TRIBUTE

The National Agricultural Research, Education, and Extension System

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Introduction

India has made the fascinating journey from being a country of starvation to a food-surplus country. India's food grain production rose from 51 million tonnes in 1950 to over 330 tonnes in 2023. Globally, India has today the top rank in the production of milk, pulses, and jute; second rank in cotton, rice, wheat, fruit, and vegetables, and one of the leading positions in spices, fish, poultry, and livestock production. These extraordinary achievements were possible because of the visionary view that science and technology were to be the foundation of the development of agriculture.

India witnessed remarkable progress in the agriculture sector in the post-Independence era despite facing a range of challenges with respect to natural resources, biotic and abiotic stresses, and knowhow about improved processes and inputs. Strong education and research programmes in the country boosted food production severalfold despite a decline in land and labour availability. The accelerated growth of food grain production in India, at a rate that has never been attained elsewhere, provided the basis for food security after the late 1960s. Today, India is not only a world leader in agricultural production in major commodities, but also the only country in the world to have enacted a law that guarantees the right to food to its citizens.

The National Agricultural Research, Education and Extension System (NAREES) has been in the forefront of the agricultural revolution in India. Professor M. S. Swaminathan played a pivotal role in shaping NAREES and the future of agricultural research and development in India. While many iconic figures –

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scientists, politicians, and administrators – played important leadership roles in the Green Revolution, Swaminathan was the face, voice, and soul of this most disruptive change in the history of global agriculture. He was the scientist's scientist, the farmer's scientist, the politician's and bureaucrat's scientist, and the ultimate communicator, a person who could foster trust between scientists, farmers, policymakers, and other constituents of the national agricultural research, education and extension system. He was constantly exploring new technologies, institutional systems, and processes (and anticipating emerging problems), to use science to address emerging national and global problems of food and ecological security, and to motivate and guide NAREES to connect research and education with sustainable farming. Much of the continuous evolution and self-renewal of NAREES, its empathetic farmer-centric mindset, and a science culture that enables a co-evolution of research and technology transfer, is rooted in Swaminathan's vision and approach.

Building a National Agricultural Research, Education and Extension System

The Indian Council of Agricultural Research (ICAR), an autonomous organisation of the Department of Agricultural Research and Education (DARE), Ministry of Agriculture and Farmers Welfare, Government of India, was established on July 16, 1929. The mandate of ICAR is to plan and promote agricultural research and education in the country. ICAR also shoulders the responsibility of managing agricultural education. The ICAR has 113 research institutes, 76 agricultural universities, and 731 Krishi Vigyan Kendras (KVKs) supervised by 11 Agriculture Technology Application and Research Institutes (ATARI) spread across the country. India – with approximately 30,000 scientists (6,500 in the ICAR and 23,500 in the agricultural universities), and more than 100,000 technical and support personnel – has one of the largest stocks of human resource capital in agricultural research in the world.

NAREES is a unique and complex system of organisations and relationships in which public (Central and State) agricultural research institutions and universities are networked with farmers and farming organisations, policymakers, State Governments, international agricultural organisations, seed and agribusiness companies, agri-tech start-ups, funding institutions, and others. The ICAR is the nucleus of the network that brings these diverse entities together into an integrated system that addresses common national and global goals of food and health security, livelihood security, and agricultural and ecological sustainability through research, education, and extension. That such a NAREES system could be visualised and created over a short period of about three to four years (1967–71, initially in the public sector) is the result of national policies, and the farsighted leadership, vision, strategy, and dedicated commitment of the founders of the green revolution. The contribution of M. S. Swaminathan in initiating and achieving excellence with respect to various components of the national agricultural research, education and extension system is presented below.

Agricultural Research Service (ARS)

Swaminathan was instrumental in the creation of the All-India Agricultural Research Service, which facilitated collaborative research efforts among scientists from all corners of India. This network of scientific minds fostered innovative solutions of problems in agriculture, and created a sense of unity among researchers dedicated to improving the national agricultural landscape.

Agricultural Scientists Recruitment Board (ASRB)

The ASRB was established on November 1, 1973 as an independent recruitment agency in pursuance of the recommendations of the Gajendragadkar Committee. The major objective of the ASRB is to recruit ARS scientists and research management personnel for the ICAR. The ASRB conducts all India competitive examinations for ARS to recruit scientists at the entry level. It also conducts the National Eligibility Test (NET), a prerequisite for fresh recruitment of Lecturers and Assistant Professors in Central and State agricultural universities.

Department of Agricultural Research and Education (DARE)

DARE was established in December 1973 in the Ministry of Agriculture and Farmers' Welfare. It has four autonomous bodies under its administrative control. DARE is the nodal department for international cooperation in agricultural research and education. The Department mediates bilateral and multilateral cooperation with foreign governments, multilateral agencies and international bodies or organisations through the ICAR. DARE also facilitates international student admissions in various agricultural universities and ICAR institutes. Swaminathan's leadership, vision, and advocacy extended to international arenas. Through these global engagements, he facilitated collaboration between Indian institutions and their international counterparts, enriching agricultural research and education with global perspectives and cutting-edge research to serve humanity.

National Academy of Agricultural Research Management (NAARM)

NAARM was established at the ICAR in 1976 with a mandate to address agricultural research management. The Academy imparts foundation training to newly recruited Agricultural Research Service scientists in the different ICAR institutes. NAARM also conducts research capacity-building programmes for senior professionals from national and international institutes in agriculture.

Strengthening All India Coordinated Crop Improvement Projects (AICRPs)

During his tenure as Head of the Genetics Division and later as Director of IARI, Swaminathan organised and implemented the first All India Coordinated Crop Improvement Projects in major food crops. These later became the epicentre of the green revolution. The AICRPs fostered an inter-institutional, inter-State, international, and interdisciplinary research culture that enabled multiple-location trials across different environments to facilitate a rapid co-evolution of new science and technology generation and transfer. Despite agriculture being a State subject, the AICRPs became a powerful model of institutional governance and Centre-State coordination. As Director General of the ICAR, Swaminathan extended the AICRP concept to all domains of agricultural research, including crop cultivation, natural resources management, animal science, and fisheries. His subsequent advocacy of research reforms, research priorities, and farmer-centric approaches have continued to influence the formulation of research policies to enhance the quality and relevance of agricultural research in India and elsewhere. Another legendary achievement was the establishment of several Project Directorates (the Maize, Wheat and Oilseeds Directorates) and inter-disciplinary research schools. Investigations of high-yielding dwarf Mexican wheat varieties and selection of genotypes adapted to Indian conditions resulted in the release of Sonalika, Safed Lerma, Choti Lerma, Sharbathi Sonara and Kalyan Sona. The period also saw the release of Ambar, Jawahar, Kisan, Vikram, Soan and Vijay maize composites.

Research and Innovation

After a postdoctoral programme at the University of Wisconsin, U.S., Swaminathan returned to India in early 1954. He worked as an assistant botanist at the Central Rice Research Institute in Cuttack and worked in the indica-japonica rice hybridisation programme. The indica-japonica hybridisation programme at the CRRI was the early harbinger of the green revolution movement in India. Swaminathan's work resulted in developing varieties such as ADT27 and Rasi, cultivated in Tamil Nadu. In October 1954, Swaminathan joined the Indian Agricultural Research Institute (IARI) in New Delhi as an assistant cytogeneticist. His early research focussed mainly on studying the structure and function of potato cells. He elucidated the mechanisms of speciation in the genus Solanum, section Tuberarium. Understanding the genomic affinity of the cultivated tetraploid potato $2n = 4x = 48$ (*Solanum tuberosum*), with wild diploid ($2n = 2x = 24$) enabled inter-specific hybridisation and transfer of genes to confer resistance against abiotic and biotic stresses to potato. In the United States, Swaminathan had developed a potato hybrid carrying the frost-resistance gene from a tetraploid wild relative, *S. acaule* ($2n = 48$). Later, this hybrid potato material was used to develop a frost-resistant potato variety called Alaska Frostless. At the IARI in New Delhi, he conducted outstanding basic research ranging from the elucidation of the structure of the chromatid, mitosis in yeast, mechanisms of ionising radiation and chemical mutagenesis, radio-sensitivity as a function of ploidy level, actions of low and high LET ionising radiation on diploid and polyploid wheats, and overcoming "diplontic selection" in vegetatively propagated material exposed to ionising radiation using the strategy of chronic irradiation to Drosophila genetics. He also started human cytogenetics by culturing human peripheral blood leucocytes for chromosome karyotyping of congenital abnormalities, and it gained unparalleled momentum. Swaminathan's important research interventions were made as a cytogeneticist in the field of radiation genetics, the culture of excised embryos, chemical mutagenesis, cyto-chemistry, biometrical genetics, and evolutionary sequence and monosomic analysis of Triticum genus. Under Swaminathan's leadership, the Division of Genetics at the IARI became globally renowned for genetic mutation research. During this time, a "Gamma Garden" was developed at the IARI to study radiation mutation. Swaminathan's association with Homi Bhabha, Vikram Sarabhai, Raja Ramanna, M. R. Srinivasan, and other Indian nuclear scientists allowed agricultural scientists to gain access to facilities at the Atomic Energy Establishment, Trombay, which later become the Bhabha Atomic Research Centre. Swaminathan's early basic research on the effects of radiation on cells and organisms partly formed the base of future redox biology (Kesavan and Iyer, 2014). The path-breaking basic research at the IARI added new knowledge, and above all opened up avenues for more vigorous pursuits in basic and applied research in cytogenetics and chemical and radiation mutagenesis in important food crops.

In 1964, Swaminathan established the Fundamental Genetics Laboratory in the Division of Botany to facilitate advanced research in the fields of biometrical, microbial, and molecular genetics. The Cereal Laboratory was established to intensify research in nutritional quality breeding of cereals with automated analysers. It was named the Cummings Lab after R. W. Cummings, the first Dean of the Post Graduate School of IARI. Swaminathan was instrumental in elevating the sections of Biochemistry, Plant Introduction, Plant Physiology, and Seed Technology to the status of independent divisions at the IARI, enabling their further growth in terms of infrastructure facilities and staff position.

Swaminathan also started a separate Division of Agricultural Chemicals to undertake research on botanical pesticides (neem, mahua and tobacco) and pesticide residues in farm products. The Water Technology Centre, the Algal Laboratory, and the Pulses Laboratory were established during this period. Tissue culture research also received new support with the establishment of an Anther Culture Laboratory, funded by the Indian National Science Academy, for the exploitation of haploids in heterosis breeding in rice and other crops.

During his early career at the IARI, Swaminathan made valuable contributions to the breeding and genetics of wheat, linseed, chilli, tobacco, bajra, maize, and forage crops, generating outstanding publications in major journals. The journals in which he published at the time included *Nature*, *Science*, *Genetics*, *Current Science*, *Radiation Research*, *Radiation Botany*, *Environmental and Experimental Botany*, *Experientia*, *Die Naturwissenschaften*, and *Experimental Cell Research*.

Swaminathan's efforts defied the Malthusian prediction that low yields and high population growth would produce mass starvation in India. In the 1960s, he recalled, many books were published by doomsday experts who said that Indians had no future. Another group of "experts" said Indians would die like sheep going to the slaughterhouse. But Swaminathan's determination defied all these predictions and India became self-reliant in food production. New wheat varieties were sown and in 1968 production rose to 17 million tonnes, 5 million tonnes more than the previous harvest. Subsequently, in 1971, the Government of India declared India to be self-sufficient in food production. A postage stamp to celebrate the "Wheat Revolution" – with images of wheat stalks, the Indian Agricultural Research Institute (IARI) building, and a bar graph showing the increase in wheat production – was released on July 17, 1968. It was the success achieved through the green revolution that led ultimately to the enactment of the National Food Security Act 2013.

Swaminathan was, of course, known around the world as the father of India's green revolution. Early on, he was keen to increase agricultural productivity and production, especially of wheat and rice, both staple food grains in India. He planned for shorter plant height without reduction in the length of the grain-bearing panicle, and for higher crop responsiveness to the application of fertilizers. In order to achieve these objectives, he pursued interspecific hybridisation and mutation through radiation and chemicals. Although these efforts contributed substantially to the enhancement of our basic knowledge of crop biology, the goal of developing the dwarf or semi-dwarf wheat plant type with normal spikes was not realised. However, his awareness of major innovations and developments in all parts of the world helped him trace the *Norin 10* dwarfing genes from Japan in wheat and the *Dee-jee-woo-jen* dwarfing genes from China in rice. His initial contact with Orville Vogel of the Washington State University, Pullman, helped him connect with Norman E. Borlaug, Director of the International Maize and Wheat Improvement Centre (CIMMYT), Mexico City. Swaminathan and Borlaug collaborated on a range of Mexican dwarf varieties of wheat, which were to be bred with Japanese varieties. Swaminathan was instrumental in the import of 18,000 tonnes of quality seed of high yielding varieties of wheat from CIMMYT, Mexico, for large scale planting in India. This was to be the harbinger of the green revolution in India. Initial testing in an experimental plot showed good results. The crop was high-yielding, of good quality, and disease-free. However, there was hesitation among farmers to plant the new variety, whose high yields were unnerving. In 1964, following repeated requests by Swaminathan to help demonstrate the new variety, he was given funding to plan small demonstration plots. A total of 150 one-hectare demonstration plots were planted. The results were promising and anxieties of the farmers were allayed. Modifications were made to the grain in the laboratory to better suit Indian conditions (Gopalakrishnan, 2002).

The Swaminathan-Borlaug combination – the sharing of new technologies for the good of humanity – was a unique international collaboration. This legendary bond also demonstrated the value and role of germplasm conservation, sharing, and utilisation in ensuring food security. Norman Borlaug was conferred the Nobel Prize in Peace in 1970 for his work on the green revolution; before he received the award, he wrote:

> To you, Professor Swaminathan, a great deal of the credit must go for first recognising the potential value of the Mexican dwarfs. Had this not occurred, it is quite possible that there would not have been a green revolution in Asia.

Growth of Seed Industry

The All India Coordinated Research Project (AICRP) research at the IARI also laid the foundation of the public seed industry in India in the early years of the green revolution, and encouraged the growth of the private seed industry after the mid-1980s. Subsequent policy changes have enabled collaborative research between the private and public sectors and easy access to quality seeds for farmers. India today has become a major player in the global seed industry.

Agricultural Education

Swaminathan's deep involvement in post-graduate education and research at the IARI during the green revolution period had a profound impact on the expansion of the agricultural university system in India and influenced its structure and curriculum by promoting specialisation, incorporating modern technologies, and emphasising student engagement in collaborative research and technology transfer. Many elements of the new model of higher education proposed in the National Education Policy (NEP 2020), including its emphasis on student research, interdisciplinary coursework, and experiential learning, have been integral to the agricultural university system in India since its inception. Swaminathan led the effort that led to the IARI Postgraduate School being awarded the status of a deemed university by the University Grants Commission and being authorised to award M.Sc. and Ph.D degrees. He thus became the chief architect of postgraduate education in agriculture in India. The IARI pattern was followed in agricultural universities across the country – in Punjab, Uttar Pradesh, Kerala, Karnataka, West Bengal, Assam, Odisha, Andhra Pradesh, Madhya Pradesh, and Tamil Nadu. Swaminathan played a leading role in the establishment and promotion of the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) in India; the International Board for Plant Genetic Resources (now known as Bioversity International) in Italy, and the International Council for Research in Agro-Forestry in Kenya. He helped build and develop and provide institutional support to teaching and research institutions in China, Vietnam, Myanmar, Thailand, Sri Lanka, Pakistan, Iran, and Cambodia (Kesavan and Iyer, 2014).

Institutional Relevance and Renewal

Swaminathan's advocacy of continuous institutional reform and renewal in agricultural research and education has been internalised in the ICAR through five-yearly independent external reviews for research (QRTs), and education (through periodic Deans' Committees on curricular reform).

Extension

National Agricultural Research Project (NARP)

The ICAR launched NARP in 1979 with the assistance of the World Bank. The objectives of NARP are to conduct need-based, location-specific, and production-oriented research. Research on problems specific to agro-climatic zones (or recommendation domains) was developed by considering the resources, constraints and environment of each zone. The participation of farmers was envisaged at the critical stage of planning research. Further, the establishment of linkages between research and extension to enhance technology adoption and utilisation was to move research in the direction of farming systems research (FSR) (Raman and Balaguru, 1988).

Lab to Land Programme

Swaminathan recognised the need for the "lab to land" programme to evolve into a "land to lab to land" programme. The breakthrough that led to the Green Revolution was not only scientific, but also political. He initiated an experiment to multiply improved wheat seeds developed by division in farmer's fields without any expenditure by the IARI. As part of this, Jaunti village was developed into a "seed village," in which farmers were encouraged to farm with the technical support of scientists.[1]

Farmers' Training

Swaminathan worked to bridge the gap between scientific know-how and farmers' do-how by using radio and television effectively. Within three weeks of conceptualising Krishi Darshan, a programme to communicate agricultural information to farmers (it became one of India's longest-running TV programmes), the programme was launched. Swaminathan continuously argued for empowering farmers through training, and for their participation in decision-making processes. These principles are now embedded in the institutional processes of NAREES.

[1] The story of the experiment and the development of the "Jawahar Jounti Seed Co-operative Society" has been recounted elsewhere in this issue by Harish Damodaran – *Editor.*

Evergreen Revolution

M. S. Swaminathan highlighted the problems associated with not adhering to recommended practices with respect to green revolution technologies and recommended pathways for an evergreen revolution by "pursuing enhancement of productivity in perpetuity without ecological harm." Edward O. Wilson, the Harvard naturalist and theorist, commented on the concept of an evergreen revolution in his book *The Future of Life* (2002), and called it a solution to the problem of feeding billions of people with less damaging consequences for the environment and rural communities. Swaminathan's vision of an evergreen revolution continues to inspire us to work on different aspects of agricultural transformation at the national and international level.

Biodiversity and Conservation of Genetic Resources

M. S. Swaminathan made great efforts to preserve biodiversity. Biodiversity is the feedstock for crop and animal improvement and the loss of every gene and species limits our options for the future. He proposed the establishment of gene banks, and at present the ICAR has a gene bank for plant genetic resources, animals, fishes, insects and microbes.[2] He highlighted the fact that, in the wake of climate change, dry spells could occur at different points, that is, in the early, mid-term or late point in the duration of a crop. Contingency options, including seed banks and nurseries of short-duration paddy crops, had to be kept ready to deal with risk and to salvage farmers' incomes in difficult situations.

Swaminathan also led the establishment of agro-biodiversity programmes run mainly by women conservators in secondary sources of origin of paddy in Kerala and Odisha. He saw the role of women not just as labourers in the field, but also as conservators of biodiversity and associated knowledge systems.

Land and Water Management

Swaminathan was deeply concerned, from the early green revolution period, with land and water management, and issues of pesticide usage, groundwater depletion, soil health, and preservation of biodiversity. In an statement that was to be quoted widely, he said, "If our agriculture goes wrong, nothing else in our economy and social fabric will have a chance to go right."

Nutritional Security

Swaminathan stressed the need to attack the problem of chronic hunger in an integrated way, paying attention to undernutrition, protein deficiency, and hidden hunger caused by micronutrient deficiencies. Science can contribute to this effort by

[2] Dr. Swaminathan's contributions to conservation are dealt with in further detail in K. C. Bansal's contribution to this Tribute.

helping to improve the productivity and profitability of farms, including small farms, and by leveraging agriculture to end malnutrition through biofortified crops. As Chairperson of the National Commission on Farmers, Swaminathan made monumental contributions to national food and nutrition security.

Science and Society

Swaminathan dedicated his life to ensuring that that scientific innovations and new technology are translated into better lives for the poor and marginalised. Prof. Swaminathan emphasised that science for development should be pro-poor, pro-women, pro-employment, pro-youth, and pro-environment. It was Swaminathan (as Chairperson of the National Commission on Farmers) who suggested that the Ministry of Agriculture be renamed the Ministry of Agriculture and Farmers' Welfare.

Epilogue

In the early to mid-1960s, India imported, primarily under the PL 480 agreement, 8 to 10 million tonnes of food grains annually. M. S. Swaminathan was the main architect of the green revolution in India, which took India from this "ship-to-mouth" existence to being a nation self-sufficient in food in the early 1970s, and thence to being a food-surplus nation today – an unprecedented achievement! Swaminathan monitored the social and environmental impact of the green revolution fairly early in the development process, pointing out where technology was not put to use scientifically, thus often causing serious social and environmental problems. In order to overcome these challenges, the legend envisioned an evergreen revolution for the establishment of a hunger-free world.

In ending, I quote from Prof. Swaminathan's advice to young scientists: "I will suggest that they should do science that can create new knowledge and technologies and at the same time help in taking science to society."

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