CHAPTER FOUR

Basmati Rice in the Indian Subcontinent: Strategies to Boost Production and Quality Traits

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Abstract

Basmati rice has long been popular in Asia due to its distinctive natural aroma and characteristic elongation of grains after cooking. Demand for Basmati is increasing worldwide, especially in the Middle East, Europe, and the United States. Basmati rice from India and Pakistan earns almost three-times the price of high quality non-Basmati rice in the domestic and the international markets. Despite this, the development of high-yielding Basmati rice varieties has not kept pace with indica rice because of its incompatibility with improved indica, resulting in highly sterile crosses of indica x Basmati. Polygenic control over some of the quality traits in Basmati rice is another limitation, complicating attempts to combine desirable traits such as high yield, superior cooking quality, and resistance to biotic and abiotic stresses. In this article, an attempt has been made to review the historical development of Basmati quality and aroma traits in the Indian subcontinent under different environmental and agronomic conditions. Special emphasis is given to the problems and prospects of Basmati rice breeding, with reference to trade, policy, marketing, and future research programs.

1. INTRODUCTION

Aromatic rice (*Oryza sativa* L.) varieties fetch high prices in agricultural markets worldwide, particularly the Jasmine and Basmati varieties. Exquisite aroma and unique cooking properties make Basmati rice a premium agricultural commodity. Locally known as "scented pearls," Basmati rice is endemic to the Indian subcontinent, where it has been cultivated by farmers for over 250 years (Nene, 1998; Singh and Singh, 2009; Siddiq et al., 2012). Basmati rice occupies premier place as specialty rice cultivated in the Indian subcontinent; thus, its production and improvement are of interest to the region. It is an important commodity in the international market, prized for its distinct and pleasant aroma, fluffy texture, palatability, easy digestibility, long shelf life, and volume expansion during cooking—which is characterized by linear kernel elongation with minimum breadth-wise swelling (Shobha-Rani et al., 2006). Basmati rice has a metallothionein-like protein composed of a sulfur-containing amino acid (cysteine),which aids in iron absorption (Chaudhary and Tran, 2001; Salgotra et al., 2015). In India, Basmati has been grown for centuries in the states of Jammu and Kashmir, Himachal Pradesh, Punjab, Haryana, Delhi, and Western Uttar Pradesh (Singh and Singh, 2009). Similarly, Basmati rice plays an important role in the livelihood of people in Punjab, Pakistan (Ashfaq et al., 2015). About 94% of the rice grown in Pakistan is produced in the Punjab province, in the traditional *Kalar* tract located between the Ravi and Chenab rivers, comprising the districts of Sialkot, Gujranwala, Hafizabad, Narowal, Mandi Bahauddin, Lahore, and Sheikhupura.

The word Basmati is derived from two Sanskrit words, *vaas* (fragrance) and *matup* (possessing). In north India, "*va*" is pronounced as "*ba*," and hence *Vaasmati* changed into Basmati (*Bas* means fragrance and *mati* means queen) (Singh and Singh, 2009; Siddiq et al., 2012). Besides these unique features, Basmati rice has a low glycemic index (Foster-Powell et al., 2002), but it is rich in micronutrients such as iron and zinc (Gregorio, 2002). More than 90% of the Basmati rice produced in India is grown in the states of Punjab, Haryana and Uttaranchal. In Pakistan, approximately 95% of Basmati rice is produced in the Punjab province (Ashfaq et al., 2015).

Basmati rice is accepted as a specialty rice all over the world and belongs to a unique varietal group that became distinguished as a result of natural and human selection (Siddiq et al., 2012). Unlike other types of aromatic rice, the unique quality traits of Basmati rice are expressed only when grown in the north-western foothills of the Himalayas (Singh and Singh, 2009). Owing to the geographic specificity regarding the manifestation of its unique quality features, Basmati rice is now considered a geographical indication (GI) of the Indian subcontinent. Until the 1960s, Basmati rice was grown as a strategic commodity by a small number of farmers in the region due to its price advantage (Leaf, 1984). Basmati rice, once enjoyed by the affluent class as a local delicacy, has transformed itself into a large-scale commercial crop due to expansion and intensification of irrigation facilities in the 1950s and 1960s. This transformation, accompanied by trade liberalization, has made Basmati rice a global commodity with consumers in Europe, the Middle East, and the United States (Singh and Singh, 2009).

Averaged over the period 2004—14, Basmati rice represented 43.7% of total Indian rice exports (Satishkumar et al., 2016). Basmati rice from India is mainly exported to the Middle East (Iran, Saudi Arabia, Iraq, Kuwait, and the United Arab Emirates). Iran and Saudi Arabia together account for over

Table 1 Export of Basmati Rice Over Years in India

Year	Basmati Rice (MT = Metric Tons) (000 tons)	Total Rice (MT = Metric Tons) (000 tons)	% Basmati Rice	Export Price (USD)	Value (Million USD)
2000–01	851.7	1534.5	55.50	556.7	474
2005–06	1166.6	4088.2	28.53	589.2	687
2010–11	2370.6	2471.3	95.92	1050.8	2491
2014–15	3702.3	11,976.3	30.91	1220.3	4518
2015–16	4045.8	10,412.3	38.85	859.6	3478
2016–17	4000.4	10,821.2	36.96	807.5	3230

Source: Data from APEDA, 2017. India Export of Agro Food Products: Product Group Report/ Country Wise–Basmati Rice.

50% of Basmati rice exports from India. Although the share of Basmati rice by volume is about 6% of the total rice produced in India, it accounts for 57% of India's total rice export. It is pertinent to mention here that Basmati rice export, in terms of monetary value from India, has increased at a compound annual growth rate of 27%, which has increased from USD 687 in 2005–06 to USD 4518 in 2014–15 (Table 1). In terms of quantity, Basmati rice export from India increased by 370% during 2016–17 as compared with 2000–01 (Table 1). During the same period, the export price of Basmati rice increased by 45%, although it was highest during 2014–15. The percentage of Basmati rice to total rice export from India was 95% during 2010–11; however, in recent years, it varied from 30% to 40% (Table 1).

Basmati rice is also the main export item of Pakistan, accounting for 3.1% of value added in agriculture and 0.6% in gross domestic product. Pakistan is the second largest exporter of Basmati rice in the world and exports the bulk of its Basmati rice to the Middle East, North America, and Europe. Traditionally, Basmati rice exports from Pakistan account for 6% of the total annual export earnings. It is the second major export commodity from Pakistan after cotton. The United Arab Emirates, Malaysia, Bangladesh, Iran, Indonesia, and Saudi Arabia import Basmati rice from Pakistan. In 1980, the rice export value was negligible and stood at USD 385 million; however, the export value has since increased to USD 2.2 billion in 2010. Such a transformation was in part due to the evolution of high-yielding Basmati rice varieties such as Basmati 385, the development of the private sector in 1988, and strong expansion of the sector starting in 1992.

Table 2 Export of Basmati Rice Over Time in Pakistan

Year	Basmati Rice (MT = Metric Tons) (000 tons)	Total Rice (MT = Metric Tons) (000 tons)	Basmati Rice (%)	Export Price (US$)	Value (Million US$)
2000−01	347.1	2139.3	16.22	492.2	171
2005−06	742.0	3591.7	20.66	570.9	424
2010−11	1137.9	3701.6	30.74	837.2	953
2014−15	676.6	3731.3	18.13	1007.3	682
2015−16	503.0	4262.2	11.80	905.0	455
2016−17	428.9	3327.0	12.89	865.5	371

Source: REAP (Rice Export Association of Pakistan).

The price of Basmati rice is highly vulnerable to cyclical price fluctuations. The high price of Basmati rice in the market in a particular season encourages farmers to grow more Basmati rice in the next season, resulting in increased supply and decreased price. This process sometimes discourages farmers from Basmati cultivation because of its low yielding ability as compared with coarse grain rice varieties. Therefore, Basmati rice is a profitable venture only if farmers get a high price for it.

Basmati export accounts for 13%−18% of total rice production in Pakistan. The international market for Basmati rice in Pakistan was highest during 2010−11, and thereafter, it decreased sharply (Table 2). During 2005−06, the Indian and Pakistan Basmati export markets were valued at USD 687 and 424 million, respectively. However, during 2016−17, the Indian Basmati export market took a quantum leap, increasing to 4.7 times the value in 2005−06; conversely, the Pakistan Basmati export market decreased during the same period. During 2015−16, Pakistan's Basmati rice export declined by 26% in quantity and 33% in terms of monetary value as compared with 2014−15 (Table 2). This was mainly due to the great demand for Pusa Basmati 1121, which captured a huge market in the Middle East due to its characteristic elongation after cooking.

The probability of retention with Saudi Arabia and Iran was found to be 93% and 85%, respectively; and these trends indicate that Iran and Saudi Arabia were the most stable markets among major importers of Basmati rice from India (Table 3). The probability of retention with United Arab Emirate, Iraq, and Kuwait was found to be 66, 59%, and 18%, respectively, indicating that these countries were also important Basmati import markets for India. Recently, the demand for Indian Basmati rice has increased manifold in countries such as the Netherlands, Jordan, and Yemen (APEDA, 2017).

Table 3 Basmati Rice Export From India to Different Countries and Transitional Probability Matrix

	Iran	Iraq	Kuwait	Saudi Arabia	United Arab Emirate	Others
Iran	0.93	0.07	0.00	0.00	0.00	0.00
Iraq	0.41	0.59	0.00	0.00	0.00	0.00
Kuwait	0.00	0.00	0.18	0.00	0.82	0.00
Saudi Arabia	0.00	0.00	0.09	0.85	0.00	0.05
United Arab Emirate	0.56	0.00	0.05	0.00	0.66	0.23
Other	0.02	0.00	0.05	0.16	0.00	0.76

The row elements indicate the information on the extent of loss in trade while competing with other countries. The columns element indicates the probability of gains in volume of trade from other competing countries. The diagonal element indicates probability of retention of the previous year's trade volume by the respective country.
Source: Modified from Satishkumar, M., Harishkumar, H., Rangegowda, R., 2016. Growth, export performance and competitiveness of basmati and non-basmati rice of India-an Markov chain approach. Int. J. Agric. Environ. Biotechnol. 9, 305–311.

2. BIOCHEMICAL BASES OF AROMA IN BASMATI

The aroma of Basmati rice is a key factor that drives its high price in the market. Genetic and environmental factors influence the retention of aroma. Khush and Dela Cruz (1998) suggested that aroma in Basmati rice is a qualitative trait, as segregation was observed in crosses of indica and Basmati rice. However, they postulated that the genotype x environment component played a large role in the expression of aroma. Aroma develops from a combination of more than 100 volatile compounds (Lewinsohn et al., 2001). Among over 100 volatile compounds that constitute aroma in rice, 2-acetyl pyrroline (2-AP) is principally responsible for the unique popcorn fragrance of Basmati rice cultivars (Buttery et al., 1983; Petrov et al., 1996). The detection of this compound has been reported in different parts of rice plants, except for the roots (Lorieux et al., 1996).

The structure of 2-AP consists of a reactive methyl ketone group and a nonreactive pyrroline group (Nadaf et al., 2006). With the advent of molecular maps and genomic sequences, a major gene for rice aroma was discovered on chromosome 8 (Sakthivel et al., 2009). The allelic variation at *badh2* (betaine aldehyde dehydrogenase homologue 2; a gene with 15 exons) controls the aroma in Basmati rice (Bradbury et al., 2005; Sakthivel et al., 2009). A full length of *badh2* protein results in nonfragrance. An 8 base pair deletion and three single nucleotide polymorphisms (SNPs) in exon 7, and a 7 base pair deletion in exon 2, is associated with fragrance in rice grains (Chen et al., 2008; Shi et al., 2008). These functional polymorphisms are conducive to truncation of the betaine aldehyde dehydrogenase enzyme and are responsible for loss-in-function induced accumulation of 2-AP in aromatic rice. This notion was supported by the recent work of Shao et al. (2013). These authors genotyped 516 fragrant rice accessions and reported that 80% of them possessed the *badh2.7* allele. Although studies have identified 2-AP as the major aroma compound in rice, with L-proline acting as its precursor (Sakthivel et al., 2009), the biochemical pathway for synthesis of 2-AP remains elusive (Fitzgerald et al., 2009). These results indicate that genome editing of very high-yielding nonaromatic rice cultivars could be a powerful approach to convert nonaromatic rice into aromatic rice.

According to Bradbury et al. (2008), the γ-aminobutyraldehyde (GABald) is an effective substrate for *badh2*, and its accumulation and spontaneous cyclization to form Δ^1-pyrroline due to a nonfunctional *badh2* enzyme is responsible for 2-AP accumulation in rice. Huang et al. (2008) revealed the increased expression of Δ^1-pyrroline-5-carboxylate synthetase in fragrant varieties compared with nonfragrant rice varieties, as well as concomitant elevated concentrations of its product, and concluded that Δ^1-pyrroline-5-carboxylate, usually the immediate precursor of proline synthesized from glutamate, reacts directly with methylglyoxal to form 2-AP, with no direct role proposed for *badh2*. Loss of enzyme function leading to the development of aroma explains the recessive nature of this trait. Nevertheless, this phenomenon could not be accepted as universal because most of the varieties were still fragrant without mutation involving 8 base pair deletions in *badh2* (Sakthivel et al., 2009); so there are probably other genes involved.

Most scientists believe that fragrance in Basmati rice is controlled by a single recessive gene. The study by Sood and Siddiq (1978) revealed that aroma in aromatic rice was a highly heritable trait and could be under the control of one to four genes, depending on the population studied. But there is growing evidence to suggest that this trait is controlled by quantitative trait loci (QTLs). Three QTLs for aroma, one each on chromosome 3, 4, and 8, have been identified in Basmati rice varieties (Amarawathi et al., 2008). It seems that besides 2-AP, numerous volatile and semivolatile compounds, either in association with a single predominant compound or a complex mixture of several compounds, might be involved to produce the characteristic flavor and strength of aroma in fragrant rice. Examples of such compounds include alkanals, alk-2-enals, alka-2,4-dienals, 2-pentylfuran, and

2-phenylethanol. Jezussek et al. (2002) found several other compounds, such as 2-amino acetophenone and 3-hydroxy-4,5-dimethyl-2(5H)-furanone (found at high levels in Basmati 370).

3. DEFINITION OF BASMATI RICE

The region encompassing India and Pakistan is the ancient home of Basmati cultivation, and the name Basmati is traditionally associated with this specific geographical location (Bligh, 2000). Despite cultivation of Basmati rice in Northern India and the Pakistani Punjab for millennia, there was no legal definition of Basmati rice until it became a major export commodity with consumer expectations and preferences, and new varieties were released to boost production and export. The critical issue in this regard was how to define a list of varieties that can qualify as "Basmati." A precise and legal definition might be that the name Basmati is used only for genuine Basmati, differentiating Basmati rice from non-Basmati aromatic rice varieties (e.g., Jasmine). After many meetings and much discussion by the Government of India, *the Export Act 1963* was modified to arrive at this precise definition of Basmati rice (notification 63, *Export Act* 2003):

> *Basmati rice is grown in the Indo-Gangetic Plains and has the following characteristics: exceptional length of grain, which increases substantially after cooking, the cooked grain has high integrity and high discreteness and distinctive aroma, taste and mouth feel; it is a traditional variety or is an evolved variety. A traditional variety shall mean land races or varieties of rice of uniform shape, size, and color traditionally recognized as Basmati and evolved Basmati shall mean a variety whose one of two parents is a traditional variety and which has been recognized as a Basmati variety under any law for the time being in force (http://www.eicindia.gov.in/eicold/eic/qc&i/enotfn-rice-68.htm).*

This definition is now also accepted by the Government of Pakistan. Key parameters to qualify rice as Basmati rice are given in Table 4. For Indian Basmati, the variety should be either traditionally known as "Basmati" or evolved through a breeding process. The idea is to qualify all varieties as Basmati provided the genealogy contains a Basmati variety (whether traditional or evolved, as notified under the *Seed Act 1966*), to pass on the quality genes of Basmati to a newly evolved variety. To be considered Basmati, one of the parents must be a traditional variety. It is compulsory for each variety to be tested and evaluated through National Basmati Trials (NBTs) as part of the All India Coordinated Rice Improvement Project, Hyderabad, Indian

Table 4 Parameters for Defining Basmati Rice Variety in India

Parameters[a]	**Value**
Minimum average precooked milled rice length (mm)	6.61
Average precooked milled rice breadth (mm)	≤2.00
Minimum length/breadth ratio (L:B) of precooked milled rice	3.50
Minimum average cooked rice length (mm)	12.00
Minimum cooked rice length/precooked rice length ratio or minimum elongation ration	1.70
Average volume expansion ratio	>3.5
Aroma	Present (qualitative sensory analysis as panel test[b])
Texture of cooked grain for high integrity (without bursting the surface), nonstickiness, tenderness, good taste, and good mouth feel	Present (qualitative sensory analysis as panel test[b])
Amylose content range (%)	20–25
Alkali spreading value range (score)	4–7
Minimum brown rice recovery (%)	76
Minimum milled rice recovery (%)	65
Minimum head rice recovery (%)	45

[a]The grain sample for analyses will necessarily have to be "aged" for 3 months under protocol conditions at normal room temperature as milled kernel.
[b]As per standardized protocol (Indian Institute of Rice Research, Hyderabad).
Source: The quality standards approved by Government of India and accepted in the global trade (Anonymous, 1998. Quality standards of Basmati rice approved by Government of India. In: Proc. 33 Rd Annual Rice Group Meeting Held on 15–8 April, a Punjab Agriculture University, Ludhiana, India, 1–1560; Anonymous, 2008. Result Cited from Progress Report 2008 (1) Varietal Improvement AICRIP, DRR, Hyderabad, 1-1302).

Council of Agricultural Research (ICAR), released/notified under the Seed Act 1966 of India (54 of 1966) and amendment made therein (APEDA, 2017; Anonymous, 1998, 2008).

A similar approach prevails in Pakistan, where the only traditional variety is Basmati 370 (developed through pure line selection), whereas the remaining varieties evolved as part of the quest for higher yields but possess Basmati quality genes. Pakistan filed an application for GI of Basmati as a collective trademark under section 82 of the Trade Marks Ordinance 2001 in December 2005, in the form of a regulation (Marie-Viven, 2008). According to this regulation, Basmati should have at least one parent of a historical land race Basmati variety and must historically be cultivated in a designated district of Punjab. Thus, the varieties claimed are Basmati 370, Basmati Pak (Kernel), Basmati 198, Basmati 385, Super Basmati, Basmati 2000, and

Shaheen Basmati. Basmati is also defined according to its elongation ratio, grain length, amylase content, length/breadth ratio, gel consistency, gelatinization temperature, aroma, shape, and appearance (Akram, 2009). Concerning the innovation in varieties, the application mentions that Basmati shall also include all other varieties of Basmati rice approved as such by the relevant authority (Marie-Viven, 2008).

The variety should be suitable to be grown in the Indo-Gangetic Plains (IGP) of India of GI of Basmati growing areas, recommended for cultivation and for its denomination as a Basmati variety. For Indian Basmati, the variety should be evaluated under NBTs for quality parameters with a minimum aging of 3 months after milling by the identified laboratories, as an integral data component involved in decision-making (Singh and Singh, 2009). The sample for the testing would be direct harvest from the current seed batch being used for the corresponding trial from the location specified by the Indian Institute of Rice Research (IIRR) within the GI area. During evaluation and decision-making for promotion and identification/release, the quality standard will have to be met and supported by a desirable range of expression of other ancillary characters as mentioned in Table 4. It should fulfill the quality parameters of primary and ancillary characters as a prerequisite as mentioned above that has to be verified by one or more laboratories identified by the IIRR, Hyderabad, ICAR, for the purpose. The variety should be proposed for release/notification with the term "Basmati" in the body of denomination of, along with its initial evaluation trial number in parenthesis (Singh and Singh, 2009).

In Pakistan, Basmati varieties are registered under Section 8 of the Seed Act of 1976 (amended in 2015). The candidate lines and varieties undergo regional adaptability trials and national uniform rice yield trials. The Federal Seed Certification and Registration Department (FSC&RD) and the Pakistan Agriculture Research Council, under the umbrella of the Ministry of National Food Security and Research (FSC&RD), appraise these Basmati varieties regarding Value for Cultivation and Use and Distinctness, Uniformity and Stability. The salient agronomic, botanical, and kernel quality traits are recorded according to descriptions established by the FSC&RD and compared with the existing commercial variety (check). The varieties found acceptable are recommended to the National Seed Council for confirmation of the registration. The registered varieties become eligible for quality control through the FSC&RD. On approval by the FSC&RD, varieties are notified in the Official Gazette and entered into the National Register with the issuance of a Registration Certificate (Anonymous, 2017a).

4. GENETICS AND BREEDING OF BASMATI RICE

There are 24 valid species that constitute the genus *Oryza*. Among the 24 species, *Oryza sativa* and *Oryza glaberrima* are the cultivated species and were derived from *Oryza rufipogon* and *Oryza longistaminata*, respectively (Vairavan et al., 1973). Since their origin and domestication, the Asian cultivars have separated into three distinct ecogeographical subspecies, viz, indica, javanica (tropical japonica), and japonica (temperate japonica) (Vairavan et al., 1973; Singh et al., 2000; Siddiq et al., 2012). On the basis of isozyme analysis, Asian cultivars have been differentiated into six varietal groups viz, indica, ashina, aus, rayada, aromatic, and japonica. Recent molecular characterization of the Basmati group reveals that it is related to the japonica group, contrary to the belief that it is closely related to the indica group by virtue of its grain shape (Garris et al., 2005; Kovach et al., 2009). Further studies revealed that traditional Basmati varieties are distinct from non-Basmati rice and might be derived from a Dehraduni Basmati or Punjab Basmati common parent, and the small amount of genetic variation in these genotypes could be the result of selection practiced over years. Studies on genetics and breeding behavior of the key traits in Basmati quality analysis revealed that all quality characteristics are polygenically controlled except aroma. High kernel elongation after cooking is basically a genetic trait but highly influenced by environmental parameters, aging, etc. Information is very limited on the inheritance of kernel elongation after cooking in Basmati rice. Kumar and Khush (1986) reported that variation in the quantity of the amylose gene in the endosperm caused variation in amylose content. Information about the factors influencing gel consistency is also lacking for Basmati rice. Khush et al. (1979) suggested that gel consistency is an important indicator of cooked texture, e.g., IR 5 and IR 8 had similar amylose content, but in a panel test IR 5 was preferred to IR 8 due to its softer consistency.

In 1926, systematic work on improving Basmati rice cultivars was started by pure line selection at the Kala Shah Kaku Research Institute (KKRI), now situated in Pakistan. The identification of Basmati 370 was the most successful example of pure line selection in Basmati rice at KKRI, selected from a locally adapted landrace by Sardar Mohammad Khan in 1933. The pure line strategy went on to develop Dehradun Basmati, Taraori, and Basmati 386 (Singh and Singh, 2009). These varieties, although superior from a quality point of view, were poor yielders and were also tall and susceptible to pests and diseases.

4.1 Varietal Development of Basmati Rice in India

After independence, the work on varietal improvement in Basmati rice in India was initiated in the 1960s by Dr. M.S. Swaminathan at the Indian Agricultural Research Institute (IARI), New Delhi. Subsequently, other universities started their own breeding programs for Basmati rice, mainly Punjab Agricultural University (PAU), Chaudhary Charan Singh Haryana Agricultural University, and Govind Ballabh Pant University of Agriculture and Technology. Traditional Basmati varieties were tall, slow maturing, prone to lodging, very poor yielders, and susceptible to bacterial blight and stem borers. Breeding efforts were undertaken to solve these issues in Basmati rice (Siddiq et al., 2012). The major breeding methodology has been hybridization followed by the pedigree method of selection. A mutation breeding program for improving Basmati cultivars has also been started but has so far remained unsuccessful. In the beginning, improvement of Basmati rice was very slow due to F_1 sterility, lack of understanding of Basmati quality characteristics, lack of reliable and rapid methods of quality evaluation, and the polygenic nature of Basmati grain and cooking characteristics (Khush and Juliano, 1991; Siddiq et al., 2012). However, in recent years eight institutions in the northwestern part of India have made significant improvements to Basmati cultivars. Combining conventional and molecular breeding has opened the door to incorporating a resistance gene against bacterial leaf blight (BLB) and blast diseases in Basmati rice. With the help of marker-assisted selection (MAS), bacterial blight (Xa 13, Xa 21), blast (Pi54, Pi9, Pita, Piz 5, Pib, and Pi5), sheath blight (qSBR11-1), and brown plant hopper (Bph 21, Bph 20, and Bph) resistant genes have been transferred into a number of Basmati varieties, namely Pusa Basmati 1, Punjab Basmati 3, Punjab Basamti 4, Punjab Basmati 5, Pusa Basmati 1121, Pusa Basmati 6, and Pusa Basmati 1121 (Siddiq et al., 2012; Bhatia et al., 2011). With the development of advanced breeding techniques, a major QTL for salt tolerance (Saltol) has also been transferred to mega Basmati varieties, Pusa Basmati 1121 and Pusa Basmati 1(Krishnan and Singh, 2016), which are widely grown in northwest India. It is worth mentioning here that 40% of the rice-growing area in northwest India has problematic soils due to brackish water used for irrigation, necessitating the development of salt-tolerant varieties. Recently, MAS focused on transferring genes for multiple biotic stresses has resulted in the development of a new Basmati genotype, Pusa Basmati 1608, which has a number of disease-resistant genes (Xa 13 and Xa for BB resistance; Pi 54 for blast resistance; and major QTL qSBR11-1 for sheath blight resistance) (Singh et al., 2012).

Phosphorus is a costly fertilizer and efforts are being made to increase its efficiency through breeding approaches. Pup1 (phosphorus, P, uptake 1), a major QTL conferring tolerance to P deficiency in rice (Wissuwa et al., 1998), has been fine mapped to the 130 kb region by International Rice Research Institute (IRRI) scientists (Chin et al., 2010). Recently, it was found that all Basmati/aromatic rice types have Pup 1, whereas nonaromatic varieties lack Pup 1 (Singh et al., 2011a); so, this finding may be useful in developing new Basmati genotypes with high P-use efficiency in future. MAS is also being utilized for improving the milling quality of rice and for increasing the grain numbers in panicles. Recently, a major QTL for milled rice length was mapped on chromosome 3 of a population of Pusa Basmati 1121, explaining 74% or phenotypic variance (Singh et al., 2011a). A local genotype of Basmati was collected from Karnal and promoted by IARI for improving quality traits in Basmati rice. At the initiative of IARI, it was accepted as a quality check in Basmati trials. In 1996, the same material was released as Taraori Basmati and Basmati 386 in Haryana and Punjab, respectively. Basmati 370 and Type 3 were popular for trade and in Basmati improvement (Singh and Singh, 2009). Since then, a large number of Basmati varieties have been developed.

Accepted Basmati varieties include the traditional rice varieties Basmati 217, Basmati 370, Taroari Basmati (HBC-19, Karnal local), Basmati 386, and Ranbir Basmati and the evolved group, Punjab Basmati 2, Punjab Basmati 3, Pusa Basmati 1, Kasturi, Haryana Basmati 3, Yamini, Pusa Basmati 1121, improved Pusa Basmati 1, Pusa Basmati 6, and Pusa Basmati 1509 (Siddiq et al., 2012). In the last two decades in India, the yield of Basmati rice has doubled and milled rice kernel length increased from 6.89 in Basmati 370 to 8.61 in Pusa Basmati 1509. Linear cooked kernel elongation has almost doubled (Table 5). This improvement has driven increases in Basmati export from India and helped in doubling the income of Basmati growers. The "Basmati revolution" is considered an established fact by the ICAR.

To break the yield barriers in pure line Basmati varieties, research on hybrid rice development was initiated at IARI, New Delhi. In this direction, the world's first superfine grained aromatic rice hybrid "Pusa RH 10" was developed that was derived from the cross of Pusa Sugandh 2 and cytoplasmic male sterility (CMS) line Pusa 6 A. In 2001, the central varietal release committee of India released this hybrid for the irrigated regions of

Table 5 Agronomic and Quality Traits of Popular Basmati Varieties in India

Cultivar	Plant Height (cm)	Growth Duration (days)	Yield (t ha^{-1})	Milled Rice Kernel Length (cm)	Milled Rice Kernel Breadth (cm)	Kernel Length After Cooking
Basmati 370	170	145	2.50	6.89	1.70	11.50
Taraori	175	155	2.00	7.35	1.75	13.65
Pusa Basmati 1	95	135	5.40	7.66	1.70	16.65
Pusa Basmati 1121	120	140	4.60	8.45	1.90	20.50
Pusa Basmati 6	90	150	5.65	7.85	1.65	18.00
Pusa Basmati 1509	90	125	6.25	8.60	1.85	21.00
Basmati 386	156	142	2.60	7.90	1.62	15.0
Punjab Basmati 3	135	140	3.70	8.56	1.60	15.1

Source: Data from APEDA, Ministry of Commerce, Government of India.

Haryana, Delhi, and Uttaranchal. Pusa RH 10 had higher yield (20%—30%) as compared with Pusa Basmati 1, with little penalty of quality characteristics. These days, Basmati hybrids are being attempted by using CMS lines, that is, Pusa 6A, 7A, 8A, 9A, 10A, and 11A, in combination with several Basmati-like restorers. Research has been initiated to develop a disease and insect pest—resistant parental line for the development of additional CMS lines. The IRRI has also developed few restores and CMS lines from aromatic rice, such as IR67684A, IR68280A, IR68281A, IR69617A, and IR70372A. These lines were identified with moderate to strong aroma and higher grain elongation than Basmati 370 (Siddiq et al., 2012).

To date, about 29 Basmati varieties have been notified in India and these are being utilized for domestic purposes and international trade (APEDA, 2017). An intensive program on Basmati rice breeding has led to the development of a landmark rice variety, Pusa Basmati 1121, which was developed by the IARI, New Delhi. This proved to be a high-yielding unique Basmati rice variety with extra-long slender grains, exceptional kernel length after cooking (22—25 mm), intermediate amylose content, high cooked kernel elongation ratio (2.5 times), high volume expansion after cooking (>4 times), and a strong aroma (Singh et al., 2002). These unique properties of Pusa Basmati 1121 have caught the fancy of traders worldwide. Currently, Pusa Basmati 1121 occupies 1.35 million ha, comprising about 70% of the area under Basmati cultivation in India (Singh and Krishnan, 2016). It was estimated that Pusa Basmati 1121 contributes approximately 4 million tons to Basmati rice production annually in India. With the recognition of Pusa Basmati 1121 as an evolved Basmati variety during 2008, the forex earning due to trade of Pusa Basmati 1121 from India has risen from USD 0.67 million to USD 4.5 billion in 2014–15 (APEDA, 2017), which includes a contribution from Pusa Basmati of about 65%. This variety has not only revolutionized the international Basmati rice trade but has also improved the livelihood of millions of Basmati growers in India. The Basmati varieties notified by the Government of India are depicted in Table 6.

4.2 Varietal Development of Basmati Rice in Pakistan

Breeding for short stature, early maturity, and higher yield remain the major objectives of Basmati rice breeding programs in Pakistan. The introduction of short duration varieties of rice led to a substantial increase in productivity; nevertheless, the inferior grain quality of these varieties failed to meet consumer preferences. Attempts to develop early maturing and high-yielding Basmati rice varieties by incorporating genes from semidwarf non-Basmati were difficult and slow due to genetic differences between the two varietal groups (Rashid et al., 2003; Bashir et al., 2007; Siddiq et al., 2012). In spite of immense genetic diversity, only a small fraction of available germplasm has been exploited in coordinated breeding programs. Consequently, high genetic similarity was observed in Pakistani Basmati rice varieties. In Pakistan, out of seven commercial Basmati varieties, five have Basmati 370 as one of the parents (Rabbani et al., 2008). Zafar et al. (2004) postulated the need to broaden the genetic base of rice crop by introgressing genes from diverse landraces. Conscious and continuous selection by humans for an array of preferences is an important aspect of genetic diversity and could be utilized in Basmati breeding programs. Susceptibility to different biotic (insect pests and diseases) and abiotic stresses (drought, salinity, and water logging) has been acknowledged as a crucial factor for lower yield of Basmati varieties. To address these issues, various approaches such as traditional breeding, mutation breeding, somaclonal variation, wide hybridization, and plant transformation have been employed (Bashir et al., 2007). Traditional breeding succeeded in developing a number of famous Basmati varieties. However, six varieties developed through mutation breeding and one through somaclonal variation failed to contribute significantly to the national economy,

Table 6 Notified Basmati Varieties in India

S. No.	Variety	Notification No. and Date
1	Basmati 217	4045—24.09.1969 361 (E)—30.06.1973
2	Basmati 370	361 (E)—30.06.1973 786—02.02.1976
3	Type 3 (Dehraduni Basmati)	13—19.12.1978
4	Punjab Basmati 1 (Bauni Basmati)	596 (E)—13.08.1984
5	Pusa Basmati 1	615 (E)—06.11.1989
6	Kasturi	615 (E)—06.11.1989
7	Haryana Basmati 1	793 (E)—22.11.1991
8	Mahi Sugandha	408 (E)—04.05.1995
9	Taraori Basmati (HBC 19/Karnal Local)	1(E)—01.01.1996
10	Ranbir Basmati	1 (E)—01.01.1996
11	Basmati 386	647 (E)—09.09.1997
12	Improved Pusa Basmati 1 (Pusa 1460)	1178 (E)—20.07.2007
13	Pusa Basmati 1121 After amendment	1566 (E)—05.11.2005 2547 (E)—29.10.2008
14	Vallabh Basmati 22	2187 (E)—27.08.2009
15	Pusa Basmati 6 (Pusa 1401)	733 (E)—01.04.2010
16	Punjab Basmati 2	1708 (E)—26.07.2012
17	Basmati CSR 30 After amendment	1134(E)—25.11.2001 2126 (E)—10.09.2012
18	Malviya Basmati Dhan 10-9 (IET 21669)	2817 (E)—19.09.2013
19	Vallabh Basmati 21 (IET 19493)	2817 (E)—19.09.2013
20	Pusa Basmati 1509 (IET 21960)	2817 (E)—19.09.2013
21	Basmati 564	268 (E)—28.01.2015
22	Vallabh Basmati 23	268 (E)—28.01.2015
23	Vallabh Basmati 24	268 (E)—28.01.2015
24	Pusa Basmati 1609	2680(E)—01.10.2015
25	Pant Basmati 1 (IET 21665)	112(E)—13.01.2016
26	Pant Basmati 2 (IET 21953)	112(E)—13.01.2016
27	Punjab Basmati 3	3540(E)—24.11.2016
28	Pusa Basmati 1637	3540(E)—24.11.2016
29	Pusa Basmati 1728	3540(E)——24.11.2016

Source: Data from APEDA, Ministry of Commerce, Government of India.

and no variety was commercialized based on plant transformation (Bashir et al., 2007).

In Punjab, rice varietal improvement work started in 1926 at Kala Shah Kaku (KSK) in the famous Kalar Tract, led by the former Punjab Agriculture College and Research Institute, Lyallpur. The pioneer work was focused on

Table 7 Agricultural-cum-Commercial Rice Groups in Pakistan

Group	No. of Accessions	Group	No. of Accessions
Bara or Hansraj	9	Muskan	50
Basmati	51	Palman	17
Begmi	9	Ratria	22
Dhan	27	Red Rice	21
Jhona Kasarwala	54	Santhi	13
Jhona	96	Sathra	24
Joni	17	Sone	42
Kharsu	13	Kangra Valley Rice	90

Source: Ahmad, C.M., Akram, M., 2005. Hand Book on Rice Varieties in Pakistan. Rice Research Institute, Kala Shah Kaku, p. 66.

purification of the rice varieties available to the farmers. About 500 locally grown rice varieties were collected from farmers' fields and classified into 16 agricultural-cum-commercial groups on the basis of morphological traits. Basmati was a major group comprising 51 pure lines (Table 7). Since then, the Rice Research Institute (RRI) of KSK holds a prominent position in the development of Basmati varieties for the region (Ahmad and Akram, 2005; Bashir et al., 2007).

The varietal development program initiated in 1926 at KSK can be divided into four distinct phases.

4.2.1 Varietal Development Phase I (Before 1947)

During this developmental phase, devoted efforts were undertaken toward pure line selection. From the 16 identified agricultural-cum-commercial groups, three promising varieties were released for general cultivation (Table 8).

These varieties were tall statured with weak stems and hence were not responsive to high nitrogen inputs. Out of these three varieties, only Basmati

Table 8 Rice Varieties Released for Cultivation From the Agricultural-cum-Commercial Groups in Pakistan

Variety	Year of Release	Parentage	Varietal Group
Basmati 370	1933	Pure line selection	Aromatic
Muskan-7	1933	Pure line selection	Aromatic
Muskan-41	1933	Pure line selection	Aromatic

Source: Ahmad, C.M., Akram, M., 2005. Hand Book on Rice Varieties in Pakistan. Rice Research Institute, Kala Shah Kaku, p. 66.

370 occupied a large acreage. Basmati 370 was high quality fine rice with long grain size, a pleasant aroma, extreme grain elongation ratio, and soft texture after cooking. Basmati 370 was the perfect example of success for a pure line breeding strategy (Siddiq et al., 2012). This Basmati rice variety became the most significant traditional rice in this category and resulted in an export boom (Mann, 1987). This variety served as a bench mark for future Basmati varietal development and remained popular with the farming community and farmers until the 1980s (Shobha-Rani et al., 2006). Yield of Basmati rice varieties released during this period was quite low and hence a common problem. Therefore, pure line selection was not a quick solution to this challenge. Hybridization, based on the phenomenon of heterosis, was employed to improve yield and other agro-qualitative traits. The results were far below that expected, due to narrow genetic variability in Basmati germplasm at that time. The typical aroma of Basmati, being a recessive trait, did not appear in the F1 generation unless both the parents were of Basmati origin. In addition to high yield, the breeders' aims were long slender grain size, better milling recovery, aroma, and good cooking quality. This was further challenged by the poor ability of Basmati rice varieties to combine with pure lines valued for their aroma and other cooking characteristics. It was not an easy task for the breeders to combine all these traits in a single Basmati variety with the limited germplasm available, as germplasm exchange with other countries was not very common during these early days. These issues restricted varietal development in Punjab.

4.2.2 Varietal Development Phase II (1948–72)

A major breakthrough in rice productivity and total production was made possible by the introduction of semidwarf, fertilizer-responsive, and high-yielding varieties in the mid-1960s from the IRRI. The first variety introduced was IR8, which was approved as IRRI—Pak. It was high yielding but due to its inferior grain quality characteristics, it failed to catch the attention of the farming community. However, another variety, IR6, was approved for general cultivation in 1971. These introductions gave momentum to the hybridization program and crossing work was intensified to develop high-yielding Basmati and non-Basmati varieties. With the objectives of early maturity, high yield, better grain quality, and resistance against borers and blast, the first cross of Basmati 370 with Pulman 46 was made in 1933. Material from other parts of the world (Australia, Egypt, Italy, Japan, Russia, and Spain), mostly of japonica type, was also evaluated and compared. The rice-growing period at KSK is characterized by long and hot summer days, and consequently the exotic japonica germplasm did not perform well—in part due to their photoperiod sensitivity. A total of 275 exotic lines were evaluated but they were not as adaptive as the local germplasm. By 1959, rice breeders had developed and tested 620 indigenous pure lines. The efforts to cross Indica (indigenous) and japonica (exotic) were unsuccessful, largely due to highly sterile progeny. A project under the umbrella of FAO was launched to develop early maturing, high-yielding, stiff stem, and fertilizer-responsive hybrids for cultivation in traditional Indica areas. At the Central Rice Research Station, Cuttack, India, the japonica varieties obtained from Japan (which failed to produce desirable results under a tropical environment) were crossed with the Indica varieties supplied by other participating countries to raise F1. The F2 was tested in countries concerned (FAO projects) for the selection of desirable plants. Seeds for various crosses were supplied by the Economic Botanist to the Government of Pakistan and were tested at KSK. Since none of the parents involved in such crosses were native to this province (Punjab, Pakistan), good results were not achieved. Most of the plants did not flower under the agroecological conditions of KSK. Later on, positive results were obtained while crossing progenies with a Basmati parent as recurrent one. In the 1960s, two fine grain varieties were released as a result of the hybridization program. Later, Basmati 198 was released for general cultivation in Punjab through introduction, acclimatization, and selection (Table 9).

4.2.3 Varietal Development Phase III (1973–2004)

The research was gradually strengthened and efforts were devoted toward high yield and better cooking quality. During this period institutional access to the exotic germplasm was increased and well-equipped labs were provided, with increased availability of technically trained staff. Four Basmati rice varieties were released for cultivation (Table 10). World famous

Table 9 Rice Varieties Released for Cultivation During 1948–72 in Pakistan

Variety	Year of Release	Parentage	Varietal Group
C-662	1964	Basmati 370 × Muskan 7	Aromatic
Basmati Pak	1968	Pure line	Aromatic
Basmati 198	1972	Basmati 3703 × Taichung Native 1	Aromatic

Source: Ahmad, C.M., Akram, M., 2005. Hand Book on Rice Varieties in Pakistan. Rice Research Institute, Kala Shah Kaku, p. 66.

Table 10 Rice Varieties Released for Cultivation During 1973–04 in Pakistan

Variety	Year of Release	Parentage	Varietal Group
Basmati 385	1988	Basmati 3704 × TN1	Aromatic
Super Basmati	1996	Basmati 320 × 10486	Aromatic
Basmati 2000	2001	Basmati 385 × 4048-3	Aromatic
Shaheen Basmati	2001	Super Basmati × Basmati 385	Aromatic

Source: Ahmad, C.M., Akram, M., 2005. Hand Book on Rice Varieties in Pakistan. Rice Research Institute, Kala Shah Kaku, p. 66.

Basmati varieties were released during this period, occupying a major percentage of the rice-growing area and fetching significant foreign exchange earnings.

4.2.4 Varietal Development Phase IV (2005–16)

Attempts were made to break the yield barrier and confer resistance against blast and other diseases. Four Basmati varieties, namely Basmati 515, Kissan Basmati, Chenab Basmati, and Punjab Basmati, were released during the period 2005–16. To overcome issues such as insect pests, diseases, salinity, drought, and submergence and improve yield and quality traits of Basmati rice, many crosses were made and successful crosses are being further evaluated. Focused research work is underway for the development of BLB-resistant Basmati varieties. Such work is being augmented by the DNA fingerprinting of BLB-resistant Xa4, xa5, Xa7, and Xa21 genes. Molecular screening for presence/absence of BLB-resistant genes in the existing rice genotypes of the crossing block is being carried out at RRI, KSK, Pakistan, and one line has been found to have the Xa21 gene. The characterization and inheritance of aroma compounds in Basmati varieties has also emerged as a major objective of the breeding program in Pakistan (Ashfaq et al., 2015; Anonymous, 2016b). Scientists at RRI, KSK are striving to develop high-yielding, early maturing, stiff-stem, and extra-long grained varieties of Basmati rice that are resistant to biotic and abiotic stresses such as stem borers, leaf folder, white backed plant hoppers, bacterial blight, and drought (Bashir et al., 2007; Akhter et al., 2014; Anonymous, 2016b). The important features of popular Basmati varieties grown in Pakistan are described in Table 11.

Early released Basmati varieties such as Basmati 370 and Basmati Pak had yield far below 3.0 t ha^{-1}. In the late 1980s, Basmati 385 was launched, which was a major success in terms of yield. The second breakthrough to

Table 11 Detail of Popular Basmati Varieties Grown in Pakistan

Basmati Variety	Parentage	Year of Release	Plant Height (cm)	Duration	Yield (t ha^{-1})	Comments
Basmati 370	Selection	1933	170	150	2.5	High quality, low in yield, weak stem
Basmati Pak	CM7-6/Basmati 370	1968	170	150	2.5	Weak stem, extra-long kernel, tolerant to poor soil conditions
Basmati 198	Basmati 370^3 × Taichung Native 1	1972	125	160	3.0	Released for Sahiwal area
Kashmir Nafis	Mutant of Basmati 370	1977	160	120	4.4	Cold tolerant, high yielding
Basmati 385	Basmati 370^4/TN1	1988	133	142	4.0	Stiff stem, early maturing, high yielding
Super Basmati	Basmati 320 × 10486	1996	115	150	3.2	Stiff stem, extra-long kernel, major export Basmati variety
Khushboo 95	Mutation	1996	130	144	4.4	High yielding
Rachna Basmati	Somaclonal variation of Basmati 370	1999	134	125	4.2	High yielding, moderately tolerant to diseases
Basmati 2000	Basmati 385 × 4048-3	2000	135	145	4.5	Stiff stem, high yielding
Shaheen Basmati	Super Basmati × Basmati 385	2001	134	150	4.5	High yielding, salt tolerant
Basmati 515	Three way cross of F1 (Basmati 320 x 10486) with 50021	2011	125	154	4.5	Moderately resistant to bakanae/foot rot and blast
Kissan Basmati	Advance line RRI 7	2016	93	128	4.5	Early maturing, short stature, stiff stem, extra-long rice especially for parboiled rice
Chenab Basmati	Advance line PK 8431-1-2-1-2-4	2016	122	137	4.4	High yielding, stiff stem, early maturing, extra-long kernel
Punjab Basmati	Advance line PK 8685-5-1-1-1-1	2016	107	132	4.3	High yielding, stiff stem, early maturing, extra-long kernel

Source: Ahmad, C.M., Akram, M., 2005. Hand Book on Rice Varieties in Pakistan. Rice Research Institute, Kala Shah Kaku, p. 66; Bashir, K., Khan, N.M., Rasheed, S., Salim, M., 2007. Indica rice varietal development in Pakistan: an overview. Paddy Water Environ. 5, 73–81; Akram, M., 2009. Aromatic rices of Pakistan. Pak. J. Agric. Res. 22, 154–160; Akhter M., Akhtar M.S. and Rizwan M., 2014. Basmati-515: a new variety with extra long grain for productivity augmentation in Punjab, Pak. J. Agric. Res. 52, 35–42; Anonymous, 2016b. Annual Abridged Report, 2015–16. Rice Research Institute, Kala Shah Kaku. Available at: http://aari.punjab.gov.pk/info-desk/publications/annual-reports/462-rice-research-institute-kala-shah-kaku-annual-report-2015-16/file.

spur yield was in the mid-1990s, with the advent of Super Basmati that surpassed Basmati 385 (Table 11). Super Basmati is now the major Basmati rice variety in cultivation (Erenstein, 2010) and dominates exports (Bashir et al., 2007; Rangnekar and Kumar, 2010). This variety represents 70% of the total Basmati rice area and production in Punjab and is a leading Basmati variety in the international market (Javed et al., 2015). It has a strong aroma and is an extra-long, fine-grained variety, with kernel length of 7.5 mm and breadth of 1.7 mm. Its milling recovery is about 70% (Muhammed and Pirzada, 2005; Bashir et al., 2007; Akram, 2009). The country's entire rice export regime has traditionally been based on this variety, which gave it a natural competitive edge in the world market. Certain geographical attributes made it the most "sought after variety" and international buyers paid a premium for its natural traits—taste and aroma. Basmati 515 has a better milling recovery and elongation ratio than Super Basmati and is gaining popularity among Basmati growers. Other recently released varieties are in the phase of adoption by farmers. Pusa Basmati 1 is an Indian variety introduced by business-oriented Pakistani farmers and is very popular now. The remarkable success of this variety can be attributed to its short duration and high yield providing potential, saving water, and facilitating cultivation of a third crop, and thereby enhancing famers' profitability.

5. TRADE AND EMERGING MARKET TRENDS

In trade, the marketability of Basmati rice depends on milling and cooking quality traits. The quality characteristics of Basmati rice desired by farmers, millers, and consumers/buyers might be similar or different. For example, farmers in general are interested in high yield and net profit and millers are interested in high total recovery and head rice percentage. Consumer preference varies in different countries and among ethnic groups. Market quality is determined by physical properties such as length, breadth, translucency, degree of milling, color, and age of milled rice (Singh et al., 2008). Cooking and eating qualities are influenced by amylose content and directly correlated with volume expansion and water absorption during cooking, and with whiteness, hardness, and dullness of cooked rice (Singh et al., 2011b; Yoshida, 1981). Quality preferences in Basmati rice are so specific that farmers continue to grow traditional low-yielding Basmati rice because of its high price in the market. Improvement in grain quality along with productivity enhancement would not only help in increasing the export potential but also help in sustaining marketability. Aroma is a highly important trait in Basmati rice. Cultivation of Basmati rice in India prompted the open general license quota in 1980 that provided an outlet for Basmati rice export (Siddiq et al., 2012). The aromatic rice market represents only about ~5% of the international trade in rice and is shared mainly by India and Pakistan (Basmati), and by Thailand (Jasmine) to a lesser extent. India has the major share of Basmati export, which is evident from the fact that presently exports Basmati to over 90 countries across the world (APEDA, 2017). The large-scale export of Basmati started in the early 1970s with Taraori Basmati, Basmati 386, and Dehradun Basmati, and Uttar Pradesh (now Uttaranchal) became the first state to export Basmati rice to Arabian countries (Siddiq et al., 2012). Earlier Basmati rice cultivars were exported to Europe and America.

In India, the area under cultivation of Basmati rice increased with evolved Basmati varieties such as Pusa Basmati 1, Punjab Basmati 3, and Pusa Basmati 1121. In the beginning, only Basmati 370 and Type 3 were popular among farmers, traders, and consumers (Singh and Singh, 2009). These cultivars have a kernel length of less than 7 mm. In the mid-1970s, one of collections of Karnal germplasm was found with longer milled rice kernel length (7.35 mm) and had all the quality characteristics of Basmati 370. It was named Karnal Local. When its produce was brought to the market, it fetched even higher prices than Basmati 370 and Type 3. This opened up a new area for Basmati research (Singh and Singh, 2009). Karnal local then became the quality check for the NBT of the IIRR, Hyderabad. IARI released Pusa Basmati 1, having kernel length ~7.5 mm (Singh and Singh, 2009; Shobha-Rani et al., 2009), and it slowly replaced Basmati 370, Basmati 386, Type 3, and Karnal Local. This validated that consumer preference is for longer grain. CSR-30, Taraori, and Basmati 386 are very similar in look (size and shape), and it is very difficult to differentiate the grain of these varieties in the grain market. CSR-30 is generally preferred in sodic soils. In Haryana, Taraori Basmati was slowly replaced by CSR-30 (Yamini). Efforts were then made to develop still longer grain with high volume expansion. Then Pusa 1121, which has a longer kernel length than CSR-30 and has better linear cooked kernel elongation, replaced CSR-30 and Basmati 386. Pusa Basmati 1121 was released in 2003 by the Central Varietal Research Committee and by 2007 by PAU (Singh and Singh, 2009). Pusa Basmati gave 30%–40% higher yield than Basmati 386 and fetched a high price in the market due to its unique elongation. So, this variety was much appreciated by growers, millers, and consumers. This variety formed an export niche, particularly in Arab countries (APEDA, 2017). Currently, Pusa Basmati 1121 is grown on around 1.4 million ha and accounts for around 75% of India's annual Basmati rice exports of around 3.5 million tonnes. Due to the longer duration of Basmati cultivars, farmers in the rice—wheat cropping system faced a yield penalty in wheat due to delayed sowing of wheat. Efforts were made to develop a suitable Basmati cultivar with shorter duration. The IARI then developed a cultivar which was released as Pusa Basmati 1509, with similar yield and quality to Pusa Basmati 1121 but which matures 15 days earlier. It is becoming more popular these days and obtains a similar price to Pusa Basmati 1121. It fits well in intensive cropping systems and has proved a boon for summer mungbean, potato, and vegetable growers. Efforts were also made to shorten the height of Basmati 386, which is prone to lodging. With the help of MAS, PAU released Punjab Basmati 3 with 40%—50% higher yield than Basmati 386 and with shorter height (110—115 cm) and improved resistance to bacterial blight (Bhatia et al., 2011; Singh et al., 2014). This variety has a niche in the European market and fetches a good price in the market. The percent share of Basmati rice export to the total export of Indian rice is more than 58%. Though the Indian export market is facing tough competition from Pakistan, it is still sustaining its place of importance. It has been observed that Asian countries accounted for a major share (~74%) of Basmati rice imported from India, followed by Western Europe (~20%) (APEDA, 2017). Volume wise, the share of Basmati rice to the total rice export is not very high in India, but it generates 3—4 times higher return over non-Basmati varieties in the overseas and domestic market because of its higher price (APEDA, 2017). Over one-half of Basmati rice is exported as parboiled in the Saudi Arabia, followed by Kuwait, United Arab Emirate, United Kingdom, and United States. With the opening of new markets in countries such as Korea, Iran, Japan, China, and Indonesia under the WTO regime, and with the removal of minimum export price by the Government of India, the export volume of Basmati rice is expected to increase in future. With a view to strengthen Basmati export in India, two agri export zones (one each in Punjab and Uttaranchal) have been formed by the Indian Government (Singh and Singh, 2009). In the past 4 years, India's Basmati export has increased but Pakistan's rice export has declined by 40%, reduced from 1.1 million tonne to 676,630 tonnes in 2015 (Rice Exporters Association of Pakistan, 2016). This was due to high demand for the Indian Basmati variety Pusa Basmati 1121 in Middle Eastern countries, which has unique elongation after cooking. India entered the rice market with a huge surplus, and 20% devaluation of its rupee, enjoying an almost unbeatable comparative advantage against Pakistani exporters. To make the competition even tougher, India withdrew the minimum export price (Anonymous, 2017b). Scientists in Pakistan opined that Basmati exporters from Pakistan experience high cost at each step of the supply chain, i.e., farm—processing—transportation (Anonymous, 2016a). According to the World Bank's Logistics Performance Index, Pakistani exporters lag behind India, Vietnam, and Thailand regarding international shipments (ease of arranging competitively priced shipments) and logistics competence (competence and quality of logistics) indicators (Anonymous, 2016a).

Pakistan exports to major markets like Iran in the Middle East have dropped considerably, causing the total exports of the rice sector to plummet. Consequently, the export volume and earnings of Basmati have spiraled downward. Iran has been a traditional buyer of Basmati rice from Pakistan but in the wake of the economic sanctions placed on Iran, the recent years have seen rice exports to Iran decline sharply. Pakistan rice export has been stagnant for many years, both in quantitative and value terms (Ashraf, 2017) because of skyrocketing input prices, ever increasing cost of production, debilitating energy crisis, a discouraging law and order situation, and decreased commodity prices in the international market (International Policy Digest, 2015). Millers and exporters have to deal with challenges such as inconsistent supplies, high cost of production and processing, access to few Basmati varieties, lack of production data, price instability, and limited storage facilities. Lack of innovation in research and development, an aggressive marketing approach, and cultivation using old seeds with low viability leading to low yields have contributed enormously to such regression (Anonymous, 2016a). Since 1995, India has developed over 20 high-yielding, disease-resistant, and extra-long varieties of Basmati, its hybrids, and look-alikes. In Pakistan, it was not until recently that new high-yielding Basmati rice varieties were released since the approval of Super Basmati in 1990s and Shaheen Basmati in 2001.

In recent years, parboiled rice has captured the preference of international rice markets in Europe, Middle East, South Africa, and North America due to improved nutritional aspects and superior processing and cooking characteristics (Anonymous, 2016a). The two recent Indian-developed varieties, Pusa Basmati 1121 and Pusa Basmati 1509, have captured the increasingly parboiled-preferring global Basmati rice market.

The average grain length (AGL) of both of these varieties is 8.1–8.4 mm with yield of 5.0–6.0 t ha^{-1} compared with 7.0–7.4 mm AGL and 3.0 to 4.25 t ha^{-1} yield of Super Basmati (Ashraf, 2017). Against the backdrop of parboiled rice, the superior aroma of Super Basmati becomes a trait of secondary significance as the aromatic compounds evaporate in the parboiling process. On the processing side, India has secured a technological advantage by developing mechanized parboiling technology, which ensures color consistency and the absence of odor, which otherwise are major issues associated with manual parboiling techniques.

6. AGRONOMIC CHALLENGES AND TECHNIQUES FOR IMPROVING THE PRODUCTIVITY AND QUALITY OF BASMATI RICE

The development of appropriate production technology is a prerequisite to exploit the yield potential of improved varieties. In Basmati rice, production technologies such as optimum schedule of transplanting, age of nursery, and balanced and efficient use of nutrients have played a very important role in increasing Basmati rice production.

6.1 Soil Factors

Soil factors play a critical role in influencing the quality of Basmati rice. Soil factors affect the aroma and other quality traits due to optimum supply of nutrients to the crop and the interaction of nutrients with aroma concerning volatile compounds, but few studies have been done using Basmati rice. The study of volatile compounds for developing aroma in Basmati rice in relation to different nutrients is an urgent research priority. Several farmers in the eastern IGP have claimed that it was not only aroma but also the thickness and length of grains, taste, and fluffiness, which were influenced by the field in which the aromatic variety was cultivated. Few farmers noted a significant difference in aroma of Basmati rice produced from two adjacent fields when the crop was raised from the same seed lot (Singh, 1998). This means the nutrient supply to the crop by the soil plays a key role in influencing aroma. As per farmers' perceptions, lighter soil and upland conditions favor aroma formation. On the other hand, Basmati rice is mostly cultivated in flat and bunded fields on terraces and in clayey soils of plains in high rainfall areas or where irrigation facilities are available. A well-leveled field with sufficient water supply is the prerequisite for growing good quality of Basmati rice (Singh et al., 2002). In alkaline and poor soil conditions or if water supply is limited, particularly at the grain filling stage, the grain showed excessive abdominal whiteness, which adversely affects cooking qualities (Azeez and Shafi, 1966). Soil texture is reported to affect grain quality (Hou, 1988) and that is also true for Basmati rice. Bocchi et al. (1997) reported that the highest grain content of volatile compounds in rice was correlated with loose soils having high sand and low clay contents. These results suggest that edaphic factors play a major role in influencing the quality of Basmati rice; that is why Basmati rice exhibited high quality (greater elongation and aroma) when grown in the GI areas of the Indian subcontinent.

6.2 Age of Seedlings

The correct age of seedlings at the time of transplanting is crucial for proper stand establishment of Basmati rice (Sarwar et al., 2011). Seedling age in rice is linked with vigor, survival, and mortality in the main field. Both above and below ground attributes of rice plants in nursery as well as in the main field are known to be influenced by the seedling age (Sarwar et al., 2014). Tiller production, grain formation, yield, and related components (Ashraf et al., 1999; Ahmad et al., 2002; Aslam et al., 2015) as well as quality attributes (Brar et al., 2012) are affected by age of seedling. Transplanting shock, a setback of growth due to uprooting and replanting of seedlings, increases with an increase in age of seedlings. In addition, late nursery transplanting reduces the growing period of the crop, which not only reduces the grain yield but also impairs the quality. Generally, transplanting is delayed due to the manual method of nursery transplanting and because all the fields cannot be simultaneously transplanted, which results in above-optimal age of rice seedlings that produce lesser numbers of tillers per plant.

Rice seedlings at the 5–6 leaf stage (usually 25–30 days after sowing) are used for transplanting. In Basmati, nursery age and transplanting time differs with cultivars (Brar et al., 2012). Longer duration varieties, which are photosensitive, are grown later in the season as compared with photoinsensitive varieties. Longer stay of seedlings in the nursery bed results in node formation, which reduces tillering and yield of Basmati varieties. Due to shorter duration of Pusa Basmati 1509, it was recommended to transplant 25-day old seedlings to achieve high yields (Mahajan et al., 2016). The minimum age of a seedling for transplanting is about 15–20 days. Younger seedlings are difficult to establish and cannot cope with prevailing high temperatures. However, the ideal seedling age is about 25–30 days; tilling capacity is reduced if older (50 days) seedlings are transplanted, resulting in 30%–40% yield loss (Anonymous, 2016c).

6.3 Time of Transplanting

Transplanting time is directly linked to cultivar. Varieties that are photoperiod sensitive viz Basmati 370, Taraori, and Basmati 386 require a specific day length at flowering, and if transplanted early, boost vegetative growth leading to lodging, affecting yield and quality parameters. Photoperiod-insensitive varieties viz Pusa Basmati 1 and Pusa Basmati 1121 and weakly photosensitive varieties such as Super Basmati, Punjab Basmati 2, and Punjab Basmati 3 are sown 15 days before the sensitive varieties. For better quality, Pusa Basmati 1509 is recommended under late transplanting conditions, i.e., second fortnight of July in north India (Mahajan et al., 2016). In Pakistan, photoperiod sensitivity is considered an important criterion to distinguish a Basmati rice variety from a non-Basmati rice variety (Akhter et al., 2007; Erenstein, 2010). Super Basmati is highly photosensitive, flowering during the last week of September and first week of October irrespective of its transplanting time, with optimum transplanting in the first half of July (Rafiq et al., 2005; Akhter et al., 2007). All traditional Basmati varieties in Pakistan are highly photoperiod sensitive for flowering (Safdar et al., 2008). These authors determined that the photoperiod-insensitive rice line 98410 was an exception, which they regarded as non-Basmati fine grain rice. Photosensitivity in Basmati rice varieties is often considered an undesirable trait, such as tall stature, susceptibility to lodging, and low yield (Siddiq et al., 2012). Continued reliance on photosensitive Basmati rice varieties also limits enhancement of wheat productivity in the rice—wheat rotation by restricting timely wheat planting, especially in Pakistani Punjab (Erenstein, 2010).

Temperature at the time of flowering, grain filling, and maturity had a great influence on quality traits of Basmati rice (Akhter et al., 2007). The optimum temperature required during the grain filling stage to produce quality rice is reported to be 25°C (Jin et al., 2005). High temperature during the grain filling and dough stages impairs kernel development and limits carbohydrate in plants thereby reducing head rice recovery and other quality traits. So, the time of transplanting has a great influence on Basmati rice as it governs exposure of rice plants to prevailing environmental conditions at reproductive and grain filling stages. It is accepted that low temperature during the grain filling stage has a great influence on aroma retention and formation, so for better quality, Basmati cultivars should be grown at the recommended time. Akhter et al. (2016) reported that early transplanting (5th May) was more detrimental to milling and cooking characteristics of

Basmati rice than late transplanting (10th July). For Basmati varieties, a transplanting time of 18th June recorded the maximum head rice recovery in Pakistan; however, in northwest India, the optimum time for Basmati transplanting is the first fortnight of July. Another disadvantage of an early transplanted rice crop is panicle sterility induced by high temperature leading to inferior quality rice from a milling point of view (Hassan et al., 2003). In the Pakistani Punjab, the rice transplanting time is regulated by the time of nursery sowing, which itself is governed by the Punjab Agricultural Pest Ordinance, 1959. According to this Ordinance, the sowing of nursery before 20th of May is prohibited to control multiplication of notorious stem borers (*Scirpophaga incertulas* and *Scirpophaga innotata*)—these insects become active from the end of March or start of July) on early sown rice nurseries, which may exert greater pressure on the seasonal rice crop. Consequently, the Provincial Agricultural Department discourages sowing of rice nursery earlier than 20th of May each year. Hence, the recommended time of nursery sowing and transplanting of Basmati varieties is 1-20th June and 1-20th July, respectively, in the core rice area (Anonymous, 2016d).

Basmati rice requires relatively cool temperatures for retention of aroma, that is, 25/21°C-day/night temperature during crop maturity (Juliano, 1972; Mann, 1987). The study by Mahajan et al. (2015) on Basmati rice in India revealed that the time of transplanting in Basmati rice significantly affected the chalky rice percentage, head rice percentage, alkali spreading value, protein content, and grain amylase percentage. Therefore, the time of planting plays a great role in influencing the quality of Basmati rice. The second fortnight of July is the best time for transplanting of traditional Basmati cultivars (Basmati 386, Basmati 370) and the first fortnight of July is the best transplanting time for Pusa Basmati 1121 and Pusa Basmati 1509 from a yield and quality perspective (Mahajan et al., 2016).

Basmati sowing and transplanting are critical for ensuring high yields and better quality. Sowing nursery in the first week of June is ideal in western Uttar Pradesh, Delhi, Rajasthan, and Jammu and Kashmir. However, in the Indian Punjab, raising nursery during the second fortnight of June ensures strong aroma and high yields. In Haryana, although late sowing has been the practice in the past to ensure quality, early June sowing is now standard practice to ward off blast disease (Siddiq et al., 1997). Basmati rice is harvested toward the end of October and in November.

Mahajan et al. (2009) observed that the best quality Basmati rice is produced when planting was done during the first fortnight of July in Punjab, India. In general, temperature during crop ripening correlates negatively with amylase content and positively with gelatinization temperature (Li et al., 1989; He et al., 1999). In one study on rice, Asaoka et al. (1985) reported that ambient temperature during crop ripening not only affected the amylose content but also influenced the fine structure of amylose and amylopectin. A study by Dela Cruz et al. (1989) revealed that amylose content decreased with an increase in temperature, whereas gelatinization temperature and gel consistency did not show any response to temperature. Later, Dela Cruz et al. (1991) conducted a similar study in a phytotron and observed that gelatinization temperature of Basmati 370 was not affected when plants were grown at 33/25°C day/night temperature regime. An increase in temperature decreased the amylase content in grains; and thus, it affected the grain appearance as it caused a decrease in translucency of grains. In another study, Li et al. (1989) confirmed that environmental factors such as temperature, relative humidity, and photoperiod had little effect on the length, width, and length:width of rice grains compared with that of chalkiness, gelatinization temperature, amylose content, and gel consistency. However, they also opined that effects may vary with cultivars and characteristics. The study by Dela Cruz (1991) observed maximum grain elongation when the crop received 25/21°C day/night temperatures during ripening. So, grain elongation is strongly influenced by environmental factors, especially temperature at the time of ripening. This explains the difference in elongation of rice when Basmati is grown in Punjab and Dokri (Sind, Pakistan); rice grown in Punjab was more elongated than rice grown at Dokri due to prevailing high temperature (Khush et al., 1979). Late planting, facilitating flowering, and maturity during cooler weather enhanced the grain quality of Basmati rice, but reduction in grain yield under later transplanting depended on the cultivars (Singh et al., 1995; Rao et al., 1996; Thakur et al., 1996; Chandra et al., 1997; Mahajan et al., 2015).

Environmental temperatures during kernel development played a great role in fluctuations in rice grain quality (Cooper et al., 2006). Historical analyses have indicated that high nighttime temperature during the growing season decreased yields in rice (Downey and Wells, 1975; Peng et al., 2004). Other historical analyses have likewise determined that high nighttime temperatures during kernel development also decreased head rice yield (Cooper et al., 2006). High nighttime temperatures have been related to decreased panicle mass (Ziska and Manalo, 1996) and an increase in the number of chalky kernels (Yoshida and Hara, 1977). Yoshida and Hara (1977) noted that kernel dimensions decreased with increased nighttime temperature. Sun and Siebenmorgen (1993) and Siebenmorgen et al. (2006) showed that head rice yield is influenced by the thickness distribution pattern of a population of rice kernels. By altering the thickness distribution of kernels, an increase in nighttime temperature could potentially reduce head rice yield. In a japonica cultivar, high nighttime temperatures during kernel development caused an increase in amylose content (Resurreccion et al., 1977). Counce et al. (2005) observed that as nighttime temperatures increased, head rice yield decreased, while the proportion of long chains of amylopectin decreased. This suggests that head rice yield could be related to the cellular structure of the starch containing molecules within rice kernels and that this structure, and thus HRY, could be temperature sensitive. They further revealed that for all tested hybrids and cultivars, increasing nighttime temperatures decreased the brown rice kernel width. These authors also found that kernel width in Cypress and LaGrue cultivars decreased significantly when nighttime temperature increased from 18 to 24°C. However, Counce et al. (2005) did not find a significant difference in kernel thickness when observing effect of night temperature.

The above studies revealed that variations in growth temperature played a great role in quality variation in rice. An earlier study of the effects of temperature on kernel development also indicated that higher temperatures during the grain filling stage results in decreased grain weight and grain dimensions and a high number of chalky grains (Yoshida and Hara, 1977; Tashiro and Wardlaw, 1990). Lower growth temperatures control the amylose content in rice grains, increase the amylose content in rice cultivars having low amylose content, and decrease the amylose content in rice cultivars having high and intermediate amylose content, sometimes changing the cultivar's amylose class depending on the temperature treatment (Resurreccion et al., 1977; Paule et al., 1979). Most research studying the effect of temperature on rice quality has been performed using controlled temperature chambers in advanced countries and at IRRI. This approach has limitations in that it does not necessarily reproduce field conditions. It would be useful to use field data to study the effect of temperature on head rice yield, especially for Basmati rice cultivars that are usually photoperiod sensitive in nature. High nighttime temperatures could possibly increase respiration during the night and subsequently cause the loss of carbohydrate from the grain. Peng et al. (2004) found that increased nighttime temperatures throughout the growing season were directly correlated to decreased rice crop yield. In a controlled temperature study, Counce et al. (2005) found that an increase in nighttime temperatures during the grain filling stage resulted in a decrease in head rice yield and a decrease in the long B chains of amylopectin in rice starch granules. Early transplanting impairs cooking quality as grains are extremely opaque or exhibit abdominal whiteness between starch molecules (Ali et al., 1991; Azeez and Shafi, 1966; Singh et al., 2014). These studies suggest that the optimum transplanting time of photoperiod-sensitive and photoperiod-insensitive varieties of Basmati determine the night temperature during the grain filling stage and thereby influence the grain yield, milling, and cooking characteristics by changing the biochemical constitution and functional properties of grains.

6.4 Role of Fertilizers in Influencing the Quality of Basmati Rice

In general, Basmati varieties are low nitrogen (N) responsive. High N application results in excessive vegetative growth, thereby making the crop prone to lodging and attack by insect pests and diseases leading to low yield. Furthermore, the time of N fertilizer application is also very important. Fertilizer should be applied on the basis of soil tests. High N doses in Basmati may cause false smut and neck blast diseases in Basmati, which may impact quality characteristics. A blanket recommendation of N for Basmati cultivars in Punjab, Haryana, Delhi, Western Uttar Pradesh, Uttaranchal, and Jammu and Kashmir is 40, 60, 120, 120, 100, and 30 kg N ha^{-1}, respectively (Anonymous, 2014). In Basmati rice, application of P and K is done on the basis of soil tests.

6.4.1 Nitrogen

Soils low in N generally produce better quality grains. Perez et al. (1996) observed that late N application at the time of flowering improved the nutritional and milling quality of rice grain. So, split applications of N are necessary for obtaining high grain yield and improved quality (Hou, 1988; Perez et al., 1996; Kumar et al., 2014). Likewise, in Pakistan, application of N at 100 kg ha^{-1} in the form of urea to Super Basmati in three equal splits [one-third at transplanting, one-third at 50% tillering (8–12 tillers hill^{-1}) and the remainder at panicle initiation] improved its 1000-kernel weight and paddy yield over the control (whole of the N applied at transplanting) (Manzoor et al., 2006). In Pakistan, a high amount of N is applied to Basmati rice for yield enhancement (150–175 kg ha^{-1}), but this amount adversely affects cooking and eating qualities (Singh et al., 2011b). Suwanarit et al. (1996) reported that the whiteness, softness, aroma, stickiness, and glossiness of cooked milled rice of KDML 105 were inversely related to the increase in applied dosages of N. However, the increased application of N did not adversely affect alkali value, volume expansion, and water uptake (Ghosh et al., 1971). N application at higher dosage increased the amylase content of long slender varieties such as Kasturi, Pakistani Basmati, and Basmati 370 by 3%–9.9% (Rao et al., 1993). Grain protein content was increased with an increase in the rate of N application (Ghosh et al., 1971; Umetsu et al., 1990; Singh et al., 2011b). The study of Youssef et al. (1980) revealed that different quality traits such as water uptake, volume expansion, and alkali value were not adversely affected by application of high N rates; however, high doses of N decreased the head rice recovery and increased amylase content of long slender grain varieties such as Basmati 370, Kasturi, and Pakistani Basmati (Rao et al., 1993).

Mahajan et al. (2010) reported that with an increase in N supply from 20 kg ha^{-1}, the length of Pusa Basmati 1121 distinctly increased, resulting in a reduction in head rice recovery (%) at higher N levels (40 and 60 kg ha^{-1}). The L-B ratio for Pusa Basmati 1121 and Punjab Basmati 2 was at par, but significantly higher than Punjab Mehak 1 (IR-75483). Amylose content (%) was highest at 20 kg N ha^{-1} and thereafter at higher levels of N, it decreased significantly in all the cultivars. They also reported that Punjab Mehak 1 gave strong aroma only in the unfertilized plots and it became mild with N application, whereas strong aroma was exhibited at all levels of N up to 60 kg ha^{-1} in Punjab Basmati 2 and up to 40 kg ha^{-1} in Pusa Basmati 1121.

In another study, Singh et al. (2011b) revealed that milled rice from Basmati grown with N application showed lower gruel solid loss and water uptake ratio during cooking and higher cooked grain hardness, cohesiveness, and chewiness. Starch from Basmati rice grown with application of N showed lower amylose content and higher pasting temperature, gelatinization transition temperatures, and enthalpy of gelatinization. Principal component analysis further indicated that cooked grain hardness and cooking time were closely associated with amylose content and protein content, respectively.

6.4.2 Potassium and Magnesium

Eating and cooking qualities are highly influenced by potassic fertilizers. Application of potassium fertilizers at high dosage not only improved the grain glossiness, whiteness, and softness but also increased the aroma (Suwanarit et al., 1997). Potassium (K) fertilizers increased the starch and carbohydrate content of grain, irrespective of the stage of application, whereas its application at the grain filling stage increased the amylase content (Vil'gel'M, 1986). Oh et al. (1991) observed that K deficiency increased chalkiness, and the cooking and eating qualities of chalky kernels were inferior to perfect kernels. Application of K increased gel consistency and grain protein content but did not significantly affect gelatinization temperature or kernel amylose content (Bahmaniar and Ranjbar, 2007). Besides its role in kernel quality, K fertilization is known to improve stem strength and yield of Basmati rice (Zaman et al., 2015). These authors evaluated the response of two Basmati rice cultivars, i.e., Super Basmati and Basmati 515, to two levels of K, one with deficient (K_d) and the other with recommended (K_r), and three levels of N, i.e., deficient (N_d), half of recommended (N_{hr}), and recommended (N_r). P and Zn were applied at the recommended dose. K fertilization resulted in improved K content of rice stem, basal internode space, cellulose contents, and stem fiber contents. Likewise, paddy yield and Si content of stem was also increased. Recently, Wakeel et al. (2017) postulated that K use for Basmati rice in aerobic production systems may expand its adaptability as an alternative to flooded rice production systems in Pakistan.

Economic use of K fertilizer in K-deficient soils is especially important for Basmati growers, as K prices are continuously on the rise and its deficiency in plants impairs the quality of grains and increases plants' susceptibility to disease. The response of rice to N fertilizers has been well documented; however, the effects of N interaction with K application rates on yield and quality of Basmati rice are lacking and require systematic study.

6.4.3 Phosphorus and Zinc

Suwanarit et al. (1997) observed that aroma, softness, whiteness, and glossiness in grain is dependent on P content in grain and not on P content in the plant. High dose P application to the crop produced lower quality grains. Application of P increased the grain protein content. In another study, Chen and Fan (1997) reported that Zn application enhanced the amylase content. Many authors have reported that Zn application, particularly at low levels of N, increases grain length in Basmati. Shivay et al. (2007) reported that zinc fertilization had no deleterious effect on the quality of Basmati rice; it even increased hulling percentage and produced longer and better grains.

Pooniya et al. (2012) revealed that application of 2% zinc-enriched urea (ZEU) as $ZnSO_4 \cdot H_2O$ resulted in higher grain yield (3.8 t ha^{-1}), and this increase was to the extent of 12.8%, 2.4%, 3.3%, 5.7%, 7.0%, and 5.3% over the control (only N), 2.0% ZEU as ZnO, 5 kg Zn ha^{-1} as $ZnSO_4 \cdot H_2O$, 5 kg Zn ha^{-1} as ZnO, 0.5 kg Zn as ZnO slurry, and 1.0 kg Zn ha^{-1} through 0.2% foliar spray, respectively. Zn deficiency is the most prevalent micronutrient deficiency in humans, affecting 2 billion people and causing more than 0.8 million deaths annually (Black, 2003). Basmati varieties are generally rich in Zn; however, in Zn-deficient soils, biofortification through Zn supplementation could be a sustainable strategy to make it a specialty rice.

After N, Zn is the second most yield-limiting nutrient in rice (Quijano-Guerta et al., 2002). Basmati rice in Pakistan is traditionally cultivated on highly alkaline calcareous soils with high clay content (Qadar, 2002; Ali et al., 2014). These soil conditions lead to most of the Zn being adsorbed; and hence, very little is recovered by the rice crop. High soil pH and impaired conditions following flooding/submergence are responsible for Zn deficiency. Hasnain and Ali (2013) found that Zn fertilization had a significant influence on quality traits of Super Basmati. Application of Zn at 14 kg ha^{-1} was effective in reducing spikelet sterility and percentage of abortive and opaque kernels. Zn fertilization also increased kernel length and protein and amylose contents. Another study reported that combined application of N (120 kg ha^{-1}) and Zn (14 kg ha^{-1}) improved kernel dimensions, water absorption ratio, and protein content of Super Basmati grown at two sites, Sheikhupura and Sargodha (Ali et al., 2014). However, both N and Zn treatments had no significant effect on kernel amylose contents at both sites. Nadeem et al. (2013) recorded the highest Zn concentration in grain and straw of Super Basmati under P + Zn application at 20 days after transplanting, while the minimum Zn concentration was observed in all treatments where P was applied alone. Saleem et al. (2014)found that Zn fortification of Super Basmati during parboiling was found to increase Zn content of grains (126%–347%), Zn retention (80%),and bioaccessibility (53%), representing a pragmatic approach to combat Zn deficiency.

6.4.4 Other Micronutrients

In aromatic rice cultivars, Boron (B) application increased the alkali score, thereby enhancing the stickiness of grains (Rashid et al., 2004). B deficiency has been acknowledged as an important and widespread limiting factor in rice-growing areas of Pakistan (Shah et al., 2011). B deficiency in rice is responsible for low yields (Rashid et al., 2002a) and inferior grain quality

(Rashid et al., 2004). Basmati rice varieties are often more sensitive to B deficiency than coarse varieties (IR-6) for yield reduction (Rashid et al., 2002a,b). Nevertheless, cultivar sensitivity to B deficiency is not necessarily associated with grain length/fineness (Rashid et al., 2002b). Milling return and head rice recovery was significantly enhanced in Super Basmati due to B nutrition of rice plants. Improvements in other desirable quality traits such as quality index (L/B ratio), kernel elongation on cooking, bursting on cooking, and alkali spreading value were also observed (Rashid et al., 2009). Panicle sterility due to B deficiency has emerged as a major challenge for water-saving Basmati rice production. Supplementing B through seed priming (0.1 mM boron), foliar spray (200 mM boron), or soil application (1 kg boron ha^{-1}) had a positive effect on kernel yield, kernel length, and kernel B contents in Shaheen Basmati, while panicle sterility was significantly reduced by 60% (Rehman et al., 2016). Combined foliar application of Silicon (Si) at 1.5% and B at 1.0% promoted kernel yield and protein content of Basmati rice (Ahmad et al., 2012). Calcium present in calcareous soils is antagonistic to B, limiting its availability and inducing B deficiency. In alkaline calcareous soils, rice would be expected to respond to B application as its soil availability tends to decrease as the pH exceeds 7. Application of B at 2 kg ha^{-1} to a saline-sodic soil (ECe: 5.32 dS m^{-1}, pH: 8.52, and SAR: 18.87) resulted in the maximum 1000-kernel weight and grain yield of Super Basmati. The B concentration in rice grains also increased in response to B treatments, and the B content of grains was positively associated with rice grain yield (Hyder et al., 2012). Foliar application of B (0.32 M) has been reported to improve panicle fertility, yield, and biofortification in Basmati rice (Rehman et al., 2014). Molybdenum (Mo) application had a favorable effect on grain length. However, application of iron (Fe) decreased the grain length, besides reducing the grain width. Foliar application of Si at 0, 0.25, 0.50%, and 1.00% to Super Basmati (after 4 weeks of transplanting) had a nonsignificant effect on plant height, harvest index, number of kernels, and percentage of opaque kernels. However, paddy yield and grain starch contents were increased in plots foliar sprayed with 1.0% Si (Ahmad et al., 2013). Suwanarit et al. (1997) reported that moderate application of S fertilizer to S-deficient soil increased the aroma, softness, whiteness, stickiness, and glassiness of boiled milled grains (*Khaw Dauk Mali*-105), but rates higher than the optimum S dose decreased these quality parameters. Jiang et al. (2007) examined the relationship between mineral element contents and cooking quality traits and showed that gel consistency was significantly correlated with K, copper (Cu), and manganese (Mn) contents of rice.

Amylose content was significantly associated with K, sodium (Na), magnesium (Mg), copper (Cu), and Mn contents. The alkali spreading value was positively related with Ca, Mg, and Mn contents. In addition, eight mineral element contents had obvious correlations with different amino acid contents. Mg, Ca, and Zn contents were significantly correlated with most of the 17 amino acid contents, but Na content did not correlate with amino acid contents except aspartic acid. Application of 45 kg N in three equal splits, 30 kg P_2O_5, 30 kg K_2O, and 37.5 kg $ZnSO_4$ ha^{-1} was found to be the best rate to achieve high grain yield of good quality Basmati rice with low kernel degradation (alkali score) and high aroma score, the properties that are considered the most important for table purposes. There are limited studies on the interaction of multi micronutrients on milling and functional properties of Basmati rice. The study of these aspects might also provide cues for developing Zn- and Fe-efficient Basmati varieties in future.

6.4.5 Organic and Biofertilizers

As per farmers' observations, grain, eating, and cooking qualities of rice produced organically are better than those produced using chemical fertilizers. Organic farmers use sesbania as green manure or farm yard manure (FYM) to supplement N. The study of Latchumanan et al. (1979) revealed that application of N along with a mixed coculture of blue green algae and azotobacter increased the protein content in grains. The best aroma score was recorded under 100% FYM application, followed by 75% recommended N dose. Quyen et al. (2002) observed that rice quality parameters, that is, milling percentage, kernel length (KL), kernel breadth (KB), and L:B ratio before cooking of rice, were not affected by different sources of nutrients, but the head rice recovery, kernel length, kernel breadth, and L:B ratio after cooking showed an increasing trend with the application of organic sources. Pooniya and Shivay (2015) revealed that green manuring of Basmati rice resulted in significantly superior grain breadth after cooking compared with the summer fallow treatment, indicating that green manuring plays a significant role in quality improvement of Basmati rice.

Mahajan et al. (2012) reported that Basmati rice yield increased with organic source of nutrients as compared with the recommended level of N (40 kg N ha^{-1}) and the untreated control (without N). Green leaf manuring(5 t ha^{-1}) + vermicomposting(2.5 t ha^{-1}), green leaf manuring(10 t ha^{-1}), and neem cake(2.5 t ha^{-1}) caused 20.2, 16.7%, and 15.2% higher grain yield than the recommended level of N, respectively. However, various studies also demonstrated that integrated nutrient management in Basmati rice improved the grain yield and quality of aromatic rice. Singh et al. (2017) reported that integration of 100% recommended fertilizer along with blue green algae + phosphorus solubilizing bacteria performed best in achieving higher growth, productivity, and profitability in Basmati rice. Aulakh et al. (2016) revealed that green manuring in Basmati rice or use of FYM supplemented with 50% chemical fertilizer improved the head rice recovery (%) and protein content in grains.

7. TRADE AND MARKETING

In India, the Basmati Export Development Foundation (BEDF) is tasked with improving the productivity and quality of Basmati Rice, managing research and promotional aspects, disseminating the latest technologies for the improvement of Basmati, and infrastructure development with respect to Basmati rice (Siddiq et al., 2012; APEDA, 2017).

The mandate of BEDF is to strengthen the supply chain through diverse activities of stakeholders such as millers, traders, farmers, and exporters. BEDF also takes care of various quality parameters for Basmati rice, including DNA fingerprinting. BEDF caters for the needs of Basmati growers by imparting training and demonstrating the latest agronomic technologies that suit their agroecological regions, in consultation with state agricultural universities and extension personals. BEDF supply foundation and certified seeds to the Basmati growers. During the Basmati rice season, BEDF organized at least 15 workshops with Basmati growers, traders, and exporters and guided the growers to cultivate according to optimum management practices to have better quality produce for export (APEDA, 2017).

As Basmati rice is a registered GI product of India, it has been decided by the Agricultural and Processed Food Products Export Development Authority (APEDA) that exporters of Basmati rice must be a member of the All India Rice Exporters Association. This would facilitate participation of all exporters in trade consultations, besides providing a forum for increased trade discipline, resulting in a better brand image for Indian Basmati rice in the international market.

For promotion of Basmati exports in retail packs with Indian brands, APEDA launched a campaign recently in key markets such as Saudi Arabia and Iran. APEDA works with different agencies to launch their promotional strategy with the expectation of boosting the shipments of Basmati rice (Singh and Singh, 2009). Basmati rice accounts for close to a fourth of the total value of Indian food exports. Recently, APEDA has also started to promote Indian Basmati rice by setting up hoards of Basmati rice at international airports in India. Earlier, APEDA promoted Basmati rice via trade fairs and conferences in the international markets.

In Pakistan, until 1987–88 the Rice Export Corporation of Pakistan was the sole agency managing the country's export market. In 1987–88, the government allowed export through the private sector as well. After rice export was allowed for the private sector, a new body of people emerged in the shape of rice exporters (Aurangzeb, 2006; Paracha, 2014). A platform was lacking from where rice exporters could interact with the government. Hence, the Rice Exporters Association of Pakistan (REAP) was established in 1988–89 under the patronage of the Ministry of Commerce, Ministry of Food, Agriculture and Livestock, and the Planning Division of the Government of Pakistan (Aurangzeb, 2006; REAP, 2016). REAP played a significant role in defining rice standards in Pakistan. Consequently, Pakistan Rice Standards were established in 1992 for the first time, with the support of the Pakistan Standards Institution (Paracha, 2014). Pakistan fully privatized exports in 1996. In 1998–99, REAP became a registered body with the Director of Trade Organization, Ministry of Commerce. Also in 1998–99, membership of REAP became compulsory for all rice exporters.

The charter of REAP includes certification and accreditation of its members. The association also facilitates exporters' access to buyers and potential export markets by organizing and participating in various trade fairs (Anonymous, 2016a). With about 1900 members, REAP is the country's second largest business association. The managing committee of REAP is divided into north (11 members) and south (12 members) zones (REAP, 2016). No permit is required to export rice from Pakistan, but only registered members of REAP can engage in rice export. Registration is a one-time process, and membership is renewed annually by the payment of a membership fee. Exporters are given a REAP membership certificate, along with a membership number, which they use when engaging in export activities (Anonymous, 2016e).

8. PESTICIDE RESIDUES RELATED TO BASMATI PRODUCTION AND MARKETING

Traces of pesticides left in or on the treated products are termed "residues." The highest permissible limit of such residues in or on the food or feed products is called as the maximum residue level (MRL). The amount of such residues found in food stuffs/products must be within a safe range for consumers and must be kept as low as possible. A list of pesticides and their residue limit for Basmati rice that is causing detentions in India, the United States, and Europe are depicted in Table 12. Tricyclazole is a commonly used fungicide by Indian farmers to control leaf and neck blast in Basmati rice varieties. Recent regulation (EU) 2017/983 published on June 10, 2017, has amended the MRLs for this fungicide in or on certain products (Table 12). The main change regarding MRL was for Basmati rice, for which the MRL has been changed from 0.01 mg kg^{-1} to 1 mgkg^{-1}. The export of Basmati rice from India to the United States has plunged because many Indian firms come under an import alert by the US authorities, leading to detailed scrutiny of grain for pesticide residue (APEDA, 2017). Systematic studies have been conducted at research farms to analyze pesticide residue contents in Basmati rice. Arora et al. (2014) conducted a study of pesticide residue in Basmati rice from 2008 to 2011, by comparing integrated pest management (IPM) and non-IPM trials in Basmati rice. The study revealed that grains from IPM trials were safe for consumers as the residues of insecticides were either not detected or were below the MRL, and these results were consistent with earlier work (Arora et al., 2008; Mukherjee and Arora, 2011). Out of 109 soil samples collected from IPM and non-IPM fields of Basmati rice, a few

Table 12 List of Pesticides and Their Limit That Are Causing Detentions in India, United States, and Europe

S.No	Pesticide	Indian MRL (mg kg^{-1})	Europe MRL (mg kg^{-1})	US MRL (mg kg^{-1})
1	Tricyclazole	3	1	3
2	Buprofezin	0.05	0.5	1.5
3	Isoprothiolane	0.1	5	—
4	Carbendazim	0.5	0.01	—
5	Acephate	0.07	0.01	—
6	Tebuconazole	0.05	1	—
7	Triazophos	0.05	0.02	—
8	Propiconazole	0.05	0.05	7
9	Chlorpyrifos	0.05	0.05	—
10	Thiamethoxam	0.02	0.01	0.02
11	Primiphos-methyl	0.5	5	—

MRL, Maximum residue level.
Source: APEDA, Ministry of Commerce, Government of India.

contained traces of chlorpyrifos (0.001 mg kg^{-1}). So, IPM practices are being promoted by APEDA to increase Basmati exports.

Basmati rice is a major export product for Pakistan (Akram, 2009), and injudicious use of pesticides (Tariq et al., 2007) is making shipment clearance difficult due to pesticide residues (Munshi et al., 2011). One thousand rice samples were collected during 2005 and 2006 from different containers representing different geographical origins within the country. Residues of 37 chlorinated hydrocarbon compounds were detected including dichlorodiphenyltrichloroethane (DDT) and hexachlorocyclohexane (HCH). The DDT and HCH residues were detected in 30% and 45% of the samples, respectively. Imran et al. (2016) carried out studies to detect the concentration of four pesticides (L-cyhalothrin, malathion, monocrotophos, and cartap) using high performance thin layer chromatography of 106 rice samples collected from mills in specified areas. The average concentration of pesticide residues ranged from 0.08 to 0.1 mgL^{-1}, and they were statistically insignificant in all rice-growing areas and for all varieties of rice. Interestingly, the mean detected levels of all pesticides were below the standard lethal doses. Ahmad et al. (2008) documented similar findings for these pesticides. These authors concluded that pesticide residues were detected in both husked and unhusked rice of Basmati 385. On the other hand, a recent study carried out in major rice-growing districts of Punjab, Pakistan, revealed that samples from Narowal, Sialkot, and Gujranwala contained imidacloprid residues in excess of the permissible limit (1.5 $\mu g\, g^{-1}$) set by the European Union (Niaz et al., 2016).

9. POLICY ISSUES TO PROMOTE BASMATI RICE IN INDIA AND PAKISTAN

Recently, a satellite survey conducted by National Aeronautic and Space Administration revealed that the groundwater table in northwest India is declining at a rate of 0.33 m per year (Rodell et al., 2009). There was a net loss of 109 km^3 of groundwater, double the capacity of India's largest surface reservoir, indicating judicious use of groundwater in this region critical. Rice cropping consumes a lot of water in this region. Diversification of rice with alternative crops such as soybean and maize is being promoted but farmers are unwilling to alter their cropping system due to the advantages of assured marketing, highly mechanized systems, and stable production in rice (Hira, 2009). However, diversification within Basmati rice is possible and farmers are very receptive in this direction. As the planting time of Basmati rice coincides with monsoon, its cultivation could help in saving of irrigation water. However, there are concerns that if the entire rice production area of this region came under Basmati rice cultivation, it could create a glut because of limited export demand. Under such a scenario, the farmers would be susceptible to exploitation by the millers. So, research is being conducted into value adding in Basmati, so that more Basmati could be utilized within the country, ensuring farmers' profitability. Basmati varieties suitable for making value-added products need to be identified and promoted. In recent years, some useful chemicals have been extracted from Basmati rice bran, such as oryzanols, tocopherols, and tocotrienols, which confer several health benefits to rice consumers such as reduction in blood cholesterols and triglyceride levels, antitumor and anticancer activities, and protection against cardiovascular diseases (Zubair et al., 2012). Among the popular cooking oils, rice bran oil is the only type that contains oryzanols, and this needs to be promoted. Preliminary studies on Basmati cultivars revealed that Basmati varieties are rich in Fe and Zn. Generally red pericarp varieties are rich in iron. The pericarp of the popular variety Pusa Basmati 1121 is also red but information on functional properties of grains is limited in this direction. Ranbir Basmati and Basmati 386 were reported with high iron contents of 27.9 and 24.3 mg kg^{-1}, respectively. Similarly, Ranbir Basmati was also reported with high Zn content of 73.8 mg kg^{-1} (UshaRani, 2009; Siddiq et al., 2012). These varieties could be explored for special niches. Due to higher living standards, the demand for organic rice is increasing as people become more conscious about diet and health. In this direction, organic Basmati could go a long way. As Basmati is responsive to low-nutrient inputs, with the use of green manuring or FYM, good harvest of Basmati can be obtained. Due to fragrance in Basmati, Basmati varieties can also be explored for making wines. Till date, no information is available on products such as Basmati wine and Basmati perfumes. Ready-to-eat value-added/processed foods are popular in the modern diet of humans. A variety of processed products are made from rice, which includes beaten, puffed, and popped rice, noodles, desserts, and idli/dosa powder. The physicochemical properties of Basmati varieties must be explored and, in particular, the type of starches that decide its suitability for making a particular processed product. For instance, "Newrex" is a long slender-grain rice with superior processing quality developed in the United States. It is dry and fluffy when cooked and is suitable for manufacturing canned, quick cooking, and frozen type rice products. Basmati varieties must be explored for beaten/flattened rice. Beaten rice is a popular form of parboiled brown rice, and in rural areas it is popular for breakfast. Basmati varieties are unique in volume expansion, so these can also be explored for making puffed rice. Popped rice may also be obtained from Basmati. Popped rice is obtained when a paddy is roasted in hot sand, such that the grains burst due to presence of water vapor splitting open the husk. Fresh harvested paddy with a moisture percentage of 20–24 and heavy grain type without chalkiness, sun crack, or fissures gives large popped volume. These types of traits are unique in Basmati rice. Popped rice is also fried to make a crispy dish. These types of products made with Basmati varieties need to be promoted, as they consist of whole kernel and have a long shelf life. It is high time that policy and research issues for value-added products in Basmati cultivars are addressed.

The Basmati rice export industry functions according to market-oriented principles in Pakistan. Government intervention and assistance in this sector has been limited. Pakistan needs to adopt a brand-based approach regarding its Basmati rice to maintain its uniqueness and survival in the international market. Successful retail brand development will not only increase the market share but can also help increase the value of exports. Rice exporters are urged to carry out international market research to determine the preferences of the consumer (Anonymous, 2016a). Investment in market research seems indispensable to gauge consumer preferences regarding product and price. Such research has a good return on investment because it provides a much-needed baseline to develop branding and marketing campaigns. To cope with the increasing demand for parboiled rice, and to capture its lucrative market, millers in Pakistan should equip themselves with recent technological advancements to deliver standard quality product. Future variety development processes should also complement parboiling, as is the case with recently released Kissan Basmati (Anonymous, 2016a,b).

Harmonious collaboration between all the actors in the value chain, at all stages spanning from production to export, seems imperative. Development and implementation of a Basmati rice export marketing strategy in collaboration with REAP and Pakistan Commercial Trade Attaches in the target export markets seems a promising strategy for Pakistan (Anonymous, 2016e). REAP has decided to prepare a road map to explore and enter new markets in a bid to boost exports. REAP will focus on long-term planning with short-term targets to enhance Basmati exports, with an initial target to increase exports from US$ 2.5 billion to US$ 3.0 billion (Memon, 2013). Developing better varieties, improving farming practices, refining processing techniques, and introducing brand marketing are urgently needed to increase the export potential of Pakistan.

10. CONFIRMATION AND IDENTIFICATION OF GEOGRAPHICAL AREA

As Basmati expresses its unique quality characteristics in the native area, confirmation of the place of origin is important for export. Isotopic and multielement analysis of rice varietal samples can solve this problem. Analysis for carbon 13/12 and oxygen 18/16 ratios along with concentrations of elements such as tungsten, selenium, rubidium, magnesium, gadolinium, holmium, and boron helps in identifying a geographical area. Concentrations of these elements and isotope from the samples compared with database value from authentic rice grown in India/Pakistan, United States, and Europe are available. But this technique failed to distinguish mixtures of Basmati and long grain Basmati rice that are commonly used in adulteration. In such situations, SNP and informative molecular markers, for instance, microsatellite DNA markers, can differentiate admixture of Basmati and long grain rice (Siddiq et al., 2012).

Although traditional Basmati varieties have unique quality characteristics, they are also prone to lodging due to tall stature. Low yield and photoperiod sensitivity are other undesirable traits in Basmati. To increase the yield level in Basmati, traditional Basmati varieties were cross bred with high-yielding varieties, resulting in proliferation of many evolved Basmati varieties, which fall short of quality characteristics earmarked for true Basmati varieties (Siddiq et al., 2012). Thus, these varieties have been given a different price grading in the domestic and international market. The European Union is giving zero percent import duty for six notified traditional Basmati varieties; and this concession has encouraged some growers to continue growing traditional Basmati varieties in some pockets of the Himalayan foothills. Zero percent duty and the attractive price of traditional Basmati varieties has encouraged traders to adulterate the pure product with evolved Basmati varieties or long grain rice to gain more profits. This practice necessitates the development of precise methods/protocols to differentiate traditional Basmati from evolved Basmati varieties, which will also quantify the amount of adulteration. Basmati importing countries permit a certain limit of mixtures (5%–15%) under the assumption that some inadvertent mixture during postharvest or processing is the usual phenomena.

11. CONCLUSIONS AND FUTURE PROSPECTS

Due to improving living standards, Basmati rice earns an attractive price in the domestic and in the international markets. In the past 5 year, the area under Basmati in India has increased manifold. Taking advantage of low water requirement, premium price offered, increasing demand, and the tariff concession from the European Union, there is ample scope to increase the area under Basmati cultivation and to increase the profitability of farmers, forex earnings, and export volume. However, to sustain the export potential and farmers' profitability, governments guarantee a minimum support price for Basmati rice. The area under Basmati rice should be fixed according to the cultivar niche based on the demand position in the domestic and in the international markets. On the other hand, Pakistan is gradually retreating from a developing global Basmati market due to lack of varietal development in recent years, lack of adoption of latest processing technologies, loss of competitiveness resulting from productivity and price crisis, lack of product adaptation, poor marketing techniques (selling in bulk quantity instead of value adding and branding), and ethos. Although Pakistan is striving hard at various forums and through promulgation of legislation on GI will preserve its natural heritage of Basmati cultivation, the commercial extinction of indigenous Basmati varieties would render such protection meaningless. Registration alone may not be the only solution for Pakistan to recapture its lost share of the international Basmati rice trade.

Future research in Basmati rice should be focused on value adding for Basmati and evolving stress-tolerant and nutritionally rich Basmati varieties. Basmati rice, although being an important item of export from the Indian subcontinent, has not been systematically studied for its special quality traits, especially low glycemic index and residue in grains. The correlation of sensory quality particularly pesticide residue in rice with instrumental techniques has not been attempted so far and deserves attention from researchers. Systematic studies are needed on Basmati rice aroma, cooking, and eating quality traits with respect to varied environmental conditions, especially in this era of climate change. Efforts are needed to develop Basmati cultivars with resistance against insects (brown plant hopper), pests, and disease (blast, bacterial, and sheath blight), reducing the need to use chemical pesticides and thus strengthening export prospects. Basmati is being grown in the rice—wheat cropping system of the IGP, so more focus should be on developing varieties with shorter duration that could fit into the rice—wheat cropping system with lower water requirement. More effort is needed to develop cultivars with high grain number panicle (>150 grains per panicle), high brown rice percentage (>80%), and high head rice recovery (>50%) in all the elite lines of Basmati. It is also important to discover why Basmati varieties with similar amylose content, gelatinization temperature, and gel consistency show different cooking behavior, sticky nature, and time of aging. What are these factors? Again, a challenging task for Basmati rice breeders.

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