DOI: 10.5958/0974-4444.2024.00001.5

Vol. 53 (Special Issue), pp. 1–20 Indian Journal of Nematology March, 2024

Nematology in India: The Journey, Perspectives, and a Vision

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ABSTRACT: Nematodes are the most numerous, widely distributed and diverse group of multicellular, pseudocoelomate invertebrates with unique morphological and metabolic features with a high degree of adaptations to the trophic and environmental variability. Majority of their species have an important role in regulating the decomposition process and soil health. However, many species of nematodes are parasites of plants and animals, including humans. Nematodes were known to man for several centuries, but nematology as a subject emerged in the beginning of the 20th century in the USA and Europe. The detection of root-knot nematodes in the tea plantations in the Nilgiri hills in 1901 can be said to be the first record of plant parasitic nematodes in India. It was followed by the reports of *ufra* disease of rice in 1913 and white-tip disease of rice in 1936. In independent India, the zoologists started describing the diverse kinds of plant parasitic and free-living nematodes. The food shortages in the 1950s and 1960s raised big concerns. The discovery of *molya* disease of wheat and barley by the cereal cyst nematodes in Rajasthan in 1957, and the discovery of the exotic potato cyst nematodes in the Nilgiri hills in 1961 were big concerns. This led to the foundation of Nematology as a separate discipline of plant protection in India in 1966. This article traces the major historical milestones, generational changes and directions in nematology, with special reference to India in fundamental and applied nematology research, education and extension. In spite of the sustained effort of nematologists, nematodes have outsmarted nematologists in most of these areas in practice, not only in India but also in the rest of the world. Failures in truly understanding nematodes and developing dependable management technologies are still lamented. Crop losses and economic impact; development of eco-friendly and economically viable integrated nematode management modules to fit into overall IPM; reliable identification and diagnostic tools; good level of nematode resistance through breeding or molecular techniques; safer nematicides; effective biocontrol agents; use of entomopathogenic nematodes, and understanding the role of nematodes in regulation and prediction of ecosystem function, are still areas that will continue to invite our attention for decades to come. Besides assessing the importance of plant parasitic and entomopathogenic nematodes, the salient achievements made so far, the major limitations, possibilities and a vision for the future are given.

Keywords: Crop losses, ecology, education, entomopathogenic nematodes, history, nematode management, nematology, physiology, taxonomy

The Nematodes, also commonly known as roundworms, threadworms or eelworms are the most numerous and most widely spread multicellular organisms on our planet earth. Nematodes are triploblastic, pseudocoelomate, metamerically unsegmented, bilaterally symmetrical, bisexual, vermiform, poikilothermic invertebrate animals, with well-developed digestive, reproductive, nervous, excretory organ systems and musculature, but lacking appendages, skeleton, circulatory and respiratory organ systems. They came into existence billions of years ago at a peculiar stage of evolution between the acoelomate and coelomate animals, somewhere intermediate in the evolution of organ systems and complex metabolism. Their typical ontogeny, biology and physiology make them valuable biological models. Synchrony and adaptations of nematodes to changing environments and their survival strategies explain their diversity, persistence, ubiquity and relative invincibility. Majority of their species are microbivorous and play important roles in regulating the decomposition process and nutrient recycling. However, there are thousands of nematode species that are parasites or predators of other animals or plants. It is said that all species of plants and animals, including humans, on earth are parasitized by one or more species of nematodes. Nematode infections cause a general reduction in health with non-specific symptoms, but some of their species cause specific symptoms. In association with other pathogens like

bacteria and fungi, nematodes induce or aggravate disease complexes that can even kill the host.

MILLIONS LOST EACH YEAR DUE TO THE UNSEEN FOES AND THE UNSEEN FRIENDS IGNORED!

Plant parasitic nematodes have serious implications in agriculture since they reduce the growth and yield of all kinds of crops and also reduce the quality of produce. International estimates show that nematodes cause an average of 6–20 per cent damage to production besides adversely affecting product quality. Crop losses due to nematodes were projected to be about eight per cent in temperate and 12.5 per cent in tropics and subtropics. In monetary terms, the global estimates show as much as USD 173 billion worth of crops lost due to nematodes. Various estimates and guesses have been made in India too for the key nematode pests. Some estimates arrived at in India under the ICAR-AICRP-Nematodes show that crop losses worth Rs. 102,039.79 million (USD 1.58 billion) annually segregated into the losses in 19 horticultural crops at Rs. 50,224.98 million, while for 11 field crops at Rs. 51,814.81 million may be happening annually (Kumar *et al*., 2020, National Academy Science Letters 43(5) DOI:10.1007/s40009-020-00895-2). These figures would be obviously much greater if we consider many of the other important crops, forage, sugarcane, cotton, orchards, tea, coffee, spices, medicinal plants, various plantation crops and many other field and horticultural crops than the 19 horticultural and 11 field crops in the above estimate.

The gross value of India's agriculture and allied sector was Rs. 22219.92 billion at 2010–11 prices as per *Agricultural Statistics - At a Glance 2022*, Govt. of India. Although various reports state per cent crop loss estimates at 6–20 per cent, up to total crop failures in some cases; even if we assume conservatively that overall, only 4 per cent of the gross value is lost due to nematodes, the value of loss due to nematodes can be put at Rs. 906934 million or Rs. 90693.4 crore (USD 10.92 billion) at 2010–11 base price. Due to the nonspecific symptoms, losses due to nematodes often go unnoticed or unreported. It may never be possible to arrive at the exact value of loss due to nematodes. Monetary values of inputs, produce and gains or losses are dynamic. Also, the nematode populations, per cent crop losses as well as crop production are influenced by many dynamic human, technological, and environmental factors. Thus, much hairsplitting in this aspect is unnecessary. But the past 65 years of experimentation and demonstrations in different parts of India do suggest that losses are enormous, and necessitate proportionate research, education and extension efforts to manage nematodes, the unseen foes as well as to harness the potential benefits of our unseen friends, the microbivorous and entomopathogenic nematodes for more productive agriculture.

EARLY KNOWLEDGE

The knowledge of 'worms - *Krimis*' in India may have its roots in the *Vedas*, around 3500–1500 BCE. Yet, the first report of soil and plant nematodes dates back to 1901 CE when Barber reported the occurrence of root-knot nematodes infecting young roots of tea plants in the Nilgiri hills. That paper was not simply a first report but it also discussed the biology, ecology, and possible management methods, some of which are still followed in principle. In the world, the first report of a plant parasitic nematode was that of the ear-cockle nematode, *Anguina tritici* by Needham in 1743, a finding first in many ways. It was a foliar parasite going into the seed and surviving in anhydrobiotic state for several decades. Since 1901 the root-knot nematode in India was observed infecting many vegetable crops and papers in the 1930s reported its occurrence and non-chemical control methods in southern India. The reports of the *Ufra* disease of rice in the north-east in 1913 and the white-tip disease of rice in 1936 caused concern. Entomologists, Plant Pathologists,

Botanists and Zoologists in some institutions of the country began studying the morphology and infections, intensity of symptoms and damage caused by nematodes. From the 1940s onwards the curious and serious taxonomic studies on soil and plant nematodes commenced more prominently at Hyderabad and Aligarh. The applied nematology, involving studies on the infection, damage, and control got impetus from the 1950s at Allahabad, Aligarh, Bengaluru, Jaipur, New Delhi, Shimla *etc*.

IMPACT OF DISCOVERY OF *MOLYA* DISEASE AND EXOTIC POTATO CYST NEMATODE

The discovery of the cereal cyst nematode, *Heterodera avenae* in 1958 causing the '*molya*' disease of wheat and barley at Sikar, Rajasthan, followed by the realization and demonstration of the amount of crop losses caused by them gave a big cause for concern. The wheat and barley were the major staple food crops and any reduction in their production was taken seriously in India then facing increasing foodgrain shortages. This was soon followed by the discovery in 1961 of the presence of the exotic potato cyst nematodes, presently known as *Globodera rostochiensis* and *G. pallida* in the Nilgiri Hills. This created concerns about the dangers of exotic serious pests entering the country. It was then a localized infestation and much effort was made to eradicate these nematodes by application of high doses of nematicides. These two discoveries besides the increasing reports of root-knot nematodes led to the strengthening of the training and research centers, especially at AMU, Aligarh and IARI, New Delhi. PhDs and other international training of a number of nematologists in leading nematology centers, notably the University of California, Davis, USA; Imperial College, London; and Rothamsted Research Station, UK, *etc.* provided about a dozen trained specialized nematologists in the country. Those were the beginning of the green revolution and the application of science to all aspects of agriculture was felt necessary.

ESTABLISHMENT OF DIVISION OF NEMATOLOGY AT IARI

The country by 1965 appreciated the economic importance of nematodes as a bottleneck in agriculture, and the need for in-depth research, post-graduate education and extension in nematology. Hence, a separate Division of Nematology was established in December 1966 by merging the two sections of nematology working separately in the Division of Entomology under Dr. S.K. Prasad and Division of Mycology and Plant Pathology under Dr. Gopal Swarup. In both these units, a few post-graduate students were working on nematodes as in many other universities in the UK, USA, Russia, Germany *etc*. The focus was mainly on surveys, identification, demonstration of losses, pathogenicity, biology *etc*. Dr. A.R. Seshadri who was then heading a section of nematology at the TNAU, Coimbatore, was appointed as the first regular Head of the Division of Nematology at IARI, New Delhi.

The Division of Nematology, ICAR-IARI became the locus of Nematological research, education and extension. Extensive surveys of various crops were carried out and data was compiled from all over India. A number of paired plot experiments and demonstrations up to about 1970 were organized to assess and demonstrate crop losses due to nematodes in major crops like wheat, barley, rice, vegetables *etc*. Untreated plots were compared with plots treated with fumigant nematicides like 1,2 Dichloropropane + 1,3 Dichloropropene (DD) mixture which was required to be applied at high doses. Subsequently, other nematicides like DBCP, organophosphate and carbamate nematicides were also available. There were questions raised on the effects of these nematicides other than just controlling nematodes. Many pathogenicity trials were carried out by inoculating plants with logarithmically increasing numbers of infective stages of nematodes under pot culture. This conclusively proved that nematodes caused

loss and the damage was related to the population density of nematodes. This logic was also applied to field conditions without the use of nematicides. The aggregated nature of nematode population densities in a field, *i.e*., patchy distribution, usually following the negative binomial distribution, was helpful in plot comparisons and correlations with crop performance.

MASTER'S AND DOCTORATE DEGREES IN NEMATOLOGY, THE FIRST IN THE WORLD

The Post-Graduate School of IARI, New Delhi in 1968 introduced separate MSc and PhD degree programmes in Nematology following the course credit system and thesis requirements. Dr. S. K. Prasad was appointed the first Professor of Nematology. These became the first of the few independent post-graduate degree programmes in Nematology in the world. During 1967–75 six post-graduate training programmes were organized for South-East Asia jointly by IARI, New Delhi, and AMU, Aligarh with the support of Wageningen University, the Netherlands; Rothamsted Research Station, UK; and UC, Davis, USA. The FAO funding under UNDP provided significant financial, instrument and training support.

Although the post-graduate teaching programmes in nematology as a discipline started in 10 SAUs besides IARI, New Delhi, the number of seats was kept small because (i) job opportunities available were few, and (ii) only a few students opted for degree in nematology due to lack of awareness of plant nematodes in schools and colleges. The reason for lesser attraction towards nematology compared to the sister disciplines of entomology and plant pathology has been that the under-graduate programmes even in agriculture gave none or too little knowledge about nematodes and their importance in agriculture. There used to be a separate 1L+1P course in Nematology in the BSc (Hons.) Ag. programme in the UG curricula recommended by the ICAR Deans Committees. This got reduced to 1L and later further reduced in the ICAR 5th Deans Committee to just a mention in one or two of the courses of entomology or plant pathology. Most SAUs lacked a faculty specialized in nematology, hence no or only a passing reference to nematodes was made. The result was the agricultural graduates and post-graduates who went on to service in the KVKs, SAUs, ICAR institutes or extension services of the states had hardly any knowledge about nematodes and their effect and importance. Some of the traditional universities and institutes had some course or research work on nematodes as part of their PG programmes in botany or zoology.

ESTABLISHMENT OF THE NEMATOLOGICAL SOCIETY OF INDIA

The year 1969 became important in the history of Indian Nematology, when an All-India Nematology Symposium was organized. The Nematological Society of India was established and with the efforts of this Society, the Indian Journal of Nematology was started in 1971. The first President Dr. Abrar M. Khan, General Secretary Dr. S.K. Prasad, and Chief Editor Dr. A.R. Seshadri made a very good start. Indian Nematologists found a common platform for periodic interaction, conferencing and publication. The next five years provided a significant number of trained nematology degree holders from India and foreign universities.

The Division of Nematology in the 1970s, under the overall leadership of Dr. A.R. Seshadri got organized into six groups, *viz*., (i) Dr. S.K. Prasad *et al*. focusing on nematode ecology, botanicals and organic amendments, (ii) C.L. Sethi *et al*. on nematicidal control of nematodes, (iii) Dr. Gopal Swarup *et al*. on host-parasite relations and disease complexes, (iv) Dr. E. Khan *et al*. on nematode taxonomy and systematics, (v) Dr. D.R. Dasgupta *et al.* on nematode physiology, and (vi) Dr. K.C. Sanwal *et al*. on Quarantine.

The pioneers at IARI, New Delhi in 1960s and '70s

Dr. A.R. Seshadri

Dr. S.K. Prasad

Dr. Gopal Swarup

Dr. C.L. Sethi

Dr. Ekramullah Khan

Dr. D.R. Dasgupta

Dr. K.C. Sanwal

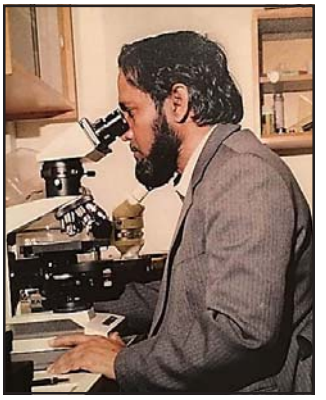
Dr. J.S. Gill

At the Aligarh Muslim University, Aligarh, the Department of Botany under the leadership of Dr. Abrar M. Khan focused on applied nematology, while the Department of Zoology led by Dr. M.A. Basir, Dr. M.R.

The pioneers at Aligarh Muslim University, Aligarh during 1960s and '70s

Dr. Abrar M. Khan

Dr. S.K. Saxena



Dr. M.R. Siddiqi

Dr. M.S. Jairajpuri

Siddiqi and Dr. M.S. Jairajpuri worked on the taxonomy and systematics of soil and plant nematodes. Dr. M. R. Siddiqi started his career at AMU Aligarh, but later moved to CIP, CABI UK. He authored a book "Tylenchida" that is considered a bible of Nematology.

Dr. K.G.H. Setty and his team at UAS, Bangalore; Dr. T.M. Manjunath *et al*. at TNAU, Coimbatore; Dr. V.M. Das at Osmania University, Hyderabad; Dr. G.I. D'Souza at Central Coffee Research Institute, in Chikamagalur; Dr. K.K. Nirula *et al*. at ICAR-CPRI, Shimla; Dr. J.C. Edward at Institute of Agriculture, Allahabad; Dr. K. Sitaramaiah at GBPUAT, Pantnagar; Dr. S.N. Das *et al*. at OUAT, Bhubaneswar; Dr. Y.S. Rao *et al*. at the ICAR-CRRI, Cuttack; Dr. H.M. Shah *et al*. at AAU, Anand; Dr. R.N. Prasad *et al*., at Jaipur; Dr. B.S. Yadav *et al*. at MPUAT, Udaipur; Dr. D.S. Bhatti *et al*. at CCSHAU, Hisar and a few others emerged as major nematology centers in the 1970s. Thus, nematology research attained an all-India presence. Many of these leaders had got their PhD or training at leading nematology centers in the USA, UK, Germany, Russia *etc*.

The pioneers in some other parts of India during 1960s and 70's

Dr. S.N. Das
OUAT, Bhubaneswar

Dr. D.S. Bhatti
CCSHAU, Hisar

Dr. H.M. Shah
AAU, Anand

Dr. B.S. Yadav
MPUAT, Udaipur

Dr. K.G.H. Setty
UAS, Bengaluru

Dr. Y.S. Rao
CRRI, Cuttack

Dr. R.P. Nath
RPCAU, Pusa

Dr. P.K. Koshy
CPCRI, Kayankulam

Silver Jubilee Symposium of Nematological Society of India and General Body Meeting (23–26 March, 1995)
Indian Agricultural Research Institute, New Delhi

ESTABLISHMENT OF ALL INDIA COORDINATED RESEARCH PROJECT ON NEMATODES

A need was felt to have a country-wide coordinated effort for the growth of nematology research. In 1977, Dr. A.R. Seshadri initiated the All India Coordinated Research Project on Nematodes with the financial support from Department of Science & Technology, Govt. of India. The project was continued under ICAR from 1979. Centers of this project were established in different parts of India, manpower was recruited, common methodology and direction were provided and the all-India level data began pouring in on regional and national nematode problems. Impressed by its project, ICAR adopted the AICRP-Nematodes as a plan scheme in 1979. This project became instrumental in the establishment of independent Departments of Nematology in 10 State Agricultural Universities (SAUs). Besides research, these departments also started their own MSc and PhD programmes in Nematology. Several other universities kept teaching a few courses and gave nematology research problems to their students in Entomology or Plant Pathology. The Division of Nematology at IARI, New Delhi which also houses the headquarters of the AICRP on Nematodes and the Nematological Society of India attained a major role in providing leadership to Indian Nematology. The SAUs having cooperating centers of AICRP-Nematodes have been providing regional leadership.

AICRP AS NATIONAL RESEARCH PLATFORM FOR NEMATOLOGY

The All India Coordinated Research Project on Nematodes has helped provide a national panorama of nematology, guiding, coordinating and consolidating the inputs, activities and outputs. The AICRP-Nematodes is a unique discipline-based project covering all the major nematode problems of the various agro-climatic zones and crops and the different nematode management approaches. The project is revised under every five-year plan with gradual shifts and upgrades in the research priorities and plans. After the first Project Coordinator Dr. A.R. Seshadri, the project was led by Dr. J.S. Gill for several years. Subsequently, Drs. S.K. Midha, R.V. Singh (Offg.), H.S. Gaur, S.D. Mishra (Offg.), R.K. Jain, Archana Singh (Offg.), R.K. Walia, Uma Rao (Offg.), Anil Sirohi (Offg.) and the present Project Coordinator, Dr. Gautam Chawla, have been able to carry forward this vitally important project for the science of nematology in India. They have made course corrections and modulated the technical programme of this project in tune with the changing scenario in different five-year plans and annual/biennial reviews over the past four decades. The ICAR has been conducting periodic quinquennial reviews by appointing QRTs comprised of eminent nematologists.

The number of cooperating (funded) and volunteer centers have been varying over the years. The good thing is that the project has been able to join and cover all agroclimatic zones of India. Some of the states of the country have still remained uncovered. This project used to be a team of about 50 active nematologists supported by 30–40 technical and supporting staff. Typically, each centre had three nematologists, two technicians, supporting staff, and a driver. This critical mass of manpower was essential keeping in view of the labour and time-intensive nature of nematological research. Over the years, unfortunately, due to the inflation and squeeze in proportionate relative funding, the centers are now left with hardly one nematologist each. Further, it is noticed that at some of the centers even that single position of nematologist has not been filled up with a qualified nematologist and stop-gap arrangements have been made by deploying either entomologist or plant pathologists, who lack sufficient relevant acumen or commitment to work with nematodes. On the one hand, they have been weaned away from their own fields of

National Symposium on Rational Approaches in Nematode Management for Sustainable Agriculture (23–25, November, 1998) Gujarat Agricultural University, Anand

research while on the other they are not able to do sufficient justice to the typical kind of work of this project.

FOCAL SHIFTS IN RESEARCH: A DIRECTED TRAJECTORY

An analysis of the plan-wise shifts would show the direction applied nematology has taken in the country over the past 45 years. (i) Taxonomy and identification, (ii) Survey and documentation, (iii) Crop loss assessment, (iv) Demonstration of losses, (v) Locating hot spots, (vi) Nematode 'management' trials, (vii) Screening for resistance, (viii) Confirmation of resistance, (ix) Soil solarization, (x) Integrated nematode management trials, (xi) Biocontrol agents and bio-suppressants, and (xii) Testing of new nematicides, have been the main themes of the AICRP on nematodes.

Some very important findings and technologies have emerged. New nematode problems have been documented which are multiple times more serious than the *molya* disease in 1958 and potato cyst nematode in the Nilgiri hills in 1961 that had led the ICAR and the Government of India to establish nematology as a discipline since those were the days of food scarcity. The manpower has been drastically reduced, leaving no critical mass of scientific and technical manpower required for the typically labour-intensive nematology education and research. The research funding on contingent grants has come down sharply in real terms. Most SAUs have too few or no nematologists of their own, but depend on nematologists under AICRP-Nematodes for their routine teaching, research and extension, thus overburdening them, leaving little time or energy for coordinated research. Many of the crop-based institutes of ICAR have no nematologists. Most of the ports of entry in the country lack qualified nematologists although exotic nematode species and races/pathotypes are definite threats.

SELF-SUFFICIENCY INDUCED COMPLACENCY MAY COST HEAVY

The presently prevailing food self-sufficiency has prevented the flutter that the widespread root-knot nematode damage in rice, failing polyhouses due to nematodes, threats to guava, pomegranate, kiwi and other precious crops due to *Meloidogyne enterolobii* and other nematodes, and the spread of potato cyst nematodes in north India ought to have caused. Given the growing climatic adversities, monsoon dependence *etc.*

that have the potential to stifle our food security, the ignorance of these new challenges due to nematodes can have serious consequences in the not-so-far future.

SHIFTING RESEARCH AREAS

Nematode ecology and Mathematical models

The understanding of the relationships between different trophic groups of nematodes and their environment (Nematode ecology) was a fascinating area in the 1960s and 1970s. The studies on the spatial distribution, abundance, and population dynamics of nematodes got impetus after similar studies in insects. The development of empirical models by Dr. J.W. Seinhorst in 1965–66 at Wageningen, the Netherlands to explain the relationships between the initial population density of nematodes with crop yield for estimation or forecasting crop damage, and with population growth in order to forecast post-crop nematode population densities, became fascinating areas coinciding with the evolution of scientific calculators and computers. Simultaneously, the application of statistics to nematode populations caught up. Dr. M. Oostenbrink preferred regression equations over Seinhorst's models. The healthy scientific debate between these two great nematologists was interesting. In India, Dr. S.K. Prasad induced the author (H.S. Gaur) to adopt both, the mathematical models of Seinhorst and the statistical models of Oostenbrink, the latter became more popular due to their simplicity, even though the former had better logic and greater accuracy.

Nematode biology, ecology and survival

Studies on the biology of different nematodes and interactions of nematodes with bacterial and fungal diseases were initiated in the laboratory of Dr. Gopal Swarup. The *tundu* disease of wheat and root-rot complexes involving root-knot nematodes and *Fusarium* and other fungi were studied.

The 1980s saw studies on the effects of temperature and moisture on nematode survival. Anhydrobiosis was already known in foliar nematodes and the soil-borne cyst nematodes. The author (H.S. Gaur) along with Dr. Mukesh Sehgal started research on long-term anhydrobiotic survival of the non-cyst forming, *Meloidogyne incognita, Rotylenchulus reniformis, Tylenchulus semipenetrans, Pratylenchus zeae etc*. The author along with Dr. R.N. Perry at Rothamsted Research Station, UK, proved that the unshed moulted cuticlar sheaths reduced the rate of water loss and helped in anhydrobiotic survival of *R. reniformis*. They also showed that the hatching behaviour varied between the early and later generations of multivoltine species of cyst nematodes with increasing retention of eggs in the cyst, lipid reserves in juveniles and dependence on host-root diffusates for hatching. A small proportion of eggs of root-knot nematodes also showed dependence on host root diffusates for hatching. These presented beautiful examples of the synchrony of the life cycles of the host and parasitic nematodes facilitating longer survival of nematodes.

Nematode management

Various cultural, physical, chemical, and biological methods of control and management of plant parasitic nematodes, especially of the *Meloidogyne* spp., *Heterodera avenae*, *Globodera* spp., *Anguina tritici*, *Aphelenchoides besseyi* have been developed. Some attempts have also been made against others like *Pratylenchus thornei, Heterodera cajani, Rotylenchulus reniformis, etc*. The nematicides, DD and DBCP were used in the 1960s and 1970s in various demonstration trials against *Heterodera avenae* in Rajasthan and the root-knot nematodes at various places. Nematicides were also intensively used with the intention of eradicating the potato cyst nematodes in the Nilgiri hills, although eradication was not successful. Various organophosphates and carbamates normally developed

as insecticides were tested as nematicides in the 1980s to 2020 with some success. However, over the years almost all have been banned for health and environmental concerns. A couple of new nematicides, the fluensulfone as Nimitz® (Fluoroalkenyle, thioether) from Adama, and fluopyram (pyridinyl-ethyl-benzamide) as Velum-Prime® from Bayer Crop Science, have recently come out and are being tested, with label claims for a few crops. The major advantage of these new nematicides is that they are required in very small quantities, raising the hope of their environmental and health safety.

A big effort was made to find plant products and byproducts with nematicidal properties. Many papers came out of AMU under the leadership of Drs. A.M. Khan and S.K. Saxena, and from IARI under the leadership of Dr. S.K. Prasad. Most other nematology centers also contributed to this area. Many products were reported, but except neem, most others remain only on paper. By the early 1970s itself, it was realized that any single method of control was not enough to achieve sufficient reduction and maintain nematode populations under economic threshold levels. Therefore, the integrated approach employing two or more of the cultural, physical, biological, and chemical methods was required for managing nematode population densities at low levels and achieving profits by improved crop performance. Therefore, the emphasis over the past 60 years has been to formulate integrated nematode management packages involving crop rotation, tillage practices, solarization, organic amendments, biocontrol agents, nematicidal seed treatment and if necessary, application of nematicides. All centers of AICRP-Nematodes also have been busy formulating and testing such packages against root-knot, reniform, burrowing and cyst nematodes in various crops.

Nematologists have to consider that the crop in the field is not only suffering from nematodes but also from a number of other biotic stresses, such as insects, mites, fungi, bacteria, viruses, and weeds. The farmer is concerned about all or some of these besides nematodes. Fortunately, several of the practices for the management of nematodes are also effective against other pests and vice-versa. This makes it easier and profitable to undertake integrated pest management including nematodes with other pests and pathogens. Hence, nematologists now must focus their research on various aspects of nematodes as well as methods of their control, but they should not remain in their own silos when it comes to practical integrated nematode management.

Physiology and Molecular nematology

In the late 1970s, the applications of biochemistry got pace in different branches of agriculture including in nematology. The main objectives were, (i) a taxonomic tool for differentiating species of root-knot and cyst nematodes on the basis of protein profiles by SDS Page and/or enzyme phenotypes such as esterase and dehydrogenases, and (ii) host-parasite relations like role of amylase and proteases or tryptophan, or PAL and TAL. In the early 1990s there was a switch towards the RNA and DNA-based techniques to define taxonomic differences and interrelationships and host-plant resistance or susceptibility. In India, Dr. D.R. Dasgupta at ICAR-IARI, can be regarded as the pioneer in initiating the use of biochemical techniques for differentiating nematodes and for understanding host-parasite relations. Drs. A.K. Ganguly, Anil Sirohi, Uma Rao, and their students continued such studies. The author in 1994–95 also tried his hand at RFLP of ribosomal and mitochondrial DNA for differentiating groups of *Meloidogyne* species in relation to their mode of reproduction and host preferences.

The 1990s also saw the identification of host resistance genes against root-knot nematodes, like the Mi-gene series, and the incorporation of resistance genes to develop nematode-resistant plants. However, in

spite of high potential, true success in these areas, both taxonomy and host-plant resistance, is yet to be seen. The reasons could be high research costs and regulatory hurdles, but more than that appears to be the little involvement of molecular biologists/biotechnologists to team up with nematologists. Attempts to develop transgenic germplasm resistance to nematodes have been made under laboratory conditions only. The complex registration processes and public resistance to GMOs have suppressed research in this area. Currently, attempts are being made by Dr. Anil Sirohi and his students at ICAR-IARI to apply the Crisper-CAS-9 and other technologies for gene-editing to impart resistance or reduce the susceptibility of host plants to nematodes.

Screening and breeding for nematode resistance

Non-hosts and resistant host plants are the best options for the management of any pest, including nematodes. Therefore, screening of germplasm of various important crops against nematodes has been an extensive activity in most nematology centers. The first success of tomato SL-120 (Pusa Nemamukta) against root-knot nematodes in the early 1970s brought in much hope. Some more tomato varieties resistant to root-knot nematodes were identified/developed at CCSHAU, Hisar and PAU, Ludhiana. A couple of cowpea varieties and ABT10 of tobacco were identified as resistant at AAU, Anand. A few potato varieties were resistant to *Globodera* spp. came out from ICAR-CPRI. Some varieties of barley and wheat have been reported to be resistant to cereal cyst nematode, *Heterodera avenae* in Rajasthan. Several other reports are available about a good degree of resistance in the germplasm of various crops against root-knot and cyst nematodes. Compendia of such germplasm have been published by AICRP-Nematodes. However, plant breeders have rarely come forward to take up breeding for nematode resistance in which the resistant germplasm identified by nematologists could be used as a donor parent. Besides the pre-occupation of plant breeders with other traits, one of the reasons for their disinterest could be the fact that much variability occurs in the infectivity of different nematode populations and their population densities as well as the environmental factors at different locations. Nematode resistance is mostly polygenic and quantitative in nature. Hence, the same so-called resistant germplasm found resistant at some nematode population density may be found susceptible at higher population density and some other locations.

Nematode taxonomy

India used to be recognized as a country with a good number of competent taxonomists among the first and second-generation nematologists. Drs. MR Siddiqi, VM Das, MS Jairajpuri, E Khan, QH Baqri, HK Bajaj, and the members of their teams used to be internationally recognized names in nematode taxonomy. India was one of the few National Nematode Collections. Over the years with the shift of the attention of nematologists to other more attractive areas, the country is not left with taxonomists of similar fame. Presently, I do not know whom one should approach for a reliable identification of a slightly different-looking nematode at the species level. Some efforts have been made to attempt nematode taxonomy with the use of protein and DNA-based identification, but these can at best be supplementary tools where traditional microscopy fails to differentiate close morphological resemblance among certain taxa. There is certainly a need to revive the very important specialization, *i.e.*, Nematode Taxonomy and Systematics at three or four places in the country, and also to develop more manpower in this area for the future.

Biological control and Biosuppressive microbes

Several Indian nematologists tried to explore nematophagous fungi and bacteria at IARI and some SAUs. The success with predatory fungi remained

rather academic. Much hope came with the bacteria *Pasteuria penetrans* specific to root-knot nematodes or pigeonpea cyst nematode, *Heterodera cajani*. The obligate parasitism, high specificity and difficulty in the mass culture of these bacteria limited its adoption. Dr. R.K. Walia tried to develop formulations based on infected root-knot nematodes. The oviparasitic fungi, *Paecilomyces lilacinum*, now named *Purpureocillium lilacinum* brought in greater hope. However, the suspicion that certain strains of this fungus are capable of causing blindness in humans prevented its adoption. In recent years, some strains of *P. lilacinum* are getting tested/ recommended at various places. Registration process under The Insecticides Act - 1968, has also become stringent for biopesticides due to biosafety concerns.

Some organisms known for benefitting plants through improving nutrient availability or otherwise promoting plant growth also fascinated nematologists due to some observations of decreased nematode infection and crop damage. The work on the adoption of VAM like *Glomus fasciculatum* and *G. mossae* raised some hopes; the main effect being through improving phosphorus availability, but also obstructing nematode invasion by forming a mycelial web called Hartwig's net. Similarly, *Trichoderma harzianum* and *T. viride* were promoted by microbiologists for improving plant growth by improving nutrient availability from organic matter and other possible biochemical interactions. Several nematologists claimed suppression of nematodes by *T. harzianum* and *T. viride* and the so-called plant growth-promoting rhizobacteria (PGPR), *Pseudomonas fluorescens* and some other microorganisms reduce nematode infection and improve crop yields. There are many commercial products and technologies, especially pre-colonization of compost *etc*. Various kinds of claims are made, and so much so some people have begun considering them as 'biocontrol agents', which is doubtful if not wrong. There is a need to understand the mode of action when it comes to the effect on nematodes.

Cyanobacteria are well-known biofertilizers. In a multi-disciplinary field experiment in the early 1990s the author noticed lower nematode populations in plots treated with cyanobacterial biofertilizers in rice-wheat cropping system. That led this author to conduct laboratory tests on some species of cyanobacteria present in the given biofertilizer. It was found that some species of *Nostoc muscorum*, *Aulosira fertilissima etc*. had nematostatic and nematicidal attributes in their exudates and cytoplasm, respectively. Inhibition of hatching and mortality of *Meloidogyne graminicola, M. triticoryzae* and *M. incognita* were observed. These effects were confirmed in a number of studies on these and some other species of cyanobacteria in Dr. Anju Kamra's lab. at IARI.

Entomopathogenic nematodes

The mermithid nematodes, which also parasitize insects were first found in 1877, but the first entomopathogenic nematode (EPN) was described in 1923 by Steiner as *Aplectana* (= *Steinernema) kraussei* isolated from *Lyda potrophica*, a hymenopterous sawfly. Weiser (1955) described a European population of *Neoaplectana* (= *Steinernema*) *carpocapsae* from codling moth larvae. Dutky and Hough in 1955 isolated the DD-136 strain of *N. carpocapsae* from codling moth larvae in Eastern North. Poinar and Thomas in 1965 described the symbiotic bacteria *Achromobacter* (*Xenorhabdus*) *nematophilus* associated with *S. carpocapsae*. The role of the symbiotic bacteria in causing insect mortality and the development of the nematode was reported by Poinar and Thomas in 1966–67. The concept of biological control of insects using EPN was introduced for the first time in 1931 when Glaser successfully cultured EPN on an artificial medium and carried out the first field trial to control white grubs in golf courses. In India, probably the first attempt to use the DD-136 strain of *N. carpocapsae* was made by Drs. VP Rao and TM Manjunath in 1966. Sporadic attempts were made during the next 30 years. More

serious research was later taken up by Dr. Sharad Mohan and Dr. Sudarshan Ganguly and their students, especially on mass culturing and the development of formulations. Hydrogel-based formulation, encapsulated *Galleria* cadaver-based formulation, *etc*. were made. An apparatus was developed by Dr. Sharad Mohan for the mass culture of the EPNs. Attempts were also made to use the isolated bacterial symbiont, *Photorhabdus luminescens* directly for control of insect pests, but this work was later halted fearing the possible damage to the beneficial insects. The desiccation survival at reduced relative humidity and cryopreservation of infective juveniles of EPN in liquid Nitrogen were tried with some success by the author along with Dr. Sharad Mohan and his students.

The international market share in EPNs is estimated at USD 22 million, unfortunately, India does not figure in it due to the lack of reliable WP/WDG products with sustained shelf-life and efficacy. We need to register products matching with the international standards. Current Indian products are non-selective to the pest, crop or geographical location, thus, defying the biological concept of niche-specificity, survival, and pathological efficacy of EPN in alien environments. Any single EPN species is indiscriminately recommended countrywide for multi-purpose applications, irrespective of the nematode's origin. With vast variations in biotic and abiotic factors governing Indian agriculture it is, therefore, critical to exploit native isolates for product development as ecological parameters shape the prevalence, sustenance and pathogenicity of EPN species within a given region.

SIGNIFICANT SUCCESSES

Major successes achieved

While we talk at larger multidisciplinary fora, the successes achieved in nematology, not only in India but also elsewhere in the world, look obscure and underestimated. When we assess success in a subject like Plant Nematology, we may not limit ourselves to the management or control of the most diverse fauna and very difficult foes. We should also include the discovery and demonstration of new problems, monitoring, academic progress in understanding their ecology, physiology, survival, host-parasite relationships, and development of alternative technologies, entomopathogenic nematodes, as well as progress in basic research keeping the country at pace with the rest of the world. However, we can take some pride in certain aspects, to cite a few:

i. Raising the status of Nematology as an independent discipline of plant protection.

ii. Identification and documentation of the major phytoparasitic nematode fauna and their distribution in the country.

iii. Identification of major previously existing and recently emerged nematode problems and hot spots in important fields and horticultural crops.

iv. Near eradication of the ear-cockle and *tundu* diseases of wheat due to *Anguina tritici* through awareness and adoption of simple seed cleaning techniques.

v. Reduction in the severity and spread of the *molya* disease of wheat and barley due to cereal cyst nematode, *Heterodera avenae* through cultural practices and cropping system changes.

vi. Nematode resistant tomato, potato, cowpea, wheat, barley, tobacco and some other crops.

vii. Development of non-chemical nematode management methods such as locally suitable tillage, solarization, crop rotations, and organic amendments for vegetable crops.

viii. Nematode management packages against *Meloidogyne graminicola* and *M. triticoryzae* in the rice-wheat cropping system.

ix. Identification of nema-suppressive micro-organisms, such as *Bacillus subtilis, Gluconoacetobacter* sp.*, Pseudomonas fluorescens, Trichoderma, harzianum, T. viride, Pochonia chlamydosporia etc*. and biocontrol agents *Purpureocillium lilacinum*, *Pasteuria penetrans etc*. and demonstration of their efficacy in multilocation trials.

x. Identification of nematode-resistant varieties in tomato, cowpea, potato, wheat, barley *etc*.

xi. Understanding survival strategies of terrestrial and multivoltine nematode species, through modified hatching and moulting behaviour and anhydrobiosis.

xii. Identification, mass-culture, formulation and demonstration of the efficacy of entomopathogenic nematodes.

xiii. Manpower development and good quality publications.

xiv. Established facilities for molecular biology research, including gene editing for nematode resistance in plants.

xv. Molecular identification of key nematode pest species.

NEW AND EXPANDING NEMATODE PROBLEMS – *MORE THAN TEN HEADS OF RAVANA*

One thing that intrigues me most is the fact that Nematology was given the status of independent agricultural science in the 1960s when threats were perceived to the wheat and barley production due to the cereal cyst nematode, *Heterodera avenae*, and the detection of the exotic potato cyst nematodes *Globodera* spp. in some area of the Nilgiri hills. Root-knot nematodes are already recognized to be causing damage to vegetables and some commercial crops. Management methods have been developed, and the seriousness of these problems has been reduced.

Over the years, several even more serious problems have emerged, or have come to the fore due to detection by nematologists, for instance:

i. Root-knot nematodes, *Meloidogyne graminicola,* including host range variants/races, in the rice-wheat cropping system area in the Indo-Gangetic belt as well as in the upland and irrigated rice crops in most states.

ii. Root-knot, *Meloidogyne* spp. and reniform nematodes, *Rotylenchulus reniformis* destroying crops in protected cultivation, especially the polyhouses.

iii. Guava wilt complex involving the root-knot nematode, *Meloidogyne enterolobii* and fungal pathogens.

iv. *Meloidogyne indica* damaging citrus.

v. Potato cyst nematodes, *Globodera rostochiensis* and *G. pallida* spread in the northern hilly regions in the states of Jammu & Kashmir, Himachal Pradesh and Uttarakhand, in addition to continued havoc in the Nilgiri hills.

vi. Burrowing nematodes, *Radopholus similis* and root lesion nematodes, *Pratylenchus* spp. in plantation crops.

vii. Root-knot nematode damage in intensive annual and perennial vegetables, fruits, ornamentals, spices and medicinal plants.

viii. White-tip nematode, *Aphelenchoides besseyi* damaging rice in some states, and even the commercial crop of tuberose in West Bengal.

ix. Nematode damage to mushrooms due to *Ditylenchus* spp. and *Aphelenchoides* spp. *etc*.

x. Increased severity of nematode damage in soils over large areas with decreasing organic carbon, and increasing abiotic stresses and climate change.

Despite the demonstrated economic importance of these problems, the desired level of flutter has not occurred at the government level. The reason, to my mind, could be that the country was facing acute food shortages in the 1960s whereas today we boast of 'food self-sufficiency' or even 'food-surplus'.

I am sceptical that the so-called food self-sufficiency or surplus may be a fragile phenomenon since the population and its needs are continuously increasing, climate change and stresses are getting more serious, and monsoons are getting erratic in intensity and timing. Abiotic and biotic stresses are increasing. Tackling persistent problems such as nematodes is not possible in the short term. Hence, there is no room for complacency. The Government needs to extend greater and continuous support and the nematologists need to be alert, active and ready with practically and economically feasible eco-friendly nematode management modules to fit into overall integrated pest management packages for various crops and cropping systems.

SPREAD OF NEMATODES FROM NURSERIES - A CASE FOR INSPECTION AND CERTIFICATION

We know that the active dispersal of nematodes is rather slow, but they are passively spread far and wide rather quickly. They go with infested soil, wind-blown dust, water, seeds, seedlings and other plantings. We know that the potato cyst nematodes have reached the potato growing areas of north Indian hilly areas of Jammu & Kashmir, Uttarakhand and Himachal Pradesh most likely with the infested seed potato and debris, from the Nilgiri hills of southern India. The local quarantine regulations might have slowed, but could not prevent the spread, all due to ignorance and neglect. The infested plant nurseries transported over long distances intra- and interstate have become the major means of spread of serious nematode problems, including the root-knot, reniform, root-lesion, burrowing and citrus nematodes. Seedlings of field crops like rice spread *M. graminicola*. The serious guava root-knot nematode, *M. enterolobii* has spread to almost all states and threatening guava orchards. Pomegranate and grapevine orchards have similarly suffered due to *M. incognita* infected seedlings. Root-knot nematodes spread through mulberry saplings threaten the silk industry. Seedlings of roses and other ornamentals have given a good ride to nematodes to new heavens. The list can go on and on. Even the nematode-infested soil used for hardening tissue culture-raised seedlings has become a means of rapid and wide dissemination of nematodes. There are simple methods available for diagnosing the presence of nematodes as well as for treating the nursery-beds and infested soils, yet ignorance is rampant. Also, the business interests of nursery owners come in the way. Ignorance among them as well as among the recipient farmers are the major reasons facilitating the spread of such problem nematodes. This is also true for many other soil-borne pests and pathogens. The country urgently needs a mandatory inspection and certification mechanism to prevent further spread of such serious problems.

PUBLICATIONS

Prior to 1971 the Indian scientists working on nematodes in different disciplines were publishing in *Nematologica* or various other national and international scientific journals. The Nematological Society of India, established in 1969, launched the *Indian Journal of Nematology* in 1971. This provided a good platform to publish research papers for the Indian nematologists who were exhorted to raise the standards of this journal to prefer their papers in it rather than publishing in foreign journals. The number of subject-specific national and international journals was limited and most nematologists read almost every paper published in the subject.

Over the period the faculty assessment and promotion policies of the UGC and ICAR started giving greater weightage to papers published in 'foreign' journals. Gradually, the quality of most Indian journals began falling. Then came the policy of evaluating research papers based on citation indices. Many Indian journals suffered, and greater sufferers were discipline-specific journals, particularly of disciplines with small numbers of scientists. Nematology is one such discipline; the number of readers and citations also remained low. Hence, the dilemma is whether to publish in our discipline-specific journal like the *Indian Journal of Nematology* or to publish in some other broader-based journals of popular publishers, most of them big commercial houses. Further came the onslaught of 'paid journals' or open-access paid journals that demand big monetary payments for publishing papers in their journals. Many scientists are compelled to shell out money to publish. It is a pity that publishers make business on the effort of authors who should indeed be rewarded, rather than being asked to pay for publishing their own work. Some institutions have started providing financial assistance to publish in such paid journals, but most do not.

FUNDAMENTAL OR APPLIED NEMATOLOGY?

There has been another division in research within agriculture disciplines, nematology no exception: The scientists are (a) involved in fundamental and (b) applied aspects. The fundamental research involved new concepts and techniques, be it biochemistry, molecular biology/biotechnology well supported by sophisticated, expensive instrumentation systems. This looks sophisticated. The applied research usually addressed some location-specific problems and involved previously known techniques. This looks traditional. Nematologists in India have been largely engaged in applied research, with only a few engaged in fundamental research. The publications on fundamental research get published in highly cited international journals compared to the papers based on applied research. However, there is a clear need to improve the standards of publications/research papers to match those of the more reputed international journals.

Another important group of publications is the authored or edited text and reference books. Some useful books have been published by nematologists such as P.P. Reddy, D.S. Bhatti, G. Swarup, D.R. Gupta, M.S. Jairajpuri, R.K. Walia, H.K. Bajaj, P.C. Trivedi, Wasim Ahmed, M.R. Khan, N.G. Ravichandra, and a few others. Some Indian nematologists have also contributed chapters in several books published by reputed foreign and Indian publishers. There is still much dependence on many books by famous nematologists published by CABI, Academic Press, CRC, Springer *etc*. which are quite expensive to be afforded by individual nematologists. Recently, a few open-access e-books, for instance, '*Integrated Nematode Management: State-of-the-Art and Visions for the Future*' by R.A. Sikora, J. Desaeger and L.P.G. Molendijk (2021) have come out that can be easily accessible on the web to everyone interested because its publication was sponsored by Syngenta. The latest is '*Nematode Problems in Crops and their Management in South Asia*' edited by R.K. Walia and M.R. Khan, published by Cambridge Scholars Publishing. Many Indian and foreign nematologists have contributed to it. Books are essential for students as well as for teachers and practising nematologists. There is a need for more high-quality books that may become easily affordable or freely available everywhere as e-books. Some books published by ICAR are available cheaply as hard copies or as e-books on portals like Agrimoons. There are commercial interests of publishers who need to recover the cost of publication and make some business. It may be a good idea if some funding bodies or philanthropists come forward to sponsor the publication of more open-access e-books in the interest of science and the public at large.

NEMATODE AWARENESS

The knowledge about nematodes, the problems caused by them and the methods of their management are still limited to only a fraction of the farmers. Even the majority of the agricultural scientists engaged in teaching, research and extension in various disciplines of agriculture are hardly aware of various nematodes and their identification or management. The nematologists have been doing some extension work by themselves through demonstrations/awareness meets and publications such as booklets/bulletins in various local languages. Digital content including databases and documentary video films, *e.g*., *Unseen Enemies* (English) and *Sutra krimi-Chhipe Shatru* (Hindi) produced by the author and available free on YouTube, were also developed. More digital content in local languages needs to be developed for dissemination through the internet/social media.

Most of the subject-matter specialists engaged in the approx. 730 *Krishi Vigyan Kendras*, and the departments of agriculture in different states know little about nematodes. The quarantine stations at the various ports of entry rarely have experts trained about nematodes. The reason is that only a passing reference, if all, is made about nematology in the UG and PG programmes. Even the single position of SMS-Plant Protection in KVK is occupied by graduates in either Entomology or Plant Pathology even if they have never studied sufficient Nematology. Often, they do not consider nematology graduates as eligible for the position of SMS-Plant Protection in spite of the fact that nematology is a valid branch of plant protection, and most of the nematology students study entomology and/or plant pathology as minor disciplines. Nematology graduates have been facing difficulty in getting proper employment to be able to use their expertise for the benefit of agriculture and the nation. Many of them are compelled to take up irrelevant avenues for employment. This anomaly has been waiting for resolution for long.

VISION FOR THE FUTURE

Should nematodes concern only Nematologists?

Nematodes are going to gain greater importance in future for their roles as (i) plant parasites causing crop losses themselves and in association with other pathogens, (ii) insect-parasitic/entomopathogens as potent biological control agents, (iii) microbivorous nematodes playing important role in ecosystem functioning, (iv) biological models in ecological, biotechnological and pharmaceutical research, (v) sources of genes for abiotic stress tolerance, *etc*. Thus, nematodes will be important not only in fundamental and applied nematology but also in fundamental research in other biological disciplines.

Crop damage due to nematodes will further increase due to the increasing abiotic stresses with changing climate and the degradation of natural resources. Reduction in crop yields and quality will attract greater concern since more and better will have to be produced from a lesser land area to address the needs of the increasing population and changing expectations of consumers. The latest crop improvement technologies, molecular biology, computing and artificial intelligence need to be employed in research on nematodes. At the same time, the traditional farming and natural resource management systems will remain important while developing practical nematode management technology and their integration, not replacement, with the new technologies.

Crop improvement to incorporate nematode resistance will not be possible by nematologists alone; plant breeders and biotechnologists will have to join with nematologists. Practically feasible and commercially viable microbial biological control agents against plant parasitic nematodes will be required. Safer nematicidal molecules will be required but this will not be possible without active collaboration with chemists and industry.

Spread of nematodes: Wake up - it is already late!

The infested plant nurseries transported over long distances intra and interstate have become the major means of spreading serious nematode problems, including the root-knot, reniform, root-lesion, burrowing and citrus nematodes. Serious problems such as failures of guava and pomegranate orchards are already alarming. Nematologists have developed simple diagnostic methods as well as nearly dependable disinfestation methods. The country urgently needs a mandatory inspection and certification mechanism to prevent further spread of such serious problems.

Should nematologists understand only nematodes?

Nematologists will also need to expand and modify their research to fit into the '*One-Health*' system. Incidentally, the majority of the nematode management methods also help in reducing the intensity or damages due to other soil-borne pests and pathogens, so it should be easy to fit into a common scheme at the farmers' level. Nematologists also need to focus on understanding the fundamental aspects, such as taxonomy, mechanisms of resistance, mode of action of botanicals, biopesticides, bio-suppressants, survival mechanisms *etc*. Mere application of certain products and reporting a reduction in nematode populations and increases in yields will not suffice.

Who and when should know nematodes?

Awareness of farmers and the public about nematodes remains very poor still. More campaigns using AV and digital mass media with specially developed content will be necessary. A chapter on harmful and useful nematodes relevant to agriculture, veterinary and human health should be included in biology books at the Secondary, and Senior Secondary School levels. Introductory Nematology course will be necessary at the UG level in all agriculture curricula, so that the graduates may know about nematodes, recognize the problem and find opportunities to tackle these or collaborate with professional nematologists in future. Fundamental research on nematodes should also be carried out in various botanical and zoological programmes in non-agricultural institutions. Even farmers must know the basic detection techniques or should avail services of the nematologists before they sow a crop or build a polyhouse similar to a practice in vogue in the state of Haryana.

Nematodes are ideal biological models

Nematodes possess more easily understood organ systems and metabolic processes that resemble to a great extent those of higher animals. They have short life cycles and are small, countable and culturable. There are no ethical restrictions on killing them for research. Therefore, they can be ideal biological models for various kinds of biological research including those in pharmacology and biotechnology. The work on genome sequencing and understanding the functional roles of genes responsible for pathogenicity, anhydrobiosis, fecundity *etc*. can pave the way for developing novel management methods. Recent work in Dr. Anil Sirohi's lab. on sequencing of *Anguina tritici* genome in relation to the nematode's anhydrobiotic capability is a step in this direction.

Private support is necessary

There have been some contributions from the industry especially in nematicide development, but nematology has largely remained a domain of a small number of public sector institutions. The sufferer due to nematodes and the beneficiary of nematode management are the farmers and the industry. There is an urgent need for a Public-Private-Participation (PPP) for spreading awareness, diagnosis, inspections and fundamental and applied research. Participation is also necessary in development and adoption of reliable resistant varieties, biocontrol agents, EPNs and even in the production of nematode-free planting materials.

Nematodes understand soil health and climate change better than we do!

The programmes on soil health may take into account the role played by microbivorous nematodes in the decomposition, nutrient dynamics and mineralization processes. Nematode community structure can become an important bioindicator of soil health. Nematode life cycle, fecundity and survival are measurably influenced by climatic variations at the local and regional levels and such multi-regional measurements can make nematodes reliable bioindicators of climate change at different geographic scales.

Nematology will be even more important - Nematologists need to beat their drums harder!

In view of the facts highlighted in the above discussion, I foresee the greater importance of nematodes and nematology in the times to come. Nematology will be important in agriculture as various abiotic and soil-borne biotic stresses will increase. Nematodes will also serve as model organisms in various biological, pharmaceutical, medical, and climate research and even in developing pest management systems. Yet, due to the very nature of nematodes, their habitats, effects and adaptations, nematologists will continue to face the challenge of convincing the public, policymakers, bureaucrats and farmers of the importance of nematodes and nematology. Nematologists will need to continue beating their drums to make these hidden, voiceless and invisible enemies uncovered, heard and seen. Then only we can suppress these numerous and varied unseen foes or harness the unseen friends amongst them.

A PERSONAL NOTE AND ACKNOWLEDGEMENT

I was induced by Dr. Raman K. Walia, Dr. Matiyar R. Khan and some other colleagues to write a non-conventional review on *The Journey of Nematology in India: Perspectives, and My Vision*. I have tried to summarize the past and present scenario of nematology in India, mainly recalling facts and events that I came across during my journey over the past 53 years. My own journey through nematology has taken me to all the steps of the ladder on my career path, starting as an MSc student on 21 September 1971, completing PhD in 1975, joining ARS in 1976 to reach the higher levels of Principal Scientist, Project Coordinator, Head of Division of Nematology moving further as Dean & Joint Director, ICAR-IARI and Vice-Chancellor, SVPUAT, further moving on to two reputed private universities. At all these steps and places, I have learnt, advocated for and promoted nematology. The Nematological Society of India too gave me opportunities to serve as General Secretary, Vice President, President and Chief Editor, all infusing more nematology into me. I would have forgotten some events or skipped many for the sake of brevity. The statements made may often have been in accord of my personal views and/or my passion for nematology, without any intention to undervalue anyone's contribution. I do solicit information on issues or facts I might have omitted inadvertently and shall surely consider the same if I ever have a chance to pen down again. I express gratitude to all my eminent and inspiring teachers, nematologists, collaborators and dear students who have immensely contributed to the science of Nematology in India. I have avoided listing references since it was not possible to include the entire bibliography of nematology that would be relevant here. I am critical but very optimistic about a great future of fundamental as well as applied Nematology in India.

CONFLICT OF INTEREST

None.