mm)	Mean* Yield (t/ha)
IRGC 3647 Basmati	126	126	5.3	2.1	2.9
IRGC 10608N31 Basmati	135	127	7.5	1.8	2.2
IRGC 27827 Basmati 375A	137	133	6.9	1.8	2.4
IRGC 27833 Basmati 406	138	135	7.3	1.8	2.1
IRGC 53639 Basmati (Begmi)	137	129	6.9	1.8	2.4
Basmati D (ck.)	135	133	5.4	1.7	2.2
BR5 (ck.)	120	135	3.6	1.7	2.0

* averaged over years and locations.

BREEDING LINES

Breeding efforts are continuing to develop aromatic rice varieties having improved plant type; 100-115 cm tall, 115-130 days life cycle, yielding 4-5 t/ha. Grain quality includes grain size 6-7 mm long with 1.5-2.0 mm breadth, cooked rice elongation 1.5-2.0 times and 20-24 per cent amylose content. Three aromatic breeding lines BR4384-2B-2-2-HR3, BR4384-2B-2-24 and BR4384-2B-2-2-6 derived from a cross between Basmati (D) and BR5 have the prospect of being recommended as *T. Aman variety* (BRRI 1997). BR4384-2B-2-2-HR3 has Kataribhog-type grain, BR4384-2B-2-2-4 has Basmati-type grain and BR434384-2-2-6 has Panjam-type grain. Ancillary and grain characteristics of these aromatic lines are furnished in table 3 and 4, respectively.

Table 3. Ancillary characters of the proposed aromatic rice varieties (BRRI 1997).

Designation	Seedling height (cm)	Plant height (cm)	Growth duration (days)	Yield (t/ha)	*Disease score		
					RTV	BB	BL
BR4384-2B-2-24	29	130	140	3.8	537	3	7
BR4384-2B-2-2-6	26	125	140	3.5	354	5	4
BR4384-2B-2-2-HR3	28	125	140	3.7	345	4	5
Brridhan 34 (ck.)	29	143	136	2.5	566	6	6

* Inoculated result, RTV = Tungro, BB = Bacterial blight, BL = Blast.

Table 4. Grain quality of the proposed aromatic rice varieties (BRRI, 1997).

Designation	Milling recovery (%)	Length (mm)	Breadth (mm)	Size Shape	Chalkiness	Tenderness	Protein (%)	Amylose (%)	1000-grain wt. (g)
BR4384-2B-2-2-4	72	6.0	2.0	LS	Tr.	Soft	8.2	23.8	20.0
BR4384-2B-2-2-6	72	4.5	2.1	SB	Tr.	Soft	8.3	23.9	16.5
BR4384-2B-2-2-HR3	72	5.5	1.9	MS	Tr.	Soft	8.6	23.6	16.2
Brridhan 34 (ck.)	72	4.2	1.8	SB	Tr.	Soft	8.2	23.5	12.0

LS = Long slender, SB = Short bold, MS = Medium slender, Tr. = Translucent

EXPORT POTENTIAL

Aromatic rices of Bangladesh have got the potential to enter the export trade. Whilst Basmati rice (long grain) is well-known in the world markets and is supported by a strong trade lobby, the Bangladeshi aromatic rices (SB grain) are virtually unknown. Even then 50-55 tons aromatic rices of Bangladesh are exported to Europe, the United States and the Middle East where Bangladeshis are living in large numbers. Contrary to belief, Basmati rices are imported into Bangladesh. However, the exact data on amount of aromatic rices, exported or imported annually, are not available. The demand of aromatic rice for internal consumption and also for export is on the increase. The export of aromatic rices is not expected to hamper the over all food-grain production for domestic consumption because the aromatic varieties are grown on lands where the existing modem varieties are un-adaptable (Baqui et al. 1997).

CONCLUSION

Aromatic rice receives premium price and is profitable for the growers as well as the traders. To boost up aromatic rice production, specific land areas are to be identified and quality seeds of the selected varieties are to be made available to the farmers. Also, package of practices related to crop production and post-harvest technologies specific to aromatic rices will be needed to minimize cost of cultivation and to increase the profit margin.

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AROMATIC RICES OF VIETNAM

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INTRODUCTION

In Vietnam, aromatic rices have been surveyed, described and studied to some degree for about a century. They have been considered as *in-situ* conservation or on-farm conservation due to their specific target areas to express the aroma, like Lua Tam in the North and Nang Thom in the South. Currently, cultivation of traditional aromatic rices in Vietnam is limited only to some areas, due to their small market.

AROMATIC RICE GERMPLASM

All cultivars were collected and sent to IRRI Gene Bank. Some of the important traditional aromatic rice cultivars alongwith their main features are given in Table 1. The scentness is very specific to certain target areas. For example, Nang Thom Cho Dao only shows its aroma in Can Duoc, Long an (Mekong Delta), while Tam Xoan expresses its aroma only in some areas of Red River Delta. However, some glutinous rices like Nep Hoa Vang can maintain its slight aroma everywhere. Normally, the traditional varieties show their scentness under unfavourable conditions such as salinity (Tam den, Tam trau, Nang Cho Dao) or acidic soils.

Actually, Nang Thom Cho Dao in the South and Tam Xoan in the North are the two very common varieties in domestic markets. Lua Ngu specifically served to the Kings in Central areas is now very rarely grown. The spread of some of the important currently grown scented rice varieties in Vietnam are:

- Tam Xoan, Tam On in Tien Hai (Thai Binh), Hai Hau (Nam Dinh), Phu Xuyen (Ha Tay)
- Tam Canh in Hai Hau, Nam Dinh
- Di Huong in An Lao (Hai Phong), Lam Thao (Phu Tho)
- Nep Hoa Vang in Vinh Phuc
- Nep Rong in Hai Duong
- Nep Bac in Hung Yen
- Nang Thom Cho Dao in Can Giuoc, Can Duoc (Long An)

EXOTIC RICE GERMPLASM

Khao Dawk Mali 105 (from Thailand) and Basmati 370 (from India) were introduced to Vietnam in 1980's and were tested in different sites of

Table 1. List of aromatic traditional rice cultivars in Vietnam

Designation	Aroma	Origin	Flowering date	Grain shape
Bang Thom	1	3	186	Medium
Di Huong	9	1	145	Long
Heo Thom	1	2	145	Medium
Lua Ngu	5	2	171	Medium
Lua Tam	9	1	170	Medium
Nang Huong	5	4	107	Long slender
Nang Huong Ran	9	4	107	Long slender
Nang Thom Cho Dao	9	4	196	Long slender
Nang Thom Muon	9	4	202	Long slender
Lang Thom Som	5	4	145	Medium
Nep Bac	1	1	145	Bold
Nep Hoa Vang	1	1	132	Bold
Nep Huong	1	1	125	Bold
Nep Rong	1	1	140	Bold
Nep Thom	1	1	145	Bold
Re Thom Ha Dong	1	1	–	Medium
Tam Canh	9	1	145	Long
Tam Cao Vinh Phuc	5	1	159	Medium
Tam Den	9	1	171	Long
Tam Den Bac Ninh	5	1	159	Long
Tam Den Hai Phong	9	1	136	Long
Tam On	9	1	145	Long
Tam Thom Ngoc Khe	5	1	–	Long
Tam Thom Trang Liet	5	1	–	Medium
Tam Xoan	9	1	171	Long
Tau Huong Lo	9	4	197	Long slender
Tau Huong Muon	9	4	202	Long slender
Tau Huong Som	5	4	148	Long slender

Origin: 1 North Vietnam mostly in Red River Delta, 2 Coastal areas of Central Vietnam, 3 South-east Vietnam, 4 Mekong Delta.
Flowering date: 120-140 days (flowering in September or October), 141-180 days (flowering in November), 181-205 days (flowering in December). Some have no data, as they existed only in the past.
Aroma: 1 slightly aromatic, 5 aromatic, 9 strongly aromatic.
"Nep" means glutinous rice; "Thom" means scentness.

Mekong Delta. Unfortunately, Basmati could not maintain its scentness and produced very low yield. However, the variety was used as a parent in CLRRI's breeding program. Two of these crosses, IR68/Basmati 370 and OM576/Basmati 370, produced some promising lines with high yield and good grain quality but had no aroma. Further, the progenies have often not been uniform. They continued segregating even after 10-12 generations.

Khao Dawk Mali 105 was tested and introduced in large areas of the Mekong Delta. It reached the maximum cultivated areas of 5,000 ha in 1992, then the area reduced approximately to 2,000-3,000 ha. Mostly, it is grown in State Farm 30-4 (Soc Trang) on more than 1,000 ha every year. It still maintains the aroma when grown in coastal areas under salinity intrusion in dry season, but it shows no aroma in the alluvial soil.

The price of aromatic rices in the South Vietnam's market is 2.0-2.5 times higher as compared to normal rices. But they are usually mixed with other varieties. The purity is difficult to control.

BREEDING/IMPROVEMENT

At CLRRI, hundreds of crosses were made to improve the aroma content of new varieties to meet the demands of some markets. We have failed so far to release new lines with aromatic trait. From the mutation induced progenies from Khao Dawk Mali 105, we have released some promising lines, having dwarf plant height, and high yields, but without aroma and photoperiod sensitivity. One good grain quality line was released in 1992, but without scentness. It was a selection from the cross Om43-26 [Nep Thom (aromatic glutinous)] /IR19794-8-3-1

AROMATIC RICES OF IRAN

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INTRODUCTION

Rice is the staple food in Iran, with the quality of cooked rice outweighing all other considerations for Iranian consumers. The total area under rice is more than 600,000 ha and it is distributed in 15 provinces, more than 80 percent being concentrated in two Northern Provinces, Mazandaran and Gilan. It is estimated that Mazandaran occupies 230,000 ha (including areas in Gorgan) and Gilan 200,000 ha. The monthly temperature and rainfall of Gilan, which are similar to those of Mazandaran during the rice growing season, vary from 19° to 25°C and 25 to 125 mm, respectively. From 1.90 million tonnes in late 1980s, rice production in Iran has increased to 2.36 million tonnes in 1991, 2.30 million tonnes in 1995 and 2.40 million tonnes in 1998; with the average yield of 4,170 kg/ha (rough rice). In Iran, rice is grown under irrigated conditions in normal soils (pH 7.0-7.5), and yields are in the range of 2.5 to 4.0 tonnes/ha for local and 5.0 to 8.0 tonnes/ha for improved varieties. Normally one crop of rice is taken from April/May to August/September with 100 to 130-day varieties, with more appropriate duration being 110 to 125 days.

Considering Iran's population of over 60 million, and 38 kg per capita requirement, the local production is not sufficient enough to cover total demand of rice. About 0.5 million tons of rice is imported every year (Anonymous, 1998). High quality rices (Sadri group) have shown maximum consumption (43.3%) followed by imported long grain type (40.2%), and lowest of high yielding improved varieties (11%). The increased consumption of imported long grain types is mainly due to their low price. The distribution of low-priced imported rices have resulted in less dissemination of high yielding improved varieties even with good cooking and eating characteristics. Although, the prices fluctuate much, but due to increasing demand, the prices of the high quality aromatic rices of Sadri group have increased 2-3 times since early 1990's.

The research priorities in Iran are : breeding for high yielding, quality rices and stabilizing yields through the incorporation of genes for resistance to blast, which is the major disease. Bakanae disease, sheath blight and sheath rot are of minor importance. Research on stem borer is focused on biological control as well as chemical and agronomical management and, recently, the utilization of transgenics. The Rice Research Institute of Iran (RRII) located at Rasht in Gilan Province, together with its affiliate at Amol in Mazandaran is making a concerted effort to increase productivity so as to attain self sufficiency. There is also scope for increasing the area under rice in the Southern provinces.

VARIETAL STATUS

Despite the low yields of local varieties (averaging 2 to 4 tones/ha), around 70 percent of the total rice area in Iran is still devoted to these varieties because of their excellent quality traits, which are similar to Basmati types. Tarom, Sadri, Hassan Saraie, Domsiah and Hassani are some of the most important local varieties.

The primary classification of Iranian rices are based on physical grain shape and market value. They are broadly classified into three categories by grain shape and size (Khodabandeh, 1992).

i) **Sadri group:** very long slender grain; >7 mm kernel length; superior cooking and eating qualities; aromatic; high grain elongation; susceptibility to blast and stem borers, average yield of 2.5-40 tones/ ha. These rices are among the most expensive ones available in the market.

ii) **Champa group:** medium grain, smaller kernel and lower market value than the Sadri category, but more tolerant to environmental stresses, diseases and insects; higher yield but lower price than Sadri group.

iii) **Gerdeh group:** short and round grain; much lower market value but more resistant and higher yielding than the first two categories.

The Iranian rices are also categorized based on the intensity of aroma as: very strong, strong, moderate, slight aroma and non-aromatic. The analysis of Iranian scented rice germplasm suggests that 1% of the local cultivars are very strongly scented, 65.6% strongly scented, 22.1% moderately scented, 10.1% slightly scented and 1.2% were non aromatic type (Farrokhzad and Nematzadeh, 1998).

CHARACTERIZATION OF LOCAL RICE GERMPLASM

As mentioned earlier, rice is the staple food of Iranian and the main income source of the farmers living in the Northern part (Gilan and Mazandaran). Grain type, shape and its physicochemical characteristics, specially aroma, are important for Iranian consumers. Local rice cultivars such as Salari, Mirza Anbar-boo, Domsiah, Mosa Tarom, Mehr are highly aromatic and high quality rice varieties.

Almost all Iran local rice cultivars contain intermediate amylose content and gelatinization temperature, low gel consistency with strong to very strong aroma (Nematzadeh et al., 1995). Quality laboratories were established at Rasht and Amol in 1991. Since then these laboratories are cooperating with rice breeders nation-wide. The local cultivars were analyzed to determine their physicochemical characteristics (Tables 1-4).

Table 1. Characterization of rice germplasm based on grain length.

Scale	Size category	Length in mm	Number	Percentage
1	Extra long	More than 7.50	27	10.67
3	Long	6.61 to 7.50	78	30.83
5	Medium	5.51 to 6.60	132	52.17
7	Short	5.5 or less	18	6.32

Table 2. Grain type and length/breadth (L/B) ratio of the local varieties

Scale	Size category	L/B ratio	Number	Percentage
1	Slender	Over 3.0	130	51.38
3	Medium	2.1 to 3.0	114	45.05
5	Bole	1.1 to 2.0	19	3.55
9	Round	1.0 or less	-	-

Table 3. Amylose content, gel consistency and aroma distribution among local rice varieties

	AM*				GC**			Aroma***					
	L	LI	I	H	H	I	S	N	SL	M	ST	VST
Number		107	105	21			235	65	15	38	132	2
Percentage		42.20	49.48	8.3 0			100	65.6	5.9	15.0	52.1	0.7

*L = Low (10-15% amylose)
LI = Low intermediate (15-20%)
I = Intermediate (21-25%)
H = High (>25%)

**H = hard (20-40mm) DC
I = Intermediate (41-60 mm)
S = Soft (>61 mm)

*** N = No aroma
SL = slightly
M = Moderate
ST = Strong
VST = very strong

Table 4. Gelatinization temperature and grain elongation distribution of Iranian germplasm

	GT ****				Grain elongation *****			
	H	HI	I	L	E	G	M	N
Number	3	36	169	47	152	1.1	–	–
Percentage	1.18	14.2	66.7	17.7	60.07	39.92	–	–

****H = High (2-3GT)
HI = High/Intermediate
I = Intermediate (4-5)
L = Low (6-7)

*****E = Excellent (>2 times)
G = Good (1.5 up to 2)
M = Medium (1.1-1.5 times)
N = No elongation

RESEARCH EFFORTS ON IMPROVING AROMATIC CULTIVARS

Since 1960s, research has been carried out on all aspects of rice. However, until the 1990s, varietal improvement programs have mainly concentrated on the improvement of local varieties through mass selection, mutation and hybridization breeding. For purpose of the coordination and acceleration of these activities, the Rice Research Institute of Iran (RRII) was established in 1993. The main focus of RRII was the promotion of research for the development of high-yielding rice varieties that are resistant to diseases (particularly blast) and pests and have high quality characteristics, besides emphasis on modern techniques for increasing rice production, farm mechanization, tillage systems and post-harvest technology. The efforts towards improving aromatic rices are discussed below.

Pure Line Selection

The Iranian local rices are quite diverse. The presence of a high level of polymorphism and genetic diversity was also confirmed using DNA markers such as ALP and PBR (Ghareyazie et al., 1995, 1996). The first documented breeding program in Iran dates back to 1955 (Razeghi, 1955). Four years later (1959) the first rice and eight years later (1963) the second rice research center were established at Rasht (Gilan province) and Amol (Mazandaran province), respectively (Mojtahedi, 1969). Collection of local rice germplasm and pure line selection were among the first activities to be initiated. During the period 1962-1967, several local land races were evaluated and Firoz (from Sadri group) was the first cultivar developed with 4 tons/ha grain yield, intermediate maturity, high cooking and eating quality with strong aroma (Mojtahedi, 1969). Meher, Sadri, Binam, Hassani, Tarom were the other cultivars developed through pure line selection. Most of the local rice germplasm have been collected and maintained at National Plant Gene Bank (NPGB). To date, 2400 rice accessions are being maintained at NPGB.

Mutation Breeding

Local rice cultivars contain good physicochemical characteristics, but due to weak stems, tall stature and susceptibility to lodging, blast diseases and stem borers, their productivity is low. Beginning 1985, attempts were made to reduce plant height without affecting the other physicochemical characteristics through physical mutagenesis. Some semidwarf lines were obtained after 10 years of selection. Mosa Tarom is one of the mutant lines with 97 cm plant height, resistant to lodging and 117-day maturity duration. But the grain shape, color and its yield were not up to the desirable level. The native Mosa Tarom is about 180 cm tall and is susceptible to lodging (Shafie and Majd, 1995).

Hybridization Breeding Program

Following the introduction of improved high yielding varieties from foreign countries as well as IRRI, the first hybridization breeding program was started by making crosses between high yielding improved varieties (Century, Patna and Taichung) with local cultivars (Mosatarom, Dom safid and Tarom) (Mojtahedi, 1969). Gradually, improving the yield of local rice cultivars or improving the cooking and eating characteristics of high yielding varieties became the research strategy for Rasht and Amol rice research centers. Although high quality local rice cultivars were used in all hybridization programs, yet until 1978, selection of parents and segregating generations were made through visual observation only. Genetic studies of Iranian local rice cultivars for quantitative and qualitative characteristics, heritability, general and specific combining ability were started in 1978. A few improved high yielding varieties such as Nemat and Neda with good cooking and eating qualities and aroma were developed (Nematzadeh et al., 1996, 1997).

Mapping of Gene(s) Controlling Rice Aroma

An aromatic gene was mapped in Della by Ahn et al. (1992) and in Basmati 370 by Nematzadeh (1995). The two aromatic genes were mapped on Chromosome 8. Allelism test is being carried out to clarify whether the two mapped genes are essentially the same or they are 2 different genes. Primary analysis of F_3 population of Della/Basmati 370 cross showed segregation for aroma. Meanwhile fine mapping of aroma and reconfirmation of aroma-linked markers have been undertaken and we hope to generate sequencing tag site (STS) PCR primers for improvement of aromatic high yielding varieties through marker aided selection.

Enhancement of Insect Resistance Through Genetic Engineering

The first example of the introduction of an agronomically useful trait into an Iranian aromatic rice through genetic engineering was reported by Ghareyazie et al. (1997). The useful trait in question is the resistance to yellow stem borer *Scirpophaga incertulas,* striped stem borer *Chilo suppressalis,* green rice caterpillar *Naranga aescens* and rice leaf folder *Cnaphalocrosis medinalis.* Commercially important variety Tarom Molaii was transformed using a *CryIA(b)* gene. Four independent transformation events were detected among the transgenic plants derived from this variety. In addition to the fully characterized transgenic plants (that are reported), several hygromycin resistant calli as well as several resistant plants transformed by *CryIA(b)* gene under the control of different promoters such as pith specific promoter, and *CH1* gene from barley were also produced.

A truncated *CryIA(b)* gene was introduced into the aromatic variety Tarom Molaii. The production of toxin in the line B827 was significantly high (0.1% total soluble protein). Insect feeding studies performed to assay the resistance of line B827 against SSB, confirmed the presence of a high level of resistance in this line. Mortality rate of 100% was obtained for the insect larvae fed with stem cut of the line B827, after 4 days. One hundred percent mortality among the larvae fed on the 27 Bt-positive, T1 progeny plants of the line 8827 further confirmed the enhanced resistance in this line. This could be an invaluable source of resistance against SSB for which there is no known resistant germplasm. The *CryIA(b)*-positive T1 and T2 plants derived from B827 showed enhanced resistance to SSB larvae at booting stage and to YSB larvae at the vegetative and booting stages. For the bioassays of T2 plants, the whole plants or stem parts were infested simultaneously but subsets were dissected on different days. This process enabled us to compare the control with *CryIA(b)* plants, the time course of insect development, mortality, and dispersal. Within assays, mortality increased over time of exposure to the plants. Differences in larval mortality and development between *CryIA(b)* - positive and control plants was generally apparent three or four days after infestation. The positive plants suffered less feeding damage. No deadhearts formed on T2 vegetative stage plants in the whole plant assay with YSB. Only one whitehead was formed of the eight T2 plants tested at booting stage with SSB. Confirmation of stem borer resistance under field conditions are still required.

Stability of the expression of the two agronomically important genes were confirmed by western analysis and several bioassay against 4 insect pests and the pathogen up to T7 germination.

Three of the four fully characterized transgenic lines were highly fertile and set seeds. The seeds were 100% viable. The genes were transmitted to the T1 progeny and co-segregated in the 3:1 ratio as expected for a single locus.

By simple back crossing, this gene is being introduced into many popular cultivars in IRAN and at IRRI. PCR-based analysis that was used in this study, is being used for the selection of Bt positive plants in the progeny, leading to a significant advancement of the breeding program.

FINGERPRINTING IRANIAN RICE GERMPLASM USING ALP AND PCR-BASED RFLP

The usefulness of converting mapped restriction fragment length polymorphism (RFLP) markers to polymerase chain reaction (PCR)-based markers, such as amplicon length polymorphism (ALP), and PCR- based RFLP was evaluated (Ghareyazie et al., 1995). This is the first report on classifying Iranian rice varieties at the DNA level. A set of 35 Iranian varieties along with three indica and two japonica varieties (as references) were used. A set of 15 pairs of primers were used to amplify genomic DNA isolated from the 40 varieties.

A dendrogram was built from the genetic distances matrix. A clear distinction was observed between the major rice subspecies, Indica and Japonica. Three groups were distinguished among Iranian varieties, (indicas and japonicas, and varieties that are genetically distinct from both indica and japonica types). The varieties are traditionally divided into the major groups of Sadri, Champa, and Gerdeh.

One major group included all of the Sadri-type varieties from northern Iran (Gilan and Mazandaran provinces), where rice is the major crop. This group was clustered with two japonica standards. The second group included only six varieties. It was not clustered with any of the standard varieties, indicating that these varieties probably evolved independently within the country.

The third group, the smallest one, included only three Champa varieties from Iranian germplasm and was clustered with the three indica standard varieties.

Sadri—type varieties, which are strongly scented and are well known for their cooking quality, are genetically closer to japonicas than to indicas. Despite their very typical indica morphology (long and cylindrical seed, tall stature, narrow leaves), these varieties, as well as some of the Champa type varieties, are clustered with standard japonicas. This suggests that the morphological characteristics are not representative of the genetic status of a given variety, and as revealed by Glaszmann (1987), these varieties may belong to isozyme Group V and are therefore neither pure indica nor pure japonica.

PROBLEMS AND CONSTRAINTS

Susceptibility of Local Cultivars to Blast and Stem Borer

Blast and stem borers cause significant losses to rice production. Stem borer (*Chilo suppresalis*) emerged in the Northern part of Iran during 1971, and has gradually become a serious problem. Chemical, biological and agronomical approaches are practiced to control the stem borer.

Blast (*Magnaporthe grisea*) is a serious disease of rice and almost all local cultivars are susceptible to it. Germplasm survey has shown that 25% of local varieties are highly susceptible ($\geq$ 8 and 9 score).

Lodging

All popular local high quality rice varieties are tall (> 130 cm) and have thin and fragile stem, and are very susceptible to lodging. Besides, the harvest index of local varieties is also low.

Due to early start of rains in some years and lodging, pollination and fertilization is not completed, so the rate of sterility significantly increases or at maturity due to continuous rain fall, seeds germinate in the panicle in the field it self. This not only reduces the final product (paddy) but also affects cooking and eating qualities, and finally the market value.

Water Logging

A large rice area (about 80,000 ha) in the Northern part of Iran (Gilan and Mazandaran) suffers from water-logged condition. This area is covered with water for about 80 to 90 percent of duration of the year. Generally local rice cultivars are planted in this condition. Thus, water-logged condition is really a problem for optimum rice production.

Salinity Problem

Soil and Water Department of Iran reported that about 20-30 thousand hectare of rice fields face different levels of salinity problem in Golestan (northern part) and Khozestan (southern part). Hence, the productivity of these areas is low. Research records indicate that Hassan Sarai, Hassani (local cultivars), and Sepid roud (improved variety) are tolerant to salinity compared to other varieties.

Cold During Early Crop Season

Low temperature (less than 10°C) during early crop season in northern part (Gilan and Mazandaran) of Iran is an other limiting factor. Timely sowing of the seeds and transplanting in proper time are necessary for maximizing harvest as it also provides opportunity to the plants to escape from third generation of stem borers and early season rainfall in northern part of Iran. Most farmers cover the seed nursery with plastic to avoid cold injury.

Water-shortage Problem

In spite of the location of maximum rice area in northern part of Iran with high rate of rain fall (> 1000 mm), and existence of several permanent and seasonal rivers, water deficit is a problem, particularly in some years due to less rainfall during rice crop season (May to August). It is a severe problem especially in eastern and central part of Mazandaran province. In spite of vast and suitable land, due to water deficit the expansion of rice cultivation is limited in areas such as Khozestan, Esfetan and Fars.

RESEARCH PROSPECTS FOR LOCAL QUALITY RICES

High quality local cultivars are potentially low yielding. So, there is no doubt that with the increasing demand for more rice, the area of local rice cultivars will decrease in near future. The key point is that we have to explore the quality controlling genes from local cultivars and integrate them into high yielding varieties or *vice versa,* through classical breeding approaches facilitated by biotechnology tools. The Rice Research Institute of Iran has been mandated to train the necessary man-power, equip laboratories and develop infrastructure to cope with the difficulty of employment of quality controlling genes.

Fine mapping of aroma and gelatinization temperature genes and generation of Sequence Tagged Site (STS) markers for marker aided selection (MAS), transferring the *Bacillus thuringiensis (Bt),* chitinase and other agronomically important genes into the local varieties, field testing of aromatic transgenic plants, precise genetic evaluation for heritability, combining ability, gene action and breeding of local germplasm through different genetic mating systems are among the future plans for local rice cultivars improvement program.

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Chapter 11

Crop Husbandry and Environmental Factors Affecting Aroma and Other Quality Traits

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INTRODUCTION

Rice is the staple food of a vast majority of people around the world. There are thousands of rice varieties, genotypes and land races which differ with respect to plant and grain characteristics—plant type, height, nature of leaves, grain size, texture, glutinous nature, aroma and cooking and nutritive quality.

In the United States of America, the most common and familiar rice used is the long grain rice. This type of rice, when cooked, separates easily and its kernel is 4 times longer than its breadth. The most popular rice in the Orient is the short grain type, which is sometimes also known as "sticky rice". It is easily handled with a pair of chopsticks because it is almost round. It has a higher starch content than other rices and thus makes the grains cling (stick) together when cooked. Another type of rice is the medium grain rice. Obviously, it is sized between long and short grain rice. The kernel is about 2 to 3 times longer than its breadth and when cooked, the grains are moist, tender and slightly clingy.

Another type of rice is aromatic rice sometimes known as "scented rice". Due to the special aroma, taste, and flavor, aromatic rice is highly favored. There are many known groups of aromatic varieties, such as Basmati rice from India and Pakistan, and Jasmine rice from Thailand. These groups, and varieties within a group differ greatly in the grain length, shape, weight and density, and in their cooking and eating quality. These groups are highly priced for aroma and milling, cooking and eating quality. Many people prefer these scented, long, slender rices which elongate considerably and remain moist, soft and non-sticky after cooking. These rices gained wider acceptance in Asia, Europe and the United States.

The productivity and quality of the aromatic rices depend on the environmental conditions of the area where they are grown and the crop management practices followed to grow the crop. In other types of rices, these aspects have primary influence on the productivity, but not on the quality as in them there is not much variation in quality aspects, particularly the aroma, and flavor. This paper reviews the influence of environmental and crop management aspects on the productivity and quality of aromatic rices and identifies the gaps in research on these aspects.

RICE GRAIN QUALITY

Rice grain quality is determined by its physical and physicochemical properties. Physical properties include kernel size and shape, milling recovery, degree of milling and grain appearance. Cooking and eating qualities are governed by some physicochemical properties such as amylose content (AC), gelatinization temperature (GT) and gel consistency (GC). Tang and co-workers (1989) reported highly significant and negative correlation between AC and GC and between AC and GT, but a significant positive correlation between AC and grain elongation (GE). Most of the high quality rices are flaky and soft in texture. Degree of flakiness and volume are determined by amylose content (Chikkalingaiah et al., 1997).

Rices with very low amylose content (1-2%) are waxy. Such rices are sticky, firm and do not expand in volume. Intermediate amylose rices (<30%) cook moist, tender and does not harden after cooking. Many traditional rice varieties grown in India are of this type. Rices with high amylose content ($\geq$ 30%) have high expansion volume are non-sticky but become hard on cooking and are generally less preferred. Gel consistency is another major character responsible for the texture of cooked rice. Intermediate and low amylose rices usually have soft gel consistency and are preferred. The protein content of rice grain has also been reported to influence the linear elongation of rice during cooking (Chaudhury and Ghosh, 1978).

Aromatic rice varieties differ in their degree of aroma and are broadly classified as strongly, moderately and weakly scented types. Volatile compounds of rice provide their characteristic aroma and flavor. Some of these compounds of commercial importance, have been identified. The concentration of 2-acetyl-1-pyrroline (AP) is one of the important compounds that contributes a popcorn-like aroma in several aromatic rice varieties (see Chapter 4 of this volume). This compound is chiefly responsible for the characteristic odour of aromatic rice varieties.

Kim (1999) identified several volatile compounds in aromatic rices, which included 16 hydrocarbons, 15 alcohols, 16 aldehydes and ketones, 4 acids and 10 other miscellaneous compounds. The most common hydrocarbon was paraffin, whereas the most common aromatic (alcohol) compounds included n-pentanol, 1-octen3-ol, l-menthol and estragol. The aldehydes and ketones included n-pentanal, n-heptanal, and n-nonanal. The n-butanol and n-hexanol were detected in aromatic rices only after cooking. All the volatile compounds were affected by the planting time and location, most closely related to the temperature regime. Hydrocarbon compounds were not significantly different between aromatic and non-aromatic rice, but aromatic rice had higher levels of alcohol, aldehyde and ketone, acidic and other compounds. Aromatic rice had 15 times more 2-acetyl-1-pyrroline content than non-aromatic rice, 0.14 and 0.009 ppm, respectively.

Rice grain qualities are perceived differently depending upon several factors such as end use of the grain and specialization and ethnic background of the consumer. In marketing appearance is of foremost importance. Producers and millers emphasize on milling characteristics. Food manufacturers insist on physicochemical properties. Dietitians require nutritional qualities and consumers demand a widely divergent array of cooking and eating qualities like aroma, grain length, elongation, flakiness, taste, etc.

Quality preferences are different in different countries. Aging is considered a desired phenomenon in tropical Asia but the same is not preferred in other countries such as Japan, Australia, Korea, parts of China and Italy where they consume soft and sticky Japonica rice (Yap, 1987). Strong preference exists for the long grain aromatic Basmati rice in the middle east countries while the same is sometimes considered as contaminant in the West (Shobha Rani et al., 1996). Indian consumers value aroma most, followed by elongation after cooking (Singh and Singh, 1997). Bangladesh, Nigeria and Liberia consume parboil rice, while glutinous rice is the staple food in parts of Thailand and Laos (Shobha Rani et al., 1996). Thus historical and socio-cultural factors of a particular region play an important role in defining what consumers consider as quality rice.

Rice grain qualities are highly influenced by environmental factors. Each variety performs best, with respect to quality traits, in its own native area of cultivation. A variety can be cultivated widely without any effect on its yield, however, produce from different areas will vary with respect to quality traits, particularly aroma. In India native areas of cultivation are known for most of the indigenous aromatic rices (Table 1). These areas are identified from thousands of the years of experience of farmers. Grains of a variety from its native area fetch higher price than same variety cultivated in other areas. Almost every state in India has its own varieties of aromatic rices and specific areas for the best expression of their quality traits are known. Khao Dawk Mali 105 (KDML 105), the most popular aromatic rice grown in Thailand can adapt well to a wide range of environmental condition, however, wide variation in aroma content is observed in rice grain obtained from different areas. Milled rice from North Eastern region have strong and stable aroma while samples from some areas from central plains and other regions have very weak aroma or no aroma at all. Although no experiment has been conducted to determine the reason, it is believed that the aroma in KDML 105 varies depending upon the location, soil type and soil fertility. It is not affected by seed sources (Somrith, 1997). Two aromatic varieties of Vietnam, Nang Thom Cho Dao and Tam Xaon express their aroma only in specific areas. (See chapter by Bui Chi Buu in this volume).

In a farmers' survey across all major aromatic rice growing areas of India, it was noticed that as per farmers' perception indigenous aromatic rices are gradually loosing their aroma (Singh et al., 1998). However, little systematic studies have been conducted to define factors responsible for it. Therefore, the present article gives due importance to not only scientific studies but also farmers' perception about factors influencing aroma and other quality traits (Table 2). However, caution should be exercised while accepting the farmers' views. There is need to verify them by proper experimentation.

FACTORS

Although all the aromatic rice traits are genetically governed (see Chapter 5 of this volume) and inherited, their expression under natural condition is very much dependent on environmental and soil and management practices. These situations in the literature, however, are poorly defined.

Although the aromatic and other high quality rices have been cultivated for a long time, the research attention on these rices has been given only in recent years. Also the focus has been mainly on the varietal development and productivity aspects. Information on the influence of management aspects and environmental conditions on the quality of rice are meagre. Whatever information is given in this section is based not only on experimentation but also on experience of farmers, which need confirmation by scientists.

Table 1. Native areas of cultivation of some of the indigenous aromatic rices in India

Variety/Landrace	Native areas of cultivation
Ache, Bhanta-phool, Chimbal Basmati, Panarsa local, Seond Basmati	Pockets of Himachal Pradesh (H.P.).
Adamchini, Laungchoor	Mirzapur, Sonabhadra and Varanasi districts of Uttar Pradesh (UP.)
Ambemohor	Maval tract of Pune (Maharashtra)
Amod, Abdul, Ramjain, Shyamjeera	Louria (West Champaran, Bihar)
Badashabhog, Badshapasand, Bhilahi Basmati	Bargaon (West Champaran, Bihar)
Bindli	Small pockets in Bijnor and Pauri districts of U.P.
Bisunparag	Kanpur (U.P.)
Brahmabhusi	Semra Ramgarhwa, Bamkul (West Champaran, Bihar)
Bhugui, Boga Joha, Boga Tulsi, Bogi Joha, Bokul Joha, Borjoha, Borsal, Cheniguti, Chufon, Kalajeera, Kamini Joha, Kola Joha, Krishna Joha, Kunkuni Joha, Manikimadhuri Joha, Ramphal Joha	Pockets of Assam
Chahao Amubi, Chahao Angangbi	Valleys in Manipur
Champaran Basmati	West Champaran (Bihar)
Chinisakkar	Raiganj (West Bengal)
Chinoor	Vidharbha Region (Maharashtra)
Dehraduni Basmati	Seola-Majra, Palio, Gungnani villages of district Dehradun (U.P.)
Debhog, Bhopalbhog, Kariakamod	Pockets of West Champaran and Sabor (Bihar)
Ghandheswari	Pockets of W.B.
Hansraj, Tilak	Bijnor (U.P.)
Jeerabatti	Basti, Siddharthanagar and Varanasi (U.P.)
Kalo Nunia	Foothills of Duaras (W.B.)
Kalumooch	North West Madhya Pradesh
Kamini, Katami	Bhagalpur (Bihar)
Kanakjeera	Newtan (West Champaran, Bihar)
Karmuhi	Pockets of U.P.
Katanbhog	West Coochbihar (W.B.)
Kataribhog, Sitabhog	Uttar and Dakshin Dinajpur (W.B.)
Laloo	East M.P.
Mircha	Ramnagar, Louria, Chanpatia, Narkatiaganj (West Champaran, Bihar)
Moongphali	Azamgarh, Gazipur (U.P.)
Radhuni Pagal	Birbhumi, Bankura, Burdwan (W.B.)
Sataria	Mithilanchal (Bihar)

(Contd.)

Table 1 *(Contd.)*

Variety/Land race	Native areas of cultivation
Sonachur	Mirzapur, Varanasi, and Sonabhadra (U.P.); Bojpur and Rohtas (Bihar)
Tulsibhog	Tarai zone of W.B.
Vishnubhog	pockets of M.P.
Vishnuparag	Barabanki, Bahraich (U.P.)

Table 2. Factors affecting aroma formation/retention in aromatic rices as perceived by farmers*.

Factors favouring aroma
- Cool weather during flowering and grain development
- Farm yard manure
- Fertile soil
- Direct sowing
- lighter soil and upland conditions
- Low soil moisture during grain filling
- Manual dehulling

Factors adversely affecting aroma
- Hot weather during flowering and development
- Nitrogenous fertilizers particularly urea
- Poor soil
- Transplanting
- Heavy soil
- Delayed harvesting after maturity
- Mechanical dehulling

Singh et al., 1997

Temperature

Quality traits of aromatic rices are known to be highly influenced by temperature particularly at the time of flowering, grain filling and maturity. Both in scientists and farmers' circles it is accepted that the aroma formation (and retention) in grain is enhanced at lower temperature during the grain filling stage. Basmati rices require relatively cooler temperature (25°C/21°C-day/night temperature during crop maturity) for better retention of aroma (Juliano, 1972; Mann, 1987). Meng and Zhou (1997) observed that the mean daily temperature of 18°C produced best quality rice. Head rice percentage, chalky rice percentage, alkali spreading value, grain amylose and protein contents are also markedly affected by temperature.

In general temperature correlates negatively with AC (Lee et al., 1996) and positively with GT (Resurrencion et al., 1977; Li et al., 1989; He et al., 1990). Asaoka and co-workers (1985) reported that ambient temperature during ripening influenced the fine structure of amylopectin and amylose of rice starch apart from the effect on total AC. Dela Cruz and co-workers (1989) stated that AC decreases with increase in temperature whereas gel consistency (GC) and GT did not show any interaction with temperature. In a phytotron study, Dela Cruz (1991) observed that GT of Basmati 370 was unaffected at a constant day/night temperature of 33°C/25°C. Decrease in amylose content due to increase in temperature affected grain appearance as it resulted in decrease translucency of grains. Higher alkali disintegration value and grain protein content were observed at constant day-night temperature of 22°C/22°C in Japonica rice cultivar Dongjinbyeo (Lee et al., 1996). He and co-workers (1990) studied the effect of high (32°C/27°C) and low (22°C/17°C) temperature in the early and late ripening stages on some physicochemical properties of starch in outer and inner layer portion of rice grains of a Japonica rice cultivar Koshihikari. They found that GT increased under high temperature for the inner portion starch at early ripening stage and for the outer layer portion at late ripening stage. Similarly the fatty acid composition of the lipids of the outer layer starch responded to temperature differently from that of inner portion starch.

Li and co-workers (1989) reported that environmental factors like temperature, photoperiod and relative humidity had little effect on the length (L), breadth (B) and L : B ratio of rice grains compared with that on chalkiness, GT, AC and GC. However, effects varied between cultivars and characteristics. Grain elongation is also influenced by environmental factors especially temperature at the time of ripening (Dela Cruz, 1991). Maximum grain elongation was observed at 25/21°C-day/night temperature during the ripening. This explains differences in elongation between basmati grown in Punjab, which elongated more than the one grown at Dokri (Sind) due to high temperature (Khush et al., 1979). Late planting, coinciding with the flowering and maturity in cooler days has been also reported to enhance the grain quality but reduction in grain yield in all aromatic rices tested by Singh et al. (1993, 1995), Chandra et al. (1997), Rao et al. (1996) and Thakur et al. (1996).

Soil Factors

Soil factors do affect aroma and other quality traits presumably through plant nutrition and the interaction of volatile nutrients with aroma related volatile compounds, but they are not properly defined. Several farmers of West Champaran (Bihar) and Sidharthanagar and Basti (U.P.), India claimed that it is not only aroma but also even thickness and length of grains, taste and fluffiness are influenced by the field in which an aromatic variety is cultivated. Few farmers claimed significant difference in aroma of rice produced in two adjoining fields even if the crop, in both the fields, was raised from the same seed lot (Singh et al., 1998).

In farmers' perception lighter soils and upland conditions favour the aroma formation. On the other hand, aromatic rices are mostly found to be grown in flat bunded fields on terraces and plains having clay loam soil in high rainfall areas, or where irrigation facilities are available. A well-levelled field with clayey soil and sufficient water supply is also reported suitable for the cultivation of Basmati rice (Singh et al., 1979). Basmati rice grown in alkaline and poor soil or under poor water supply conditions during grain filling time shows excessive abdominal whiteness in grains whereas these factors adversely affect cooking qualities (Azeez and Shafi, 1966). However, diminishing soil moisture at the time of grain filling is reported to favour the aroma formation (see chapter by Sarkarung et al. in this volume).

Soil texture is reported to affect grain quality (Hou et al., 1988). Two different Taiwanese cultivars, Tainung 67 and Taichung Sen 3, grown under greenhouse conditions and at four different sites with sandy, sandy-loam, clay and clay-loam soil showed that percentage head rice, white belly translucency, GC, AC, protein content and eating qualities varied significantly among locations. Quality differences in green house trial were less as compared to field indicating that factors other than soil types also influenced the quality. Besides amylose content, milling quality and alkali spreading values also showed location effect (Lu et al., 1988).

Bocchi and co-workers (1997) investigated the effect of soil characteristics on aromatic quality of rice in a field trial at Pavia, Italy. They concluded that highest grain contents of volatile compounds were correlated with loose soils having low clay content and high sand contents. Effect of genotype x soil interaction on rice grain quality of Japonica rice was also reported by Lee et al. (1997).

Plant nutrition and Fertilizer Application

Nitrogen

Application of nitrogen fertilizers adversely affects cooking and eating quality. Suwanarit and co-workers (1996) reported that aroma, softness, whiteness, stickiness and glossiness of cooked milled rice of Khao Dawk Mali 105 were adversely related to applied dosages of nitrogen. Soil low in nitrogen generally produced higher quality aromatic rice grain. Perez and co-workers (1996) observed that late nitrogen fertilizer application at the time of flowering may improve milling and nutritional quality of rice grain. Split nitrogen applications are recommended for obtaining high grain quality (Hou, 1988; Perez et al., 1996).

Increased application of nitrogen did not adversely affect alkali value, volume expansion and water uptake. Nitrogen application at higher dosage increased the amylose content of the long slender varieties like Kasturi, Pakistani Basmati and Basmati 370 by 3 to 9.9 percent (Rao et al., 1993).

The grain protein content was increased with increase in rate of nitrogen application (Ghosh et al., 1971; Umetsu et al., 1990). Water uptake by rice kernel (at 77°C) showed a definite reduction and the alkali value remained unaffected by N application (Ghosh et al., 1971).

Eating quality in Japanese rices has been reported to be lowered by an increase in protein content due to the increased nitrogen translocation in the fertile grains (Nishimura, 1993). The percentage of fertile grains was found to be negatively affected by cooler irrigation water at booting stage. The sterility induced by cool water increased the protein content and lowered the eating quality.

Youssef and co-workers (1980) reported that when nitrogen was applied @ 150 kg/ha in four equal split dressings to the rice cultivars IR 579, Giza 159 and Giza 170, it resulted in high grain yield and protein contents combined with good quality. Different quality traits like alkali value, volume expansion, and water uptake were not adversely affected. However, higher level of nitrogen decreased the head rice recovery and increased the amylose content of long slender grain varieties Kasturi, IET 8579, Pakistani Basmati and Basmati 370 (Rao et al., 1993). Chander and Pandey (1996) observed that neither herbicides nor nitrogen caused noticeable change in grain quality traits like hulling, milling, head rice recovery, grain length (L), breadth (B) and L : B ratio.

Potassium and magnesium

Potassium fertilizers favourably influence cooking and eating qualities of rice. Application of potassium fertilizer at higher dosages beyond which produced maximum yields of aromatic rice cultivar Khao Dawk Mali 105 increased the aroma and made the grain whiter and more glossy but less soft (Suwanarit et al., 1997). Potassium application also increased yields of scented rices through increased grain weight, reduced sterility and had less lodging (Mehla et al., 1995). Potassium fertilizer, when applied at different stages of organogenesis, increased the starch and carbohy drate content in grain irrespective of stage of application while its appli cation at 7^{th} and 9^{th} stage increased the amylose content (Vil′gel′M, 1986). Soils favouring better quality grains in Japonica rice cultivar Dongjinbyeo were having higher content of Mg and Mg/K (Lee et al., 1997). Oh and co-workers (1991) observed that K deficiency increased chalkiness. Chalky kernels are worse than those of perfect kernels with lower cooking and eating qualities.

Sulphur

Moderate application of sulphur to a deficient soil increased aroma, softness, whiteness, stickiness and glossiness of boiled rice of aromatic cultivar Khao Dawk Mali 105. However, the higher rates than the optimum required adversely influenced these quality characteristics (Suwanarit et al., 1997).

Phosphorus and zinc

Phosphorus and zinc application favourably influenced the rice grain quality parameters. Aroma, softness, whiteness and glossiness in Khao Dawk Mali 105 rice were related to P content in paddy grain and not to the P content in the plant (Suwanarit et al., 1997c). These qualities were best expressed at the rate of P application, which resulted in maximum yield. Application of P at higher rate produced lower quality grain. Phosphorus increased the grain protein content. Amylose content was enhanced by zinc application (Chen and Fan, 1997). Zinc application particularly at low level of N:P:K (30:15:10) increased the grain length of Taraori Basmati (P. Srivastava and P.C. Srivastava, personal communication).

Organic and biofertilizers

Organic fertilizers have no effect on rice cooking qualities (Jeong et al., 1996). Application of nitrogen along with mixed culture of *Azotobactor* and blue green algae increased the grain protein content (Latchumanan et al., 1979).

Cultivation Practices

Cultivation practices like land preparation method, cultivation type, time of transplanting and harvesting have great influence on quality and productivity of aromatic rices (Canellas et al., 1997). Ali and co-workers (1992) studied the different land preparation methods on rice grain quality. They observed that complete puddling (under 30-day wet condition) before transplanting gave highest 1000-grain weight, total and head rice recovery, cooked grain length, protein content and gel consistency. Whereas dry land preparation followed by flooding and transplanting gave the lowest value. Bursting of cooked rice was lowest from the field where complete puddling was done.

Thousand-grain weight, grain length, total milling recovery, head rice recovery and protein content decreased with increased plant densities in two Basmati rices (Karim et al., 1992). The effect of plant densities on kernel dimension, amylose content and grain length was inconsistent.

In farmers' perception there is better aroma in direct sown rice crop than transplanted particularly in Hansraj (Singh et al., 1998). Cheong and co-workers (1995) reported that machine transplanting of rice seedlings, broadcasting of seedlings on flooded soil and direct sowing on to puddled and flooded soil produced the best quality grain and higher yields.

Generally, 30-day old seedlings of Basmati cultivars are transplanted during first half of July. Early and late transplanting significantly influence the milling recovery and cooking qualities of rice. Transplanting of Basmati 370 and Basmati 385 on 1st and 16th July, respectively, produced the best quality rice. Aroma in both the cultivars was lower when transplanted earlier. Amylose content and alkali spreading value increased with the delay in transplanting (Ali et al., 1991). Younger seedlings (30-day old) yielded better when transplanted on July 15, but the older seedlings had beneficial effect under late transplanting and closer spacing (Dhiman et al., 1995). There was a significant yield reduction when scented varieties were transplanted after 15 July (Dhiman et al., 1997; Singh et al., 1996; and 1997; Thakur et al., 1996; Chandra et al., 1997; Singh et al., 1993 and 1995). Late transplanting of Basmati 370, Pusa Basmati-1, Haryana Basmati-1 and Kasturi in August improved hulling, milling and head rice recovery (Rao et al., 1996).

In a farmers' Survey of Kalanamak rice belt of Sidharthanagar, UP, India, it was found that a noble practice of rice transplanting, which is locally known as *Kalam,* is reported to enhance the aroma, taste and fluffiness of Kala Namak. In this practice rice is transplanted twice; first in a bunch and after 15 days it is uprooted and transplanted at normal spacing. Kala Namak produced by *Kalam* fetches approximately Rs. 100.00 per q higher price than rice produced by normal transplanting method. Plant height in *Kalam* is shorter and due to this there is less lodging problem. Double transplanting of rice is also common in other parts of the country like Bihar, Chhatishgarh region of Madhya Pradesh and practice is limited to the land races and traditional varieties (personal experience).

Time of harvest is another factor, which may influence aroma and other quality traits in rice. Delay in harvesting after maturity may reduce aroma and also influence eating qualities. Chaudhary and Iqbal (1986) reported maximum yield and head rice recovery when the rice crop was harvested at 35 days after 50% flowering when the moisture content ranged from 20-22 percent. Both yield and the recovery reduced with the delay in harvesting beyond this time. Rahim and co-workers (1995) observed that harvesting at 25 and 30 days after flowering were optimum for grain quality and yield for the cultivars BR11 and Nizersail, respectively. The effect of delayed harvesting on the quality of rice is mainly through the degradation or changes in the grain components inflicted by the temperature, moisture and insect-pest and microbial organisms.

Varietal Purity

In most of the native aromatic rice growing areas in India farmers are using their own seeds since ages. There is no seed production or seed improvement programme for these rices. This has resulted in impurity of seeds leading to decline in aroma (Singh and Singh, 1997). Although some of the farmers are aware of the importance of the quality seeds and they do select seed from their field for planting in the next season, almost all such farmers give major emphasis to yield rather than quality in selection (Singh and Singh, 1997).

Storage and Processing

For rices, particularly Basmati types, proverb 'old is good' suits best. In almost all countries rice is stored and transported as unhulled rice. Rice storage for few months favorably influences its quality. Stored rice cooks relatively dry, hard, fluffy with thin gruel and good elongation as compared to freshly harvested rice that becomes very soft, moist and sticky after cooking and results in thick gruel and less elongation. Some consumers, mainly in Indian sub-continent and middle east therefore, prefer old rice for consumption. Rice storage for few months increases its water absorption ratio by an average of 15 per cent during cooking in excess water (Perdon et al., 1997). During storage grain hardness and GT increase which increase swelling and elongation of rice grain during cooking (Ahuja et al., 1995).

Studies conducted on rice cultivar Cypress, Daniels and co-workers (1997) observed that temporary wet storage prior to drying had significant effect on the cooking properties and sensory characters of the cooked rice. Some physicochemical properties of the rice grain such as grain translucency, alkali spreading value, gel consistency and eating qualities decreased with prolonged storage particularly under bulk storage without air circulation (Song and Hong, 1988). Total amylose content hardly changed during storage whereas, the amylase activity decreased during storage at higher temperature (30 to 45°C) (Takami et al., 1988; Rehman, 1995). Contrary to this an increase in amylose content during storage was observed by Kim and co-workers (1980). Song (1978) observed that grain discoloration decreased during storage when stored in sacks at low temperature.

Although not properly defined method of dehulling might influence the aroma content of the processed grains. Farmers at Tapovan (UP) claim that manual dehulling results in more aromatic and better quality grains as compared to mechanical dehulling (Singh et al., 1998). The milling process also affects cooking behavior of rice grains. Rice, which is milled to remove the bran but leaves more of the aleurone and sub-aleurone layers in place cooks drier and fluffier than the rice which has been milled to a much higher degree (Sarreal et al., 1997). No single milling pressure optimizes all desirable grain quality characteristics (Karim et al., 1993).

CONCLUSION

It is now well realized that in addition to genetic composition, cultivation practices and environmental and soil factors do influence expression of aroma and quality traits in aromatic rices. Same variety cultivated at different places may not produce grain of similar quality. Quality traits of these varieties are expressed best in their native areas of cultivation. So far while improving the aromatic rices or defining the cultural conditions for their cultivation not much emphasis has been placed on any other quality traits or factors affecting them except yield. Farmers have their own perceptions about the factors affecting aroma and other quality traits. However, there is need to scientifically verify and define these factors so that genetic potential of different cultivars with respect to quality traits could be exploited beyond their native areas of cultivation.

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Chapter 12

Plant Protection in Aromatic Rices

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INTRODUCTION

Most diseases and pests attacking normal rice cultivars also attack aromatic rices. The major difference is with respect to those diseases and pests which are favoured by late maturity, dense crop canopy and/or low nitrogen. These diseases and pests are likely to be more serious on long duration and tall aromatic rices as compared to short and medium duration and dwarf and semi-dwarf non-aromatic rices.

DISEASES

Since aromatic rices are grown under irrigated and rainfed ecosystems which include lowland, upland and high altitude ecologies, most of the diseases are reported from one or other areas. Most destructive diseases on aromatic rices are neck blast, bacterial blight, sheath blight and brown spot. These and some other important diseases are discussed.

Brown Spot

Helminthosporiosis or brown spot disease of rice, caused *by Cochliobolus miyabeanus* (Ito and Kuribayashi) Drechsler (anamorph *Bipolaris oryzae*

[Breda de Haan] Shoemaker), is one of the most important diseases of aromatic rices. The disease appears as small oval or circular, dark brown spots on leaves and glumes (Figure 1C). The spots are relatively evenly distributed on the leaf surface. This disease is primarily seedborne, however, secondary spread is rapid under favorable conditions. This disease is aggrevated by poor fertility conditions like low nitrogen, phosphorus and potassium (Chakrabarti, 1992). Due to lodging problem in tall aromatic rice varieties, low dosage of nitrogen is applied. This results in high incidence of brown spot. Although proper application of nitrogen, particularly in slow release form, suppresses disease development, it may not be practical due to lodging problem. The disease can be managed by seed treatment followed by foliar spray of fungicides like mancozeb, carboxin, bitertanol, etc. (Table 1). Seed treatment or spraying of ferric chloride, nickel nitrate,

Table 1. Chemical control of important rice diseases

Disease	Chemical	Dosage (a.i.)	Application
Blast	Carbendazim/ Thiophanate methyl or	0.05 %	Spray in nursery, at boot leaf stage and at panicle emergence
	Ediphenphos	500 ml/ha	
	Tricyclazole or	0.2% + 0.06%	Seed treatment + spray at panicle emergence
	Pyroquilon	0.1% + 0.1%	Seed treatment + spray at panicle emergence
Sheath blight	Carbendazim/ Thiophanate-methyl or	125 g/ha	First spray at tillering or when disease appears; second spray after 15 days
	Pencycuron/ Propiconazole or	110 g/ha	
	Iprodione	560 g/ha	
Brown spot	Mancozeb or	0.2%	First spray at the time of disease appearance and second after 10 days
	Carboxin/ Bitertanol or	0.1%	First spray at the time of disease ap pearance and second after 14 days
	Iprodione	560 g/ha	
Foot Rot	Carbendazim/ Benomyl	1g/kg	Seed treatment
Sheath rot	Carbendazim or Mancozeb/foltaf	0.05 % 0.20 %	First spray at the time of disease appearance and second after 15 days if needed.

sodium molybdate, sodium selenite and thioglycolic acid provide appreciable protection against the disease (Sinha and Hait, 1982). Application of Silicon also reduces disease intensity (Datnoff et al., 1989). Biocontrol agents like *Bacillus subtilis,* applied thorough seed, soil or foliar spray have been found to be effective (Nanda and Gangopadhyay, 1983). A number of aromatic rice land races/germplasms have been identified as resistant under natural condition (U. S. Singh, R. K. Singh and G. S. Khush, personal observation). However, among aromatic rice varieties only Pusa Basmati-1 is reported to be resistant (Table 2).

Sheath Blight Complex

In rice sheath blight complex three species of *Rhizoctonia: R. solani* (teleomorph-*Thanetephorus cucumeris*), *R. oryzae* (teleomorph- *Waitea circinata*) and *R. oryzae-sativae* (teleomorph-*Ceratobasidium oryzae-sativae*), are involved. *Rhizoctonia solani,* inciting sheath blight, is the most widely distributed disease affecting rice. First symptoms are greenish-gray spots that develop on leaf sheath near the waterline. The elliptical or oval spots enlarge to 2 to 3 cm and coalesce with each other (Figure 1A). The disease may spread to upper sheath and occasionally to leaves. Losses may vary depending upon the time of appearance of the disease. *Rhizoctonia solani* has got very wide host range. However, based primarily on the anastomosis behavior, it has been subdivided into 13 intra-specific groups [anastomosis groups (AGs) and sub-groups]. However, all the isolates of *R. solani* obtained from rice belong to AG-1 IA and only isolates from AG-1 IA and AG-1 IB are capable of producing typical symptoms of rice sheath blight. Isolates from other groups were either non-pathogenic or induced hypersensitive/resistant reaction on rice (Singh et al., 1999). However, rice isolates of *R. solani* exhibit a wide variation in their morphological and virulence characteristics even if they are obtained from same field (Figure 2). Disease is favored by high nitrogen and Potassium, high plant density and dense canopy. High yielding dwarf, broad leaf, N and P responsive varieties like Pusa Basmati-1 are particularly susceptible to sheath blight. Nitrogen increases sheath blight essentially via indirect effects: increased tissue contacts in the canopy and higher leaf wetness (Savary et al., 1995). In addition to dosage, time of application of nitrogen also affects sheath blight development. High potassium disfavours disease (Dasgupta, 1992). There is lack of resistance against sheath blight. However, some of varieties/lines of aromatic rices have shown reasonably good degree of tolerance (U. S. Singh, R. K. Singh and G. S. Khush, personal observation). Crop rotation, if exploited properly, could be one of the effective methods in keeping the soil population of rice isolates in check. Balanced application of NPK, spray of borax, and sulphates of Zn, Cu and Fe reduce sheath blight incidence. A number of fungicides like propiconazole, pencyuron, diclonazine, flutolanil, mancozeb, iprodione, carbendazim etc. have been found to be effective against the disease (for commonly used fungicides, see Table 1). A number of biocontrol agents like *Pseudomonas fluorescens, Bacillus* sp (Gnanamanickam and Mew, 1990),

Fig. 1. Symptoms of different diseases on aromatic rice cultivars.
A. Sheath blight on cv. Pusa Basmati 1.
B. Sheath rot on cv. Pusa Basmati 1.
C. Brown spot on cv. Kalanamak.
D. False smult on Hansraj.

Table 2. Aromatic rice varieties reported to be tolerant/moderately resistant/resistant to diseases and/or insect pests

Disease/pest	Resistant/tolerant aromatic rice varieties	Reference
Bacterial blight	Pakistani Basmati, HBC 19, Ghanal, IET 9691, Hyangmibyeo, Basmati Sufaid 100, Basmati 5888, Basmati 410, Basmati 6129, Domsiah, Gopalbhog, Basmati Surkf 112, Basmati Aman, Guangling Xiangnuo, Bishnubhog, Kalanamak, Rambhog, Badshahbhog, Hansraj, Basmati 370, Kamal Local	Chand et al., 1986; Kaur et al., 1997 Choi et al., 1995; Rani et al., 1996; Pan et al., 1993; Mahto and Singh, 1988: Sahu and Khush, 1988; Rao et al., 1989; Kumar et al., 1996
Bacterial leaf Streak	Pakistani Basmati, IET 8579, T 412	Reddy et al., 1989
Blast	Amrihari H22, Ram tulsi, Hyangmibyeo, IET 12609, IET 13548, IET 12021, Basmati 6311, Basmati 375, Karnal local. Guangling Xiangnuo, HKR 228, HBC 5, Basmati 405, Domsiah, Badshahbhog, Gopalbhog, Basmati 242, Minpal, Type-3, Sita-Bo-tabo, Sonsal, Multani, Paesungulla, Pae woltu, HBC 178, HBC 145, Basmati 180, Guinata, Azucena, Basmati 5853, Basmati 5854, Basmati 153, GR101, Dehont, Basmati 6129	Choi et al., 1995; Singh, 1997; Rani et al., 1996; Pan et al., 1993; Panwar et al., 1991; Ahuja et al. 1994, Ou, 1973, Desai et al., 1987, Bollich et al., 1993; Kumar et al., 1996
Brown spot	Pusa Basmati-1	Singh, V.P. Personnel communication
Sheath blight	Basmati 410, Basmati Aman, Badshahbhog	Rani et al., 1996; Panwar et al., 1991
Foot rot	Guangling Xiangnuo	Pan et al., 1993
Sheath Rot	Basmati 370, Pb Bas1	Grewal and Kang, 1988
Stem rot	Pakistani Basmati, HBC 19, HKR 228, Basmati 370, Bara 62	Chand et al., 1986; Panwar et al., 1991; Seetharaman et al., 1972; Raina and Saini, 1991; Srivastava and Ahuja, 1973
Tungro	Basmati 370, Ambemohar 59, Krishnabhog	Bhaktavatsalam et al., 1988; IRRI, 1992
Stem borer	HKR 243, Basmati 370 (Sel), Rodjolele-2, Rodjolele-4, Rodjolele-5, Gamanasanna, Basmati Aman, Dubraj, Chok-jye-be-chal, ARC 7057, Abor Bora, Boka Chakara, Haru Chokura	Kushwaha et al., 1992; Rani et al., 1992; Manjunath, 1977
BPH	IET 13153, Bengawan Solo	Singh, 1997; Partoatmodjo et al., 1994
WBPH	Basmati Kota, HBC 19, IET 13548, Dehradun Basmati, HBC 5, Basmati 405, Basmati 6129 Gopalbhog, Basmati Surkf 112, Basmati 370, Taraori Basmati, HKR 228, Basmati 5854, Basmati 6129, Hansraj 54, Kamal Local	Rani et al., 1992; Rani et al., 1996; Singh, 1997, Panwar et al., 1991; Heinrichs et al., 1985; Kumar et al., 1996
Gall midge	IET 13153, IET 12609, IET 12603, Badshahbhog	Rani et al., 1996; Singh, 1997
Rice hispa	Type-3	Haque et al., 1987

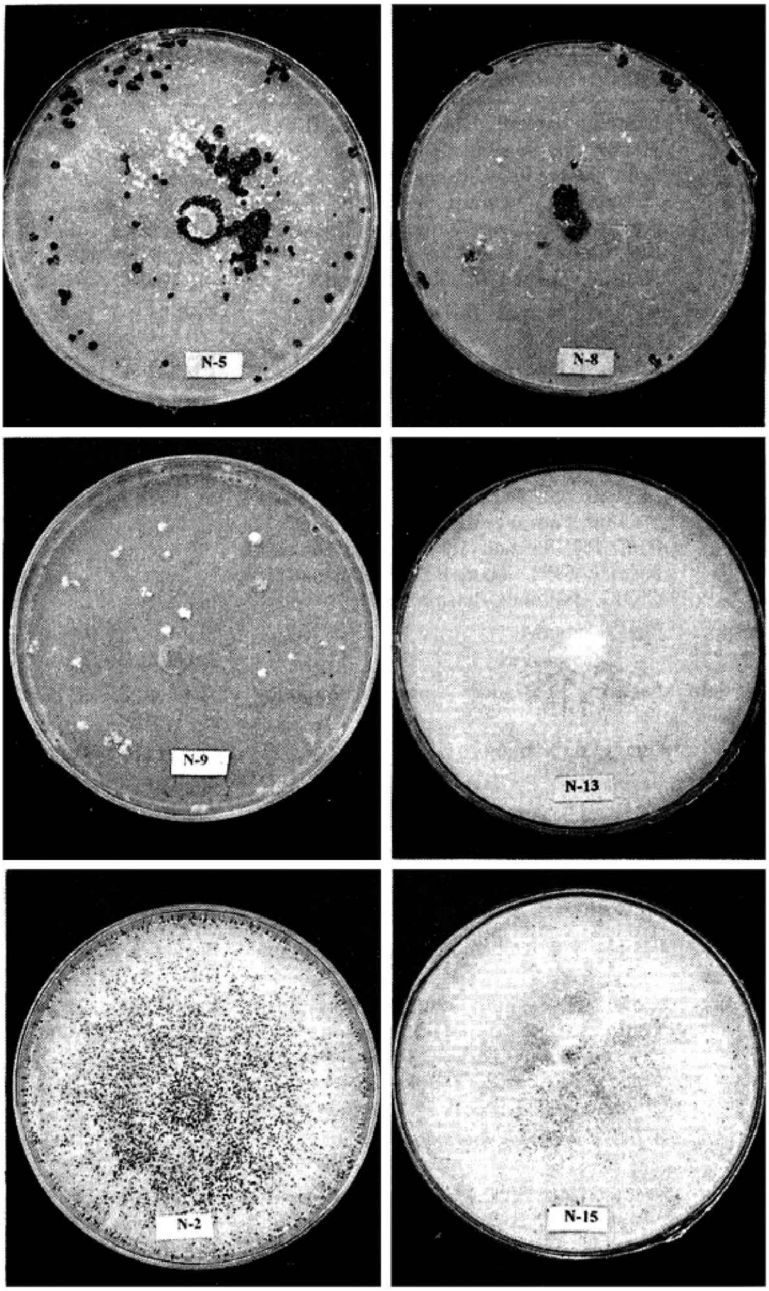

Fig. 2. Cultural and morphological variation in different isolates of *Rhizoctonia solani* collected from infected aromatic rice plants from same field.

Gliocladium virens or *Trichoderma harzianum* alone or in combination with organic manure (*Gliricidia maculata* leaves) (Baby and Manibhusanrao, 1993) have been tried and found to be effective in reducing the sheath blight infection under field conditions (Dasgupta, 1992). Spray of seed extract of the *Trachispermum ammi* and leaf extract of *Ocimum* sp. reduced the sheath blight infection by 70% (Ansari, 1995). Preliminary studies have shown that rice–wheatrotation, which is the most popular in northern India does not favour sheath blight development (Singh, U.S. and Singh, Amita, Unpublished) in spite of the fact that wheat is susceptible to rice isolates of *R. solani*. There is an urgent need for the integration of various methods for the management of this disease.

Blast

Rice blast caused by *Magnaporthe grisea* is a serious problem in aromatic rices even under low land irrigated system because of the long duration of crop. It is most serious problem in aromatic rices in Iran, Pakistan and India. In 1964 neck blast epidemic was experienced in Basmati rices in Punjab province of Pakistan (Khan, 1996). During 1989, blast epidemic in Basmati in Haryana (India) resulted in loss of Rs. 110 millions (Ahuja et al., 1995). This disease has two phases: leaf blast and panicle blast. Leaf blast is characterized by elliptical or spindle shaped lesions with whitish-gray or greenish centre and brown or purple margins with yellow halo. Panicle blast, which is more damaging, appears as a dark necrotic lesion covering partially or completely around the panicle base or secondary branches (Figure 3). It may lead to breaking of panicles resulting in few or no grain setting. At the time of grain filling in aromatic rices temperature is comparatively low, which favours panicle blast development. Disease is favored by high nitrogen. Soils with poor silica availability are blast conducive (Singh et al., 1995). Good sources of resistance are available and under modem cultivation in different parts of the world population of the pathogen is reported to be simple clonal (Levi et al., 1997). With clonal population of the pathogen, it was proposed that by proper gene deployment this disease can be managed quite effectively. However, recent studies by J. Kumar in association with Robert Zeigler of IRRI on population structure of *M. grisea* in Himalayan hills have shown high diversity in rice strains. Some evidence suggest recombination of rice and non-rice infecting strains in Indian Himalayas as a cause for this high diversity (Kumar et al., 1999). A number of effective fungicides are available against rice blast (see Table 1). These fungicides are being used widely by the farmers in the cultivation of aromatic rice. New generation chemicals like tricyclazoles, carpropamid, etc., are environmentally safe and provide quite long protection. Rather than being directly fungitoxic these

Fig. 3. Symptoms of neck blast on Pusa Basmati-1 (Top left); combined infection of sheath rot and white head on Tilakchandan (Top right); view of Taraori Basmati field showing heavy incidence of white head (Middle); panicle of cultivar Bindli showing grain discolouration (Bottom).

chemicals act as antipenetrants by blocking melanin biosynthesis in appressoria (Rohilla et al., 1999). Some of the biocontrol agents like *Pseudomonas fluorescens* (Vidhyasekaran et al., 1997), *Bacillus* sp are reported to be effective against the disease (Bhatt and Singh 1992). Application of silica fertilizers reduces blast incidence (Datnoff et al., 1989). Host resistance is the most effective method for the management of rice blast (see Table 2). However, most of the popular varieties of aromatic rices are susceptible to neck blast. Nevertheless, a wide variation in reaction towards neck blast was noticed in different Indian germplasm/land races of aromatic rices (U. S. Singh, R. K. Singh and G. S. Khush, personal observation).

Sheath Rot

Sheath rot caused by *Sarocladium oryzae* (Sawada) W. Gams and Hawksw, considered a minor disease till a few years ago, has attained status of a major disease. It is primarily because of the introduction of the some of the high yielding varieties. It might increase further with the popularization of the hybrid varieties. Typical symptoms are oblong to irregular brown to gray lesions on boot leaf sheath near panicle. Lesions may coalesce covering the entire sheath. Disease is highly damaging as it infects boot leaf sheath (Figures 1B & 3) and under severe condition it may totally inhibit panicle emergence. Burning of the infected stables, planting of the tolerant varieties, spray of fungicide like carbendazim (Table 1) at tillering and boot leaf stage (Swain et al., 1997) and biocontrol agent are some of the methods recommended for the disease management. A wide variation was observed in natural incidence of sheath rot in different germplasms/land races of Indian aromatic rices (U. S. Singh, R. K. Singh and G. S. Khush, personal observation). Early planted rice crops could escape disease incidence (Swain et al., 1997).

False Smut

Like sheath rot false smut caused by *Ustilaginoidea virens* is another disease which has become important only during the last few years with the introduction of some of the high yielding varieties. Infected grains are transformed into yellow-greenish or greenish-black velvety looking spore balls (Figure 1D). Incidence of the disease is likely to increase with the popularization of hybrid varieties. Disease is favored by high nitrogen. Sanitation practices like manual removal of sclerotia before harvesting, proper dose of nitrogen, and spray of fungicides like foltaf, mancozeb etc. (Anonymous, 1989) are some of the recommended management practices.

Foot Rot

Bakanae or foot rot, is a seed borne disease, *Gibberella fugikuroi* (Anamorph: *Fusarium moniliforme).* Infected seedlings/plants are elongated nearly twice the height of the normal plants with thin yellow green leaves. Elongated plants die. Infected plants that survive until maturity bear only partially filled grains or empty panicles. High nitrogen and temperature range of 30 to 35°C favour the disease. This is one of the major diseases in the Basmati belts of Haryana (India) and Punjab (India and Pakistan). In 1991 most of the Basmati fields in Punjab (Pakistan) were badly affected by this disease (Khan, 1996). Outbreaks of this disease were observed in Haryana during 1989, 1990 and 1992 (Ahuja et al., 1995). Foot rot can be effectively controlled by seed dressing with fungicide like MEMC and carbendazim.

Stem Rot

Stem rot caused by *Mugnaporthe salvini* (sclerotial stage) *Sclerotium oryzae* is endemic in eastern U.P. (Chakrabarti, 1978). Infection starts near the waterline as blackish dark irregular lesions on the outer leaf sheath and gradually enlarges. Eventually fungus penetrates into culm and weakens the stem leading to lodging. This disease is also favored by high nitrogen. K and Si application reduce disease incidence. Application of balanced fertilizer, burning of stubble after harvest, avoidance of water logging for long period and planting of moderately resistant varieties are some of the recommended methods for the disease management. Some of the aromatic rice varieties are reported to be resistant to stem rot (Table 2).

Narrow Brown Leaf Spot

This disease is caused by *Cercospora oryzae.* Incidence of the disease has increased in recent past particularly in Bijnore and Dehradun districts of U.P. (India). The disease is characterized by small, narrow, elongated dark brown spots spread uniformly over the leaf surface. Work is in progress to develop disease resistant varieties. Some of the non-aromatic resistant varieties like Mahssuri, Bhawani, IR 26, IR 28, IR 29 and IR 30 (Panduranjan, 1976) may serve as donors.

Bacterial Blight

This disease is caused by bacterium, *Xanthomonas campestris* pv. *oryzae* (Ishiyama) Dye. The disease may appear both in nursery (Kresek phase) as well as in field. Kresek phase is characterized by wilting of seedlings. In mature plants lesions usually start near the leaf tip or margins or both and extend down the outer edges. Young lesions are pale green to grayish green later turning yellow to gray necrotic. Lesions may extend to entire leaf length. Disease is more serious under irrigated conditions. Bacterial blight is widely distributed and devastating disease of rice (Devadath, 1992). Some of the aromatic rice cultivars like Pusa Basmati-1 are highly susceptible to bacterial blight. It is favoured by high N (Reddy et al., 1989). Planting of resistant cultivars is the best method of disease management. A number of resistant varieties are available among non-aromatic rices (Khush et al., 1989). Among aromatic rices HBC 19, Pakistani Basmati, Ghana1 and IET 9691 showed resistance to bacterial blight (Table 2). However, in aromatic rice growing belts of UP., India, Pusa Basmati-1 was found to be highly susceptible to bacterial blight. Proper use of nitrogen and avoidance of water stagnation in field help in keeping disease in check.

Grain Discolouration

It is characterized by darkening of glumes of spikelets brown to black including rotten glumes (Figure 3). Disease intensity ranges from sporadic discolouration to discolouration of entire glumes. A number of fungi viz. *Sarocladium oryzae, Cochliobolus miyabeanus, Alternaria alternata, Magnaporthe salvini, M. grisea* etc. are reported to be involved in grain discolouration. High rainfall at the time of maturity favours development of grain discolouration.

Integrated Management of Rice Diseases

In nature rice crop is infected by more than one diseases. Quite often diseases like blast, sheath rot and sheath blight, and brown spot and narrow brown spot tend to occur together. Sheath blight and stem rot appear to be negatively correlated (Kumar et al., 1998). Except brown spot and narrow brown spot, most other diseases are favored by similar set of factors like high nitrogen and phosphorus, low K, high plant density and crop canopy etc. Intensity of these diseases is likely to increase with introduction of high yielding nitrogen responsive aromatic rice varieties. Some of the cultural practices (e.g. proper spacing, early sowing, balanced fertilizer, micronutrients), fungicides (Table 1), biocontrol agents (Ps. *fluorescens, Bacillus* sp., *and G. virens*), botanicals etc. are effective against multiple diseases (Tewari et al., 1999). Breeding for disease resistance in aromatic rices is still in infancy. Some of the aromatic rice varieties are reported to be resistant or tolerant to different diseases (Table 2). A few lines have been identified which show multiple field resistance. Haryana Basmati-1 is resistant to blast and tolerant to stem rot and stem borer (Ahuja et al., 1995). Basmati 6129 is tolerant to bacterial blight, neck blast and whitebacked planthopper (WBPH). HBC 5 and Basmati 405 are tolerant to leaf blast and WBPH. Domsiah is tolerant to bacterial blight and neck blast (Kumar et al., 1996). Korean aromatic variety Hyangmibyeo showed multiple resistance to leaf blast, bacterial blight and rice stripe virus (Choi et al., 1995). Therefore, it is desirable to integrate disease/ pest management (IDM/IPM) strategies involving cultural practices, host tolerance/resistance, biocontrol agents, defense inducers and need-based application of fungicides for the management of multiple diseases. However, IDM/IPM strategies ought to be location specific.

INSECT PESTS

More than 800 insects species have been recorded damaging rice in one way or another although majority of them are of little importance (Dale, 1994; Grist and Lever, 1969). In a particular area insect pests attacking aromatic rice are the same as those prevalent on non-aromatic rices. In Basmati rices in India major insect pests are yellow stem borer, leaf folder, brown plant hopper and gall midge (Kushwaha et al., 1992; Rani et al., 1992). In Pakistan stem borer, leaf folder and whitebacked plant hopper (WBPH) are the major problem in Basmati rices. Stem borer and leaf folder reach their economic threshold level in third/fourth week of August and WBPH one month later depending on weather conditions (Khan, 1996). More often reported insect pests from rice are listed in Table 3.

Soil Inhabiting Insect Pests

Termite

Termites are pests of upland rice but damage has also been observed in rainfed medium land areas having light soil. Workers of these termites initially feed on rice roots and later tunnel through stem. Attacked plants die and can be pulled out easily which are characteristically filled with soil and may have few workers. Its attack may start from day of sowing/ transplanting and continue till harvest. Incidence is usually noticed from bund side in patches. Due to incidence, the plants stand becomes poor and yield is adversely affected. Drought, which is regular feature of rainfed rice, favours termite attacks.

Although termites have been reported as major pests of rainfed rice and four species viz. *Odontotermes brunneus; O. obesus; Microtermus obesi* and *Microtermus* sp. have been recorded in eastern U.P. infesting rice (Rizvi et al., 1996), no work for their management has been carried out. Based on experience in other crops, farmers are being advised to follow recommendation in the fields having history of termite attacks:

Table 3. List of common insect-pests of rice

Category	Common name	Zoological name
(a) Soil inhabiting pests	(i) Termites	*Odontotermes brunneus* (Hagen)
		O. obesus (Rambur)
		Microtermus obesi (Holmgren)
		Microtermus sp.
	(ii) Mole Cricket	*Gryllotalpa sp.*
	(iii) Crabs	*Spiratothelpusa hydrodroma*
		Sartoriana spinigera
	(iv) Root weevil	*Echinocnenos oryzae* Marshell
(b) Tissue borer	(i) Yellow stem borer	*Scirpophaga incertulus* (Walker)
	(ii) Dark headed striped borer	*Chilo polychrysus* (Meyrick)
	(iii) Sorghum stem borer	*C. partellus* (Swinhoe)
	(iv) Gold fringed borer	*C. auricilius* Dudgeon
	(v) Pale headed striped	*C. suppressalis* (Walker)
	(vi) Pink stem borer	*Sesabaniainferens*(Walker)
	(vii) Gall midge	*Orseolia oryzae* (Wood Mason)
(c) Defoliators	(i) Whorl maggot	*Hydrellia philippina* Ferino
	(ii) Grasshopper	*Hieroglyphus banian* (F.)
		Oxya cinensis (Thunberg)
	(iii) Leaf folder	*Cnaphalocrosis medinalis* (Guenee)
	(iv) Rice Hispa	*Decladispa armigera* (Oliver)
	(v) Case worm	*Nymphula depunctalis* (Guanee)
	(vi) Rice butterfly	*Melanitis leda ismene icramer*
	(vii) Rice skipper	*Parnara mathias* (F.)
	(viii) Green semi-looper	*Naranga aenescens* (Moore)
(d) Sap feeders	(i) Thrips	*Stenchtothrips biformis* (Bajnall)
		Haplothrips aculeatus (F.)
	(ii) Green leaf hopper	*Nephotettix virescens* (Distant)
		N. nigropictus (Stal)
	(iii) Brown plant hopper	*Nilaparvata lugens* (Stal)
	(iv) White backed plant hopper	*Sogatella furcifera* (Horvath)
	(v) Zig zag leafhopper	*Recilia dorsalis* (Motschulsky)
	(vi) Big white plant hopper	*Cofana spectra* (Distant)
(e) Ear damaging	(i) Rice bug	*Leptocorisa acuta* (Thunberg)
	(ii) Stink bug	*Menida histrio* (F.)
	(iii) Climbing cut worm	*Mythimna separata* Walker

1. Removal of crop residue like leaves, stubble etc. after harvesting.
2. Restriction on the use of raw FYM.
3. Avoid taking green manure.
4. Use of neem cake @ 250-625 kg/ha.

Mole cricket

Mole crickets (*Gryllotalpa* sp.) usually occur in the upland rainfed rice and become serious pests especially when there is drought. Both nymphs and adults feed on roots and basal part of the plants/hills. Its damage is quite similar to termites but pulled plant tillers are recognized by presence of slant cut and absence of soil/workers of termite. No experiment on the losses and management of the pest has been carried out hence there is no recommendation for management of crickets except flooding of the fields, if possible.

Crabs

Crabs are generally carnivorous but *Spiralothelpusa hydrodoma* and *Sartoriana spinigera* have been found damaging nursery and newly transplanted rice by cutting the plant/tillers from basal region and causing 60-80 per cent loss (Chatterji and Dutta, 1980). So far no measures have been suggested for its control.

Rice root weevil

Grubs of rice root weevil, *Echinocnemus oryzae* attack roots and rootlets of the rice plants at tillering stage in the fields having clay and heavy loam soils. Leaves of attacked plants become yellow and finally die. Tillering is adversely affected. Such fields show sick and patchy appearance. Adult weevils feed on leaves but do not cause noticeable damage.

Tissue Borers

Stem borers

Stem borers viz., yellow stem borer (*Scirpophaga incertulas*) and Pink stem borer (Sesamia *inerans*), Dark headed striped borer (*Chilo polychrysus*), Pale headed striped borer (*C. suppressalis*), sorghum stem borer (*C. partellus*) and gold fringed borer (*C. auricilius*) have been reported infesting rice (Pangtey and Sachan, 1983; Dutt and Kundu, 1984; Rai et al., 1989). However, yellow stem borer is of common occurrence and causes economic loss. Stem borers may damage plants before (dead heart) or after (white head) flowering. Dead heart damage may occasionally be mistaken for kresek or rat damage but the leaf of a plant with dead heart is easily pulled from the tiller. White head causes the entire panicle to dry (Figure 3). Studies on characterization of rice pests and quantification of yield losses in rice revealed that of 1.43 tones/ha loss caused by various agents like diseases, insects and weeds, 0.46 tones/ha is contributed by stem borer alone (Savary et al., 1997). Until 1960, the stem borers were considered major pests of rice in India, however, their damage declined during the last decade. Now again it is increasing as the borers are being observed in large numbers in fine rice and hybrid rice especially being grown in low lying rainfed and irrigated areas. During 1998 *Kharif* season epidemic of yellow stem borer was recorded in Basmati belt of Haryana and Punjab where as high as 50 percent incidence of white head was noticed. Stem borers, emerged in northern parts of Iran in 1971, has now become a serious problem in both aromatic and non-aromatic rices.

The economic injury threshold as dead heart and white head was reported to be 5.7-12 and 9.4-14.7%, respectively (Rao et al., 1990).

Gall midge (*Orseolia oryzae*)

The bright red female usually lays eggs singly or in groups of 3 to 4 near the base of the plants on the legules. The larvae feed on growing buds. The feeding results in gall formation, which is commonly known as 'Silver shoot' or 'Onion shoot'. There are several generations in a year when there is continuous good rain and rice is planted late i.e. in August, as high as 65% incidence is reported in non-aromatic rices (Rizvi and Singh, 1980).

Defoliators

Whorl maggot

Whorl maggot, *Hydrellia philippina* is a pest of early stage of rice plants grown both in irrigated and rainfed conditions. Fields having standing water first for 3-4 weeks are infested more than the fields without standing water. The maggots feed by nibbling the inner margins of leaves when they are in whorls. Damage is seen when infested leaves open. Typical symptom is degenerated tissue along the inner margins of emerging leaves. As leaves expand yellow damaged areas become conspicuously visible. Damage occurs from seedling to maximum tillering stages. Crops planted during middle of July to August suffer more.

Grass hopper

Several species of grass hoppers viz. *Hieroglyphus banian; Oxya chinensis* etc. feed on rice leaves from margins leaving midrib, if hard. The damage is more pronounced when there is long gap in rains during August to September. An outbreak of *H. banian* occured in about 3,000 ha area of rice in West Bengal (Chatterjee and Debgoswami, 1981).

Leaf folder

Cnaphalocrocis medinalis is a minor insect pest but now becoming a major pest due to growing of high yielding varieties under high management conditions. Unbalanced use of fertilizers especially excessive application of nitrogenous fertilizers seems to be one of the important factors of increasing menace of leaf folders (Dhaliwal et al., 1984).

The first instar larva feeds on young leaf in whorls while later instars larvae feed within folded leaves. The larvae feed on leaf tissues except the epidermis causing typical white streaks. They create a leaf tube during the later stages of feeding. Several natural enemies viz., *Cotesia* sp., *Trichogramma* sp., *Bracon* sp. etc. have been found parasitizing leaf folder larvae in the field and keeping the population below ET level.

Rice hispa (*Decladispa armigera*)

Both grubs and adults feed on rice plants. Grubs mine the leaves and cause blotches. Adults remove green matter of leaves between veins and cause parallel white streak. In severe cases of attack the field shows dry appearance similar to hopper burn. Early intermittent rains may cause high population. The damage is observed after transplanting.

Rice case worm (*Nymphula depunctalis*)

It is a minor pest but some times it becomes serious. It feeds from the leaf surface and removes tissues leaving the upper white papery epidermis. The infested plants show no growth, poor tillering and the formation of small panicles resulting in poor yield.

Draining of the field, for 2-3 days, after dislodging the larvae with the help of rope is proved to be useful in the management of the pest.

Rice butterfly (*Melanitis leda ismene*)

Rice butterfly is also a minor pest. The catterpillars feed on leaves from margins and tips quite similar to grasshoppers and army worms.

No control measure has been recommended for this pest, however *Andrallus spiniolens,* a hemipteran bug is active in the area predating upon large number of larvae of rice butterfly.

Rice skipper

Rice skipper, *Parnara Mathias,* is also a minor pest. Damage is caused by larvae by rolling and stitching two or more leaves together and eating them from the margins inwards.

Green semi looper

Larvae of green semi looper, *Naranga aenescens,* feed on the leaves causing defoliation at nursery to tillering stage. Early instar larvae feed by scrapping green tissues while older ones eat leaves from the edges. As yet no control measure is available for the pest.

Sap Feeders

Two species of thrips viz. *Stenchatothrips biformis, Haplothrips aculeatus,* two species of green leafhoppers (GLH) *Nephotettix virescens, N. nigropictus,* Brown plant hopper (BPH) *Nilaparvata lugens,* white backed planthopper (WBPH), *Sogatella furcifera,* zig zag leaf hopper, *Recilia dorsalis* and big white plant hopper, *Cofana* spectra come under this group. Among these, thrips, BPH and WBPH cause severe damage to crop in certain years. GLH is of regular occurrence. The predominant species i.e. *N. virescens* reaches its peak during August-September and continues till early

November but due to absence of tungro virus inoculum, in spite of high population it does not cause severe damage. Hopper burn is characterized by partial to pronounced yellowing and increasing severity of stunting. Extreme signs are wilting to death of plants. Infested area in field may be patchy. Hopper burn due to WBPH and BPH have been observed in rice fields grown under high fertility level.

Adult and nymph thrips slash the plant tissue and feed on sap. Damage causes yellow to red plant discolouration and makes the leaf blade roll. Spikelets may have unfilled grains or completely empty heads. Plants may be damaged from seedling stage to maturity.

Ear Damaging Pests

Among ear damaging insect-pests Rice bug, *Leptocorisa acuta,* Stink bug, *Menida histrio* (Rizvi, 1978) and Climbing cut worm, *Mythimna separata* (Kulshreshtha et al., 1970; Kalode, 1976 and Rizvi and Singh, 1981) have been reported as major, serious and sporadic pests.

Nymphs and adult bugs suck the sap from different parts of the plant. These also remove milk liquid from developing grains, cause chaffy grain and heavy yield loss. Staggered planted rice suffers more due to these bugs.

In case of *M. separata* damage is caused by caterpillars. During early stages of the crop, larvae feed on green and dry leaves while at dough stage they climb on the ear at night and cut the spikelet bearing few grains. Damage continues till harvest and causes severe damage to the crop. During the day they remain hidden in the clump or on the soil under fallen leaves.

Integrated Pest Management

Rice ranks second in consumption of pesticides and their indiscriminate use has affected the ecology adversely. This has led to resurgence of pests, pesticide resistance, environmental pollution, and health hazards. It is well established that most BPH outbreaks in tropical rice are caused by overuse of broad-spectrum insecticides, which disrupt biological control by spiders and predaceous and parasitic insects (Way and Heong, 1994; Cuong et al., 1997). The integrated approach to pest management, which involves host plant resistance, use of biocontrol agents, botanical pesticides, cultural practices and only need based use of chemical pesticides, have efficiently controlled the pests and have proved eco-friendly and cost effective in irrigated system. IPM packages developed for BPH, gall midge and stem borer are widely adopted in endemic areas (Siddiq, 1995). Similar IPM packages should be developed for aromatic rices.

Although, cultivation of resistant varieties have been found very effective in reducing the crop losses due to insect pests, unfortunately, not many such varieties are available in case of aromatic rices (Table 2). Under such condition, cultivation of local selections tolerant to most severe pests of the area may help up to some extent. Haryana Basmati-1 is reported to be resistant to blast and WBPH and tolerant to stem rot and stem borer. Taraori Basmati shows resistance against WBPH and stem rot (Ahuja et al., 1995). However, in absence of many such selections early maturing varieties may escape the damage of late coming pests or reduce the period for population buildup of GLH, BPH, WBPH and Stem borers.

Several insects infest the crop in the seedbed and quite often they are carried over to the main crop. In the plant hopper endemic area the nursery should be raised away from light source because the insects are attracted towards it. The seedbed should not be flooded if the case worm is a serious problem in the area. Before using the seedlings for transplanting they should be checked to destroy the eggs of stem borers. Since the eggs of stem borer are laid near the tip of the leaf blade, clipping of seedling before transplanting reduces the number of eggs carried from seed bed to transplanted crop and also minimizes the carry over of leaf folder, rice case worm and rice hispa. Method of sowing is also known to be helpful in reducing damage of some insects. Direct seeded crop is less damaged by whorl maggot as compared to transplanted ones. Furthermore, transplanting of old seedling has been found effective in reducing the damage caused by whorl maggots and case worms. A number of pests such as Stem borers, BPH, and WBPH complete several generations in a cropping season. Planting fields in an area within 3-4 weeks has been found effective in reducing the number of generations of these insects. In the rice hispa endemic area transplanting the seedling closely and early at the beginning of monsoon reduces the damage due to this insect (Tiwari et al., 1999).

Weed management is also essential to check the population buildup of insect pests as so many grassy and other weeds serve as alternate hosts of rice pests. In the area inhabited by gall midge, army worm, cut worm, leaf folder, rice hispa, and rice bug all such weed should be removed from seed bed, crop or surrounding areas (Tiwari et al., 1999).

Water standing in the field affects the biology of the insect. Draining out water from the field at regular intervals in the first month of transplanting reduces the egg laying of whorl maggot the adult of which are attracted to standing water. In case of worm endemic area, draining of water for several days have been found effective in reducing the damage by this insect. When the crop is infested heavily by BPH or WBPH, the field should be drained for 3-4 days. On the other hand, flooding eliminates soil-borne insects and also controls army worm, earhead cutting caterpillar and cutworm up to some extent.

Fertilizers are known to play a very important role in population build-up of different insect pests. Heavy application of nitrogen fertilizer to high yielding but pest susceptible varieties aggrevate the pest problem. On the other hand moderate level and split application of nitrogenous fertilizer makes the crop tolerant to stem borers, BPH, WBPH, gall midge and leaf folder (Tiwari et al., 1999).

Stem borer and gall midge hibernate in the stubble of rice plants. Cutting the stubble at ground, burning or plowing the stubble and leaving the ground fallow for 3-4 weeks have been found very effective in reducing the population build up of these insects.

Most of the rice insect pests are attacked by a large number of parasitoides, predators and pathogen under natural condition (Tables 4 & 5).

Table 4. Important parasitoids of rice insect pests

Scientific name	Common name	Host	Stage
Anagrus optablis	Mymarid wasp	Brown plant hopper, White backed plant hopper	Egg
Anagrus sp.	Mymarid wasp	Whitebacked plant hopper	Egg
Apanteles flavipes	Braconid wasp	Striped rice borer, Yellow rice borer	Larva
Bracon albotineatus	Braconid wasp	Striped rice borer	Larva
Bracon chinensis	Braconid wasp	Pink borer	Larva
Charops sp.		Stem borers, Leaf folder	Larva
Elasmus elbopistus	Elasmid wasp	Yellow rice borer	Larva
Eriborusrus sinicus	Ichneumonid	Yellow rice borer	Egg
Gonatocerus sp.	Mymarid wasp	Brown plant hopper, White backed plant hopper	Egg
Macrocentrus sp.	Hymenopterus	Stem borers, Leaf folder	Larva
Mymar taprobanicum	Mymarid wasp	Brown plant hopper, White backed plant hopper	Egg
Oligosita sp.	Hymenopterus	Brown plant hopper, White backed plant hopper	Egg
Rhaconotus oryzae	Braconid wasp	Striped rice borer	Larva
Rhaconotus scirpophagae	Braconid wasp	Yellow rice borer	Larva
Stenobracon nicevillei	Braconid wasp	Yellow rice borer	Larva
Sturmiopsis inferens	Techinid wasp	Pink borer	Larva
Telenomus dignoides		Yellow rice borer	
Tetrastichus hegenowii	Eulophid wasp	Dark-headed rice borer	Pupa
Tetrastichus israeli	Eulophid wasp	Yellow rice borer	Pupa
Tetrastichus schoenobii	Eulophid wasp	Yellow rice borer	Pupa
Topobracon schoenobii	Braconid wasp	Yellow rice borer, Pink borer	Larva
Trichogramma japonicum	Trichogrammatid	Striped rice borer, Yellow rice borer	Egg
Trichogrammatoidea nana	Trichogrammatid	Yellow rice borer	Egg
Xanthopimpla	Ichneumonid	Stem borers, Leaf folder	Larva

Table 5. Important predators of rice insect pests

Scientific name	Common name	Host
Agriocnemus sp.	Damsel fly	Brown plant hopper, White backed plant hopper, Green leaf hopper
Araneus inustus	Spider	Leaf folder, Case worm, Brown plant hopper, White backed plant hopper
Araneus sp.	Spider	Green leaf hopper, White rice leaf hopper, Whorl maggot, Chironomids
Argiope catanulata	Orb spider	Green leaf hopper, Brown plant hopper, White backed plant hopper, Whorl maggot
Bianor hotingchlehi	Spider	Green leaf hopper, Brown plant hopper, White backed plant hopper, White rice leaf hopper, Case worm
Callitrichia formosana	Spider	Green leaf hopper, Brown plant hopper, White backed plant hopper
Clubiona japonicola	Spider	Green leaf hopper, Brown plant hopper, White backed plant hopper, Zig zag leaf hopper, Whorl maggot, Case worm
Clubiona drassoides	Spider	Green leaf hopper, Brown plant hopper, White backed plant hopper, Whorl maggot
Clubiunica nr. japonica	Spider	Green leaf hopper, Brown plant hopper, White backed plant hopper
Conocephalus sp.	Meadow grasshopper	Rice bug, Stem borers, Plant hoppers, Leaf hoppers
Crocothemis sp.	Dragon fly	Green leaf hopper, Brown plant hopper, White backed plant hopper
Cyrtaphora cicatrosa	Spider	Green leaf hopper, Brown plant hopper, White backed plant hopper
Crytorhinus lividipennis	Myrid bug	Green leaf hopper, Brown plant hopper, White backed plant hopper
Dyschiriognatha sp.	Spider	Green leaf hopper, Brown plant hopper, White backed plant hopper
Ecuta javana	Spider	Green leaf hopper, Brown plant hopper
Gea corbetti	Spider	Green leaf hopper, Brown plant hopper
Heteropoda venatoria	Spider	Green leaf hopper
Larinia tabida	Spider	White backed plant hopper, Green leaf hopper, Zig zag leaf hopper
Lycosa pseudoannulata	Wolf spider	Green leaf hopper, Brown plant hopper, White backed plant hopper, White rice leaf hopper, Zig zag leaf hopper, Whorl maggot, Case worm, Leaf folder, Chironomids
Lyctocoris beneficus	Anthocorid bug	Striped rice borer
Micraspis vincta	Lady bud beetle	Brown plant hopper, White backed plant hopper
Misumenoides sp.	Spider	Green leaf hopper, Brown plant hopper
Neoscona elliptica	Spider	Green leaf hopper, Brown plant hopper, White backed plant hopper

(*Contd.*)

Table 5. *(Contd.)*

Scientific name	Common name	Host
Neoscona nautica	Spider	Green leaf hopper, Brown plant hopper, White backed plant hopper
Neoscona theisi	Spider	White backed plant hopper, Brown plant hopper, Green leaf hopper, Zig zag leaf hopper, Leaf folder, Whorl maggot, Chironomids
Ophionea indica	Carabid beetle	White backed plant hopper, Brown plant hopper
Oxyopes javanus	Lynx spider	Green leaf hopper, Brown plant hopper, White backed plant hopper
Oxyopes nr. sertatus	Spider	Green leaf hopper, Brown plant hopper, White backed plant hopper
Oxyopes shweta	Spider	Green leaf hopper, Brown plant hopper, White backed plant hopper
Paederus fuscipes	Staphylinid beetle	White backed plant hopper, Brown plant hopper
Pardosasumatrana	Spider	Green leaf hopper, Brown plant hopper, White backed plant hopper
Plexippus paykuli	Spider	Green leaf hopper, Brown plant hopper, White backed plant hopper, White rice leaf hopper
Runcinia roonwali	Spider	Green leaf hopper, White backed plant hopper
Singa pygmaea	Spider	Green leaf hopper, Brown plant hopper
Tetragnathajaponica	Spider	Green leaf hopper, Brown plant hopper, White backed plant hopper, Zig zag leaf hopper, Whorl maggot
Tetragnatha maxilosa	Long jaw spider	Brown plant hopper, White backed plant hopper
Tetragnatha nr. virescens	Spider	Zig zag leaf hopper, Green leaf hopper
Tetragnatha sp.	Spider	Green leaf hopper
Theridiosoma	Spider	Green leaf hopper, Brown plant hopper, White backed plant hopper
Thomisus cherapunjeus	Spider	Green leaf hopper, Brown plant hopper, White backed plant hopper, Zig zag leaf hopper
Zygoballus sp.	Spider	Green leaf hopper, Brown plant hopper, White backed plant hopper

Depending upon their population and weather conditions these biological control agents effectively control most of insect pests of rice e.g. spiders control the population of plant hoppers effectively when their number is 3 spiders/hill. Mirid bug also control them when predator: host ratio is 1:4. To increase the effectiveness of parasitoides and predators in the rice field it is essential to conserve and enhance their population by adopting production and protection practices harmless to them.

For the conservation and enhancement of the natural enemies, which are already present in the field, it is advisable to leave a pest residue in the field at non-economic level, for natural enemy. To reduce the harmful effect of pesticides on the natural enemy, it should be applied only when pest population reaches Economic Threshold Level. It is also recommended to select insecticide, which is less toxic to natural enemy. As direct application of insecticide on the plant also kills the natural enemies, application of granules in the soil should be preferred.

Mass release of parasitoides have also been found effective in the management of lepidopterous pests. For this purpose, *Trichogramma japonicum* is released at the rate of 50,000/ha/week for six weeks starting from 30 days of transplanting for the control of stem borers, leaf folder and other lepidopterous pests. For the management of BPH, mirid bug, *Cyrtorhinus lividipennis* is released at the rate of 100 bugs or 50-75 eggs / sq. m.

Sex pheromone have also been found very useful in the management of yellow stem borer (Pathak, P.K., personal communication). Single application of controlled release formulation of sex pheromone at the rate of 40 g a.i./ha through 625 point sources checks the population buildup of this pest by disrupting mating. Sex pheromone have also been found effective in trapping male moth of this insect when used at the rate of 0.5 g pheromone dispensed in traps installed at 20 points/ha at the time of transplanting.

When the pest problem is not controlled by manipulation of cultural practices or conservation, enhancement and release of natural enemies, the application of pesticides becomes inevitable to check the population reaching economic injury levels. However, it is also used some time as a preventive measure. Soaking of sprouted seeds in 0.2 per cent chlorpyriphos for three hours before sowing has been found effective in protecting the seedling from the gall midge attack. Similarly, seedling root dip in 0.02 per cent chlorpyriphos for 12 hours or 0.02 per cent chlorpyriphos +1 per cent urea for 3 hours protects the seedling from the damage of stem borers, gall midge and whorl maggot. Soil application of carbofuran before sowing or transplanting of rain fed low land rice followed by need based spray of quinalphos or monocrotophos has been found effective against stem borers and hoppers.

Rodents, mostly rats, cause considerable damage to rice crop in the field by cutting the plants in different stages. Cultural and chemical control methods have been found very effective in reducing the damage due to rodents. Deep ploughing leads to destruction of old burrows which deprives shelter to rats. Reduction in size and trimming of field bunds also destroy old burrows. Weed management deprives food and alternate hosts. Simultaneous planting prevents rodent migration from one to another field after harvesting. When the rodents are not managed by these practices zinc phosphide bait (2.5%) is used to kill the rodents or their burrows are fumigated with aluminium phosphide tablets (Tiwari et al., 1999).

Till resistant varieties are available, for BPH altering planting dates, crop sanitation, formation of alley ways, optimum plant density and conservation of natural enemies through need based use of chemical pesticides may help to keep the population of BPH well below injury threshold. Similarly against gall midge, early transplanting, crop sanitation and need based use of pesticides may greatly reduce crop losses.

Both panicle blast and stem borer (*S. incertulus*) were managed effectively by soil amendment with burnt rice husk before transplanting (@ 10 t/ha) and Nimbicidine spray after 30 and 60 days of transplanting (@ 20 ml/l water) (Dodhan and Roshan, Unpublished).

BIRD DAMAGE

Because of late harvesting due to long duration, aromatic rices face serious problem of birds. Although no systematic research work has been carried out, different varieties seem to show differential susceptibility towards birds. In a field trial different selections of aromatic rice cultivar Brahmamusi exhibited a wide variation in their susceptibility towards bird damage even though they were planted side by side (Figure 3) (Singh, U.S., Singh, R.K. and Khush, G.S., unpublished information). This information could be quite useful for breeding aromatic varieties less susceptible to bird damage.

MOLECULAR BIOLOGY IN MANAGEMENT OF DISEASES AND PESTS

The advent of genetic engineering approaches to diseases and pests resistance in crop plants now raises the possibility of achieving for the first time high level of resistance even against those diseases and pests where resistance donors are not available for exploitation by conventional breeding. Among the advantages of this approach are: (1) the availability of several diverse mechanisms of resistance from rice, other crops or microbes; (2) the ability to introduce one or several such genes directly into popular cultivars without the disadvantages associated with sexual hybridization; and (3) the availability of three different methods of rice transformation based on protoplast, microprojectiles or *Agrobacterium* (Ghareyazie et al., 1997). A large number of potential genes, which can provide resistance against diseases and pests, have been cloned. (Table 6). Some of these genes have already been transferred to rice and

Fig. 4. Field view of aromatic rice cultivar Brahmamusi showing heavy bird damage- white seed on panicle are due to bird damage (Top); single panicle showing bird damage (Middle); one of the selection of cultivar Brahmamusi which was free from bird damage (Bottom).

Table 6. Potential disease and pest resistance genes and their donors which are being used in rice to generate diseases and pest resistant transgenics.

GENE	TRAITS (resistance against)	DONOR	REFERENCE
Bph-10(t)	Brown plant-hopper (BPH)	*Oryza australiensis*	Ishii et al., 1994
GNA	BPH	Snowdrop (lectin gene)	Gatehouse & Gatehouse, 1997; Rao et al., 1997; Muthusamy et al., 1997
GNA	BPH & Green leaf hopper	Snowdrop (lectin gene)	Rao et al., 1997
CryIA (b)	Yellow stem borer (YSB)	*Bacillus thuringiensis*	Ghareyazie et al., 1997
	YSB & stripped stem borer	*Bt*	Cheng et al., 1997
CryIA (c)	YSB & stripped stem borer	*Bt*	Cheng et al., 1997
CryIIIA	Coleopteran insects	*Bt* var. *tenebrionis*	Das et al., 1995
Gm-2	Gall midge (GM)	Phalguna	Mohan et al., 1994
Gm	GM	Duakang #1	Katiyar et al., 1994
Gm4(t)	GM	Abhaya	Nair et al., 1995
Gm6(t)	GM	Daqiuqi	Katiyar et al., 1995
Glh	GLH	ARC 11354	Sebastian et al., 1995
Hbu	Hoja blanca	Fanny	Tohme (cited in Zheng et al., 1995)
Wbph-1	White back plant hopper resistance (WBPH)	N-22	McCouch, 1990; Maheswaran & McCouch, 1997
Wbph2	WBPH	ARC 10239	Maheswaran & McCouch, 1997
Wbph3	WBPH	ADR 52	Maheswaran & McCouch, 1997
Wbph4	WBPH	Podiwi A 8	Maheswaran & McCouch, 1997
Wbph5	WBPH	N'Diang Marie	Maheswaran & McCouch, 1997
Trypsin	insect	Cowpea	An et al., 1995
inhibitor		Soybean	Nandi et al., 1995
PR-5	Sheath blight	–	Datta et al.,1997c
Chitinase	Sheath blight		Datta et al.,1997d
(Chill,	Sheath blight	Rice	Datta et al.,1997d
RC7,	Sheath blight	Rice	Datta et al.,1997d
Serpin,	Sheath blight	*Menduca sexta*	Datta et al.,1997d
Msc)	Sheath blight	*Menduca sexta*	Datta et al.,1997d
PR-5	Sheath blight	Rice	Datta et al.,1997d

(Contd.)

Table 6. *(Contd.)*

GENE	TRAITS (resistance against)	DONOR	REFERENCE
PR-protein	Blast	CO39 & IR36	McGee et al., 1995
Pi-1	Blast	LAC 23	Yu, 1991; Mew et al., 1994
Pi-z^{5}	Blast	5173	Yu et al., 1991; Mew et al., 1994
Pi-ta	Blast	Tetep	Yu et al.,1991; Mew et al., 1994, Sharma, 1997
Pi-ta^{2}	Blast	Tadukan	Rybka et al., 1995
Pi-5(t)	Blast	Moroberekan	Wang et al., 1994
Pi-6(t)	Blast	Apura	Yu, 1991
Pi-7(t)	Blast	Moroberekan	Wang et al., 1994
Pi-9(t)	Blast	–	Reimers and Nelson (cited in Zheng et al., 1995)
Pi-9(t)	Blast	*O. minuta*	Zhang et al., 1997
Pi-11(t)	Blast	Zhaiyeqing	Zhu et al., 1992
Pi-?	Blast	IRAT 13	Tohme (cited in Zheng et al., 1995)
Pi-12(t)	Blast	Hong jiao zhan	Zheng et al., 1995
Pi-157	Blast	Moroberekan, Tadukan	Chattoo et al., 1997
Pi-b	Blast–	–	Myamoto et al., 1995
Pi-ql, Pi-q5 & Piq6	Blast	Teqing	Tabien et al., 1997
Pi-b2	Blast	Lemont	Tabien et al., 1997
AVR2 YAMO	Blast	*Magnaporthe grisea*	Wu et al., 1995
RTSV	Rice tungro spherical virus	ARC 11554	Sebastian et al., 1995
RTSV-CP & Polymerase	Tungro disease	RTSV	Huet et al., 1997
RTBV-CP	Tungro disease	RTSV	Kochko et al., 1997
RTBV-RT	Tungro disease	RTBV	Kochko et al., 1997
RYSV-N	Rice yellow stunt virus	Xiushui 11 & Bing 88	Fang et al., 1997

(Contd.)

Table 6. *(Contd.)*

GENE	TRAITS (resistance against)	DONOR	REFERENCE
RRSV-CP & non-structural protein	Rice ragged stunt virus	RRSV	Upadhyaya et al., 1997
RYMV-CP	Rice yellow mottle virus	RYMV	Kouassi et al., 1995
Xa-1	Bacterial blight (BB)	Kogyoku	Yoshimura et al., 1992
Xa-2	BB	Tetep	Yoshimura et al., 1992
Xa-3	BB	Chugoku 45	Yoshimura et al., 1992
Xa-4	BB	IR 20	Yoshimura et al., 1992
Xa-5	BB	IR-1545-339	McCouch et al., 1991
Xa-13	BB	Long grain	Zhang et al., 1994
Xa-21	BB	*O. longistamimta*	Ronald et al., 1992
		O. minuta	Zhang et al., 1997b
Xa-23	BB & Bacterial leaf streak (BLS)	*O. rufipogon*	Zhang et al., 1997a
Cecropin B	BB & BLS	*Hyalophora cecropia*	Zhu et al., 1995

their expression demonstrated (Table 7). Status of diseases and/or pest resistant rice transgenics is summarized in Table 8. However, most of the efforts on generating diseases and pest resistant transgenics have concentrated on non-aromatic rices. Only recently some efforts are directed towards improving high quality aromatic rices using molecular techniques. Methods for the regeneration and transformation in important aromatic rices have already been standardized (see Chapter 5 of this volume).

Ghareyazie and coworkers (1997) transformed aromatic rice cv. Tarom Molaii with a synthetic *cryIA(b)* gene using microprojectile bombardment. The *cryIA(b)* gene was controlled by the promotor of the maize C_4 PEP carboxylase gene and was expressed in leaf blades but was not expressed to a detectable level in the dehulled mature grain. The transgenic plants showed enhanced resistance to stem borer (Figure 5). Maqbool and coworkers (1998) generated transgenic aromatic rice varieties Basmati 370 and M7 expressing the novel *cry2A (Bt)* insecticidal gene by particle bombardment. Transgenics were resistant to yellow stem borer and rice leaf folder. Transgenic Basmati 370 with *cry 1A (c)* or *crylla* (Bt) insecticidal gene were generated by Husnain et al. (1997) and Bano et al. (1997), respectively. These transgenics showed enhanced resistance towards lepidopteran and dipteran insects. Rice chitinase gene was transferred to Pusa Basmati 1 (Gill et al., 1997) and Basmati 370 (Datta et al., 1997b) with the aim of incorporating resistance against sheath blight.

FUTURE OUTLOOK

Since aromatic rices are in general long duration but low yielder, attempts to increase productivity has not been very compatible with quality characteristics. Therefore, there is urgent need to minimize the losses due to diseases and pests by developing location specific technologies for the integrated diseases and pest management and ensure the rapid transfer of such technologies to end users, farmers. Aspects needing immediate attention are as follows:

1. Assessment of crop loss and development of economic threshold levels for different diseases and insect-pests.
2. Effect of crop rotation, fertilizers, micronutrients, Si, tillage practices and residue management on quality traits, yield and diseases and pests incidence.
3. Characterization and augmentation of natural enemies and naturally occurring antagonists in aromatic rice growing areas.
4. Systematic studies on bird damage particularly inheritance aspect.
5. Generation of multiple diseases and pest resistant varieties using molecular tools without sacrificing the quality traits.

Table 7. Rice transgenics resistant to biotic stresses

Rice variety	Genes transferred	Resistant Traits	Reference
lndica/japonica	*bar*	Herbicide	Christou et al., 1991; Datta et al., 1992
Japonica	*cp-stripe*	Stripe virus	Hayakawa et al., 1992
Japonica	*Bt*	Insect	Fujimoto et al., 1993
Indica	*Chitinase*	Sheath blight	Lin et al., 1995
Japonica	*cc*	Insecticidal	Irie et al., 1996
Japonica	*Xa-21*	Bacterial blight	Song et al., 1996
Indica (IR58)	*Bt*	Insect	Wünn et al., 1996
NPT/IRRI breeding line	*Bt/Chi11*	Stem borer & sheath Blight	Alam et al., 1996
Japonica	*pinII*	Insect	Duan et al., 1996
Indica	*Bt/chitinase*	Stem borer & sheath Blight	Datta et al., 1997a
Indica	*Bt*	Stem borer	Tu et al., 1997a
Indica/Japonica	*Bt*	Stem borer	Datta et al., 1997b
Indica (IR72)	*Xa-21*	Bacterial blight	Tu et al., 1997b,
Indica/Japonica	*Bt*	Rice walker	Tian et al., 1997
	cp-RTBV	Rice tungro	Tian et al., 1997
	Cecropin B	Bacterial blight & bacterial leaf streak	Tian et al., 1997
Japonica	*cp-RTSV* *cp-RTBV*	Rice tungro	Fauquet et al., 1997
Japonica	*RYSV-N*	Rice yellow stunt	Fang et al., 1997
Japonica	*RHBV-N*	Rice hoja blanca	Lentini et al., 1997; Lee et al., 1997
Japonica	*Antisense rhibozyme (S5IIIR)*	Rice dwarf virus	Yang et al., 1997
Japonica	*bar*	Blast	Tada et al., 1997
Indica	*PR-5*	Sheath blight	Datta et al., 1997c
	PR-3(ChiII, RC7)	Sheath blight	Datta et al., 1997d
		Sheath blight	Oatta et al., 1997d
	PR-5(TLP-D-34)	Sheath blight	Datta et al., 1997d
Japonica	*RTBV-CP*	Tungro Disease	Kochko et al., 1997
Japonica	*RTSV-CP Polymerase*	Tungro Disease	Huet et al., 1997
Indica (Basmati 370)	*CyIIa*	Insect	Bano et al., 1997
Japonica (Taipei 309)	*BPTI(Trypsin inhibitor)*	Insect	Bharadwaj & Thomas, 1997
Indica (Basmati 370)	*CryIA(c)*	Insect	Husnain et al., 1997
Japonica (Senia & Areite)	*CryIA(C)*	Striped stem borer	Bretler et al., 1997
	CryIB	Striped stem borer	Bretler et al., 1997
Indica (Pusa Basmati-1)	*Chitinase*		Gill et al., 1997
Indica/Japonica	CHI 11	Sheath Rot	Thara et al., 1997

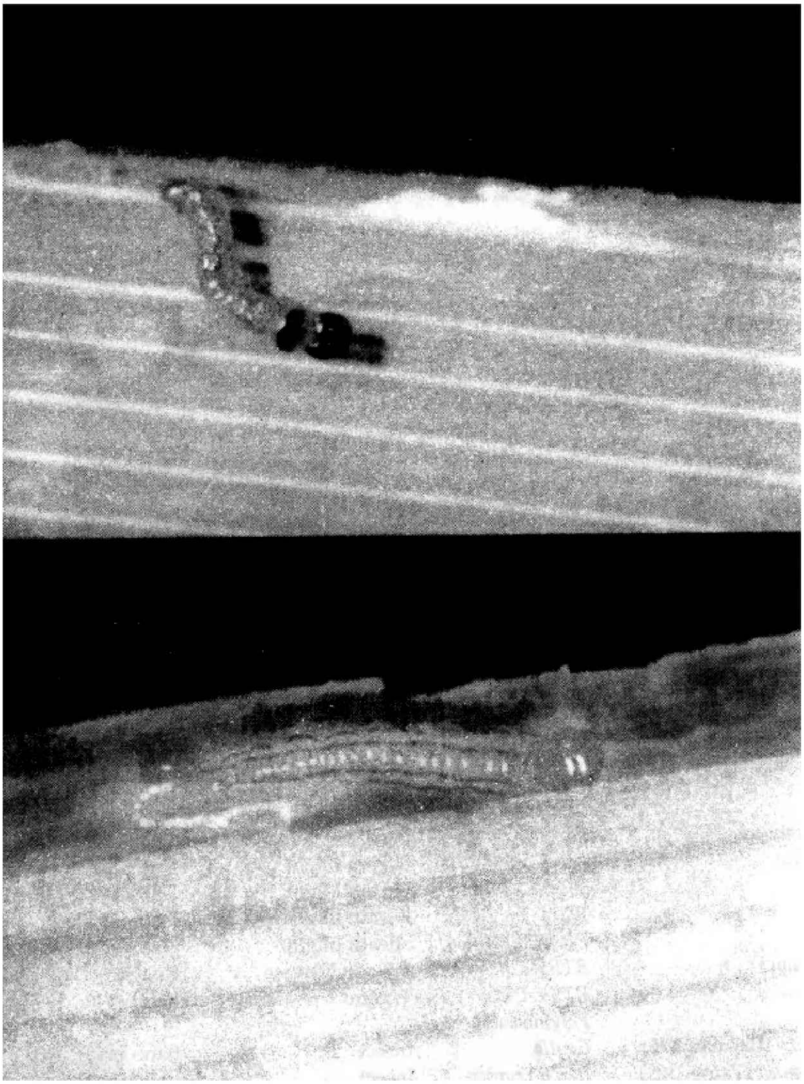

Fig. 5. Bioassay using striped stem borer *(Chilo suppressalis)*.

A. Dead first instar larva on stem section of transgenic line 827 containing *crylA(b)* gene. No visible damage, no live larvae recovered.

B. Stem section of non-transgenic control plants, Larvae were alive and had progressed to second instar. Extensive visible damage, no dead larvae recovered.

Table 8. Status of rice transgenics resistant to diseases and/or pests.

Trait	Genes transferred	Status of trials*			Reference
		Green house/ Phytotron	Field	Breeding Program	
Herbicide	*bar*	yes	yes	yes	Christou et al., 1991; Datta et al., 1992
Sheath blight	*Chitinase*	yes	yes		Lin et al., 1995
Bacterial blight	*Xa-21*	Yes			Song et al., 1996
Insect *Bt*		Yes			Wünn et al., 1996
Rice dwarf virus	*Antisense rhibozyme (S5IIIR)*	Yes	Yes		Yang et al., 1997
Tungro Disease	*RTBV-CP*	Yes			Kochko et al., 1997
Tungro Disease	*RTSV-CP*	Yes			Huet et al., 1997; Siddiqi, 1999
Leaf folder	*CryIA(c)*	Yes			Husnain et al., 1997
Striped stem borer	*CryIA(c)*	Yes			Breitler et al., 1997
Striped stem borer	*CryIB*	Yes			Breitler et al., 1997

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Chapter 13

India and the Emerging Global Rice Trade

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INTRODUCTION

India is the second largest producer of rice in the world, next only to China and accounts for about 21 per cent of the total global rice production. Indian rice exports have shown a phenomenal growth during recent years. There has been a remarkable increase in the country's forex earnings from rice exports over the past few years. In fact, rice promises to boost India's export earnings substantially during the next few years with the growing global rice markets offering plenty of opportunities in this regard. Indian rice industry is now all set to venture into new territories and ensures that by the turn of this century India gets a leading slot in the international rice trade, including the Asian region. In its export policies enunciated over the last couple of years the government has, therefore, identified rice as a major export item.

Besides India, other important players in the rice trade are Thailand, United States and Vietnam. Thailand continues to occupy the first position followed by India, Vietnam and the United States. Turn of events around the globe has placed India amongst the leading rice exporting nations for the last two to three years. It would be no exaggeration to describe India as the only country capable of making up for any shortfalls elsewhere in the international rice market. India has made a definite dent in the global rice trade and has the confidence of retaining this status provided sincere endeavour is made to remove various bottlenecks that impede the smooth flow of exports.

So far as Basmati rice is concerned, Pakistan and India are the only privileged exporters. Thai Jasmine rice is another group of aromatic rice with substantial market in some parts of the world. The competition in Basmati rice export is likely to grow stiffer in the future. Many non-traditional Basmati producing countries like the United States, Australia, etc., have expanded and intensified their Basmati rice breeding programmes. Development and patenting of a Basmati type variety—Taxmati (Basmati 6187)—by the American company Rice Tech is a glaring example of this effort. This chapter discusses India's potential as a reliable supplier of rice in the context of the changing world scenario in rice trade. Status of export and import in some major rice producing and consuming countries are also discussed in this chapter. At the same time, an endeavour has been made to bring out various constraints and opportunities in expanding rice trade to meet ever growing global demand.

TRANSFORMATION OF INDIA INTO A LEADING RICE EXPORTER

The year 1995 was witness to a capricious blend of elements, exciting as well as despairing. While some countries had to withdraw themselves from the rice export scene altogether, a few others had to, perforce, throw their rice markets open for imports. Paddy output dipped below normal levels in some of the major rice producing nations, whereas India had a bumper crop. World rice prices started moving up, while Indian prices were pegged at their lowest levels. Similarly, India had a very comfortable stock position as against China's lowest ever inventory levels. Whatever the circumstances might have been, there could be no second opinion that all the changes in the rice sector world-wide went in India's favour. Some of the key factors which positioned India in the top slot during the financial year 1995-96 are:

a) A large scale vacuum was created by China's withdrawal from the export market. The country which was a major rice exporter turned into a net importer.
b) Steady increase in Thai and US rice prices.
c) Increased demand from Bangladesh, Iran, Indonesia, Malaysia, West Africa, Philippines and African countries.
d) Food Corporation of India's decision to release rice for exports and the resultant availability of cheaper rice from India.

Favourable Policy Regime

The ability to sustain growth in exports depends on the one hand on research establishment and on the other, on supportive government policies. India, in this regard, has been very fortunate and the country has witnessed an era of a very friendly and favourable policy regime. The government has taken a series of steps to boost rice exports. Rice has been identified as a major 'export thrust' item. Various licensing and procedural bottlenecks have been done away with. The government has abolished all pricing and movement restrictions on export of rice. Import policies have been simplified for import of capital goods for the rice Industry and credit facilities have now been liberalised for exporters.

Till March 1991, exports of non-Basmati rice were not very significant. India exported a mere 25 to 30 thousand tonnes between 1987 and 1990 for the simple reason that prevailing foreign exchange rates made Indian export prices uncompetitive vis-a-vis the world rice prices. The devaluation of the Indian rupee in 1991 changed the situation rather dramatically and made Indian rice competitive in the world market. Subsequent abolition of the quota system on non-Basmati exports made things still better.

Indian Rice Milling Industry's Commitment

Ever since Indian economy started getting integrated with global economy there has been a sea of change in the mindset of businessmen and industrialists. This has led to a radical transformation in production technologies and management. The industry has opted for graders, sorters, polishers and other sophisticated processing machineries. One can form an idea of the almost frantic pace of modernisation in rice industry from the fact that during the last two years as many as eighty Sortex machines—perhaps the best colour sorters in the market today—have been installed, their prohibitive costs notwithstanding. In addition, Indian rice exporters have gone in a big way to import the best technology rice machineries from Buhlers of Germany, Cimbria of Denmark, Satake of Japan, Carter Days of United States, etc. A few exporters have even gone in for turnkey projects with these countries.

THE GLOBAL RICE TRADE

Only 6.6 % of all world rice is traded on the international market (IRRI 1998-1999). The rest is eaten in the countries where it is produced (Table 1). This makes the prospects for alleviating rice deficits through imports a bit complex. With economic growth, the comparative advantages in rice will shift to poorer countries. But as these countries struggle to feed their own burgeoning populations, will they have surplus to export?.

In view of the huge buying by various nations the global rice exports are poised to touch an all time high of about 20 million metric tonnes during 1999 as against the average of 14.5 million metric tonnes per year. This, together with the short - availability of cheaper rice from other regions has played a major role in transforming India into a leading rice

Table 1. Rice Production and Consumption in Major Countries (1989-90)

S.No.	Country	Production (Million Tonnes)	Consumption (Million Tonnes)	Consumption: Production Ratio
1	China	126.1	123.3	0.98
2	India	74.1	71.7	0.96
3	Myanmar	13.5	7.0	0.52
4	Pakistan	3.2	2.4	0.75
5	Thailand	13.7	8.6	0.63
6	USA	5.1	2.7	0.53
7	Vietnam	12.0	10.3	0.86
8	Bangladesh	18.0	17.9	0.99
9	Japan	9.4	9.7	1.03
10	Indonesia	29.1	28.2	0.97

exporting nation. Though purchases would not be at the same levels in years to come, the global demand is likely to be in the region of 17 MMT per annum in future. India, which has established its capability for supplying huge quantities of rice consistently, has a good chance to play a key role in this sector.

Quality preferences vary from country to country (Table 2). Apprecia-tion of ageing, for example, is considered a desired phenomenon in

Table 2. Preferences for particular rice types in various countries

Origin	Preference for rice types
Japan	Short grain, well-milled, new, *japonica* rice, glossy and sticky
Thailand	Long slender, well-milled, aged-*indica* soft texture; flavour and fragrance
India	
Non-Basmati	Long slender grain, flaky, high volume, also parboiled rice
Basmati	Elongation, extra long grain, soft texture, aroma
Middle East	Long grain, aromatic
China	Long slender grain, suitable for fried rice (Sew Mew), high volume
Jordan	Treated with paraffin oil (Camolino)
Papua New Guinea	Vitamin-enriched rice
Bangladesh, Sri Lanka, Nigeria, Liberia	Parboiled
Parts of Thailand & Laos	Glutinous
Surinam & Uruguay	Extra long slender
USA	
Long grain	Flaky, hard texture, suitable for meat preparations
Short grain	Soft texture
Australia	Long and short grain, soft texture
Senegal, Madagascar Mali, Mauritius, Liberia	Brokens
Italy	Short grain, chalky, neither soft nor hard

Adapted from Shobha Rani et al., 1996.

tropical Asia, but not in other countries such as Japan, Australia, Korea, China and Italy that consume *japonica* rice which is soft when cooked and relatively sticky (Yap, 1987). Strong preference exists for long grained aromatic Basmati rices in the Middle East, but this is not the case in non-traditional rice markets such as those in the west (Shobha Rani, 1996). Parboiled rice is eaten in Bangladesh, Nigeria and Liberia while glutinous rice is preferred in Thailand and Laos. Besides quality, processing, packaging type, lot size and absence of foreign matter are other consideration in rice trade.

Non-Basmati rice forms the major part of the global trade in rice. The share of Basmati and Jasmine rices is minimal. India and Pakistan contribute to the total Basmati rice in the world market, while Thailand is the sole supplier of Jasmine rice. Current scenario of non-Basmati and Basmati/Jasmine rice import and export is discussed below.

Major Importers and Emerging Markets

China

China is the largest producer of rice in the world accounting for about 35 per cent of the world paddy output. Of the total rice area in China, about 60 per cent is under the high yielding hybrid varieties. Rice production is characterised by the contract responsibility system which was started in China beginning 1980. Under this programme, land is assigned to local collectives or production units. Individual farmers are freed from communal labour to work on their own plots of land leased from the collectives. The farmers deliver a specified quota of rice to the government's Grain Bureau at a procurement price decided by the State and the quantities produced over and above the quota are sold either in the free market or to the government at negotiated prices.

As far as international trade is concerned, China National Cereals, Oil and Foodstuffs Import/Export Corporation (CEROILS), under the Ministry of Foreign Economic Relations and Trade, controls the entire rice import-export trade of the country. Presently the Chinese rice industry is characterised by decreasing stock levels caused by imbalance in supply and demand situation. Paddy production fell from 186.22 million tonnes in 1992-93 to 177.7 million tonnes in 1993-94. The reduction in output was because of adverse weather conditions as well as a shift in the farmer's interest in favour of higher quality but lower yielding varieties. On the other hand, domestic prices of rice have increased because of abolition of the rice ration scheme which has sparked off an increased import demand. In view of this, imports are projected to increase in future.

It could be said that China has played a pivotal role in changing the overall world rice scenario. The country had been exporting to the tune of about 1.5 MMT of rice per annum. However, the reduction in output and increase in prices due to floods and typhoons in the past few years in a row have pushed the country to the status of a net importer of rice and this year alone China would be importing around 2.6 lakh tonnes of rice. Though the country is trying to attain self-sufficiency, she will have to resort to imports at least for the next three years. China's earlier market share of about 1.5 million metric tonnes which was mainly going to Africa and Bangladesh will now have to be met by other countries.

Indonesia

This is an important market as far as rice is concerned. Indonesia is the third largest rice producing country in the world accounting for more than 9 per cent of world rice output. Rice is a major food crop of Indonesia with annual per capita consumption of 140-150 Kg. Over the years, Indonesia has achieved remarkable success in increasing rice production.

Over a period of time, Indonesia has entered the world rice market in a big way either by importing or exporting rice depending upon its domestic availability. During 1977-80, it was world's largest importer of rice accounting for about 20 per cent of the world rice trade. From 1985, it started exporting and again from 1995 onwards the country has been importing rice.

The country is one of the signatories to GATT which have agreed to open their rice markets for import, and as per the agreement Indonesia would be importing 9 lakh tonnes of rice per annum. However, the country has far exceeded its commitment under GATT since the actual buying by Indonesia this year are likely to be in the range of 2.5 million tonnes, the largest volume in the past decade. At this level of purchases, Indonesia which had achieved self-sufficiency in rice in 1984, has reverted to previous trade status when it was the world's largest importer of rice.

South Africa

The rice market in South Africa is very competitive. The existing players, the Thai and US exporters, are well entrenched in the market. South Africans have developed a taste for Thai glutinous rice.

Other factors which go against penetration of this market by Indian rice are:

- India suffers a freight disadvantage vis-a-vis Thailand (US$ 55 per MT as against US$ 30-40 per MT in break bulk)
- South African affinity with western culture
- Suspicious attitude towards Indian rice exports (due to bad record of non-adherence to delivery schedules and not keeping up to promised quality of rice)

Yet, this market holds a lot of potential for India. Though till now, India caters to less than 1% of market demand in the country, an appropriate marketing effort can change all that. The Basmati segment of the market is very small. Plus, India suffers a US$250-300 per MT disadvantage vis-a-vis Pakistan. Yet a niche market for rice can be developed. The awareness about Basmati as a quality rice is very high in the metropolitan cities, especially Durban. What needs to be put across is the universally accepted better quality of Indian Basmati. Thereafter an appropriate marketing strategy which positions Basmati rice brands for the elite segment of the South African society can be successful. The top segment of the society is very brand and quality conscious and price plays an insignificant role in such segments. Very high quality Basmati rice can create a super premium niche in the market and gain very high realisations. However, this market will take some time to develop.

South Africa has no local rice production at all. Yet rice is consumed in considerable quantities even though the staple diet of a majority of the population is maize. Consequently, all the domestic requirements of rice in South Africa are met through imports.

The South African rice market is overwhelmingly dominated by Thailand and the US who have 65% and 31%, respective, shares of the market. The rest of the rice is sourced from other countries like Pakistan, India and Hong Kong etc. The market is expected to grow at about 10-12% per annum.

Saudi Arabia

This is a niche market for Basmati and parboiled non-Basmati rice. India, no doubt, enjoys a clean majority of the Basmati market share, whereas the non-Basmati sector was being served by U.S.A & Thailand. The high price levels ruling in U.S.A and Thailand have given a first time opportunity for India to enter the parboiled non-Basmati market of Saudi Arabia in a big way. Total rice imports by this country stand in the region of 8 lakh tonnes per annum.

Malaysia

Rice is one of the important cereal crops of Malaysia with per capita consumption of 236 grams/day. It accounts for 80 per cent of the total cereal consumption and 57 per cent of the total caloric intake. The total rice production during 1992 was 1,211,840 metric tonnes as against the consumption of 1,573,000 metric tonnes. Thus, the domestic production meets only 77 per cent of the total demand and the rest is met by imports. A majority of consumers prefer well-milled long grain *indica* rice but ethnic consumers consider grain elongation and aroma as important attributes.

The National Paddy and Rice Authority (LPN) controls the rice trade in Malaysia. The major functions of this body include implementation of the Guaranteed Minimum Price (GMP), maintenance of stock, licensing of paddy purchase and rice sale enforcement and imports. At present, Thailand is the major exporter of rice to Malaysia meeting 80 per cent of its total requirements. Myanmar and Pakistan are the two other sources of supply of rice to Malaysia. India has also started exporting rice to Malaysia from 1987. In 1992, 38,500 tonnes of non-Basmati and 1000 tonnes of Basmati rice were sold by private exporters from India to Malaysia. Prior to 1987, rice was mainly imported on government to government basis but since 1987, the LPN has also started purchasing rice from private bodies in exporting countries.

Malaysia is expected to be an importer of rice as its requirement of rice is expected to rise every year with the growth in population and limited domestic supplies. The policy of the government is to have self-sufficiency to the level of 60-70 per cent and to import the rest.

Japan

Rice is the staple food of the Japanese. The traditional Japanese diet consisted primarily of rice and other cereals. However, after the Second World War, with the increase in the national income, there is a trend of declining consumption of rice and increasing consumption of meat and milk. In the year 1963, rice consumption was 13.41 million tonnes which came down to 10.5 million tomes in 1988.

Until the mid-l960s, Japan was a net rice importer. But increased domestic production and declining consumption forced it to ban imports. From 1967 till 1993, an average of 15,000 to 20,000 tonnes of long grain rice were imported annually for industrial use only. The Food Agency of the Government of Japan is the sole authority controlling rice imports into the country. Imports of rice are made from only those countries which are in the government's shopping list. Imports of long grain rice are being made from Thailand whereas emergency imports are made from the U.S, Australia and China. Presently, the Japanese government is being pressed by the U.S. Rice Millers' Association to open up Japan's rice market. The Japanese government has been forced to reconsider the 48-year old ban on rice imports. Under GATT agreement, Japan would be importing 4 per cent of its domestic consumption of rice during the year 1995-96, which would increase to 8 per cent by the year 1999.

Though the Japanese like only sticky short grain *japonica* rice varieties, the younger generation is gradually developing a taste for long grain varieties. This offers an excellent market for the long grained, soft structured and aromatic Indian Basmati.

There are around 80 restaurants in Tokyo and many more in other parts of Japan, offering Indian cuisine. Built for the peculiar import laws of the country they would already be importing Basmati from us directly. Since there is no provision for bulk imports of Basmati, these restaurants get their supplies from Hongkong through what is euphemistically called "the home delivery system" in which individuals are permitted to bring in 40 Kg of rice per head. But it is not only the ethnic Indians who go to these restaurants to relish Indian dishes. There has been a significant change in the eating habits of the people in the post-war Japan under Western influence. Basmati could as well benefit by this change in their outlook.

It is important to promote joint ventures exclusively for export of *japonica* varieties from India. But the most important part of the strategy has to be the government's active support to these projects in India aimed at developing rice varieties that will be acceptable to the Japanese consumer. If Switzerland can recently grant more than 3.5 million dollars for rice research to Philippines which has one of the lowest yield averages in the world, India the home of the best rice in the world is surely a much safer bet for Japan.

Iran

Iran is one of the major importers of rice, regularly buying about 8-10 lakh tonnes of rice per annum, mainly from U.S.A. and Thailand. However, the windfalls of higher price levels prevailing in these two countries have helped India to penetrate into the Iranian rice market. Sustained stay in this market would enable India to hold its present position of a leading rice exporting nation.

Bangladesh

This is another key importer of rice. The 1995 saw Bangladesh turning out to be a major buyer for India with huge shipments of rice moving from India. Total rice imports by Bangladesh during 1995 were in the region of about 10 lakh tonnes. This country which was mainly buying from China has now turned towards India owing to a nil supply position in China and large scale availability of coarse rice varieties from India. The fact that Indian rice prices continue to be the most competitive would help India to retain this market in the future also.

West African countries

This is a vast market for non-Basmati where India so far has had a meagre presence. However, with non-availability of rice from elsewhere, the region has resorted to large scale buying from India. African countries import around 3.4 million metric tomes of rice per annum.

EC countries

EC member countries import about 7-7.5 lakh tonnes of rice per annum, major suppliers being U.S.A. & Thailand. India has a limited presence in this market, exporting mainly the Basmati rices. Pending the final outcome of the EC Rice Offer under the GATT agreement, buyers in these countries were buying only bare minimum quantities. Large scale buying has once again been resumed following the announcement of EC offer. In a bid to protect the domestic rice milling industry, the European Union (EU) imposes a differential import levy on milled and dehusked rice. However, a reduction of 250 ecu per tonne on import duty for Indian brown Basmati was given by EU recognising the high price of the same. Pakistan got a reduction of 50 ecu per tonne.

Major Exporters

India

There has been a remarkable progress in our rice exports during the recent years. This assumes larger significance with increased buying interests from quality conscious markets like Europe, America, Korea, etc. Indian non-Basmati export figures have touched an all-time high of 31,00,476 tonnes during 95-96, which were so far pegged at a more or less stagnant level of 3,00,000 tonnes per annum.

The non-Basmati front has seen exciting developments and India is now being looked upon as a strong market force. In a major policy change, the Government of India had decided in April '95 to release 2 million tonnes of rice from the FCI stocks (Food Corporation of India) for exports. The idea was to reduce the excess stock holdings of FCI that were swelling at an alarming rate. Understandably, the offer came at such a time when the rice supply position was so poor in various leading rice exporting nations that it gave India an opportunity to emerge as a leading player in the global rice trade. Whether the Government proposes to continue with FCI supplies for exports in future or not, India would continue to remain in the top slot for ever. It is an avowed fact now that the world today identifies India as potentially a reliable and a perpetual supplier of all varieties of rice. The private trade had been exceedingly active.

Thailand

Thailand continues to be the world's largest rice exporter accounting for roughly 30% of the global rice exports. During the year 1995, where the world rice exports are poised to touch an all time high of 17.8 MMT, Thailand's share was 5.5 MMT. The country's main strength is its advanced milling technologies which enable them to retain their leading position at fairly good prices.

Rice is the main staple food in Thailand. About 25 per cent of a common man's budget on food is spent on rice. Rice occupies about 10 million ha of land (approximately 60 per cent of cultivated land). The share of rice production in the country stands at about 30 per cent of the value of all the food crops produced.

The government does not intervene much in marketing. The local traders purchase rice directly from the farmers through open bidding in the central markets. No tax/levy is imposed on purchase or sale of paddy/rice. The rice traders are not at all bound by any kind of restriction on movement or price of paddy/rice. The occasional purchases by the government are stored and are used for government to government exports. About 30 per cent of the rice produced is exported and the rest is retained for domestic consumption and for use as seeds. Rice is mainly exported by the private exporters while about 10 per cent of the total exports are on government to government basis. Inspection of export rice by a government agency is not mandatory. The government extends liberal credit to the exporters at a concessional interest rate of 10 per cent per annum.

In order to boost exports further, the Thai government is stated to be considering various proposals as listed below:

1. Setting up stocks abroad and appointing agents in the importing countries for taking rice to customers, instead of waiting for orders from abroad. The agents would sign consignment contracts with Thai exporters; they would take delivery of the rice but would not have to pay until the rice has been sold.
2. Rice should be stocked in Europe for re-export to west and east European markets.
3. Rice should be bartered for fertilizer and crude oil.
4. Setting up a private company run by professionals under the state supervision to handle export order on the government-to-government basis.

U.S.A.

The United States has been the second largest exporter of rice in the world accounting for almost 18 per cent of the world rice trade. However, recently the Indian rice exports have pushed U.S.A to third place, although the coming years would determine whether India manages to stay at this level. U.S.A. caters to the premium market sector offering the world's costliest long grain rice varieties, other than Basmati. U.S. long grain is sold at par or at times even at higher rates when compared with Pakistan Basmati.

Rice is the ninth major field crop grown in the U.S. with an annual production of 5.17 million tonnes. The domestic consumption of rice is around 3.1 million tonnes. The domestic consumption of rice is in the form of direct food, processed food and inputs to the beer industry. Direct food use accounts for 60-65 per cent of the total consumption of rice and the long grain rice claims the major share in it.

The United States exports almost 50 per cent of its rice production. Its rice exports are about 12 times the rice imports. Japan has been an important market for the U.S. medium grain milled and brown rice. The other major markets for the U.S. rice include Iran, Saudi Arabia, Turkey, Canada, Brazil, Peru, Belgium and Switzerland.

It appears that consumption trend in the U.S. is not likely to absorb the bulk of domestic production in the near future. As a result, the exports will continue to remain a vital means of maintaining income for the rice producers and millers.

Vietnam

The most significant development in the world rice trade in recent years has been emergence of Vietnam as a major exporter. A net importer of rice until 1988, Vietnam now ranks as the third largest exporter in the world, exporting an average of 1.8 million tonnes annually. In 1998, it accounted for 13.8 per cent share of the world rice trade.

This spectacular achievement can be attributed mainly to the reform measures undertaken by the government in the '80s. In 1981, the government introduced the contract system which gave farmers the responsibility of managing their own farms. As a result, land improvements began. While the authority to import agricultural inputs remained with the state, private trade was allowed in domestically produced inputs. Additionally, farmers were no longer required to sell a portion of their production to the state. From 1989, trade in food grains was completely privatised and the subsidised sale of rice to the army and government employees was discontinued. Thus due to a combination of policy reforms coupled with favourable weather, significant quantities of rice first became available for export in 1989.

Vietnam is largely known as the exporter of low grade rice in the international market. But gradually there has been a shift in favour of higher grades of rice in its composition of export. By virtue of its lower price policy, Vietnam would be giving stiff competition to Thailand, U.S.A. and, of course, India. It will be no wonder if Vietnam surpasses the U.S.A. in the world rice trade in the near future.

Pakistan

Pakistan is another key rice exporting nation, being India's sole competitor in Basmati exports. Rice is not the staple food of the majority of the people of Pakistan, but it is a very important foreign exchange earner; export earnings from rice being about one-fifth of the total export earnings of the country.

The General objectives of Pakistan's rice export policy are:

1. To sell in the world market the annual surplus of rice.
2. To export rice on a commercial basis, so that foreign exchange earnings can be maximised.

In Pakistan, export of rice has been in the public sector until August 1987, and RECP (Rice Export Corporation of Pakistan) enjoyed a monopolistic position. However, from July 87, export of Basmati rice was allowed in the private sector at the first instance. Then from August 90, export of all varieties of rice from Pakistan was allowed in the private sector in addition to RECP.

Main export markets for Pakistan are Malaysia, Middle East, Mauritius, U.K., USA., Canada, etc, for Basmati, and Sri Lanka, Turkey, Bangladesh, West African countries for IEEI-6 rice.

Basmati-Jasmine Rice Export

India and Pakistan are the traditional producers and exporters of Basmati type rices. The best quality rices are produced on either side of Indus River. For choicest preparations like *Biryani* and *Pulao,* Basmati rices are the most preferred and, therefore, command a very high premium in both international and domestic markets. Basmati rice is generally judged by three main factors: appearance, aroma and taste. Basmati rices are characterised by superfine grain, pleasant aroma, soft texture and extreme grain elongation with least breadth-wise swelling on cooking. The Basmati rice has traditionally been grown in the north and north-western part of the Indian sub-continent for centuries. Though a number of aromatic rices are known to be cultivated in one part or the other of India, it is only a few varieties like Basmati 370 (Punjab Basmati), Pakistan Basmati, Type 3 (Dehradun Basmati) and Karnal Local (Taraori Basmati) which fulfil the quality requirements of exports. Among the Pakistani Basmati varieties, Basmati Pak, Basmati 198, Basmati 385 and Super Basmati are most preferred.

Though paddy is grown in 14 states in India, the Basmati variety of rice, which forms the bulk of Indian exports, is concentrated in the northern belt consisting of the districts of Karnal, Ambala and Kurukshetra in Haryana, Gurdaspur, Amritsar and Pathankot in Punjab, and Dehradun, Saharanpur, Muzaffarnagar, Nainital and Pilibhit in Uttar Pradesh. The largest area under Basmati rice is in Uttar Pradesh. Basmati is also grown in Delhi, Rajashthan and Jammu and Kashmir. From a total area of 7,00,000 hectares under Basmati rice in the country, nearly 6,00,000 tonnes of milled rice is produced annually.

As for export potential, demand for superfine scented Basmati rice is on the increase in the international markets. Every year 50-70% of the Basmati rice produced in India and Pakistan is exported. During the last one decade, the export of Basmati rice from India increased more than six times from 67,100 tonnes in 1978 to 6,00,602 tonnes in 1999.

Basmati rice export from India has shown phenomenal growth in the last few years. Today, Basmati export alone has touched Rs 1866 crore (Table 3). Around 70% of the entire Basmati export from India is going to the Middle East. In addition to these countries, there is ample scope for its export to USA and the European countries, as their maximum import of rice is from India.

Table 3. Export of Basmati from India

Crop Year	Quantity (MT)	Value (Lakh - Rs.)
1993-94	527227	108125.58
199495	442125	86531.56
1995-96	373314	85066.86
1996-97	523157	124763.58
1997-98	581791	119739.64
1998-99	600602	186600.00

Since 1970, two markets have expanded particularly rapidly: Middle East and the EEC. Saudi Arabia, Iran and Iraq are the most important importers in the Middle East, and the UK and France in the EEC. Thus, there is vast scope for further expansion of Basmati exports, provided we could supply to farmers dwarf high-yielding Basmati varieties along with appropriate production technologies.

The Basmati varieties are grown in Pakistan too, which is India's major competitor in the world market. The main rice growing area are Punjab, Sindh, NWFP and Baluchistan. The trend of Basmati rice production in Pakistan is given in Table 4. During 1994-95, the total export of Basmati rice from Pakistan was to the tune of 452,300 tonnes (Khan, 1997).

India is finding herself in an extremely tight position today. The palpable threat of Pakistan to oust Indian rice exporters from the Middle East is looming large. India is experiencing the toughest and a perilous competition at the hands of Pakistan. Pakistan is all out to snatch India's Middle East and European market as she is selling Basmati at a rate which is lower than Indian by about US$550 per tonne.

Table 4. Production and Procurement of Basmati Rice (Milled) in Pakistan (1981-82 to 1993-94)

Crop Year	Production	Procurement(MT)
1981-82	1035410	388213
1982-83	987280	337482
1983-84	925800	264623
1984-85	854980	266884
1985-86	785200	230280
1986-87	791000	237200
1987-88	904000	222553
1988-89	1042000	504734
1989-90	1160000	579421
1990-91	1059000	315070
1991-92	1034000	315000
1992-93	1074000	No Procurement (All the produce was surplus by private sector's exporters)
1993-94	1214000	247756

Source: Mr. Anwar Kabir Sheikh, Chairman Rice Export Corporation of Pakistan, paper presented on Major Problems and Constraints to Expanding Inter-regional Rice Trade in Asia : Pakistan Perspective at UN; Bangkok

White long-grained aromatic rices of Thailand are called Jasmine rice. KDML 105 and RD6 are the two most preferred Thai varieties. In 1997, Thailand exported around 5.24 million tons of rice of which 2.2 million tons came from KDML 105 alone, accounting for 42 % of the total rice export. As shown in Table 5, there has been a steady growth in the export of Jasmine rices from Thailand.

Table 5. Quality of Thai Hawn Mali rice imported by selected countries (1988-95)

	Quantity of imported rice (tonnes) by		
Year	China	USA	Canada
1988	5,250	22,256	4,459
1989	6,700	96,923	18,483
1990	12,145	122,577	24,548
1991	34,818	145,015	29,453
1992	83,249	143,734	29,040
1993	91,314	168,990	31,756
1994	239,120	171,883	36,399
1995	261,553	175,036	39,407

Adapted from DIT (1996)

FALL OUT OF GATT

Signing of the GATT envisages gradual pulling down of various protectionist measures across the globe by reducing farm subsidies and export subsidies, trimming tariffs and provision of minimum access opportunities to signatory nations. The agreement is set to bring about both quantitative and qualitative changes in world trade in agro-commodities. One can expect a boom in rice trade.

Various counties have thrown their rice markets open for imports, viz. Japan - upto 8 lakh tonnes, Korea - upto 1 lakh tonne and Indonesia - upto 9 lakh tonnes per annum. All these together would push the global purchases upwards by about 3 million metric tonnes per year. India is already supplying rice to Korea and Indonesia. Japan, however, is still a distant market for us. But, here also we have an indirect advent; the purchases of Japan would create demands in other countries, and we can try to catch up with the shortfalls faced by other countries for diverting their supplies to Japan.

The impact of GATT would be felt more effectively in the next two years since there would be a gradual pulling down of subsidies. As advanced countries of America, Europe, etc. would be reducing their subsidy levels, one can expect a major shift to other activities since farming may not be a very profitable proposition. This would reduce the rice availability from these regions which would further increase global purchases. India and other rice growing countries in Asia will have the opportunity to exploit this since their subsidy levels are as such very low and no further trimming is warranted. However, the question is, will they have enough surplus to export ?

CONSTRAINTS AND OPPORTUNITIES

Exporters are faced with a widely fluctuating demand which cannot be fully anticipated because it is determined largely by the weather. Although demand is uncertain, exporters still need to have supplies of rice at hand. This requires capital as well as expertise in managing and storing supplies. Rice is a perishable product and has a fixed life-span. Kept too long or under poor conditions, pest infestation, a problem which has caused many countries to disqualify and ban rice from Asia, can occur. Pest infestation is among the main reasons why countries attempting to export from stocks normally kept for domestic food security purposes or public distribution programmes, seldom succeed except at a loss and, possibly, considerable damage to their reputation as bonafide exporters. Vietnam, India, Pakistan and newly emerging exporters such as Bangladesh and Indonesia are among the main counties where some of these problems feature strongly. Understanding and overcoming the problems exporters face in the management of export supplies, and the costs involved, are crucial for promoting export trade.

Many new exporters and even traditional ones have logistical problems in reaching buyers and ensuring timely delivery. Port congestion and untimely deliveries have often resulted in drastic delays in exports. In India, similar internal logistical and marketing problems have hampered its emergence as a major exporter despite large availabilities of rice. Most of the rice is exported from the port of Kandla, but production is widely dispersed. It may be relevant to state that in China, poor transportation and quality control have been among the main factors causing Japan to discard the rice it purchased from the country.

Rice exports, for example, in India are constrained by a lack of marketing and processing technology. Most exporters sell in bulk. Knowledge and investment in new approaches to rice marketing are still limited. Consumers, by contrast, are becoming increasingly sophisticated and unless the new trend in demand is met, exporters within the region could stand to lose future trade in rice to exporters from outside the region. Expanding the capabilities of Indian exporters to meet new demands could require a complete reorganisation of the existing processing, marketing and distribution structures. Traditional exporters of rice in bulk will have to examine the costs and benefits of expanding into the different stages of processing, packaging and exporting. Alternatively, joint investment ventures between exporters and importers could be explored, with exporters selling in bulk and assisting buying partners to pack and market the rice at the importing end.

Meeting export demands is not just a matter of increasing supplies. Exporters have to produce and supply the type and quality of rice demanded by importers. At the moment, India, for example, has one of the largest supplies of long grain *indica* rice for the export market. However, the commercial demand for *indica* rice of Indian origin from Far Eastern countries is limited, partly because the latter countries consume a different type of long grain rice. Indeed, India's rice exports, which until recently consisted mainly of Basmati rice, go mainly to the Middle East. Basmati rice produced in India and also Pakistan, has a higher amylose content and a harder gel consistency than rice grown and eaten in many Far Eastern countries. When cooked, Basmati rice elongates to twice its original length but does not expand in girth, the characteristics favoured in Northern Europe and the Middle East. In the Far East, however, a more intermediate amylose content which allows for a moist and tender rice (i.e. softer gel consistency) when cooked is preferred. Hence, for India to succeed in exporting rice to other Asian countries, it has to increase its production of *indica* rice with a more intermediate content or to engage in an extensive promotion programme of its existing varieties.

However, India alone is not facing the problem of matching supply to demand. Vietnam is another example. It produces *indica* rice but many of the varieties grown do not provide the length needed to fetch a premium price in the market. Hence, the lack of knowledge of the characteristics of the rice demanded in the international market has been a serious factor impending the correct choice of modern varieties to be grown for export. Very often, the selection of varieties to be produced is influenced by yield potential and not market demand.

For exporters to compete effectively in the market, the country has to produce at a cost that would enable it to sell competitively and still give farmers and traders a comfortable profit margin.

There are various extraneous factors that indirectly hit the international rice trade. As rice is a staple food and a source of income for the majority of farmers, governments in most of the growing countries protect both consumers and farmers from price variations by maintaining barriers between the domestic market and the international market. As a result, international trade in rice has become a function of the excess domestic supply over demand, and not in response to the world prices. Besides, the world rice market is thin in relation to world production because it has always been a residual market. Only 5-6 per cent of the annual rice production is traded internationally. The ratio of trade to production is small because the bulk of rice production occurs in the Asian countries which are also major consumers (Pingali, 1995).

Most countries have a declared policy of raising productions and achieving greater self-sufficiency. This leads to further thinning of the international rice market. As a result, countries with little resources tend to import relatively low-cost rice, while they try to maintain self-sufficiency by encouraging high-cost domestic production by extending various subsidies to the farmers.

The world rice market is also characterised by fluctuations in the participants' share in the market. The import volume of the major importing countries can get reduced to negligible figures in a matter of few years and the same holds true for the exporters as well. The absence of fixed trade channels leads to high search and transaction costs. With no central market for rice, each decision to enter the market generally requires a new search for trading partners.

Rice is not a homogenous commodity. Different varieties and grades are preferred by different consumers. Within a grade again many attributes influence the value of the given lot, resulting in large price differentials among different grades. This particular feature makes trading of rice a complicated task. Attempts have been made in the past to introduce a standardised international grading system for rice, but they have not permeated to the national level. Differences in national grading systems continue to contribute to the difficulties of buyers in international markets.

In many rapidly expanding developing economies in Asia, changes in dietary patterns have led to declines in per capita consumption for rice in recent years. With the influx of western foods and food chains, the younger generation has moved further away from a traditional rice-based diet. In some countries rice is now consumed, on average, only twice and not three times daily. The fast growing economies of the Republic of Korea, Japan, Malaysia, Singapore and Thailand have all experienced such falls in per capita consumption. In the Republic of Korea, for example, per capita consumption of rice in 1994 was just 109 kilograms per annum compared to over 126 kilograms a decade ago. Therefore, efforts to raise demand must be based on a greater understanding of rice demands and their trends as well as influences on them, because only then can ways be sought to revive demand. Investigating on how to maintain and promote per capita consumption levels may be one of the best options for promoting trade because increases in demand also help to support farm prices and production.

The market for rice, and consequently import demand, is very segmented. Meeting the demand of each country requires information and knowledge and focuses on the specific features of its rice market, but such information is available only in very broad terms. For example, rice consumed in one country may not be accepted in another. Parboiled rice is preferred in Bangladesh but is hardly eaten in South East Asian countries (Juliano et al., 1964, Azeez and Shaff, 1966). *Indica* rice commands a premium in the South East Asian market but is disliked in Japan and the Republic of Korea. Numerous varieties exist of *indica* rice but they are not all interchangeable because of differences in cooking qualities, physical appearance, alkali spread, gel consistency, per cent head rice recovery, acceptability and colour. Helping overseas markets to acquire the rice they need requires an understanding of the demand for the different rices. It is not uncommon, for example, to find the international market saturated with supplies, but not of the type of rice in demand. Detailed information on buying habits and the type and size of packaging required in retail/wholesale markets is typical of the data required. The current lack of information on consumer preference has created considerable bottlenecks in the rice trade.

US, Europe and the Japanese market—a vast untapped market so far as India is concerned—are, in particular, fastidious not only about food products being absolutely free of pests, but are also allergic to any trace of chemicals in them. The Indian farmer's traditional dependence on organic manure and his distrust of chemical fertilizers have contributed in no small measure to the low yield per hectare. But what has been a bane could now prove to be a blessing. The chemical residue free rice would be welcomed in many developed countries where health consciousness is no more a mere fad.

It is well-known that excessive use of chemical fertilizers causes loss of flavour in food; what is less known is that it can also cause loss of nutritive value and even create some serious health problems. "The use of high analysis chemical fertilizers, which is part of the modern intensive agricultural technology, had not always gone hand-in-hand with appropriate measures for soil testing and soil replenishment, with the result that, as shown by the studies of FAO (1982), there are disturbing evidences of micronutrient depletion of soils in some areas; these are likely to be eventually reflected in imparted nutritive value of food grains grown in such soils" (C. Gopalan, personal communication)

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Chapter 14

Epilogue

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In rice research, grain quality was initially overshadowed by the need for higher yields and greater pest-resistance. Food self-sufficiency for an expanding population was, necessarily, the primary goal. However, as many traditional rice importing countries achieved self-sufficiency, real rice prices declined in many Asian countries and in the world market over the last two decades. The price decline renewed interest in grain quality in international and national research programs. Although secondary to the goal of increasing and sustaining yield, grain quality improvement is important because it enhances consumer's welfare and expands market potential.

Although, aroma is an important quality characteristic of high quality rices, there has not been much progress in development of aromatic varieties so far. This may be due to the low priority given to this trait in breeding programs, and to problems of intergroup incompatibility. Basmati and many aromatic varieties belong to Group V. Crosses of Group V varieties with improved *indicas* belonging to Group I, do not yield good progenies. Efforts are being made to search for aromatic rices that belong to Group I, to use them as donors. New developments like tagging of genes for aroma, kernel elongation and other grain quality traits, and the QTLs for yield, provide opportunities for improving both yield and the grain quality.

Large variability is known to exit in the scented rice germplasm. However, due to the neglect and overemphasis on yield increases during the green revolution and after, most of them are already lost and many are at the verge of extinction. It is more true for the small and medium-grained scented rices which are mostly grown for home consumption than the long-grained basmati types which form the bulk of the rice export. Some of the locally adapted small and medium grained scented rice cultivars possess excellent aroma and other grain qualities like kernel elongation after cooking and taste, etc. These could be excellent source for improving quality in high yielding varieties. With the availability of new tools and techniques in biotechnology and wide-compatibility genes, transfer of these properties to high yielding *indicas* might not be a hurdle any more. What is required, now, is to properly understand the genetics of these traits and adopt proper breeding approach to enhance the process of breeding high yielding high quality aromatic rice varieties.

Attempts are being made to develop hybrids to improve yield and quality of aromatic rices. However, increasing yields of aromatic rices through hybrid breeding has several problems. Since the seed produced by F1 hybrids are F2, the quality of the grain is likely to be affected due to segregation. Low genetic diversity is another problem. Extensive use of the small and medium grain aromatic rices provides viable alternatives to diverse the basmati genepool. Identifying heterotic QTLs for yield from aromatic, non-aromatic rices and wild species using molecular markers and their transfer to potential lines through MAS are likely to enhance the level of heterosis in basmati hybrids. Diversification of CMS sources is another area that needs attention. Wide hybridization offers scope of diversifying CMS sources.

Our objective should not be limited to the maintenance of germplasm of the indigenous scented rices. Attention should be paid to promote on-farm conservation, their proper characterization and development of data base. There is need to identify aroma components, their distribution, and also to understand which of the synthetic metabolic pathways are involved in aroma development. Factors affecting aroma should also be thoroughly understood. Besides, using some of them as donors for specific traits, it will be worthwhile to improve some of them through purification and selection. One of the prime future concerns seems to be the ever increasing restrictions on free exchange of germplasm, an issue that needs urgent attention. Sharing of germplasm and information among the aromatic rice growing countries will enhance the process of varietal improvement.

Rice grain qualities are highly influenced by environmental factors. Each variety performs best, with respect to quality, in its own native area of cultivation. A variety can be cultivated widely without any effect on yield, however, produce from different areas will vary with respect to grain quality, especially aroma. So far while improving the aromatic rices, or defining cultural conditions for their cultivation, not much emphasis has been given to any other quality traits or factors affecting aroma and other quality traits. There is need to scientifically identify and define these factors, so that the genetic potential of different cultivars with respect to quality traits could be exploited beyond their native areas of cultivation. Genotype x Environment studies will be helpful in understanding the environmental factors influencing aroma formation as well as determining the suitability of cultivars for specific growing regions for further promotion and expansion. There is also the need to validate some of the farmers' observations on aroma and grain quality. Identification and manipulation of post-harvest features would also be quite useful.

Aromatic rices, due to their long duration, week and tall stature, and lodging susceptibility, suffer most from pests and diseases. Among the diseases, neck blast, bacterial blight, sheath blight, brown spot are most disastrous, while stem borer, leaf folder, brown plant hopper and gall-midge are the most common insect pests. Although cultivation of resistant varieties is most effective in reducing crop losses, not many such varieties are available in case of aromatic rices. Since most of the Basmati produce is exported, limited use of chemicals is recommended. There is urgent need to minimize the losses by developing integrated disease and pest management strategies. Development of multiple disease and pest resistant varieties using molecular tools without sacrificing the quality traits, offers the best opportunity.

India and Pakistan are the traditional producers and exporters of Basmati, while Thailand has been supplying Jasmine rices. Many other countries are now also trying to enter the Basmati/Jasmine rice trade, and have started vigorous quality improvement programs. As a result, besides competition, the Intellectual Property Rights (IPR) and trade and tariff related issues have cropped up creating confusion both for the exporters and the consumers. These issues need quick solutions to ensure availability of high quality aromatic rices, internationally.

Preferences for quality rices have expanded from south and south east Asia to Europe, Africa and United States. This added interest requires more efforts and research support. There is a need to establish special network for aromatic rices enjoining these regions, and improve collaboration among the scientists, institutions and countries concerned with production and export of these rices. Germplasm acquisition from all countries should be initiated and tested for their similarities and differences. Most importantly, international agreement on sharing of germplasm and information would be the key issue for scented rice improvement. Involvement of advanced laboratories would be needed to develop methods for detection of aroma and taste, and to unravel the mystery of aroma development.

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About the Editors

Dr. Ram Kathin Singh, an eminent plant breeder and rice scientist, is currently serving International Rice Research Institute as a liaison scientist for India. Dr. Singh has got more than 35 years of experience in agricultural teaching, research and extension. Dr. Singh obtained his Ph.D. degree in 1969 from Rostock University, Germany. He served Technical University, Hannover as post-doc fellow, university of Birmingham, U.K. as visiting scientist and Vietnam as FAO consultant. Dr. Singh became university professor in 1975. He served Haryana Agriculture University, Hisar as Head, Department of Plant Breeding for 4 years and Narendra Dev University of Agriculture & Technology, Kumarganj as Director of Research for 10 years and Dean, College of Agriculture for two years. Dr. Singh has authored 6 books and more than 125 research publications. He has guided 9 M.Sc. and 17 Ph.D. students. Dr. Singh has received several honours and awards including 'Honorary Senior Research Fellow' award conferred by the Academic Executive Committee of the University of Birmingham, U.K. He was nominated as a member of the U.P. Council of Science and Technology by the Government of State of Uttar Pradesh for the Year 1992-95 and Dean's Committee for State Agricultural Universities (1992) by the Indian Council of Agricultural Research.

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Dr. Gurdev Singh Khush is the world's premier rice breeder and has led the rice varietal improvement programme of International Rice Research Institute (IRRI), Los Baños, Philippines for the last 33 years. Rice varieties developed under the leadership of Dr. Khush occupy about 65 percent of the world's rice area. For his contribution to increased food supply, Dr. Khush has been honoured with world's most prestigious awards such as World Food Prize, Japan Award, Borlaug Award, Erik M. Mrak International Award, Rank Prize, Wolf Prize in Agriculture, International Agronomy Award, Friendship Medal by Government of Vietnam, Friendship Award by People Republic of China and Padam Shree by Government of India. He has been conferred honorary degrees by several universities throughout the world. Dr. Khush has been elected to world's most prestigious academies, such as US National Academy of Science, The Royal Society (London), Indian National Science Academy, The Third World Academy of Science etc. Dr. Khush obtained his Ph.D. in year 1960 from University of California, Davis, USA. He served the same university as an Assistant Geneticist up to 1967. Dr. Khush has trained more than 40 students at MSc. and Ph.D level and more than 100 for non-degree programmes from various parts of the world. He has authored/edited several books and numerous research papers.

Aromatic rices are distinct from normal rices in various ways. They have fragrance and other grain quality characteristics, and their requirements of environmental conditions are also different. They show poor compatibility with *indica* and *japonica* rices; are low yielder but highly priced and are traded internationally. They require separate dealing. Present publication is the first complete and comprehensive attempt in this direction. It provides in-depth and critical information on all aspects of aromatic rices like taxonomy and origin, estimation of quality traits, chemistry and biochemistry of aroma, genetics and molecular biology, breeding, factors affecting aroma and other quality traits, crop protection, status of aromatic rice research and development in different countries and international trade. The eminent scientists from various aromatic rice growing countries who are actively involved in research on aromatic rices contribute individual chapters. Editors themselves are actively involved in research on aromatic rices. Book is intended for a wide range of readers like researchers, extension workers, traders, agricultural policy makers and teachers and students of agriculture, plant breeding, plant pathology and botany. The book is not merely a review but it is a collection of most comprehensive, analytical and thought-provoking articles giving due weightage to authors' own perceptions and views on the present status as well as future outlook, including problems requiring immediate attention of scientists, policy makers and traders.

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