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Basmati Revolution: Transforming farmers' livelihood through research

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Rice is a staple food for over half of the world's population and accounts for over 20 per cent of global calorie intake. Global rice production in 2013 is expected to be 494.2 million tonnes milled rice (FAO, 2013) as compared to India's production of 104.4 million tonnes during the same period. In order to feed the projected rice consuming population in 2050, especially the population from Asian countries, the rice yields have to be increased by 50%. Genetic enhancement of rice through conventional breeding approaches in tandem with modern molecular tools can aid in realizing the projected targets.

Basmati rice improvement –translating the promise of genetic enhancement

Basmati rice from the Indian subcontinent is unique in its grain and cooking quality characteristics which fetches premium price in the international markets. The traditional Basmati cultivars are tall, prone to lodging, photoperiod and temperature sensitive and very low yielding. The genetic improvement of Basmati rice was initiated at IARI in the early 1960s' to combine the Basmati quality in high yielding background under the leadership of eminent scientist Dr. MS Swaminathan (Siddiq et al., 2009). Genetic improvement of Basmati rice at Indian Agricultural Research Institute, New Delhi through classical breeding approaches has led to development of a number of high yielding Basmati rice varieties, wherein the duration of traditional Basmati rice varieties has been reduced from 160 days to 115-140 days with enhancement of productivity from 2.5 tons/ ha to 6-8 tons/ ha (Fig. 1). Through systematic breeding efforts, IARI developed and released 29 rice varieties, out of which 17 varieties are central releases while 12 varieties were state releases. Noteworthy among them, five are Basmati rice varieties namely Pusa Basmati 1, Pusa Basmati 1121, Improved Pusa Basmati 1, Pusa Basmati 6 and Pusa Basmati 1509; four varieties are aromatic long slender grain varieties namely Pusa Sugandh 2, Pusa Sugandh 3, Pusa Sugandh 5 and Pusa 1612; a semi dwarf high yielding, non Basmati rice variety Pusa 44 and the world's first superfine grain aromatic rice hybrid, Pusa RH 10.

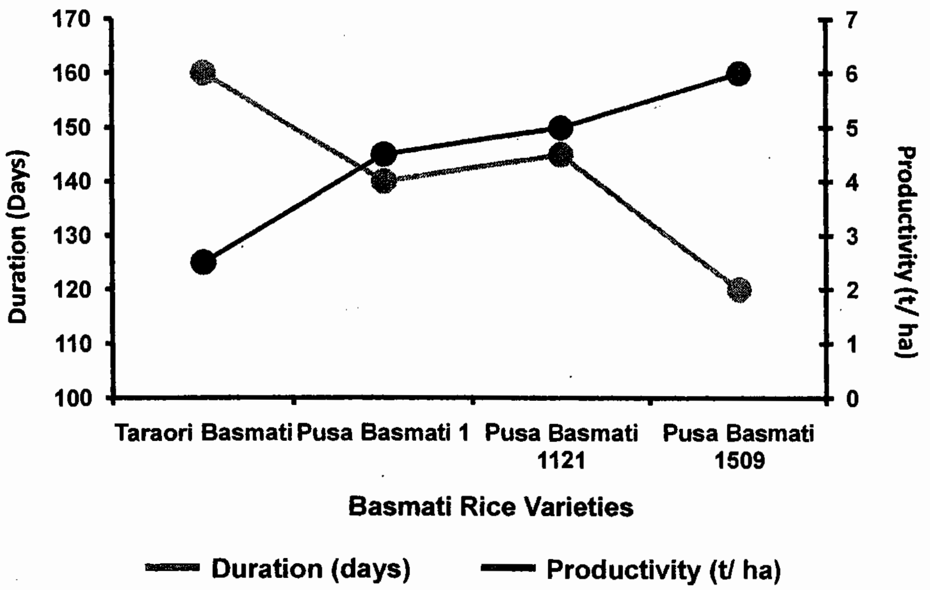

Fig. 1. Breaking the undesirable alliance through breeding - Combining high yield with short duration in Basmati Rice

Recently, IARI achieved another landmark through the development and release of 'Pusa Basmati 1509', which combines semi-dwarf stature, early maturing and better grain, cooking and eating quality at par with Pusa Basmati 1121. The cultivation of Pusa Basmati 1509 has given an unprecedented return of Rs. 100,000/ acre to the farmers during Kharif 2013 (the average yield being 25q/acre and average price being Rs. 4, 000/q of paddy). Reduction in duration by 30 days in improved Basmati rice varieties has brought a paradigm shift in rice-wheat cropping system making it more sustainable by reducing 5-6 irrigations in rice crop and the irrigation saved in rice is good enough to raise wheat crop. The improved Basmati rice varieties are climate smart and have very high input use efficiency.

Improvement of grain quality in Basmati rice

Through intensive breeding efforts, the grain and cooking quality traits of improved Basmati rice varieties has shown a marked improvement. The cooked kernel length of Taraori Basmati is 12 mm, while it was improved to 14 mm in Pusa Basmati 1. Further breakthrough was made by developing the exceptionally long cooked kernel variety, Pusa Basmati 1121 with cooked kernel length of 20 mm and the shape of the cooked kernel was improved in Pusa Basmati 1509 with cooked kernel length on par with Pusa Basmati 1121 (Fig. 2).

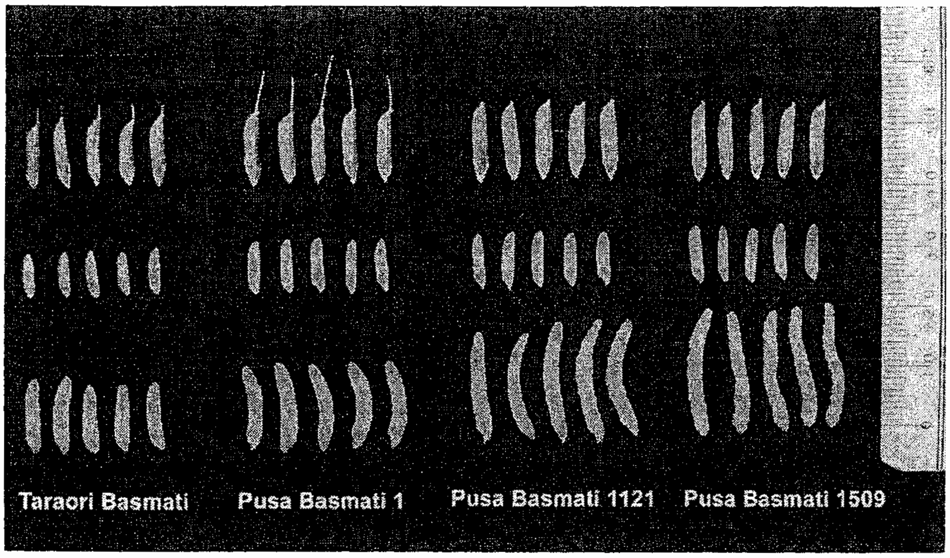

Fig. 2. Improvement in grain and cooking quality of Basmati rice varieties

Quantum leap in Forex earnings through translational research in Basmati rice

IARI developed Pusa Basmati 1, the first semi dwarf high yielding variety with shorter growth duration and longer milled rice kernel length (7.6 mm) and better cooked kernel elongation ratio (2.15) in 1989. Due to its high yield, longer mild rice kernel length faster ageing and better cooking quality compared to traditional Basmati varieties, Pusa Basmati 1 soon became a landmark variety. In the mid nineties, Pusa Basmati 1 became very popular in the trade and the forex earnings through export of Basmati rice increased from Rs. 294 crores in 1990-91 to 854 crores in 1995-96. Further, IARI developed Pusa Basmati 1121 in 2003 which recorded the cooked kernel length of up to 22 mm and five times volume expansion on cooking. Currently grown on 1.35 million ha area, Pusa Basmati 1121 has taken the forex earning through Basmati export to an all time high figure of Rs. 28,000/- crores while bringing prosperity to Basmati farmers and other stakeholders. As a result of large scale adoption of the Basmati varietal technology developed at IARI, the Basmati rice productivity has improved from 2.5 tons/ ha to 6 tons/ ha and India's forex earning from export of Basmati rice has gone up from US $ 5.6 million in 1990-91 to US $ 4.5 billion in 2013-14 (Fig. 3) to which the contribution of IARI Basmati rice varieties is more than 75% (Rs. 21,000 crores). Currently, India is exporting approximately 4.0 million tons of Basmati rice and approximately equal quantity is consumed in the domestic market, all this would have been a dream without genetic enhancement of productivity and quality of Basmati rice.

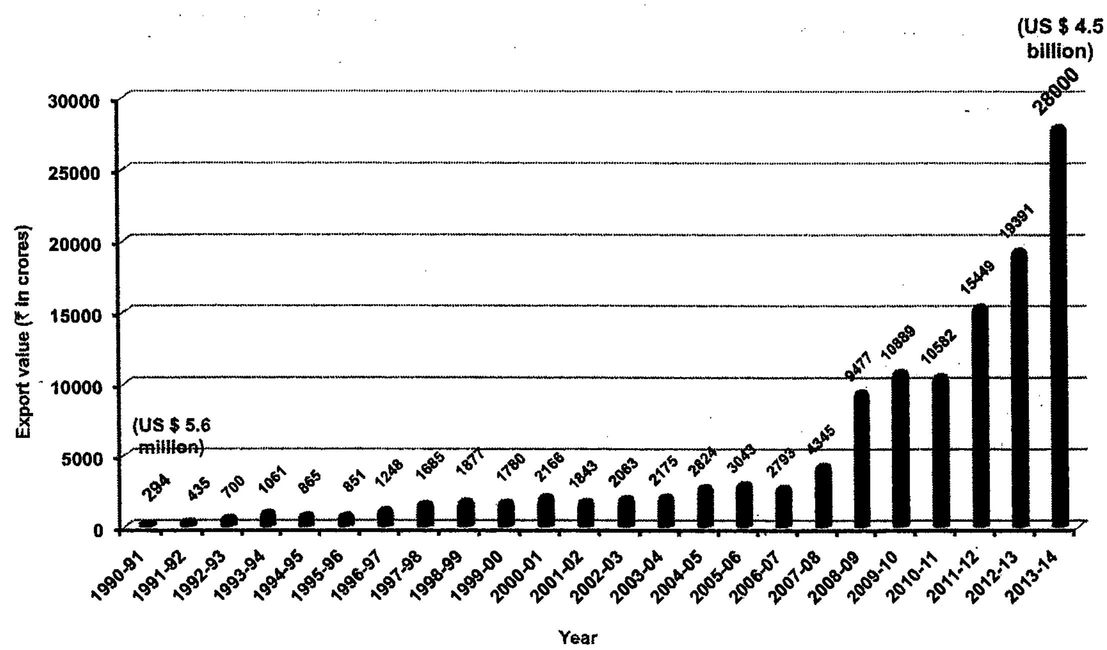

Fig. 3. Forex earnings from export of Basmati rice since 1990.

Towards sustaining Basmati rice productivity through molecular breeding

Basmati rice in general are highly susceptible to various biotic stresses such as bacterial blight (BB), blast, brown plant hopper (BPH) and abiotic stresses such as salinity. In order to avoid losses due to these insect pests and diseases, farmers adopt preventive application of insecticides and pesticides, irrespective of incidence of pests and diseases. This not only increases the production cost but concerns has emerged on the risk of pesticide residues in the international market. Therefore, resistance breeding approach has been advocated for sustaining the production of Basmati rice through the incorporation of genes conferring resistance to various biotic and abiotic stresses into the genetic backgrounds of the high yielding Basmati varieties and hybrids.

Marker assisted backcross breeding (MABB) has provided an unprecedented opportunity for precise transfer of genes responsible for biotic and abiotic stress tolerance genes/QTLs into various popular basmati rice varieties. In our lab, MABB was used for incorporating bacterial blight (BB) resistance genes (*xa13* and *Xa21*) into the genetic background of Pusa Basmati 1, which led to successful release of India's first MAS bred rice variety, Improved Pusa Basmati 1 (Gopalakrishnan et al., 2008). With the success of the Improved Pusa Basmati 1, marker assisted breeding is being effectively utilized in improving our varieties/ parental lines of the Pusa RH10 with the resistance genes/ QTLs for bacterial blight, blast, brown plant hoppers, sheath blight, salinity tolerance and increased efficiency of phosphorous uptake (Singh et al., 2011).

Further, the Improved Pusa Basmati 1 has been incorporated with blast resistance gene *Pi54* and a QTL *qSBR11-1* tolerance to sheath blight to develop a multiple biotic stress resistant genotype Pusa 1608. Additionally, the parental lines of superfine grain aromatic rice hybrid Pusa RH 10 namely, Pusa 6A, Pusa 6B and PRR78 were improved for resistance to BB and blast by transferring genes *xa13 + Xa21 and Pi54 +Piz5*, respectively (Basavaraj et al., 2010). Presently, the pyramiding of genes for resistance to BB (*xa13, Xa21, Xa33, Xa38*), blast (*Piz5* and *Pi54*) and brown plant hopper (BPH; *Bph 18, Bph20* and *Bph 21*) into Basmati rice varieties *viz.*, Pusa Basmati 1121 and Pusa Basmati 6 is under way. In addition, a major QTL for salt tolerance (*Saltol*) has been transferred to

Pusa Basmati 1121, which is widely grown in Haryana, the state having problem of salinity owing to underground brackish water. In order to develop genetically enhanced donor sources for resistance to biotic (BB, blast and BPH) and abiotic (salt tolerance, and phosphorus uptake) stresses in Basmati background, isogenic lines are being developed for major resistance genes/QTLs for respective stresses in the background of Pusa Basmati 1. Molecular mapping of fertility restorer gene(s) in Basmati restorer line PRR78 led to identification of two *Rf* gene linked molecular markers, RM258 and RM6100. Validation of RM6100 in a set of rice germplasm showed 97.4% efficacy in identifying restorers. QTL mapping using RIL population has unveiled several novel QTLs for yield and yield related traits, grain and cooking quality traits.

Farmers' Participatory Seed Production: Taking Basmati rice varieties to farmers:

Considering the huge demend for seed and limited land resources and infrastructure available, IARI has developed a very effective Framers' Participatory Seed Production model wherein the farmers within 100 Km distance with a minimum holding of 5 acres, these farmers are provided with breeder seed and know how from IARI, the seed production plots are monitored by IARI scientists from time to time for rouging operations and purity. The produced seed is brought back to IARI and processed/packaged and sold by IARI from its counter. The seed producing farmers are paid 65% of the sale price fixed by IARI. This programme has been very effective in 10 villages connected with IARI New Delhi and its regional station, Karnal. The seed producing farmers have been earning Rs. 15,000 to 20,000/acre additional income compared to commercial crop. At the same time this arrangement has helped IARI to produce large quantity of 'Pusa Beej' to meet the demands of farmers.

The way forward

Genetic improvement of Basmati rice at IARI has revolutionized Basmati rice cultivation in India. Further, through an effective integration of marker assisted breeding with conventional Basmati rice breeding program at IARI, New Delhi (Singh et al., 2011), we have been able to pyramid genes for stress resistance has aided in developing Basmati rice genotypes, which are in advanced stages of testing. With the availability of high throughput genomic technologies, their judicious utilization in molecular breeding can aid in developing commercially viable improved Basmati rice cultivars to address specific problems in Basmati rice production.

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Dr. A.K. Singh *is an involved rice breeder having been associated with development of eight Basmati rice varieties including the first superfine grain aromatic rice hybrid Pusa RH 10, these varieties earliness with higher per day productivity and excellent grain and cooking quality. Dr. Singh has also successfully integrated marker assisted selection strategy for improving rice varieties for resistance to biotic and abiotic stresses. Dr. Singh has published more than 70 papers in the journals of international repute and has been honoured by several awards including Best Teacher Award of IARI-2003 and B. P. Pal Memorial Award-2007 and Borlaug Award-2012. Dr Singh is the Fellow of National Academy of Agricultural Sciences, India.*