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STUDY ON BASMATI RICE IN INDIA

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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.

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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 cookingdwhich 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 2004e14, 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 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.

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.

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.*

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 g-aminobutyraldehyde (GABald) is an effective substrate for badh2, and its accumulation and spontaneous cyclization to form D1 -pyrroline due to a nonfunctional badh2 enzyme is responsible for 2-AP accumulation in rice. Huang et al. (2008) revealed the increased expression of D1 -pyrroline-5-carboxylate synthetase in fragrant varieties compared with nonfragrant rice varieties, as well as concomitant elevated concentrations of its product, and concluded that D1 -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).

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.

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 F1 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 salttolerant 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 Haryana, Delhi, and Uttaranchal. Pusa RH 10 had higher yield (20%e30%) 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 pesteresistant 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 (22e25 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 2014e15 (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.

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