TRIBUTE

Founder of the Rice Breeding Programme at the Indian Agricultural Research Institute

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M. S. Swaminathan began his scientific career in India at the Central Rice Research Institute, Cuttack in 1954, where he focused on transferring genes for fertilizer responsiveness between different varieties of rice. Later the same year, he joined the Indian Agricultural Research Institute (IARI), New Delhi as an Assistant Cytogeneticist and began working on varietal improvement in wheat. He went on to become the Head of the Division of Botany, renamed the Division of Genetics during his tenure, and Director of IARI. During the IARI years, he played a pivotal role in research and policy interventions relating to rice cultivation.

In the 1950s, rice cultivation in the Punjab region was limited to areas affected by waterlogging, salinity, and alkalinity, an area of around 120,000 hectares. Swaminathan believed that developing high-yielding rice varieties could help expand rice cultivation in non-traditional areas and increase productivity and production. To achieve this, he initiated, with the involvement of his students, a systematic rice varietal improvement programme at the Indian Agricultural

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Research Institute. Since only a *kharif* (monsoon) crop could be grown in New Delhi's climate, the need for an off-season nursery was felt. To accelerate the rice genetic improvement programme, a shuttle-breeding approach was adopted, utilizing the facilities at the Paddy Breeding Station in Aduthurai from 1968. Swaminathan played a crucial role in establishing an off-season nursery at the Tamil Nadu Rice Research Institute in Aduthurai in 1981, now known as the Rice Breeding and Genetics Research Centre.

Germplasm Collection and Conservation

To address the issue of genetic erosion of rice landraces in the north-eastern states of India, Dr. Swaminathan initiated a project focused on the collection of rice landraces. This project was developed under the PL-480 grant of the United States Department of Agriculture (USDA). As part of this initiative, more than 6000 rice landraces were collected. These landraces were given the suffix ARC (Assam Rice Collection) to signify their origin and to distinguish them from other rice germplasm collections. The collection aimed to preserve and conserve the genetic diversity of rice in the region, which was threatened by the prevalent practice of traditional shifting (*jhum*) cultivation. Among the collection of landraces, spontaneous dwarf mutants were also identified. These dwarf mutants are significant as they are of shorter stature than their original counterparts. This trait can be valuable in breeding programmes, as it contributes to increased lodging resistance and facilitates higher yields. Through the project on collection of rice landraces, Dr. Swaminathan not only sought to address the issue of genetic erosion but also contributed to the identification of valuable traits for rice improvement and breeding.

Development of High-Yielding Rice Varieties

To ensure multiple cropping, Swaminathan emphasised early-maturing high-yielding rice varieties with biotic stress resistance. Two crosses namely, IR8/TKM6 and IR8/Tadukan were generated and stringent phenotypic selection for earliness and high yield led to development and release of Pusa 2-21 (Kannagi) and Pusa 4-1-11, respectively, for the State of Tamil Nadu. Both varieties were early-maturing and popular among farmers. Later, Pusa 2-21 was released and notified for cultivation across India. Another early maturing rice variety, Pusa 33, was developed from the cross Ratna/Improved Sabarmati, which also became popular across the country. These varieties yielded 5 to 6 tonnes/ha on farmers' fields and, for more than a decade, Pusa 2-21 and Pusa 33 were the mega rice varieties of India (as recommended by the then Directorate of Rice Research, Hyderabad).

To further increase production in the rice-wheat belt, Pusa 44 was developed from a cross of IR8 and IARI-5901-2, a spontaneous dwarf mutant from the Assam rice collection. Pusa 44 is a medium-duration rice variety with long slender grains and a

potential yield of 10 tonnes/ha. This variety replaced IR8 and Jaya in Punjab and Haryana because of its higher yield and better grain quality parameters.

Basmati Rice Improvement at IARI

Genetics of Basmati Quality

Pioneering research work was carried out on the standardisation of protocols for estimating various Basmati quality parameters and analysing their inheritance patterns (Singh *et al.*, 2004). A simple, high throughput method for sensory evaluation of aroma by adding 10 ml of 1.7% Potassium hydroxide (KOH) solution to a small petriplate containing about 2 g of finely minced sample of green leaf or stem was developed (Sood and Siddiq, 1977). This method could be used for estimating aroma from any plant part (including single grains) other than roots. In addition, polygenic control of kernel elongation was demonstrated by analysing segregating population, which has now been amply established by quantitative trait loci (QTL) analysis. In one of the first reports studying the mechanism of kernel elongation, it was found that as against nearly equidistant pentagonal or hexagonal cells arranged in a bee-comb fashion in the elongating types, the cells were found to be long, rectangular and arranged radially in columns extending from the centre to the periphery in the breadth-wise swelling types (Sood *et al.*, 1979).

Acquisition and Characterisation of Aromatic Rice Germplasm

A total of 84, 162, and 152 aromatic rice germplasm lines were received from IRRI, Philippines in 1976, 1986, and 1990. Dr. Swaminathan personally enriched the rice germplasm by collecting Randhuni Pagal from West Bengal and Jeera Bali from Assam. Further, Basmati landraces were collected from the Dehradun Valley and areas around Karnal in Haryana. A systematic characterization of these landraces was undertaken to identify the donor sources for various quality traits. This helped in identifying a local Basmati rice genotype with a longer grain than Basmati 370, which was named Karnal Local. It became popular among farmers as it fetched better prices than that Basmati 370 (Table 1).

Market surveys identified Karnal Local as more popular than Basmati 370 and Type 3 rice. The longer kernels of Karnal Local were preferred by customers and the grain

Table 1. *Characteristics of traditional Basmati rice varieties and their market prices*

	Type 3	Basmati 370	Karnal Local
Plant height (cm)	130 — 140	145 — 150	155 — 170
Growth duration (days)	130-135	140-150	150-160
Milled rice length (mm)	6.61	6.89	7.25
Cooked kernel length (mm)	11.50	13.60	14.70
Average market price in the early 1970s (Rs/quintal)	150	200	250

fetched better prices in the market. Therefore, Karnal Local replaced Basmati 370 as the national quality check in the National Basmati Trials in 1992. In this way, a Basmati rice breeding programme was oriented towards developing semi-dwarf high yielding varieties with a focus on increased milled and cooked rice kernel length.

Most of these varieties were weak-stemmed, of tall stature, and highly prone to lodging. They were also photoperiod sensitive with long maturity duration. For these reasons, a systematic breeding programme for the genetic improvement of rice was initiated at IARI in 1966 under the leadership of Dr. M. S. Swaminathan to develop varieties with semi-dwarf plant architecture, strong-culm genes and high yields.

A farmer from Uttar Pradesh, the late Shri Meghraj Singh Khokhar of Datiana village, Muzaffarnagar district, described the properties of Basmati rice thus:

> the milled rice should be long in length, the neighbours should know that Basmati rice is being cooked in the house (that is, it must be very aromatic), the cooked rice should be as long and slender as a needle (that is, there must be no breadth-wise swelling), a cup of milled rice should result in 5 cups of cooked rice (that is, the kitchen yield must be more than from other rices), the rice should be as soft as freshly-prepared butter, it should be so tasty that you feel like eating more but do not, at the same time, feel that the rice sits heavy on the stomach (that is, it must be easily digestible), it should spread like pearls (that is, the cooked rice must be non-sticky), and left-over rice should not turn stale till next day (that is, it must have a long shelf-life).

The Basmati rice programme spearheaded by Swaminathan at IARI introduced these quality parameters into the breeding objectives of the programme, while also attempting to improve grain yields by reducing plant height and making the plant stem more sturdy.

The Development of Pusa Basmati 1: The Beginning of the Basmati Revolution

The first breakthrough in Basmati rice breeding came in 1989 with the release of Pusa Basmati 1 (Figure 1), the world's first semi-dwarf, photoperiod insensitive and high-yielding Basmati rice variety developed from the cross between Pusa 150 and Karnal Local. Pusa 150 was derived through a convergent breeding approach involving a high-yielding non-aromatic variety Taichung Native 1, among several others and traditional Basmati rice variety, Basmati 370, which was used as a donor for quality traits. Extra-long slender aromatic grains, lower cooking time and higher linear cooked kernel elongation of freshly harvested rice coupled with potential grain yield of 6-7 tonnes/ha and medium early duration (135-140 days seed to seed maturity) made Pusa Basmati 1 the variety most sought after by farmers, exporters, and consumers. The release of Pusa Basmati 1 revolutionised Basmati rice production in India. Export earnings rose from 8,650 million rupees in 1994-95 to 43,450 million rupees in 2007-08 (www.apeda.gov.in). During the period 1995-2007, this variety contributed nearly 60 per cent of total Basmati rice export value and brought prosperity to the Basmati rice

Figure 1 *Pusa Basmati 1, the world's first semi-dwarf, photo-insensitive high yielding Basmati rice variety, developed and released for commercial cultivation by IARI in 1989.*

farmers of Punjab, Haryana, western Uttar Pradesh, and Uttarakhand. Pusa Basmati 1 became a benchmark variety and was used extensively as a donor for Basmati quality traits and high yields in national and international breeding programmes.

Pusa Basmati 1121 and Pusa Basmati 6: Enhanced Grain Quality

Pusa Basmati 1121 was developed by intercrossing the sister lines of Pusa Basmati 1 (Figure 2). Pusa Basmati 1121 is a medium-duration variety that combines unique Basmati quality characteristics, that is, with extra-long, slender (7.71 mm), highly aromatic grains with 52.9 per cent head rice recovery and very occasional chalky grains. It has the longest kernel length after cooking (up to 22 mm) with an

Figure 2 *A crop of Pusa Basmati 1121 in the farmer's field*

exceptionally high cooked kernel elongation ratio of 2.5, a volume expansion of more than a factor of four, intermediate amylose content, an appealing taste, good mouth feel, and easy digestibility (Singh *et al.* 2018).

Pusa Basmati 6 (Pusa 1401) was derived from a cross between Pusa Basmati 1 and Pusa 1121 with semi-dwarf plant stature with longer maturity duration. Pusa 1121 and Pusa 1401 were entered into coordinated trials during *kharif* 2002. Pusa 1401 was released as Pusa Basmati 6 for the States of Haryana and Uttarakhand; and Pusa 1121 was released as Pusa Basmati 1121 for the States of Delhi-NCR, Haryana, and Punjab in 2008.

The phenomenal popularity of the new varieties among consumers across the globe stimulated a steep increase in demand in national and international markets. Foreign exchange earnings from exports of Basmati rose from Rs. 43,450 million in 2007-08 to an all-time high of Rs. 385,240 million in 2022-23.

Pusa Basmati 1509: An Early-Maturing High-Yielding Basmati Rice Variety

A diminishing water table in zones of the north-western plain is one of the major constraints to increased rice cultivation. A cross between Pusa 1301 and Pusa Basmati 1121 led to the development of an early-maturing semi-dwarf Basmati rice variety with grain and cooking quality at par with Pusa Basmati 1121 but higher yielding than Pusa Basmati 1121. This variety was released in 2013. It became popular among farmers because it vacates the field earlier than any other Basmati variety, providing farmers an opportunity to take up potato cultivation (the crop duration also reduces the problem of burning straw).

The Development of Biotic Stress Resistant Basmati Rice Varieties Through Marker-Assisted Selection

By 2015 three varieties, namely, Pusa Basmati 1121, Pusa Basmati 6 and Pusa Basmati 1509 occupied more than 95 per cent of the area under Basmati rice and contributed 95 per cent of the foreign exchange earned from the export of Basmati rice. However, these varieties are susceptible to various biotic stresses, including bacterial blight, blast, bakanae, sheath blight, and brown plant hoppers. In recent years, marker-assisted breeding has been used to develop varieties that are resistant to biotic stress, particularly bacterial blights and rice blast. These varieties include Improved Pusa Basmati 1, Pusa Basmati 1718 and Pusa Basmati 1728 (Ellur *et al.* 2016) and Pusa Basmati 1885, Pusa Basmati 1886 and Pusa Basmati 1847 (Sagar *et al.* 2020, Singh *et al.* 2023a, 2023b, 2023c).

Closing Remarks

The rice improvement programme initiated by Dr. M. S. Swaminathan laid the foundation for a strong breeding programme at IARI, one that has resulted in bringing prosperity to many. The new Basmati varieties have generated higher production, incomes, and employment. Farmers speak of "Basmati, the debt-reliever" (*karza paad*

Basmati)" and of the wonders of Pusa Basmati (*Pusa Basmati da kamaal*). The vision of Dr. Swaminathan resulted not only in improving farm incomes but also helped in the creation of world-class infrastructure and rice processing facilities in the form of modern rice mills and grain markets. The technology envisioned by him has revolutionised the lives of millions of farmers, millers, and exporters while also making Basmati rice available to consumers at affordable prices.

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