M. S. Swaminathan: a journey from the frontiers of life sciences to the state of a 'Zero Hunger' world

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Professor Monkombu Sambasivan Swaminathan ('MS' to his numerous friends and colleagues throughout the world) started his epoch-making research career with cytogenetic studies in potato in 1949 at the Agricultural University, Wageningen, the Netherlands, and later at Cambridge University, England where he obtained his Ph D in Genetics in 1952. He did his post-doctoral research in Wisconsin, USA. All these were from late 1940s until mid-1950s. In a span of 6 to 7 years, he obtained the Ph D degree of Cambridge University and published significant original research papers in journals such as *Genetics*, *Nature*, *Journal of Heredity*, *Genetica*, *Euphytica*, *Bibliographica Genetica*, *American Journal of Botany*, *American Potato Journal*, etc., wherein 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 hybridization and transfer of genes to confer resistance against abiotic and biotic stresses to potato. When he was a young research scholar in the Wisconsin University (USA), he 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'. Although he was offered an attractive research-cum-teaching position in Wisconsin, MS chose to return to his motherland where he had no job then.

Impressed with his brilliance and highly noteworthy contributions to the cytogenetics and breeding of potato, MS was appointed in the Central Rice Research Institute (CRRI; Cuttack) and assigned to work in the *indica–japonica* rice hybridization programme. The idea was to develop fertilizer-responsive varieties of rice suitable for the rice-growing tracts in India. In later years, he would reminisce that these *indica–japonica* hybridization programme at CRRI was indeed the early harbinger of the Green Revolution movement in India. The work resulted in varieties like ADT27, RASI, cultivated in Tamil Nadu. After six months of his stay at CRRI, MS was selected by the Union Public Service Commission and joined as Assistant Cytogeneticist in the then Botany Division of the Indian Agricultural Research Institute (IARI), New Delhi in October 1954. Nearly a decade later, when MS became the Head of the Botany Division, he appropriately changed its name as Genetics Division. It is here that his most outstanding basic research ranging from the elucidation of the structure of the chromatid, mitosis in yeast, mechanisms of ionizing radiation and chemical mutagenesis, radio-sensitivity as a function of ploidy level, actions of low and high LET ionizing radiations on diploid and polyploid wheats, overcoming 'diplontic selection' in vegetatively propagated material exposed to ionizing radiation using the strategy of chronic irradiation (for which he had set up a 'Gamma-Garden' with 200 Curie cobalt 60 source at IARI) to *Drosophila* genetics and human cytogenetics by culturing human peripheral blood leucocytes for chromosome karyotyping of congenital abnormalities in syndromes gained unparalleled momentum. The original and path-breaking basic researches emerging from his laboratories in the IARI Genetics Division substantially added new knowledge, refined a few earlier concepts and above all opened up new avenues for more vigorous pursuits in basic and applied research in the areas of cytogenetics of wheat, monosomic–nullisomic analysis in hexaploid wheat, radiation and chemical mutagenesis, 'Oxygen effect' in low and high LET radiobiology. Research papers on the above-said topics were published in *Nature*, *Current Science*, *Science*, *Genetics*, *Radiation Research*, *Radiation Botany*, *Environmental and Experimental Botany*, *Experientia*, *Die Naturwissenschaften*, *Experimental Cell Research*, etc. In recognition of his leadership in a wide range of basic research areas he was awarded the Bhatnagar Memorial Award, Fellowship of Indian National Science Academy (FNA), Fellowship of the Royal Society of London (FRS) and Fellowships of almost all leading National Academies in the world, including those of USA, UK, USSR, Sweden, Japan, Italy, Germany, the Philippines, Bangladesh, Pakistan and China.

While his intellectual curiosity was driving him towards excellence in basic research, his sense of social responsibility of science and technology tilted his focus on applied research to achieve greater food and nutrition security as well as freedom from dependence on food imports from other countries. Most people of India above 60 years of age would still remember that the poignant backdrop to India's independence in August 1947 was the Bengal Famine of 1942–43. This famine just half-a-decade before India's independence portended an ominous future for independent India. Pandit Jawaharlal Nehru, the first Prime Minister of independent India hence declared that '*Everything else can wait, but not agriculture*'. This came as a clarion call to MS who in his days as a young boy had witnessed Mahatma Gandhi visiting Kumbakonam in Tamil Nadu and staying at his residence on two occasions. So, it was quite agonizing for MS that post-independent India's food security was appalling with a 'ship to mouth' existence and India's image was that of a 'begging bowl'.

Swaminathan examining chromosomes of irradiated cells under microscope.

Box 1. Early life and family

Monkombu Sambasivan Swaminathan was born on 7 August 1925 in Kumbakonam in Tamil Nadu. His illustrious father, M. K. Sambasivan hailed from a well-known agricultural family of 'Kottarathu Madom' of Kuttanad in Alleppey District of Kerala. Sambasivan was a well-known surgeon in Kumbakonam. He also served the community as an elected Chairman of the town's municipal corporation. Most importantly, he was held in great affection and esteem for a successful campaign toward the eradication of diseases caused by mosquitoes, notably malaria, filariasis or elephantiasis. His mother Parvathy Thangammal was a simple and spiritual person who enabled her three sons and a daughter develop their full mental and spiritual potential; Sambasivan died young at the age of thirty-six when Swaminathan was only eleven years old. In the joint-family system, his uncle, Narayanaswami as the head of family took care of his brother's family. Swaminathan got married on 11 April 1955 to Mina Boothalingam, whom he had met in 1951 at Cambridge University (UK) from where she obtained M A degree in Economics. Mina is an eminent authority in the field of education with particular reference to pre-school education. She played a key role in the development of Integrated Child Development Services (ICDS) as well as Mobile Creches catering to the needs of migrant labour children. She is currently Distinguished Chair on Gender and Development at MSSRF. Her father, S. Boothalingam was a distinguished ICS, and served the country in highly responsible positions such as Secretary of Ministry of Steel as well as Ministry of Finance. Her mother, Mrs Mathuram Boothalingam, was a well-known writer of novels on contemporary themes, Hindu religion and philosophy, as well as children's books both in Tamil and English, under the pen-name Krithika.

The Swaminathans are blessed with three highly talented daughters: Soumya the eldest trained as a paediatrician and currently the Director, National Institute of Tuberculosis, Chennai; Madhura the second, was a Rhodes scholar, obtained D Phil degree from Oxford University (UK), now Professor of Economics at the Indian Statistical Institute, Bengaluru (is also currently the Chairperson of M.S. Swaminathan Research Foundation), and Nitya is Professor of Gender and Development at the University of East Anglia, Norwich, UK.

The question was how to increase agricultural productivity and production especially of our staple foodgrains (wheat and rice). MS who recently wrote that the seeds of Green Revolution were first sown in the fields of CRRI through the *indica–japonica* rice crosses, decided that the plant type should be tailored to be functionally responsive to external application of fertilizers. The height of plants should be reduced without reducing the length of grain-bearing panicle. This is what he strived to achieve by pursuing interspecific hybridization, induced radiation and chemical mutagenesis and use of plant growth regulators. While all these substantially added to our basic knowledge of biological processes/ responses induced by physical and chemical agents, the goal of obtaining dwarf/semi-dwarf wheat plants with normal spikes was, however, not realized. Fortunately, the trait in him to keep himself abreast of major innovations and development anywhere in the world, helped him to trace the *Norin-10* dwarfing genes from Japan in wheat and *Dee-jee-woo-jen* dwarfing genes from China in rice. His initial contact with Orville Vogel of the Washington State University (Pullman) led him to Norman E. Borlaug, Director of CIMMYT, Mexico. The Swaminathan–Borlaug partnership led to India's Green Revolution in 1968. Norman Borlaug won the Nobel Prize for Peace, and he subsequently acknowledged in a letter that 'to you Dr Swaminathan, a great deal of the credit must go for first recognizing the potential value of the Mexican wheat dwarfs. Had this not occurred, it is quite possible that there would not have been a Green Revolution in Asia'. There is no doubt that the quantum jump in wheat yields changed India's image from a 'begging bowl' to a 'bread basket'. Yet, when India was to commemorate 'Wheat Revolution' by releasing a special postal stamp by Prime Minister Indira Gandhi in June 1968, MS was greatly concerned that excessive use of chemical fertilizers and pesticides, flooding the soil in the name of irrigation with groundwater and monocropping with a single cultivar over large contiguous areas could result in an agricultural doom rather than agricultural prosperity in the long run. He foresaw that '*Green Revolution*' (the term coined by William Gaud of USDA much later) could degenerate into a *Greed Revolution* and therefore, it should be taken as providing only a breathing space. As forewarned by him, in his Presidential Address delivered in January 1968 at the Agricultural Section of the 55th Indian Science Congress at Varanasi, the Green Revolution practised in an unscientific manner has caused in about two decades salinization of soil, precipitous fall in water table, depletion of agro-biodiversity and increase in the incidence of cancer among members of farming families due to excessive contact with chemical pesticides. The great benefits of Green Revolution were unfortunately marred by disconcerting negative effects. His earlier apprehension that Green Revolution could degenerate into a Greed Revolution, and therefore, it should be used only as 'breathing space' and not as sustainable agriculture was totally justified.

One of the superb virtues of MS is not to be deterred by negative consequences which may sometimes result in a major endeavour and development, but to become more involved in finding out a better and long-lasting solution. His blueprint for an 'Evergreen Revolution' is exactly that. Green Revolution was a commodity centred intensive chemical inputs-based agriculture. Its major drawback is the lack of adequate care without concurrent attention to ecological foundations (soil health, fresh and good quality irrigation water, biodiversity and renewable energy) of agriculture. Hence, Swaminathan's 'Evergreen Revolution' was based on a 'Systems Approach' with concurrent attention to each and every component of ecological foundation. In addition, 'Evergreen Revolution' which is most suitable for hundreds of millions of resource-poor small and medium farmers, necessarily has social and gender dimensions. The M.S. Swaminathan Research Foundation (MSSRF) which he set up in 1988 as a Registered Society in Chennai for harnessing science and technology has become an 'epicentre of sustainable agriculture' including fisheries and 'sustainable rural development'. Knowledge and rural technology-based skill empowerment of the largely illiterate and unskilled rural women and men towards sustainable management of natural resources, on-farm and non-farm livelihoods are components of the Evergreen Revolution. In an era of climate change and rising cost of chemical fertilizers and energy requirements for the various farm operations, the Evergreen Revolution is the best available option for hundreds of millions of resource-poor small and marginal farmers. E. O. Wilson, a Harvard University biologist of rare distinction referred to Swaminathan and his Evergreen Revolution in his epoch-making book – *The Future of Life* (Vintage, London, 2002). He noted that Evergreen Revolution is the best option available to feed the burgeoning human population and at the same time to save the remaining biodiversity as well. Wilson wrote: 'The problem before us is how to feed billions of new mouths over the next several decades and save the rest of life at the same time, without being trapped in a Faustian bargain that threatens freedom and security. No one knows the exact solution to this dilemma. Most scientists and economists who have studied both sides of it agree that the benefits outweigh the risks. The benefits must come from Evergreen Revolution.'

The eco-agricultural approach of Evergreen Revolution takes into account the ancient Hindu view of 'Vasudeiva kutumbakam'. That is all forms of living

Swaminathan playing with a rural household child in Puducherry biovillage of MSSRF.

beings—from microbes to humans—form an inter-dependent 'web of life'. The US President Barak Obama had received a copy of Swaminathan's book '*From Green to Evergreen Revolution*' (Academic Foundation, New Delhi, 2010, pp. 410) that was released on 28 September 2010 at the residence of the then Prime Minister Manmohan Singh. President Obama, who after going through the book, made a mention of the need for 'Evergreen Revolution' in his address to the Indian Parliament on 8 November 2010. He said: 'Together, we can strengthen agriculture. Cooperation between Indian and American researchers and scientists sparked the Green Revolution. Today, India is a leader in using technology to empower farmers, like those I met yesterday who get free updates on market and weather conditions on their cell phones. And the United States is a leader in agricultural productivity and research. Now, as farmers and rural areas face the effects of climate change and drought, we will work together to spark a second, more sustainable Evergreen Revolution.' (http://www.whitehouse.gov/the-press-offfice/2020/11/08/remarks-president-joint-session-indian-parliament-new-delhi-india)

Swaminathan also got several e-mails from American scientists and friends in US that they were very happy that he had adopted the innovative approach of an Evergreen Revolution. Nevertheless, in India little has been done so far to make this a reality. India probably would take this up after the USA.

In an article in *Yojana* of 14 February 1965, MS wrote that science and technology are the prime movers of change. He added that farmers are not aware that crop yields can be trebled with appropriate scientific approaches. Within a few years thereafter, he doubled the yields of first wheat and then rice.

A distinction between many working in the frontier areas of life sciences and Swaminathan is what is done with the fruits of their research endeavours. Some are content with publication of their papers in journals of high Impact index, a few others go for patenting, but MS's goals are to take these to the fields of millions of resource—poor, small and marginal farmers. It is not that MSSRF shuns patenting; in fact several new innovations resulting from recombinant DNA-based genetic engineering of rice for abiotic stresses caused by salinity and drought have been filed for patent. A non-governmental research foundation needs to maintain itself financially sustainable as well. Yet, in several cases which could accelerate poverty alleviation and enhance the food and nutrition security at individual household levels of rural women and men, field-based action is his dictum. Alongside a combination of basic and applied research to find solution to an imminent problem (he refers to these as anticipatory research), he also fosters 'participatory breeding' in which farmers are assisted to develop new locally adapted varieties. Way back in 1988 at a Climate Conference in Tokyo, he observed that global warming and melting of polar ice and glaciers would cause sea level rise and that would result in salinization of coastal soil and aquifers, and therefore, the coastal agricultural crops should be genetically shielded against salinity and drought. Under his guidance, the scientists of MSSRF led by Ajay Parida have genetically engineered the salinity-tolerance genes of a mangrove species (*Avicennia marina)* into the cultivated rice plant. Whereas some aspects of the work are filed for patenting, the transfer of the 'transgene' from engineered rice variety to numerous locally adapted rice cultivars will be through the mode of 'participatory breeding'. Of course, MS insists that at first the environmental and health safety aspects of the transgenic rice should be rigorously evaluated using the best food safety evaluation methods and practices. He is also quite emphatic that safety of human health and environment should be the bottomline. Any transgenic crop not known to be absolutely safe to biological systems should not be introduced into the environment.

Swaminathan is widely respected for his unparalleled contributions to food and nutrition security of not only India but several other developing countries. Since food is the most basic human need, nations without adequate food security cannot remain in peace. No wonder, the *TIME* magazine of USA of August 1999 cited Swaminathan as one of the three most influential Indians (Mahatma Gandhi and Rabindranath Tagore being the other two) among a galaxy of 20 most distinguished Asians of the 20th century. Yet, MS is such an unassuming pleasant person, that meeting him for the first time, one would never guess the outstanding achievements behind this mild-mannered genius. Along with food security, he also brought about the political sovereignty of India. With this prelude, we now would like to bring out the major milestones in his 65 years of journey in science towards the destination of a 'Zero Hunger' India, and 'Zero Hunger' world.

Basic research contributions

The global basic research endeavours since the 16th century across the world could be roughly divided into three categories: (i) research for adventure of ideas, and satisfying curiosity, which of course, might be found in later years to have applied value; (ii) research for solving problems of humanity and environment of our planet; and (iii) research for increasing profit margins of corporate enterprises in a globalized world.

Swaminathan's basic research in life sciences of which genetics is the vital core, during the first three of his six and-a-half decades of scientific career, has been with the purpose of 'knowing the unknown' to solve specific problems of management of stresses in crop plants and optimizing their productivity. His basic research on 'Species differentiation and the nature of polyploidy in certain species of the genus *Solanum*, section *Tuberarium*' formed the basis of his Ph D thesis submitted to Cambridge University (England) in 1952. His published papers on cytogenetics and speciation in potato during 1950–55 in leading scientific journals, reveal an extremely high quality and originality of his studies. What, however, has made his basic research in *Solanum* species relevant to humanity is that it helped in developing several new potato varieties possessing resistance to diseases and tolerance to frost for cultivation in the northernmost USA. By transferring the gene for frost resistance from *Solanum acaule* growing at 4000 m high in the Andean ranges of Peru in South America, a commercial potato variety named 'Alaska Frostless' was bred and released for cultivation in Alaska. His paper in *Nature* (5 November 1955) on overcoming the cross-incompatibility among some diploid species of *Solanum* reveals his simple yet most ingenious way of overcoming cross-incompatibility. This is particularly important in the crosses between *S. pinnatisectum* and *S. bulbocastanum*, the only species then known to possess genes for resistance against late blight of potato. His elegant method combined microsurgery of the style of *S. pinnatisectum* and placing agar–sucrose at the site where the top section of style had been cut off to facilitate pollen tube growth of *S. bulbocastanum.*

The idea of genetic manipulation of cereal crops for fertilizer response was intellectually stimulating, yet a challenging task. We should go back to late 1940s and 1950s when people's memory was fresh about the Bengal famine of 1943 in which tens of thousands of people perished of hunger. So, when MS moved from CRRI to IARI, his focus shifted from rice to the development of high dose fertilizer-responsive wheat varieties. All the locally adapted and greatly preferred wheat varieties were tall, and these 'lodged' (i.e. fell flat on the ground) when their earheads were full of well-filled heavy grains produced in response to the application of about 80 to 100 kg of nitrogenous fertilizer per hectare. None of the varieties of the hexaploid cultivated wheat (*Triticum aestivum*, $2n = 6x = 42$) had the 'genes' for dwarfing the height of the plants without also reducing the length of the grains-bearing spike (earhead). However, a closely related hexaploid species *T. sphaerococcum* was comparatively shorter, but unfortunately possessed short and compact earhead. The decades of 1950s and 1960s were also the peak period of interest in artificial transmutation of genes (alleles) using high and low LET ionizing radiations as well as a variety of chemical mutagens variously acting on the DNA. MS used fast neutrons as the high LET (i.e. linear energy transfer expressed in terms of keV/μ) and gamma rays from Cobalt-60 and Cesium-137 gamma cell as the low LET ionizing radiation of high dose-rate acute exposures of plant seeds and fruitfly *Drosophila melanogaster*. He had close association with Homi J. Bhabha, Vikram Sarabhai and several senior nuclear scientists of that time like Raja Ramana, M. R. Srinivasan, A. R. Gopal-Ayengar and others. Therefore, access to neutron irradiation facilities at Trombay was readily available to researchers of the Division of Genetics of IARI of which MS was the then Head. His first Ph D student A. T. Natarajan initiated work on the clastogenic (i.e. chromosome lesions) and mutagenic (i.e. point mutations) actions of ionizing radiation and several mono- and poly-functional chemical mutagens. Under Swaminathan's leadership, the Genetics Division of IARI became globally known for its pioneering research on the mode of action of physical and chemical mutagens on chromosomes. Directing research in mammalian radiobiology at the Strahlenzentrum of the University of Leiden (the Netherlands), Natarajan became a global authority on biological dosimetry for radiation exposures. Several other students of MS had distinguished themselves in several facets of life sciences. Some of them even became Secretaries to Government of India in scientific departments like DBT, DST, DARE-ICAR, etc.

Swaminathan is gifted with an innate ability to combine *excellence* in research and teaching with *relevance* to solving complex problems particularly in the domain of food and nutrition security. For example, his setting up laboratories for research in radiation and chemical mutagenesis led to achieving his twin primary goals: (i) elucidation of cellular mechanisms of physical and chemical mutagenesis/clastogenesis and how to enhance their efficiency and effectiveness, and (ii) achieving control over the induced frequency and spectrum of mutations in crop plants so that the desired mutants for crop improvement could be obtained. The Genetics Division produced many useful mutant varieties of crop plants, and in mutation breeding it had gained the recognition at par with the best institutions in Sweden, USA, UK, Japan and a few other countries. In short, the 'Swaminathan School of Cytogenetics' at IARI was receiving global attention because of its excellence in basic researches in cytogenetics and radiation biology.

Although MS had been focusing on radiation and chemical mutagenesis, cytogenetics and crop improvement, he was also keeping himself abreast of developments in a wide range of genetics and plant breeding researches. He was also quick to grasp major developments in other disciplines like biotechnology, biochemistry, biophysics, atmospheric sciences, remote-sensing, etc. He also wanted his students to get interested in various domains of science and integrate the principles, tools and techniques of physics and chemistry in their own studies in biology. This can be illustrated with an experience of one of us (PCK) then working as a Ph D scholar under his guidance. In the doctoral programme of the post-graduate school of IARI, it is obligatory that students must take a certain number of credits in the course work and pass the comprehensive examination before embarking on full-time research. MS assigned cytogenetics as the major core course with physics and human genetics as the two subsidiary subjects for PCK's credit programme. No student of the Genetics Division at that time had ever entered the Physics Division (then called Agricultural Physics), leave alone taking courses for credit purposes. So, when PCK met the Head of the Division (Dakshinamurthy), he was kind but firm in testing PCK's knowledge on the structure of the atoms, nuclear binding energy, etc. He did not have to tell the obvious that the student's performance was dismal. That alone was not upsetting, but his suggestion that PCK should take a remedial course in relevant mathematics was. So, PCK decided to meet MS to explain the predicament and request him for a change from physics to any other course as subsidiary. The coffee time in Lab No. 4 at about 11 AM frequently provided opportunity for free and leisurely discussion with him. So, PCK broached the topic. He patiently listened and advised that the Head, Physics Division was very pleased to have PCK as his student, and that he would help him to grasp the fundamentals of atomic and nuclear physics. He also emphasized that the idea was to enable PCK to get an idea of the structure of an atom and nuclear interactions with matter. He also advised that it would help PCK in his doctoral thesis on the 'Indirect effects of ionizing radiation' – a relatively unexplored area in radiation research at that time. The teachers in the Physics Division were exceedingly helpful and the learning was quite exciting. Later in PCK's professional career as a radiation biologist there were many occasions to gratefully acknowledge how his teacher, Swaminathan had foreseen his student's future requirements and equipped him accordingly. He similarly guided several of his students who in their later professional career had to work on entirely different aspects of life sciences and crop improvement programmes across the world. No wonder, his students did exceptionally well.

There is also something unforgettable about the way he introduced PCK to the doctoral research programme. It was again at the same coffee room sometime in September 1963, that he handed out a piece of handwritten sheet of paper with the title 'Indirect effects of radiation'. It had several sub-titles and one of these was 'Oxygen effect'. At that time, PCK had not yet credited Swaminathan's course on 'Radiation genetics' in which he dealt with this topic in detail. So, PCK went to the well-equipped IARI library and picked up a couple of books on the *Actions of Ionizing Radiation on Cells.* The one by Douglas Lea (Cambridge University, 1950) was supposedly the best and in that book of about 400 pages, the word 'oxygen' had been mentioned just a couple of times, but nothing really appreciable on what it exactly does in an irradiated cell and how it does. Later in the radiation genetics class, MS taught how oxygen enhances the radiobiological damage, and how this was indeed a problem in cancer radiotherapy of tumours consisting of hypoxic fraction of cells that are relatively radio-resistant. He also explained how oxygen effect is rather significant in the case of exposures involving low LET (linear energy transfer) radiation (e.g. gamma rays) than high LET radiation (e.g. thermal neutrons). The foundation he had laid was so strong that it was so easy for PCK in later years to make noteworthy contributions to the elucidation of mechanisms of oxygen effect in radiobiology. Within the few years of PCK's research career, he was invited to be a Member of the Editorial Board of *International Journal of Radiation Biology* in which capacity he still continues. The major purpose of this narration is to emphasize the ease and elegance with which MS *mastered entirely different facets of life sciences*. This is also illustrated by the fact that the Founder Vice-Chancellor of the Jawaharlal Nehru University (JNU), (late) G. Parthasarathi sought Swaminathan's expertise and advice in setting up the School of Life Sciences at JNU in the late 1960s. MS was the Chairman of the Working Group to develop the blueprint of the programmes of research and teaching in the frontier areas of life sciences. Some of the areas suggested by MS for intensive research and teaching are: photosynthesis (photobiology) to enhance plant productivity in an era of environmental degradation and climate change (note his research publication on 'Climate change and agriculture' was as early as 1984, in *Climate and Development* (ed. Asit K. Biswas; Tycooly Publishing Co. Dublin, pp. 65–95), radiation biology (since he realized long before the declaration by the Royal Society of London that nuclear fuels, unlike fossil fuels, do not cause emission of greenhouse gases but the biological mechanisms of health and environmental risks, if any, should be thoroughly elucidated), plant molecular biology, neurobiology, membrane biophysics, etc. His contributions to the establishment of the Academic and Research foundations of Life Sciences at JNU have been the keystone for its truly interdisciplinary character even today—45 years after its establishment. A grateful JNU felicitated Swaminathan and other living members of his Working Group on Life Sciences in February 2014.

His major involvement during the last three decades in promoting sustainable agriculture and rural development using innovative paradigms such as ecotechnology-based biovillages and modern information and communication-based Village Knowledge Centres (VKCs) have obscured his absolutely outstanding contributions to life sciences in general, and cytogenetics and radiation and chemical mutagenesis in particular. His election as Fellow of the Royal Society (FRS) in 1973 was in recognition of his original and most innovative theoretical and experimental basic research in cytogenetics, radiation and chemical mutagens-induced clastogenesis and mutagenesis. These also formed the basis for his winning the Shanti Swarup Bhatnagar Award in 1961, and several other honours. During the last three or more decades, his deep involvement in harnessing science and technology to fight the famines of food availability and access to food for over 1 billion people of the world has notably obscured his earlier outstanding research contributions to basic sciences. We would like to highlight some of these with brevity and clarity in Table 1.

Swaminathan as a teacher

Swaminathan taught cytogenetics-I and radiation genetics at the Post-Graduate School of IARI during late 1950s through 1960s. Without exception, every student looked forward with great interest and enthusiasm to listen to his lectures. Whether rain, heat or biting cold in Delhi, he would ride on his bicycle to the class room in the Botany Division from

Table 1.

Basic research	Goal/impact
1a. Cytogenetics—speciation–species interrelationships-induced polyploids in *Solanum* species in 1950s. Journals in which papers are published: *American Potato Journal*; *Euphytica*; *Genetics*; *Genetica*; *Nature*; *American Journal of Botany*; *Journal of Heredity*; *Genetica Agraria*; *Bibliographica Genetica*, etc. 1b. In late 1950s and 1960s in cytogenetics of wheat and related hexaploid species.	To transfer genes for biotic and abiotic stress resistance from wild species to the cultivated potato, *Solanum tuberosum.* This is to prevent recurrence of a famine as serious as that of the Irish Potato Famine of 1845. His work led to the development of 'Alaska Frostless Potato'. Genes for frost resistance were transferred from *S. acaule* to the cultivated potato.
2. Radiation and chemical mutagenesis – Mechanisms of action of the physical and chemical mutagens to achieve control over the frequency and spectrum of induced mutations in crop plants. To elucidate the mechanisms of action of alkylating agents on the cells in different phases of the cell cycle (G_1, S, G_2, M). Journals in which papers are published: *Nature; Current Science; Indian J. Genetics; Die Naturwissenschaften; Experientia; Vererbungslehre*; *Science; Evolution*; *Proc. Natl. Inst. Sci (India)*; *Proc. International Atomic Energy Agency*, Symposium on 'Effects of Ionizing Radiations on Seeds, and their significance for Crop Improvement', Karlsruhe, pp. 279–288; *Advances in Genetics; Radiation Botany; Caryologia; Radiation Research*; *Z. Pflanzenzuchtg*; *Journal of Indian Botanical Society*; *Hereditas*; *Science*; *Drosophila Information Service*; *Journal of Science & Industrial Research*; *Indian Farming*; *Mutation Research*; *Mutations in Plant Breeding II*, IAEA, Vienna; and several Symposia held under the auspices of the joint IAEA/FAO, etc.	To alter the plant type in such a way that it is highly fertilizer-responsive, but does not lodge. Studies revealed a pleiotropic gene action of the dwarfing genes on the length of the spike. The work done by MS and his students firmly established the usefulness of induced mutations in crop improvement. Today, there are over 4000 mutant crops throughout the world and about 400 mutants in India alone. This number includes field crops and horticultural species.
3. Cobalt-60 Gamma Garden – for chronic irradiation of crops particularly vegetatively propagated plants. Basic studies brought out the fact that radiation energy deposited in the cells of the tissues following a Poissonian distribution would be greater in the case of chronic exposures. It is a matter of dose-rate to deliver an intended dose. When several cells are mutagenized in a vegetative clone, the elimination of mutated cells by 'diplontic selection' is greatly diminished.	Acute exposures of vegetatively propagated plants (e.g. potato, banana, etc.) induce mutations in just few cells of a cluster of a propagule, say a bud or stolon. Not all the cells are affected by an acute dose. The problem is that numerous normal cells (i.e. non-mutagenized) outcompete the fewer mutant cells in multiplication and forming a new plantlet. This process known as 'diplontic selection' eliminates the mutant cells from gaining survival and expression. However, with chronic exposures over protracted periods, many more cells are mutagenized and the proportion between normal and the mutant cells is better balanced for the mutant cells also to develop and gain expression.
4. Establishing laboratories for basic research in cytogenetics/genetics – using *Drosophila melanogaster* and human peripheral leucocytes *in vitro*. The question posed to him by his senior officials of IARI was why should all these be set up in 'Botany Division' (Swaminathan got it changed to Genetics Division, after he became Director of IARI in 1966) when H. K. Jain became the first Head of the newly christened Division of Genetics.	Swaminathan pointed out that after the initial work with garden pea (*Pisum sativum)* by Mendel led to the laws of inheritance in 1865, subsequent advances in genetics, including the chromosomal theory of inheritance and mutagenic activity of X-rays, fine structure analysis of the gene by Seymour Benzer came from researches with the fruit-fly, *Drosohila melanogaster*. Hence, he pointed out that there would be no effective teaching and research without reference to and studies involving the *D. melanogaster.* Until 1960, the chromosome number of the human was variously reported ranging from $2n = 44$, 46 and 48. Only in 1960, Moorhead *et al*. reported a simple method of human chromosome preparation for obtaining a precise counting of the diploid number. This involved inducing the 'GO'-phase of the nucleus in the peripheral blood leucocytes *in vitro* to initiate cell division. The cells arrested at metaphase provided a sharp view of the well spread-out somatic chromosomes. Swaminathan was among the first and foremost to use this method to study the indirect effects of radiation on the human chromosomes. His student PCK at that time (1963–65) was excited for working in a frontier area of human cytogenetics.

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Table 1. (*Contd*)

Basic research	Goal/impact
5. Indirect effects of ionizing radiation on cells and organisms – mechanisms Journals: *Nature; Radiation Botany*; *Indian Journal of Genetics*; *Current Science*	These studies were among the earliest to correct the fallacy that ionizing radiations act like 'bullets' hitting vital targets ('target theory') in the cells and inactivate them. The findings that unirradiated organisms cultured on or fed irradiated media/food show increased incidence of chromosomal aberrations and mutations (sex-linked recessive lethal) in *Drosophila melanogaster* revealed a radiation-induced chemical dimension in the biological effects of ionizing radiations. The formation of radiolytic substances in the irradiated medium accounted for the observed radiomimetic effects. His early work forms at least in part the foundation of today's 'Redox Biology'.
6. Monosomic–nullisomic analysis in the hexaploid ($2n = 6x = 42$) bread wheat. Deletion of one (monosomic $2n = 6x = 41$) or a pair of homologues ($2n = 6x = 40$) without causing inviability is possible in polyploids. Monosomics for all the 21 pairs of chromosomes of the bread wheat had been produced. Journals: *Indian Journal of Genetics; Euphytica*	The monosomic analysis is useful to identify the chromosomes carrying desirable genes for biotic and abiotic stresses. Chromosome substitution in a polyploid wheat was yet another dimension of crop improvement.
7. Elucidation of mitotic division in yeast Journals: *Stain Technology*; *Nature*; *Memoirs of Indian Botanical Society*	Until his paper with his student A. T. Ganesan was published (*Nature*, 1958, **168**, 610–611) there were doubts about the nature of mitosis in yeast nucleus. Their work showed that the only difference in the case of yeast is that the nuclear membrane does not disappear, but persists during prophase to telephase.
8. Polyploidy and radiosensitivity Journals: *Nature* (1957); *Experientia* (1957); Proc II U.N. Int. Conf. on Peaceful Uses of Atomic Energy, Geneva (1958); *Genetica* (1960); *Evolution* (1960); *Radiation Botany* (1961); *Genetica* (1961a and 1961b); *Die Naturwissenschaften* (1961); *Exptl. Cell Research* (1961); *Radiation Botany* (1962); *Hereditas* (Suppl. 1963); *Current Science* (1963); *Radiation Botany* (Suppl. 1965)	Bread wheat has three sets of chromosomes ($2n = 6x = 42$). The homologous chromosomes have identical or similar genes present in six doses as compared to just two in the diploids and four in the tetraploid wheats (*durum* used for making porridge, 'Uppuma', etc.). So, the question was about possible buffering effects of normal alleles against a mutated allele. The related question was about chromosomal aberrations induced in the diploids, tetraploids and hexaploids exposed to low and high LET (i.e. linear energy transfer) radiations. His work also elucidated the differential radiosensitivity among the probable genome donors of bread wheat. • His inference based on his work on polyploidy and radiosensitivity indirectly explained the advantage of the use of neutrons (high LET) over gamma-rays (low LET) in cancer radiotherapy. Research carried out by MS and his students in the late 1950s and 1960s revealed that: (i) Neutrons with higher LET have greater relative biological effectiveness, than gamma rays. (ii) Polyploids have lower 'oxygen effect' when exposed to low LET gamma rays.
9. DNA content and organization of eukaryotic chromosomes Journals: *Current Science* (1959, 1964); *Experimental Cell Research* (1960, 1967).	• Stage of DNA synthesis during mitosis and meiosis. This work in 1959, just six years after the publication of the structure of DNA by Watson and Crick (*Nature*, 1953) was pioneering. • They also determined the metaphase chromosome length and DNA content in relation to polyploidy in *Triticum* species. • Elucidation of the number of DNA double helix copies in a single chromatid. His work with his student Deepak Bastia revealed that chromatid is uninemic (i.e. only one DNA double helix per chromatid).
10. 'Diploidization of polyploids in *Triticum*' Journals: *Indian Journal of Genetics*; *Genetics*	Elucidation of the genetic mechanism of diploidization in polyploids with homeologous chromosomes. Despite homology among all the six sets ($2n = 6x = 42$) of chromosomes, there are no hexavalents, and only 21 bivalents are regularly formed in diakinesis and metaphase I of meiosis. So, the question was 'what is the genetic mechanism for the "diploidized" behaviour in the hexaploid wheat'. His work with his student M. D. Upadhaya elucidated the genetic basis of diploidization. They showed that a genetic locus controls the chromosome pairing as biovalents in meiosis.

his Bungalow No. 12 via the wheat and mustard fields. His punctuality was such that students could reset their wrist watches at 8.15 AM. In Cytogenetics-I, his lectures on the differences in the mode of formation of 'asynapsis' and 'desynapsis', or how the 'pericentric' and 'paracentric' inversions act as cross-over suppressors (i.e. inhibitors of genetic recombination) or the evolutionary blind alley of *Rhoeo discolor* ($2n = 12$ forming a ring of 12 chromosomes in meiosis) as also *Oenothera lamarkiana* ($2n = 14$) and *O. muricata* ($2n = 14$), the evolution of hexaploid bread wheat, tetraploid New World Cotton (*Gossypium hirsutum* $2n = 52$) were absolutely inspiring and imprinted on the minds of students. He would provide references of text books and original papers. After reading these, one would invariably arrive at the conclusion that MS had elegantly simplified, for the benefit of students, the complex structural and functional aspects *without* losing the essence of the science involved. In a nutshell, he was a 'born teacher' who made the students grasp the fundamentals with amazing clarity of expression.

In the Radiation Genetics Course, he would inspire students with elaborate of construction of the 'CLB' – *Drosophila melanogaster* with which Hermann J. Muller unequivocally demonstrated that X-rays induce sex-linked recessive lethal mutations. For this work published in *Science* in 1927, Muller won the Nobel Prize in 1946. And when Swaminathan set up the *Drosophila* Genetics laboratory in the Botany Division of IARI, he introduced a strain called Muller-5 instead of Muller's original CLB. When asked, he elegantly explained that CLB ('C' an inversion to inhibit recombination, 'L' for lethality (a small deletion) and 'B' (bar eye with reduced number of eyelets 'ommatida' in the compound eyes of Diptera)) had only one 'C' (cross-over suppressor, which could sometimes fail), but the Muller-5 had two such cross-over suppressors to reinforce the inhibition of crossing-over. In fact, it also revealed his innate passion and capacity to be the front-runner of any branch of science. In his own words, 'Teachers must be passionate'.

In the 1960s, nothing much was known about the 'Oxygen effect in radiation biology'. Just a couple of text books had been written and these had just a reference in passing on the oxygen effect. Yet, based on the post-Second World War research publications in *Nature* and *Int. J. Radiation Biol.*, he elaborated the advancing knowledge on the mechanisms of oxygen effect. It was those inspiring lectures which made PCK choose research programmes in radiobiology.

Swaminathan: crusader of conservation and sustainable use of biodiversity

Just a few geneticists involved in crop improvement are known to have also become deeply involved in conservation of biodiversity, particularly agro-biodiversity. It is not that they do not realize the essential requirement of several desirable genes to shield the vulnerable crops against a variety of biotic and abiotic stresses, but they probably believe that conservation is the job of others, say conservation ecologists. Against this compartmentalized notion of plant breeding and conservation of biodiversity, MS stands out as a towering crusader against loss of biodiversity due to anthropogenic causes related to climate change.

He gave forceful expression to his conviction of biodiversity being the feedstock of genetic improvement of crop plants (and farm animals) at the XV International Congress of Genetics held at New Delhi in December 1983. In his Presidential Address titled, 'Genetic conservation: microbes to man', he pleaded for international efforts involving the *ex situ* preservation of germplasm by cryogenic gene banks and *in situ* on-farm conservation. Preservation of seeds and propagules in cryogenic gene banks maintained at between –10°C and –20°C prolongs/extends their viability, but new variation through mutations and recombinations cannot occur. Furthermore, the energy requirement and prohibitively expensive cost in storing the seeds at –10°C and –20°C are often beyond the economic means of developing countries which are rich in agro-biodiversity. However, in regions of the Earth which have sub-zero temperatures throughout the year, the precious germplasm could be preserved under permafrost conditions. His inspiration was the driving force for the Norwegian Government to create a *Noah's ark* in the form of the *Svalbard Global Seed Vault*. At 78° Northern latitude, the Norwegian Village of Longyearbyen on Svalbard island, a 120 metre tunnel was chiselled out of solid stone in the middle of an ice mountain. This resulted in the establishment of three giant vaults, capable of storing 4.5 million distinct varieties of crops. The vaults are located under permafrost conditions where the natural temperature is about –4°C year round. With a little bit of additional energy, the temperature is lowered to about –18°C, the optimal temperature for maintaining long-term seed viability. On the occasion of the commemoration of the first anniversary of the Svalbard Gene Bank, the Norwegian Government organized in February 2009, a seminar on 'Frozen seeds in a frozen mountain: feeding a warming world'. Knowing full well that MS has been the source of inspiration, the Norwegian Government invited him to deliver a lecture on that occasion. The title of his lecture was 'Freezing seeds: a humanitarian issue' that provided a social dimension to the Svalbard Gene Bank. Thanks to his Presidential Address in December 1983 at the XV International Congress of Genetics, the Svalbard *ex situ* preservation of millions of cultivars is indeed a Noah's ark serving as a safety net for food security in an era of global warming and climate change.

Cryogenic preservation is just a 'safety net'. What is ideally required is '*in-situ onfarm*' conservation and maintenance of ecological integrity in primary, secondary and tertiary centres of origin and divergence of crop plants. Towards this important objective, MS established field stations of MSSRF at Kolli Hills (Tamil Nadu), Koraput (Odisha) and in Puthoorvayal near Kalpetta in Wayanad (Kerala). These centres not only revitalize the conservation traditions of tribal women, in particular, but also provide recognition and economic benefits. The elegant idea of conservation, cultivation, consumption and commercialization ('4Cs') proposed by him is an outstanding example of reconciling conservation and development in the sphere of farming activities.

It is well known that Swaminathan played a pivotal role in developing the 'Protection of Plant Varieties and Farmers' Right Act 2001' (PPVFRA 2001) as India's response to its obligation to provide *sui generis* protection to plant varieties under TRIPS. This Act is unique in that it recognizes the important role played by farmers not just as cultivators, but also the role of tribal and rural

Box 2. Excerpts from what the most eminent citizens of the world have said about Swaminathan.

Norman E. Borlaug, Nobel Laureate of International Maize and Wheat Improvement Centre, Mexico, 10 November 1970:

‘The Green Revolution has been a team effort and much of the credit for its spectacular development must go to Indian officials, organizations, scientists and farmers. However, to you, Dr Swaminathan, a great deal of the credit must go for first recognizing the potential value of the Mexican dwarfs. Had this not occurred it is quite possible that there would *not* have a Green Revolution in Asia…’

Ronald Reagan, President, USA, 11 September 1987:

‘It is with great pleasure that I congratulate you on being chosen as the First World Prize Laureate. This award recognizes what many in the global food and agricultural community have known for a long time that your efforts have made a dramatic and lasting impact on improving world food supply.’

Joshua Lederberg, 1958 Nobel Laureate in Medicine and Physiology, 25 September 1987:

‘I was so pleased to hear the news of your award. There could not have been a more appropriate choice. I can think of no one who has combined the insights of the cutting edges of biological science with attention to the most urgent needs with the competence, devotion and energy that you have given. The world is and will be a better place on account of your contributions to its welfare…’

Javier Perez de Cueller, Secretary General, United Nations, October 1987:

‘Dr. Swaminathan is a living legend. His contributions to agricultural science have made an indelible mark on food production in India and elsewhere in the developing world. By any standards, he will go into the annals of history as a world scientist of rare distinction…’

R. Venkataraman, former President of India on the occasion of Swaminathan’s 70th birthday, National Academy of Agricultural Sciences, New Delhi, August 1995:

‘Pleasant, soft spoken, dignified but unassuming, Dr. Swaminathan has a demeanor which conceals his brilliant intellect, unparalled achievements in science and research, and countless awards, prizes, fellowships and honours showered on him by national and international institutions. The Green Revolution which transformed our chronic food-deficit country with three hundred sixty million people into a food self-sufficient one with nine hundred million has earned for him an indelible place in our national history…’

Sartaj Aziz, Minister of Foreign Affairs, Islamabad, 13 September 1999:

I was delighted to see your name in the list of ‘100 Most Influential Asians of the 20th Century’ in Time Magazine of 23–30 August 1999:

‘To be bracketed with political giants like Mao Zedong Ho Chi Minh, Sukarno, Mahatma Gandhi and M.A. Jinnah is a great achievement in itself, but for me the more gratifying aspect is the recognition of the role of scientists in changing the course of history. Having watched and admired your outstanding contributions to the Green Revolution in Asia at first hand, I can say without hesitation that this recognition is well deserved.’

Ismail Serageldin, Chairman, CGIAR, 27 January 2000:

Dr. Swaminathan is a great humanitarian, an International scientist, and a bold and imaginative visionary. The results of his efforts have had a multiplier effect, helping small farmers to produce more food, increase incomes and protect the environment. This has resulted in the elimination of major sources of discord and conflict. Dr. Swaminathan’s contribution to the development of sustainable agriculture is unassailable, and is universally acknowledged…. He has broadened the concept of agricultural sustainability to include not only consideration of ecology and economics but also of ethics, social and gender equity and employment generation…’

A. B. Joshi, former Director, IARI, 14 August 1995:

‘Dr. Swaminathan has been the most eminent research scientist which India has ever produced – none like him in the past, and there shall be none in the far distant future.

But for Dr. Swaminathan, the Green Revolution in India would never have taken place! But for his contributions, India today would have been a decimated, depopulated country as prophesied by the American doom-sayer Paddock Brothers! Dr. Swaminathan alone has been the Saviour of India!’

farming women and men as conservers and enhancers of agro-biodiversity. The Act legally provides for their recognition and monetary reward.

Swaminathan's science-based approach to conserve what he prefers to call, the nutritious millets (once referred to as coarse minor millets) which had been neglected for over several decades in the Kolli Hills (Tamil Nadu) is doing immense good to the health of urban consumers and to the resource-poor marginal and small farmers from the point of view of income generation, poverty reduction and enhancing food security. The fact that minor millets belonging to the genera *Panicum*, *Paspalum*, *Setaria*, *Eleucine* and other under-utilized millets are highly nutritious and could also be ideal dietary items for those suffering from diabetes type-2 was utilized to link their conservation and cultivation with consumption and commerce. Ecology, nutrition and economics are integrated in a mutually reinforcing manner.

Swaminathan's interventions to strengthen the conservation ethos of the tribal women in Koraput (mainly landraces of rice) led to the tribal women winning the prestigious *Equator Initiative Award* at the UN Conference on Sustainable Development at Johannesburg (South Africa) in 2002 and the *Genome Saviour Award* of the Protection of Plant Varieties and Farmers' Rights Authority of India in 2007. In an era of climate change with increasing biotic and abiotic stresses, the future of food security largely rests on the availability of genes to shield the crops against floods and submergence, drought and heat, salinity and degraded soils, and a host of fungal, viral and bacterial diseases as well as insect pests. After all, the present and future generations would be ill-advised to forget the Irish potato famine of 1845 and the Bengal famine of 1943. The humankind got over these by introducing genes for resistance for these two biotic stresses respectively. The question is as to the future when the much-required genes might have been lost due to loss of biodiversity. For these reasons, present efforts of MS for the future food security and human well-being would hardly have any parallel. Yet, his contribution to sustainable management and conservation of about one million acres of undisturbed Amazonian prime rainforest of Iwokrama in Central Guyana brings out the fact that his endeavours encompassed the forests, and in fact the entire biosphere. In February 1990, Shridath Ramphal, Commonwelath Secretary-General invited MS to help convert about one million acres of rainforest into an implementable international project under the Commonwealth auspices, to demonstrate the concept of sustainable management and conservation of tropical rainforests. MS who headed a Commonwealth Team to Guyana prepared a project proposal that resulted in the formation of the 'Iwokrama International Centre for Rainforest Conservation and Sustainable Management'. He also served as the Chairman of Board of Trustees of this Centre from 1992 to 2000 with the support of several agencies such as Global Environment Facility, European Union, Commonwealth Secretariat, UK Government and several others.

Back home in India, MS saved the evergreen rainforest, called the 'Silent Valley' (so named due to the absence of chirping cicadas), where it was proposed to set up the Silent Valley Hydroelectric Project. The 'Swaminathan Report' recommended the development of Silent Valley into a 'National Rainforest Biosphere Reserve'. It also suggested alternate avenues to generate energy.

Swaminathan was the President of the International Union for Conservation of Nature and Natural Resources (IUCN) during 1984–1990. One of the several things he did was to establish a Global Network of Mangrove Genetic Resources Conservation Centre (MGRCC) to arrest degradation of mangrove forest ecosystem and to restore it. During the signing of the Global Biodiversity Protocol at the UN Conference on Environment and Development in June 1992 at Rio-de-Janeiro, the International Society of Mangrove Ecosystem (ISME) was established in Okinawa (Japan) with MS as the Founder-President, who prepared and presented the charter for mangroves conservation and their sustainable use. Under his supervision, MSSRF undertook a massive programme of restoring the degraded mangrove forests along the east coast of India comprising West Bengal, Odisha, Andhra Pradesh and Tamil Nadu.

The 26 December 2004 tsunami was quite devastating to the coastal regions of Tamil Nadu. Yet, the magnitude of loss of lives and livelihood resources was substantially reduced wherever mangrove restoration by MSSRF had taken place. A paper subsequently published in *Science* (**310**, 643, doi:10.1126/science.1118387) revealed how the thick mangrove vegetation greatly reduced the velocity of tsunami waves. It must also be pointed out that Swaminathan's article 'Beyond tsunami: an agenda for action' in *The Hindu*, 17 January 2005 is even now widely referred to for its crisp recommendations to minimize the loss of lives and livelihoods in case of any such disaster occurring in the future and also to enhance the coping capacity. His major suggestions are:

Immediate action: Trauma relief, psychological support and support for life and livelihood

Medium and long-term rehabilitation:

- Strengthening the ecological foundations of sustainable human security.
- Rehabilitating livelihoods and fostering sustainable livelihood security.
- Agronomic rehabilitation.
- Putting in place a network of Village Knowledge Centres.
- Strengthening the capacity of Panchayati Raj Institutions in disaster management and mitigation.

MS played a significant role in the global recognition of the 'Gulf of Mannar Marine Biosphere (Go MMB)' and Kerala's Kuttanad known for 'traditional cultivation of paddy below sea-level' as a globally important agricultural heritage site.

As the President of Pugwash Conferences on Science and World Affairs (2002–2007), MS enlarged the concept of 'human security' by adding hunger and pandemics like HIV/AIDS as threats equal as nuclear war. He recommended that technology push should be matched by an ethical pull. He said that 'spiritual globalization' to accord 'human dignity and gender equity' was needed more than 'economic globalization'. When MS was elected President of Pugwash Conferences on Science and World Affairs, a basic change had been introduced, viz. he was the first biologist to hold that position, all the earlier Presidents being physicists.

Institution builder

R. D. Iyer in his book *M.S. Swaminathan, Scientist and Humanist* (Bharatiya

Vidya Bhawan, Mumbai, 2002, p. 245) devoted a chapter of 23 pages to elaborate the various institutions that MS built in India and other countries in the world. He built every institution with a goal or purpose to innovate and take science to farmers. With inimitable thoroughness, he ensured that these institutions fulfil the environmental, social and economic goals of sustainability. At IARI, MS established the Nuclear Research Laboratory (NRL) designed in the modular fashion similar to the Bhabha Atomic Research Centre (BARC) in Trombay. It was equipped with state of the art instruments and gadgets of that time.

The change he brought about for the annual Indian Science Congress is remarkable in linking science with social needs. For the first time in the 63-year history of the Indian Science Congress, MS introduced the focal theme concept which was implemented in the 1976 Science Congress held in Waltair, under his Presidentship. The theme chosen by him for that Congress was 'Science and Integrated Rural Development'.

His global outreach through UN Committees is almost without parallel. As Vice-Chairman of the Technical Advisory Committee (TAC) to the Consultative Group on International Agricultural Research (CGIAR) of FAO, Rome, he played a key role in the establishment of the International Crop Research Institute for the Semi-Arid Tropics (ICRISAT) at Patancheru, near Hyderabad.

He was the moving spirit behind starting the International Board for Plant Genetic Resources (IBPGR) in Rome, renamed the International Plant Genetic Resources Institute (IPGRI) now again renamed as 'Biodiversity International'. Similarly, he helped in the establishment of the International Council for Research on Agro-Forestry (ICRAF) in Nairobi (Kenya) and served as Chairman of its Board of Trustees from 1977 to 1982.

As Chairman of the UN Advisory Committee for Science and Technology, MS played an important role in setting up the International Centre for Genetic Engineering and Biotechnology (ICGEB) in New Delhi. He also played a key role in promoting a Global Institute for Co-operation in Water Management at Valencia (Spain) when he served as Chairman of the International Committee on Water Management (1996–1998).

Besides his accomplishments in India, his work has had great impact in other countries of Asia and Africa. Some of these are as follows.

- He helped to build a 'China National Rice Research Institute' at Hangzhow. Although China is the largest producer of rice in the world, there was no adequate scientific support to back production efforts. Hence, an intensive human and institutional resources development programme was carried out from 1982 to 1988. He also helped to develop a 'National Genetic Resources Centre' (Beijing), a 'Hybrid Rice Research Institute' (Changsha in the Hunan province), and an '*Azolla* Research Institute' (Fuchow). In recognition of these contributions, the Academy of Sciences, China and the Chinese Agricultural Science Academy elected him as Honorary Professor, and the Chinese Government gave him a scroll of honour. He has been a member of the China Council for Sustainable Development since its inception in 1990.
- He was deputed to Vietnam in 1975 along with a team of experts, soon after its unification, to help develop two research institutes – one for rice in the Mekong Delta (considered the 'rice bowl' of Vietnam), and another for buffalo, so that Vietnam can increase its rice and milk production. As a result, Vietnam today is not only self-sufficient in rice, but has become the second largest exporter of rice in the world. His former IARI Ph D Vietnamese student, Bui Bong, rose in ranks and became the Vice Minister for Agriculture in Vietnam.
- During the Civil War and the genocidal Pol Pot regime, research institutes in Kampuchea were practically destroyed. Rice, being the staple food of the people, in 1985 MS started a programme for rebuilding the country's rice research infrastructure, with financial support from the Government of Australia. Initially, he arranged to train 20 young Kampuchean scientists in different areas of rice research at IRRI. Then, at the request of Prime Minister Hun Sen, he rebuilt the Research Station near Pnom Penh with their help to serve both national and international sectors. As a result, Kampuchea has been transformed from a food-deficit to a food exporting country.
- Burma (Myanmar), a major rice producer prior to the World War II, started losing this position in the 1960s. Because of poor post-harvest technology, milling recovery was low. MS undertook steps to build a strong and dynamic Rice Research Institute at Yezin. He also arranged training of army officers in collecting and conserving wild rices and other important plant genetic resources in areas affected by insurgency. As a result, the Burmese Government provided funds for establishing a 'Burma Room' at IRRI's Swaminathan Hall. More recently, he led an expert team to Myanmar to prepare a Master Plan to establish a National Agricultural Research Institute on the IARI model at Yezin, near their new Capital of Nay Pe Daw.
- MS initiated two major steps to strengthen Thailand's rice and agricultural research. First, a Research Station was established near Ayuthaya for developing high yielding, deep water and floating rices. Second, in a project initiated under the inspiration of the King (known as the King's Project), MS arranged for promotion of alternative cropping systems in place of poppy and other drug producing plants.
- He helps the Government of Sri Lanka in promoting sustainable rice farming systems in the Mahavalli Command Area, the largest irrigation project in the country. He was able to introduce modern rice farming practices, including efficient water management, in this area. Later, he also served as the Chairman, Board of Trustees of the International Irrigation Management Institute (now known as International Water Management Institute) in Colombo. In this capacity, he could offer Sri Lanka considerable help in producing more crop per drop of water. The Sri Lankan Government established a 'Sri Lanka Room' in IRRI's Swaminathan Hall.
- Swaminathan helped Pakistan in strengthening rice research both in West Punjab (Kala Shah Shaku Research Station) and in Sind. He undertook a large capacity building programme, with emphasis on the breeding of salt-tolerant and high quality rice. Later, he was invited by the President of Pakistan to deliver the keynote address at the inauguration of the Pakistan National Agricultural Research Institute at Islamabad.
- Following the political transition in Iran, rice production suffered. MS took steps to strengthen rice research capacity-building activities, by training a large number of Iranian rice scientists at IRRI. As a result, Iran improved its rice production considerably.

His manifold contributions to the improvement of rice productivity in particular are so compelling as to present a brief note on his tenure at IRRI. These are briefly as follows.

Swaminathan's role as the Director General of the IRRI (1982–1988)

In March 1982, MS, as the Acting Deputy Chairman of the Planning Commission of India, informed the then Prime Minister Indira Gandhi that he would like to accept the Invitation of the Chairman, Board of Trustees, to join the position of the Director General of IRRI, Philippines and that he would like to join on 1 April 1982. She was initially reluctant to relieve him as he was indispensable, to which he replied, 'Madam, I sincerely feel that one must leave when one is most wanted and not otherwise'. She thought for a moment and said 'Yes indeed, you are right. One must leave when most wanted. You have my best wishes'.

The Swaminathan Years (1982–88) as the Director General of IRRI are epitomized as an era of growth and sustainability. He injected vigour and dynamism to scientific research and development while adhering to the ecological and social dimensions of sustainable development.

During his very first year as Director General, he received The Third World Prize and the 1982 King Baudouin International Agricultural Research Award.

During his tenure of six years (1982–1988) MS initiated and implemented several new programmes. Some of these are as follows:

Development of a programme on women in rice farming: A 'Women in Rice Farming System (WIRFS) network' was organized. He also expanded IRRI's collaboration with advanced research institutes in the world, notably Australia, France, Germany, the Netherlands, UK, USA, etc. Scientists from these countries were deputed to work at IRRI on specific collaborative projects. While at IRRI, he helped to build National Rice Research Institutes in Hangzhou (China) and the Philippines Rice Research Institute. He also played a vital role in the establishment of rice research centres in Vietnam, Indonesia, Laos, Thailand, Bhutan, Madagascar and Egypt. He also started IRRI's group training courses in several areas: Genetic conservation and organizing an international training programme on genetic resources conservation and enhancement; upland rice training; irrigation water management; integrated pest management (IPM); cropping systems training; agroeconomic research methodology; and agricultural engineering. During his tenure as Director General, there have been several significant scientific outputs.

(a) Genetic enhancement resulted in rice varieties having resistance to brown plant hopper biotypes, having higher yields and better cooking quality. Using anther culture, a cross of cultivated rice with wild rice (*Oryza officinalis*) was successfully made.

(b) Research on pest and increasing production efficiency and productivity focused on containing virus-mediated rice plant diseases.

(c) Under his supervision, women-friendly farm machines and implements were developed. With smaller threshers, women's participation in threshing rice harvests doubled from 18% to 36%.

His most significant achievement is setting-up of a rice-based demonstration farm called 'Prosperity through rice (PTR)'. What it does elegantly and effectively is to integrate the following: low-cost, yield-increasing technologies, choice of rice varieties, nutrient management, cropping patterns, integrated crop-livestock and fish, use of livestock and crop residues as organic fertilizers, and use of rice straw as substrate for mushroom culture. The basic concept behind PTR is that every component of rice plant is ingeniously used to fight both food famine and improve livelihoods of rural farming communities. He further elaborated the concept in the MSSRF's 'Biovillage paradigm' for conservation and sustainable use of natural resources to enhance rural livelihoods for income-generation, poverty reduction and food nutrient security.

Swaminathan's mission of helping other developing countries with concepts and techniques for sustainable agriculture and rural livelihoods remains unabated. Recently, with the help of the Ministry of External Affairs, New Delhi, he set up a 'Rice Biopark' at the Yezin Agriculture University (Myanmar) to demonstrate the wide spectrum of opportunities available for preparing value-added products from every part of the rice plant such as straw, bran, husk, roots and grain. As Chairman of the Advisory Committee to help war-torn Afghanistan to rebuild its agriculture, he evolved the blueprint for action.

Promotion of science and technology-based application for food and nutrition security

Swaminathan's basic and applied research work and development of new crop varieties, agronomic strategies, etc. cannot be truly put into two watertight compartments. Yet, it would also be logical as his much deeper involvement since late 1960s in shaping India's future destiny of agriculture and rural development has made people of the older generation forget his having achieved excellence in basic research in life sciences; and the younger generation is mostly unaware of these. In fact, today most people know him only for his endeavours of food security for all, and not the path of the long journey of 65 years he had taken.

Among several compulsions, there were atleast two for his more active involvement in administration, policy planning, sustainable agriculture and rural development. One is that he was absolutely certain that Green Revolution was only to provide a breathing space and that it should be transformed into an ecofriendly, resource-poor small and marginal farmers-friendly sustainable agriculture. The need was a 'systems approach' to achieve 'productivity in perpetuity without accompanying ecological and social harm'. He called this system of agriculture as 'Evergreen Revolution'. Although Green Revolution ensured food security at the national level, it failed to ensure it at the individual household levels of millions of resource-poor marginal farming, fishing and landless rural families. MS integrated ecoagriculture with ecotechnology-driven on-farm, non-farm and marine-based (in the coastal areas) ecoenterprises for rural livelihoods. His analyses revealed that food security at the individual household level requires 'access' (i.e. purchasing power which is a function of livelihoods/jobs), especially for millions of resource-poor small and marginal farming, fishing and landless labour families in rural areas. There are about 700 million people living in about 638,000 villages throughout India.

Secondly, with his appointment as the Director-General, ICAR and Secretary to the Government of India, Department of Agricultural Research and Education (1972–1979), Principal Secretary to the Government of India, Ministry of Agriculture and Irrigation (1979–1980) and Member (Agriculture, Rural Development, Science and Education) of Planning Commission (1979–1980) with additional charge as Acting Deputy Chairman (April to June 1980), his responsibilities as well as expectations of him in the national scenario became substantially different. For him, it was an opportunity to take scientific know-how to the farmer's fields. Moreover, nearly two-thirds of India's agricultural farms are rain-fed. India's agriculture is a 'gamble in monsoon'. Therefore, an entirely different blueprint for action was necessary. It was during this period that MS developed the much-needed blueprint of an Evergreen Revolution to equip hundreds of millions of resource-poor rural and tribal families to fight both famine and rural livelihoods without accompanying ecological and social harm. He played a key role in shaping the Sixth Five Year Plan (1980–1985). Where, for the first time in the history of planning, he introduced two new chapters, one on 'Women and development' and another on 'Environment and development'. He could not, however, implement these immediately mainly because of the slow and tedious government machinery always opposed to new ideas. Hence, he had decided to accept the position offered to him as the Director-General of IRRI (1982–1988). It was during this period that he became the 'First recipient of the World Food Prize' in USA. Pooling this prize money of about 2 million dollars along with various prize monies won by him resulted in the 'seed money' to set up MSSRF in Chennai as a registered society in 1988. The major goal of MSSRF has been to harness science and technology for sustainable rural development. Simply stated, MSSRF blends frontier science and technologies (e.g. space, nuclear, information and communication and biotechnologies) with the traditional knowledge and ecological prudence of the rural and tribal communities to provide a pro-nature, pro-poor, pro-women and pro-livelihood orientation to technology development and dissemination in rural areas. For a substantial period of post-independence, high level science and technology had been limited/confined to a few major Indian cities and neighbouring towns. But India's roots are in the well spread-out 638,000 villages where nearly 700 out of 1250 million people live, the bulk of them illiterate and unskilled living in abject poverty and caught in debt trap. They also account for a large proportion of the hungry, under and malnourished children, women and men. India's dismal rank in the UN Global Hunger Index (GHI) as well as the UN Human Development Index (HDI) is largely because of the unacceptable level of poverty and hunger situation in rural areas. Degradation of natural resources in rural areas further aggravated poverty, hunger and deprivation. The rural women, in particular face the brunt of the miseries. Swaminathan designed the programmes of MSSRF in such a manner that science and technology would appropriately empower rural communities to reconcile conservation of resources and development of on-farm, non-farm and marine-based livelihoods for income generation, poverty reduction and food security enhancement. MSSRF has been successful in harnessing science and technology for the skill and knowledge empowerment of the rural women and men to ensure 'availability' of food and 'access' to food in perpetuity without causing ecological and social harm. MS identified the readily available technologies suitable for rural areas. These, however, would ideally require to be blended with traditional knowledge of the local communities as well as their ecological prudence to transform them into ecotechnologies with pro-nature, pro-poor and pro-women orientation. And, many more gap-filling research and innovative technologies would also need to be developed.

Swaminathan with his wife, daughters and grand daughters.

MS pays much attention to the principles and practices for a new 'Green Revolution' that would have a 'systems approach' and would not be readily susceptible to degenerate into a 'greed revolution'. The Evergreen Revolution would also be able to fight the famines of food and rural livelihoods in an ecofriendly manner. Degradation of the ecological foundations of agriculture (i.e. soil health, fresh water, biodiversity and atmosphere) and disintegration of social harmony because of inequities would need to be avoided. The system should ensure productivity in perpetuity without accompanying environmental and social harm. It was known from the very beginning that the high level fertilizer responsive 'Green Revolution' would not be sustainable both environmentally and socially. Its immediate and limited goal was to put the cereal grain production rate ahead of the annual human population growth rate. It was successful until, as expected, the green revolution began to show signs of yield fatigue in the late 1980s. The Evergreen Revolution, on the other hand, is designed to give as much care to the ecological and social dimensions as to the economic one. A sustainable development, in order that it does not become an 'oxymoron', has to pay equal attention to all the three dimensions (viz. social, environmental and economic) of sustainable development. The Evergreen Revolution is particularly favourable to the resource-poor small family farms. And it is also the pathway to 'green economy'.

In his book *Century of Hope: Towards an Era of Harmony with Nature and Freedom from Hunger* (Chennai, Eastwest Book, 1999, p. 155), Swaminathan wrote with deep conviction: 'what nations with small farms and resource-poor farmers need is the enhancement of productivity in perpetuity without associated ecological or social harm. The Green Revolution should become an evergreen revolution rooted in the principles of ecology, economics and gender and social equity.'

The UN declared 2014 as the International Year of Family Farming (2014 IYFF). The family farms could be very big (about 100 to 250 hectares) as in the USA or very small (1.0 hectare or less) as in India. Swaminathan's concern for resource-poor small and marginal farmers in the abovesaid book refers to 'social harm as well as gender inequity'. One of the social harms is the loss of livelihoods especially for farming and landless families in rural areas. The cause of hunger and malnourishment of hundreds of millions of people is the lack of livelihoods for income generation. Data from the USA show that 'corporate farming' (i.e. 'industrial farming') only creates 9.44 jobs displacing 27.97 (http://familyfarmingahap.weebly.com/family-vs-corporatefarming.html). Corporate farming is largely fossil fuel-derived energy-based (e.g. tractors, trucks, harvesters, tube well motor pumps, chemical fertilizers, etc.) which means emission of significant levels of greenhouse gases. Small family farms use draught power of bullocks for energy. And more importantly, MS made an important suggestion regarding the role of small family farms for providing agricultural remedies for maladies caused by nutritional deficiencies. Writing the editorial on 'Zero Hunger' in *Science* (1 August 2014, **345**, 491), MS noted that with the declaration of 2014 as the International Year of Family Farming by UN, a good opportunity exists to make a shift in tackling global hunger from 'food security' focus to an agenda that promotes 'nutrition security' instead. The 'zero hunger' as viewed by him refers to the elimination of both poverty-driven hunger (under-nutrition) as well as the 'hidden hunger' caused by lack of balanced diet containing micronutrients, vitamins, etc. In the abovesaid editorial, MS points out that the monocropping system adopted by corporate farms cannot provide agricultural remedies to maladies caused by nutritional deficiencies. On the other hand, once the nature of nutritional deficiencies are identified, appropriate vegetable, fruit or any other edible plant species can be included in the cropping system of the family farms, so that agricultural remedies can be provided for nutritional maladies. He suggests that along with cereals, oilseeds and pulses, several naturally biofortified horticultural plants such as drum stick ('Moringa'), sweet potato, bread-fruit, various berries, citrus species which are rich in micronutrients and vitamins could be cultivated in family farms. This approach of MS to provide a simple practical method of alleviation of nutritional deficiencies of about 600 to 700 million Indians will also provide economic benefit to hundreds of millions of resource-poor small family farmers.

Every moment of his being in the office, home or flight signifies creative thinking, writing and productive action. 7 August 2014 marked his 89th Birthday. Two days earlier, in *Agric. Res.* (doi 10.1007/s40003-014-0119-5), he published his concept of a farming system model to leverage agriculture for nutritional outcomes. His proposal of a 'Farming system for nutrition (FSN)' is amenable for implementation in the resource-poor small and marginal farm not only to enhance food security to alleviate hunger, but also to eliminate 'hidden hunger', caused by micronutrient deficiencies. In fact, he had been writing and lecturing vigorously on three kinds of hunger prevalent in India and a few other developing countries. These are: (i) under-nutrition (due to deficiency in calorie); (ii) protein deficiency (due to inadequate consumption of milk, pulses or eggs, meat, etc.); (iii) 'hidden hunger' (due to deficiency of micronutrients like iron, iodine, zinc, vitamin A, vitamin B12, etc. in the diet). While 'under nutrition' and 'protein deficiency' can be overcome by making available cereal grains and pulses respectively, 'hidden hunger' requires a conscious focus on nutrition-sensitive agriculture in the resource-poor small and marginal farms.

Integrating food and nutrition security at individual households of hundreds of millions of resource-poor small and marginal farming, fishing and landless labour rural families would significantly reduce the number of malnourished people now numbering about 600 to 700 million in India. Despite an enviable economic growth particularly during the first decade of this millennium, India ranks high in GHI. Levels of child underweight in India at 43% are twice the average level of 21% reported in sub-Saharan Africa. The FSN in concept and practice needs to be integrated within the evergreen revolution managed by hundreds of millions of resource-poor farmers throughout India.

Epilogue

Among a galaxy of living legends in Indian science, Swaminathan may be considered as one of the most influential Asian scientists of the 20th century. He has contributed to substantial change in agricultural practice and towards better image and destiny of India. He has made India proud with dedicated work in his chosen field of agricultural sciences. The gratitude of the people towards him, is far more deep and emotionally binding. He is truly a transformational agent who brought dignity and admiration for Indians and India.

Honorary Doctorates

The Sardar Patel University, Vallabh Vidyanagar (1970); The Andhra Pradesh Agricultural University, Hyderabad (1971); The Andhra University, Waltair (1972); The Haryana Agricultural University, Hissar (1973); G.B. Pant University of Agriculture and Technology, Pantnagar (1974); Jodhpur University, Jodhpur (1976); Marathwada Krishi Vidyapeeth, Parbhani (1975); Kumaon University, Nainital (1975); Burdwan University, Burdwan (1976); Agra University, Agra (1978); Kerala Agricultural University, Trichur (1978); Sri Venkateshwara University, Tirupati (1979); University of Agricultural Sciences, Bangalore (1980); Banaras Hindu University, Varanasi (1981); Technical University of Berlin, Berlin (West) (1981); Mahatma Phule Agricultural University, Rahuri (1982); Chandrasekhara Azad Agricultural University, Kanpur (1983); University of Wisconsin, Madison, Wisconsin, USA (1983); Delhi University, Delhi (1984); University of the Philippines, Diliman, Quezon City, Philippines (1984); Asian Institute of Technology, Bangkok, Thailand (1985). Doctorate of Technology; University of

Mangalore, Mangalore (1986); University of Hyderabad, Hyderabad (1987); Agriculture University, Wageningen, The Netherlands (1988); Assam Agricultural University, Jorhat, Assam (1988); Oregon State University, Corvallis, Oregon State, USA (1988); Tamilnadu Agricultural University, Coimbatore (1989); Rajasthan Agricultural University, Bikaner (1989); Indian Agricultural Research Institute, New Delhi (1989); Pondicherry University, Pondicherry (1989); University of Tuscia, Viterbo, Italy (1990); North Eastern Hill University, Shillong (1991); University of Bologna, Italy (1992); Punjab Agricultural University, Ludhiana (1994); Indian Institute of Technology, Madras (1997); Hemvati Nandan Bahuguna Garhwal University, Garhwal (1997); The Hebrew University of Jerusalem, Israel (1998); University of Calcutta, Calcutta (1998); Kakatiya University, Andhra Pradesh (2000); University of Massachusetts, USA (2001); Dr Panjabrao Deshmukh Krishi Vidyapeeth, Akola (2001); Gujarat Agricultural University, Ahmedabad (2002); University of Bonn, Germany (2002); Bidhan Chandra Krishi Viswavidyalaya, West Bengal (2003); Soka University, Japan (2003); Ohio State University, Columbus, USA (2004); Sher-e-Kashmir Agricultural University, Srinagar (2005); Iowa State University, USA (2005); Shanumgha Arts, Science, Technology & Research Academy (SASTRA) (2005); Sathyabama Deemed University (2005); University of Kalyani (2006); N.D. University of Agriculture & Technology, Faizabad (2006); Indira Gandhi National Open University (2007); University of Bari, Italy (2007); University of Mysore, Mysore; Aligarh Muslim University (2009); Nethaji Subhash Open University, Kolkata (2008); Universidad de Talca, Chile (2009); University of Alberta, Canada (2010); Padmashree Dr D.Y. Patil University, Mumbai (2011); McMaster University, Canada (2011); IIT, Kharagpur (2011); Punjab University (2011); University of East Anglia, UK (2012); Calicut University, Calicut (2012); Deshikottama (Honorary Doctorate), Viswa-Bharati, Santiniketan (2012); Azerbaijan State Agrarian University (2013); University of Nebraska (2013); North Maharashtra University, Jalgaon (2013); Dr D.Y. Patil Vidyapeeth, Pune (2013); University of Minnesota (2014); Jawaharlal Nehru Krishi Vishwa Vidyalaya (2014); University of Agriculture, Faisalabad, Pakistan (2014).

National Awards

Shanti Swarup Bhatnagar Award (1961); Birbal Sahni Medal, Indian Botanical Society (1966); Silver Jubilee Commemoration Medal, Indian National Science Academy (1971); Barclay Medal, Asiatic Society (1978); Moudgil Prize (1978); Borlaug Award (1979); Meghnad Saha Medal, Indian National Science Academy (1981); Rathindranath Tagore Prize, Visva Bharati University (1981); R.D. Misra Medal, Indian Environmental Society (1981); ‘Krishi Ratna’ Award, Bharat Krishak Samaj/World Agriculture Fair Memorial Trust Society (1986); Dr J.C. Bose Medal, Bose Institute (1989); Lal Bahadur Shastri Deshgaurav Samman (1992); Jawaharlal Nehru Birth Centenary Award, Indian Science Congress Association (1992); Charles Darwin International Science and Environment Medal (1993); Dr B.P. Pal Medal, National Academy of Agricultural Sciences, India (1997); V. Gangadharan Award, National Development (1997); B.P. Pal Memorial Award, Indian Science Congress Association (1998); Shatabdi Puraskar, Indian Science Congress Association (1999); Prof. P.N. Mehra Memorial Award (1999); Legend in his Lifetime Award, World Wilderness Trust (1999); Asutosh Mookerjee Memorial Award for 1999–2000, Indian Science Congress Association; Indira Gandhi Prize for Peace, Disarmament and Development (2000); Millennium Alumnus Award, Tamil Nadu Agricultural University (2000); Millennium Scientist Award, Indian Science Congress Association (2001); Lokmanya Tilak Award, Tilak Smarak Trust, Pune (2001); Indira Gandhi Gold Plaque (2002); BioSpectrum Life Time Achievement Award (2003); Technology Achievement Award (2005); Raja Rammohan Roy Puraskar (2005); All India Management Association’s Life Time Achievement Award (2007); Distinguished Global Thinker Award, Institute for Integrated Learning in Management, New Delhi (2007); Lal Bahadur Shastri National Award for Excellence in Public Administration, Academics Management (2007); Fifth Panampilly Prathibha Puraskar (2012); GITAM Foundation Annual Award, Visakhapatnam (2012); Indira Gandhi Award for National Integration (2013).

International Awards

Mendel Memorial Medal, Czechoslovak Academy of Sciences (1965); Ramon Magsaysay Award for Community Leadership (1971); Bennett Commonwealth Prize of the Royal Society of Arts (1984); Bicentenary Medal, University of Georgia, USA (1985); Albert Einstein World Science Award, World Cultural Council (1986); Award for Serving the Cause of Women in Development (1985); First recipient of the Award instituted by the Association for Women in Development, Washington, DC, United States; First World Food Prize Smithsonian Institution in Washington, DC, USA (1987); The Golden Heart Presidential Award of Philippines, 1987.

In recognition of Swaminathan’s contributions to the research, training and technology transfer programmes of IRRI, the Board of Trustees named the Training and Technology Transfer Building of the Institute as ‘M.S. Swaminathan Hall’. The IRRI Trustees also established a special fund for providing scholarships in his name for candidates who wish to do research by women in rice farming systems. This is in recognition of his services to the cause of women in agriculture.

Commandeur of the Order of the Golden Ark of the Netherlands (1990); The Tyler Prize for Environmental Achievement (1991); Honda Prize, Honda Foundation, Tokyo, Japan (1991); Asian Regional Award by the Asian Productivity Organisation (1994); UNEP–Sasakawa Environment Prize, 1994; World Academy of Art and Science, Special Award (1994); Global Environmental Leadership Award, Climate Institute, Washington, DC, USA (1995); Highest award for International Cooperation on Environment and Development, China (1997); Ordre du Merite Agricole, France (1997); Henry Shaw Medal, Missouri Botanical Garden, USA (1998); The VOLVO Environment Prize, Sweden/USA (1999); UNESCO Gandhi Gold Medal, France (1999); Franklin D. Roosevelt Four Freedoms Award, Franklin and Eleanor Roosevelt Institute (2000); Planet and Humanity Medal of the International Geographical Union (2000); The Economic Times Awards for Corporate Excellence–Lifetime Achievement (2002); Toda Award for Peace Achievement, Japan; Outstanding Technology Leadership – included among the 50 world leaders by Scientific American (2004);

Soka Gakkai Hiroshima Peace Award (2005); The Crop Science Society of America Presidential Award (2005); Ordre Du Merite Agricole (Commander of the Agricol Merit) (2006), France; Sahametrei Medal of the Royal Government of Cambodia (in the grade of Chevalier) (2006); Medalla Rectoral Universidad de Chile, Chile (2009); Willa S. Cather Medal, Lincoln, University of Nebraska (2011); Living Legend of International Union of Nutrition Sciences, Granada, Spain (2013).

Books written by Swaminathan

Building a National Food Security System, Indian Environmental Society, 1981, pp. 138.
Science and Integrated Rural Development, Concept Publishing Company, New Delhi, 1982, pp. 354.
Science and the Conquest of Hunger, Concept Publishing Company, New Delhi, 1983, pp. 508.
Sustainable Agriculture: Towards an Evergreen Revolution, Konark Publishers Pvt Ltd, Delhi, 1996, pp. 232.
Sustainable Agriculture: Towards Food Security, Konark Publishers Pvt Ltd, Delhi, 1996, pp. 272.
I Predict: A Century of Hope. Towards an Era of Harmony with Nature and Freedom from Hunger, East West Books (Madras) Pvt Ltd, 1999, pp. 155.
From Rio de Janeiro to Johannesburg – Action Today and not just Promises for Tomorrow, East West Books (Madras) Pvt Ltd, 2002, pp. 224.
Swaminathan, M. S. and Kochhar S. L., *Groves of Beauty and Plenty – An Atlas of Major Flowering Trees in India*, Macmillan India Ltd, Delhi, 2003, pp. 298.
Swaminathan, M. S. and Daisaku Ikeda, *Revolution: To Green the Environment, to Grow the Human Heart*, East West Books, Chennai, 2005, pp. 138.
Swaminathan, M. S. and Kochhar, S. L., *Groves of Beauty and Plenty – An Atlas of Major Flowering Trees in India*, Macmillan India Ltd, Delhi, 2007, 2nd edn, pp. 324.
Science and Sustainable Food Security – Selected Papers of M S Swaminathan, World Scientific, Singapore, 2010, pp. 420.
From Green to Evergreen Revolution, Indian Agriculture: Performance and Challenges, Academic Foundation, New Delhi, 2010, pp. 410.
Science and Sustainable Food Security, *Selected Papers of M. S. Swaminathan*, World Scientific, Singapore, 2010, pp. 420.
Towards an Era of Biohappiness: Biodiversity and Food, Health and Livelihood Security, World Scientific, Singapore, 2011, pp. 170.
Remember Your Humanity: Pathway to Sustainable Food Security, New India Publishing Agency, New Delhi, 2012, pp. 208.

Books edited by Swaminathan

Swaminathan, M. S., Gupta, P. K. and Sinha, V., *Cytogenetics of Crop Plants*, MacMillan India Ltd, 1983, pp. 591.
Von Weizacker, E. V., Swaminathan, M. S. and Lemma, A., *New Frontiers in Technology Application*, Tycooly International, Dublin, 1983, pp. 271.
Swaminathan, M. S. and Sinha, S. K., *Global Aspects of Food Production*, Tycooly International, Dublin, 1985.
Li, Z. and Swaminathan, M. S., Proceedings of the First International Symposium on Chromosome Engineering in Plants. Academia Sinica, Beijing, 1986.
Swaminathan, M. S. and Kochhar, S. L., *Plants and Society*, Macmillan, London, 1989, pp. 629.
Swaminathan, M. S. and Vineeta Hoon, *Biotechnology: Reaching the Unreached – An Interdisciplinary Dialogue*, Proceedings No. 3, Centre for Research on Sustainable Agricultural and Rural Development, Madras, 1991.
Getubig, I. P., Chopra, V. L. and Swaminathan, M. S., *Biotechnology for Asian Agriculture: Public Policy Implications*, Asian and Pacific Development Centre, 1991.
Swaminathan, M. S., *Biotechnology in Agriculture: A Dialogue*, Macmillan India Ltd, Madras, 1991, pp. 371.
Swaminathan, M. S. and Jana, S., *Biodiversity: Implications for Global Food Security*, Macmillan India Ltd, Madras, 1992, pp. 326.
Swaminathan, M. S. and Ramesh, R., *Sustainable Management of Coastal Ecosystems*, Chrom Grafix, Madras, 1993, pp. 215.
Swaminathan, M. S., *Information Technology: A Dialogue*, Macmillan India Ltd, Madras, 1993, pp. 264.
Swaminathan, M. S., *Wheat Revolution: A Dialogue*, Macmillan India Ltd, Madras, 1993, pp. 164.
Swaminathan, M. S., ICPF. *Uncommon Opportunities: an Agenda for Peace and Equitable Development*. Report of the International Commission on Peace and Food, Zed Books, London, 1994, pp. 210.
Swaminathan, M. S., *Ecotechnology and Rural Employment: A Dialogue*, Macmillan India Ltd, Madras, 1994, pp. 396.
Swaminathan, M. S., *Farmers' Rights and Plant Genetic Resources: A Dialogue*, Macmillan India Ltd, Madras, 1995, pp. 440.
Swaminathan, M. S., *Agro-biodiversity and Farmers' Rights*, Konark Publishers, Delhi, 1996, pp. 303.
Swaminathan, M. S., *Gender Dimensions in Biodiversity Management*, Konark Publishers, Delhi, 1998, pp. 229.
Swaminathan, M. S., Medrano, P. and Bhavani, R. V., *Towards a Hunger-free World: The Ethical Dimensions*, East West Books (Madras) Pvt Ltd, Chennai, 2004, pp. 141.
Swaminathan, M. S., Medrano, P., Gustafson, D. J. and Sharma, P., *National Food Security Summit (Selected Papers)*. World Food Program, New Delhi, 2004, pp. 593.
Swaminathan, M. S. and Medrano, P., *Towards Hunger Free India: From Vision to Action*, East West Books (Madras) Pvt Ltd, 2004, pp. 470.
Swaminathan, M. S. and Chadha, K. L., *Environment and Agriculture*, Malhotra, Delhi, 2006.
Swaminathan, M. S., *Agriculture Cannot Wait: New Horizons in Indian Agriculture*, Academic Foundation, New Delhi, 2007.
Swaminathan, M. S., Ajay Parida and Shetty, P. K., *Biosecurity*, National Institute of Advanced Studies, Bangalore, 2008.

Biographies on Swaminathan

1. Ramanujam, S., Siddiq, E. A., Chopra, V. L. and Sinha, S. K., *Science and Agriculture: M.S. Swaminathan and the Movement for Self-Reliance*, IARI, New Delhi, 1980, pp. 400.
2. Erdelyi, A., *The Man who Harvests Sunshine. The Modern Gandhi: M.S. Swaminathan*, Tertia kiadó, Budapest, 2002, pp. 167.
3. Iyer, R. D., *Scientist and Humanist. M.S. Swaminathan*, Bharatiya Vidya Bhavan, 2002, pp. 245.
4. Dil, A., *Life and Work of M.S. Swaminathan. Toward a Hunger-free World*, East West Books (Madras) Pvt Ltd, Chennai, 2004, pp. 636.
5. Gopalakrishnan, G., *M.S. Swaminathan. One Man's Quest for a Hunger-free World*, Education Development Centre, Chennai, 2002, pp. 130.
6. Parasuraman, N. (Tamil), *M.S. Swaminathan – Architect of Sustainable Agriculture*, Mathi Nilayam, Chennai, 2014, pp. 239.
7. Deolgavkar, A., *Swaminathan – Bhukmukticha Dhyas* (Liberator from hunger). Akshar Prakashan, Mumbai, 2000, pp. 162.
8. Deolgavekar, A., *Swaminathan – Bhukmukticha Dhyas*, Supriya Sharad Marathe, Mumbai, 2008, pp. 183.

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