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# INDIAN ENTOMOLOGIST

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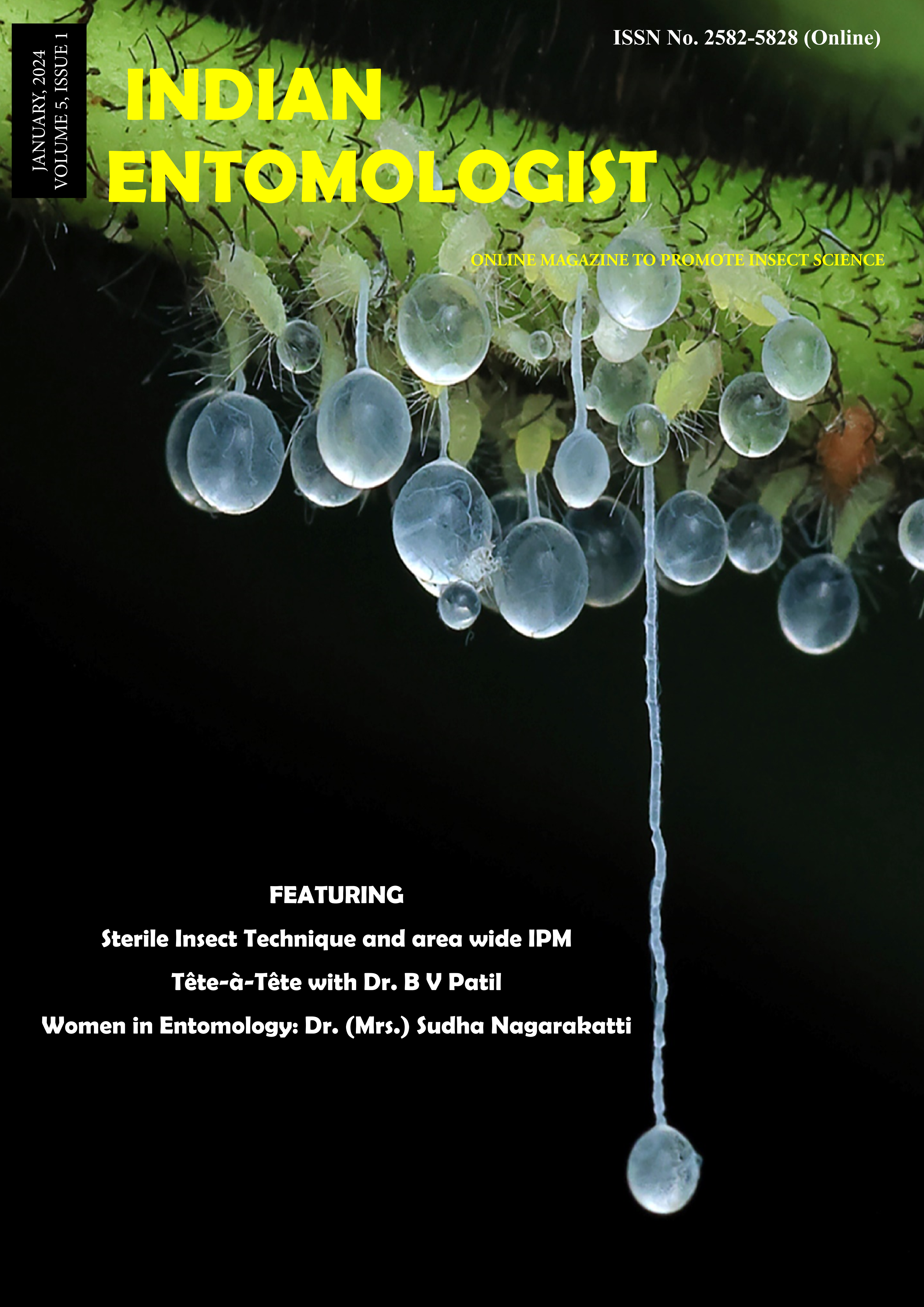

FEATURING

Sterile Insect Technique and area wide IPM

Tête-à-Tête with Dr. B V Patil

Women in Entomology: Dr. (Mrs.) Sudha Nagarakatti

INDIAN ENTOMOLOGIST

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# Editorial Board

*Cover page image: Mr. Hemanth Kumar (Photo taken at Adimalai, Kerala,) showing Nymphs of Jumping plant Lice.

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REVIEW ARTICLES

# EDITORIAL

Indian Entomologist- I would always be proud of this!!

It is a unique and potential medium for entomologists openly accessible for anyone. It has made a beginning few years back, still it is a toddler learning and refining many of its thoughts and logistics. It is run and executed by a team of young and upcoming entomologists. Their ambition is to make the aspirations of entomologists sustainable and channelised. We all know that Entomology is a science that warrants many and innumerable practitioners as demanded by the enormous diversity of insects, and their diverse role and actions in the environment. Entomologists are people who study insects, as a career, as enthusiasts or both. Entomology is mainly involved with the study of insects along with their relationship to the environment, humans, and other organisms. When this discipline has great impacts on human lives, agriculture, veterinary medicines, biodiversity, genetics, environmental science, pollination and a lot more, this becomes all the more relevant and impacting. These reflect and warrant that it is essential for us to catch up with the practitioners of Entomology in their life and profession, to provide them a platform for dissemination of their thoughts. The Indian Entomologist rightly serves this objective.

Yes, it is unique in its prime objective that it is necessary to bring together young and bright minds that make a beginning in their quest for a profession in Entomology. At the same time, it provides an opportunity to learn from interactions with learned and those excelling in Entomology. The contents of the Indian Entomologist are transforming and dynamic, as warranted by these needs. Entomology as a science gets instilled in a human's brain, heart and mind as soon as one starts childhood while getting confronted with an ant or a beetle or a fly or a butterfly. We all become entomologists as soon as we start recognising these creatures and start appreciating them as unique natural creations. In fact, this curiosity and awareness makes one know the world around, especially the uniqueness of insects. It is amazing to realise how children learn about insects when they see them up close. We find the children full of their own questions and bursting to find out what the insects ate, where they lived, what animals might eat them etc. A brilliant, natural way to learn. This passion for nature continues and many such childhood attractions continue later in our life, with many of us aspiring to be entomologists.

In general, from the foregone issues of the Indian Entomologist, it is apparent that it provides an intellectual forum for entomologists, young and old. It provides them an arena to showcase what Entomology they are doing and what's expected of it!! It provides them an opportunity to weigh what they are doing in Entomology in comparison with others!! It provides them a platform to ask questions on critical aspects of how to practice Entomology!! It provides them a window to showcase what's going on in the multifarious disciplines of Entomology and how these are getting integrated. It provides opportunities for interactions with their peers and experts. It provides them an ambience to put forward their views and projections as to how Entomology is to be practiced. It provides them an action plan as to how to orient their practices on line with the current trends and requirements.

In this task, the Indian Entomologist is an experiment. It is delightful and magnificent that it is keeping itself up with successes in this experiment. It has made a new beginning in integrating the views of young people with the established practitioners of Entomology. It provides a forum for putting forth a pragmatic perspective and for shaping the future. The players in this experiment- the editorial hands, I see, are guaranteeing themselves with more ambitions. I am sure they will leave no stone unturned in sustaining this landmark achievement and make this new beginning a masterpiece that will remain so, so that we cherish this forever!!!

**Dr. V.V. Ramamurthy**

**Editor in Chief, Indian Entomologist**

# A DIALOGUE WITH DR. BASAVARAJ VEERANAGOUDA PATIL

The best IPM specialist, teacher , administrator and eminent cotton IPM specialist who made significant contributions in the cotton pest management.
Dr. B. V. Patil shares his thoughts and experiences with Dr. A. Prabhuraj (AP), Associate Editor of IE.

Dr. Basavaraj. V. Patil was born on 1st March, 1955 to Sri. Veeranagouda Patil, an agriculturist and Smt. Saraswathemma Patil, a housewife in Kalyana Karnataka in village Hireyerdhihal of Lingasagur taluka Raichur district. Dr. B. V. Patil had his early school education at his village, Mudgal and Bagalkot till 5th standard. Dr. Patil had five brothers and two sisters and his father had a great desire to educate all his sons and daughters hence, put them in a very good schools. But, Dr. B.V. Patil only could fulfil his father's desire as he continued his studies further from 6th to 12th standard at Ramakrishna Residential Vidyashala, Mysore, one of the best education centres even today. His study at this school made him an all-round student securing second highest marks of 79% in PUC that fetched him 'Best Outgoing student' award for his curricular and extracurricular activities such as sports representing school at Mysore Junior level.

After completing his PUC education, as per the wishes of his father who was a successful farmer joined Agriculture Collage, Dharwad even though, he was selected for medical seat at KMC, Hubli. With ICAR merit fellowship Dr. Patil completed his graduation and joined M.Sc. (Agri.) in Agricultural Entomology at Dharwad itself by securing 3rd rank in ICAR junior fellowship. He worked on the Role of light traps in survey and monitoring the activity of lepidoptrous pests and continued his education by joining PhD programme at Dharwad though he had secured a PhD seat in IARI, New Delhi. This decision was mainly influenced by Dr. S.V. Patil, then DI (PGS) whom he considered as his mentor, advisor and well-wisher who asked him to work on teak skeletonizer, *Eutectona machaeralis* Walker. Dr. B.V. Patil made detailed studies on its bio-ecology, life table construction to identify the key mortality factors and management using egg parasitoid, *Trichogramma chilonis* and published research papers in National and International journals and completed PhD with University gold medal.

After completing PhD programme, he immediately joined for the permanent post of Research Assistant at Regional Research Station, Raichur in August 1980. He worked on Groundnut and Castor Pests Management and identified many parasitoid complexes in these ecosystems in a collaborative research project with ICRISAT, Hyderabad and published an important catalogue on Groundnut leaf miner and its parasitoid complex which received a good recognition. Later, he was selected for Assistant Entomologist post and moved to Regional Research Station, Bijapur and worked on Sorghum and Bengal gram in rainfed ecosystem. He developed low-cost technology for shoot fly management and on intercrops strategies for Bengal gram pod borer management. He was later selected for Associate Professor of Entomology and posted as Entomologist (Cotton) at premier Agriculture Research Station, Hebballi, Dharwad to work on cotton. During this period, he developed good contact with the entire cotton entomologists and also with the entire product development managers of different pesticide companies and tested their new products and recommended to cotton farmers. He developed IPM schedule for dry land cotton which was successfully test verified in the farmers' fields. After 5 years of work at this station, university posted him as in-charge professor of Entomology at newly established collage of Agriculture, Raichur during 1987. This gave him an opportunity to involve himself in teaching in addition to continue his research work on irrigated cotton pest management. Sooner he was selected for post doctorate programme under commonwealth academic staff fellowship programme at Southampton University, UK to work on sex pheromones with one of the world's renowned scientist Dr. Peter Lewis at his chemical Entomology Laboratory. He learnt the insect rearing techniques for pheromone isolation, standardization for their combination and testing under laboratory conditions through wind tunnel experiments. He also spent few months at Imperial college, London for better understanding of IPM principles and its implementation strategy under the guidance of Dr. G.A. Mathews.

After returning from England, he became regular professor at the Department of Entomology, Collage of Agriculture, Raichur and within short time developed very good infrastructure and equipments in the Department. This helped to attract meritorious students to undertake M.Sc. (Agri.) programme in Entomology. During this time irrigated cotton had an outbreak of cotton whitefly; *Bemisia tabaci* and bollworm, *Helicoverpa armigera* which threatened cotton cultivation resulting in a great economic loss to the farmers. Dr. B.V. Patil with his colleagues and students took up series of research studies and developed management strategies for whiteflies and bollworms and demonstrated on the Research Station and also in farmers' fields. He had an operational research project on IPM and demonstrated in 250 acre area successfully with maximum seed cotton yield and higher net profit which became very popular nationwide and made him to recognise as an eminent cotton Entomologist of the country. During this time he also collaborated and worked on *H. armigera* management on Redgram at Gulbarga area till 2002. Later, he took up higher administrative work in addition to continuing his research and teaching work concurrently as Associate Director of Research at RRS, Raichur later as Director of Instructions (Agri.) at college of Agriculture, Raichur. Later in August 2008 he was selected as Director of Research, UAS, Bangalore and developed good coordinated research programmes in a short span of time and learnt corporate culture of working and implementing the things.

Government of Karnataka selected him as a Special Officer in February 2009 and gave the responsibility of developing the new Agricultural University at Raichur covering six districts of Kalyan Karnataka. Later, he went on to became the founder Vice-chancellor of UAS, Raichur in April 2010 for four years and after the completion continued as Director of Education, UAS, Raichur from May 2014 to February 2017 before his superannuation.

Dr. B. V. Patil published more than 200 research papers in reputed peer reviewed journals of national and international standards. Under his guidance, 30 M.Sc. and 10 Ph.D. Entomology students have completed their research programmes. Dr. Patil completed more than 30 research projects and visited 22 countries. He has organized one winter school on IPM, and series of short courses to Department of Agriculture officers on pest management. He is a permanent member of Fellow of Royal Entomological Society and was appointed as 'Cotton whitefly expert' from Govt. of Iran during 2000. He was an FAO consultant for Thailand and Vietnam during 2001 besides being QRT/RAC chairman for various ICAR institutions like PDBC, CICR and NCIPM and life member of national societies like Entomological Society of India, Acaralogical Society of India, Plant Protection Association of India, Soil Biology and Ecology Society of India etc. Currently he is serving as RAC chairman for NABIR, Bengaluru and member of Advisory committee of PJTSAU, Rajendranagar, Hyderabad.

He has several awards and recognitions to his credit. To name a few, he is the recipient of "Professional Excellence Award- 2018" by Cotton Research & Development Association, Hisar, Haryana, "Lifetime Achievement award – 2016" by AIASA/ ICAR, "Dr. M. Puttarudraiah Endowment" award during 2002, "Dr. C. V. Raman young scientist" state award during 2000 and ICAR "Outstanding Teacher award" during 1998-99.

***Dr. A. Prabhuraj (AP): Briefly tell us about your motivation to choose subject "Agriculture in general and entomology in particular"***

**Basavaraj V Patil (BVP):** My first motivation is my father who hails from an agriculture family and being a successful farmer always wanted me to study agriculture and improve the production and productivity with improved technologies and practices. My second motivation is Late Dr. Katigihallimath, a renowned extension entomologist of Karnataka state who happens to be my father's close friend. After my PUC, my father took me to him and he motivated me to pickup agriculture subject quoting many successful cases. He was the principal of District Agriculture Training Centre, Bagalkot and later became state Entomologist. Later, during my undergraduate study period, I met Dr. Katigihallimath and use to discuss with him about farmers' problems caused by insect pests. Those interactions gave me a thinking to specialize in Entomology so that I can also suggest immediate solutions to farmers' problems directly. Further, a course on "Crop pests and their Management" offered by Dr. C.A. Viraktamath impressed me to a greater extent to pursue Entomology as major subject in final year. I got 3rd rank in ICAR junior fellowship and preferred UAS, Dharwad College which had excellent teachers like Dr. C.A. Viraktamath, Dr.Gubbaiah, Dr. B. N. Vishwanath and Dr. Rajagopal. After completing my M.Sc. (Agri.) programme, though I was selected for PhD at IARI, New Delhi, joined at Dharwad. This was mainly because of my well-wisher, mentor and advisor, Late Dr. S. V. Patil DI (PGS) to whom I have great respect.

***AP: Can you tell us the entomological fields of your interest and what motivated you to specialize in Integrated Pest Management "IPM"***

**BVP:** In the beginning of my carrier, I was interested to work on insect ecology, biological control and pest management. As a Research Assistant, when I was working with Late Dr. H.K. Sangappa, I understood that all the fields of entomology have to be integrated properly to combat the pest complex in any cropping ecosystem. This finally resulted in my thinking to work on Integrated Pest Management (IPM) which basically includes all the possible economic and effective methods of insect pest control.

Dr. BVP with Dr. AP in the cotton field

***AP: Tell us about the challenges you faced while developing IPM of different crops and its implementation in farmers' field.***

BVP: The library facility was not so good at Raichur and Bijapur campuses in 1980, hence, I was forced to go to Dharwad and Bangalore campuses often for reviewing the latest literature on the research developments on cotton, oil seed and rabi crops like sorghum, bengal gram and safflower. This was one of the major drawbacks I faced. After shifting to Dharwad as an Entomologist in AICCIP cotton scheme, this problem was overcome and not only I had the opportunity of visiting other cotton research centres but also interacted with other cotton entomologists across India. This gave me lot of boost for developing suitable IPM components based on their availability and cost economics under both dry land and irrigated cotton ecosystem. At Hebballi farm, I had the opportunity to meet and discuss with Sri G. Thimmaiah our senior cotton Entomologist and he exposed me many field problems besides giving suggestions on how to overcome those. All these helped me to develop a separate IPM schedule for rainfed and irrigated cotton ecosystem. Initially, I demonstrated the same in Raichur station over two acre area with good success. The next challenge was to conduct field demonstrations in the farmers' field. It was very difficult to get farmers' field and their cooperation as they were totally dependent on pesticide application on weekly schedule. I was forced to make an agreement with farmers that any yield loss in the IPM demonstration field will be compensated. I could take this risk because I had confidence that the IPM schedule work very well. For two years with the help my colleagues from other subjects, I demonstrated the success of IPM in 5 to 10 acre area in different locations of Dharwad and Raichur with higher seed cotton yield and maximum net profit to the farmers. One thing, I learnt was that we have to demonstrate Integrated Crop Management (ICM) which includes Integrated Pest Management (IPM) in farmers' fields as they are interdependent to get maximum yield and net profit.

***AP: Please share your experience on promoting IPM of cotton in Raichur in collaboration with Cotton Corporation of India.***

**BVP:** When we got success of 18% increase in seed cotton yield and 32% net profit under irrigated conditions in limit area of 5-10 acres, a thought came to us that such demonstrations can be further increased to large area in a continuous block as efficiency of biocontrol agents can be increased and cost economics can be further improved. IPM schedule developed by me and my colleagues attracted the attention of other cotton centres of AICCIP scheme across the country and they also implemented with little variation to suit to the local condition in north, central and southern parts of India. Dr. A.K. Basu, Former Director of Central Institute of Cotton Research, Nagpur and the Advisor to Cotton Corporation of India (CCI) Mumbai suggested me to submit a project in this regard for implementation in large area. Based on his suggestion, I along with other cotton scientists at RRS Raichur submitted an ICM project with emphasis on IPM for implementation in 250 acres of continues block under irrigated ecosystem around Raichur. The project was sanctioned for Rs.25 lakhs. Then, I had to face real problem of convincing farmers of 250 acres in one block which included 52 farmers as they were not ready to take any risk of getting seed cotton yield below 12 quintals and for this they were applying pesticides of all combinations at almost weekly basis. However, based on my earlier experience we made an agreement that maximum of 12 qt of seed cotton yield will be assured per acre in this 250 acre demonstration block and otherwise it will be compensated with the cost of inputs required for next year. For this agreement all the farmers agreed and cooperated to the maximum extent. Five B.Sc. (Agri.) graduates were appointed on contract basis and were trained on IPM schedule to monitor the insect pest population and implementation of IPM schedule giving them proper mobility. Continuous efforts for five months in the project area resulted in obtaining an average 15.3 qt of seed cotton yield per acre with reduction of 40% pesticide application and an increase of 52% net profit per acre to each farmer. We conducted a field day to which over 2000 cotton farmers from different cotton growing areas of Karnataka and Andhra Pradesh participated along with dignitaries from both central and state governments, ICAR and Entomologists of AICCIP scheme on cotton to showcase the success of the project. Our farmers had a great interaction with other farmers and officials. We even brought out at a booklet on highlighting the success of this project.

***AP: Can you highlight important IPM programmes you developed on crops other than cotton in Karnataka?***

**BVP:** Though my major work was on cotton, I also had the opportunity of interacting with Redgram and Groundnut entomologists as a senior person in developing IPM schedule. Based on my knowledge and with the help of post graduate students, we developed IPM schedule for pest complex in Redgram and Groundnut. Similar large-scale demonstrations upto 100 acres was taken up in Redgram and 50 acres demonstration in Groundnut ecosystem. These demonstrations also gave tremendous success in increasing the yield and reducing the cost of plant protection. One of the important things that happened in Redgram ecosystem was development of *pest prediction model* in collaboration with ICRISAT, Hyderabad based on light trap and pheromone trap catches data of *Helicoverpa* available over 15 years at ARS Gulbarga by integrating with rainfall pattern. The accuracy of the prediction of *Helicoverpa* incidence was to the extent of 80%. With the help of officers of the Department of Agriculture regular monitoring of the field incidence of the pest was initiated in Redgram under my supervision and suitable management strategy was suggested to the farmers. This became very popular not only in Karnataka but also throughout Redgram growing areas of the country and was called as “Gulbarga Model” for *Helicoverpa* management on Redgram.

***AP: You have excelled both as a teacher and researcher in entomology. please share your teaching experience?***

**BVP:** As cotton entomologist, I was offering one PG course “Insect Ecology” at the Department of Entomology, Agriculture Collage, Dharwad. But my real commitment of teaching started when I was posted as In-charge professor of Entomology in newly established Agriculture collage, Raichur. In the beginning I used to spend lot of time in developing the Department with course content suitable for practical classes with audio-visual aids and equipments required for undergraduate courses with the help of my colleagues who were very cooperative. I was teaching one course “Crop pests and their management” regularly wherein I had the opportunity of motivating many good students to take up entomology as their major subject. With the help of my colleagues, I took special classes in entomology for preparing them for competitive examinations like ICAR junior fellowship conducted by ASRB, New Delhi. Because of this, every year 1-6 students could get through the exam and in 1992 our Department could get 1st , 3rd, 5th , 6th , 10th and 13th rank at All India level. This prompted UAS, Dharwad to start a PG programme in Entomology at Raichur. With the help of entomologists placed in research and extension, I managed PG programme very efficiently. I requested my colleagues to develop their own specialization in Entomology based on their interest and this helped to teach effectively different courses in PG programme. I got many research projects and also good number of insecticide molecule testing projects which helped to develop the Department with good number of latest materials and equipments required for student’s PG research. Because of all this many of our PG students got ICAR senior fellowships for their PhD programme and few of them joined ARS, ICAR scientist position, Universities as teachers, scientists and extension workers, Officers in Department of Agriculture, Government of Karnataka and many have joined pesticide companies in R&D and sales division.

***AP: What are the innovative teaching techniques you adapted to enhance learning abilities in students of entomology?***

**BVP:** When I was doing my post-doctoral programme at the University of Southampton, England during1987-88, I also had the opportunity to attend many postgraduate classes taken by experts like Dr. Philip. House, Dr. Edward and Dr. G Williams on semio chemicals, pest management, insect ecology and insect systematics. I picked up some of the teaching skills like group discussions among students on a particular subject, practical experience on student's presentation by giving abstract of the next class on a particular subject, scope for students asking the questions during the class hour itself and making other students to answer if they know otherwise giving the answer as a course teacher which improves their thinking capacity etc. I adopted some techniques for PG programme and maximum practical exposure for UG students such as taking students to fields of specific crops and asking them identify the causal organism based on the nature of damage and symptoms of damage. Similarly, assigning PG students to carry out crop survey and record the insect pests, their damage and quantifying the incidence and working out economic threshold level for the management. Visiting farmers' fields of different crops and encouraging PG students to involve in discussion with farmers and suggesting remedial measures. I use to update all the latest audio-visual aids and digital teaching tools along with other colleagues for effective teaching for UG & PG students. I use to involve PG students in sorting out insects collected by UG students and then separating on taxonomic basis and on crop pests' basis which helped the students to remember forever.

***AP: Tell us in brief about the infrastructure in cutting edge technologies you developed in the field of Entomology?***

**BVP:** For different courses in Entomology, infrastructure and equipments required for teaching was made by purchasing out of university grants, ICAR PG grants and Adhoc projects in addition to conduct of research by students and faculty. For insect ecology studies, BOD incubators of different capacities, Walk-in growth chambers, thermo-hygrometers and for toxicology studies, potter's tower, micropipette applicators etc. and for semio-chemical studies, Electro antennogram (EAG), olfactometer and wind tunnel etc. and bionocular/trinaculor stereozoom microscopes with image analyzer were purchased. For Sterile Insect Technique (SIT) studies, gamma radiation chamber was established with the help of BARC, Mumbai. For climate change studies Open top chambers with temperature and $CO_2$ regulation, automatic weather station etc. were established. For pesticide residue studies a state-of-art Pesticide Residue and Food quality analysis laboratory (PRFQAL) was built with the financial aid from RKVY grants and GOI grants. The laboratory has high end equipments like LC-MS/MS, GC-MS/MS, ICP-MS, UHPLC etc.

***AP: Another important dimension of your personality is an outstanding administrator. You have reached the highest administrator position as Vice-chancellor of UAS, Raichur. please share your administrative experience.***

**BVP:** In administration lot of infrastructure facilities like the establishment of smart classrooms, Upgradation of laboratories, hostels, library and staff quar-

Dr. BVP with Dr. AP observing cotton pests ters in different campuses were built. Priority was given to beautification of main and sub campus. As a capacity building, recruited 135 scientists / teachers and 185 supporting staff with proper induction programme. I have introduced the sanction of increments / promotions based on annual assessment of staff by concerned higher controlling authority on cumulative score card system. Internal receipt of university from all the sources was increased to Rs. 9.60 crores from meagre Rs. 1.17 crore in just four years. All this resulted in receiving many awards / recognitions for staff and students at National level. UAS, Raichur became more popular and farmer-friendly making it a real "Farm University". I have served as a member of the selection committee in the selection of scientists in different Agricultural Universities / ASRB, New Delhi. I have served in the editorial board as advisor / councillor member for different National and International journals. I have served as Academic council and Board of studies member in different Agricultural Universities. I have also served as Member of ICAR society and ICAR Governing Council, New Delhi, as QRT member for NCIPM, New Delhi and Chairman of RAC for CICR, Nagpur. Currently, I am serving as Academic council expert member of PJTSAU, Hyderabad and member of the Board of Management RLBCAU, Jhansi and Chairman of RAC of NBAIR, Bangalore.

***AP: You are also serving as member of advisory committee to various organizations and agricultural universities. What are your emphases in providing quality entomological research?***

**BVP:** I served as QRT member for PDBC, Bangalore, NCIPM, New Delhi. My major emphases were to undertake research in the farmers' field for validation of results. I also served as chairman, research advisory council, CICR, Nagpur for 3 years. Our recommendation was to develop short duration compact cotton variety genotype suitable for high density planting and compatible for machine picking. I was member of the Governing council of Jansi Rani Laxmi Bhai Central Agricultural University, Jhansi for 5 years and suggested to start many Agricultural Diploma courses to meet the current demand in the agricultural sector in addition to UG and PG courses. I am also nominated expert in the academic council of PJTSAU, Hyderabad for 6 years. I was involved in course formulation, infrastructure development, formulation of academic guidelines and admission set up. I was also nominated as expert in the selection of teachers and scientists by Governor of Telangana State. I was the vice president of Entomological society of India, New Delhi along with Dr. N.K. Krishna Kumar, DDG (Hort.), IACR, New Delhi under the leadership of our president Dr. S.N. Puri, Former Vice-chancellor CAU, Imphal. I was specially involved in formulating guidelines for different awards like, fellow of Entomological society of India, life time achievement awards in the field of Entomology etc. Presently I am serving as chairman RAC, NBAIR, Bangalore and revised research programme of the institute for next 3 years. I have advised to give emphasis on both basic and applied aspects of Entomology research particularly on molecular taxonomy, molecular diagnosis of insecticide resistance, insect behavioural response studies, and ecological engineering studies. Suggested the institute to develop as a 'Taxonomic Hub' for the country.

***AP:Though IPM is the best option for eco-friendly management of pests, there is a great challenge in adoption of it and how to overcome it?***

**BVP:** Everyone rightly accepts IPM as the best solution for our farmers for effectively managing the pest population in different crops ecosystem. But there are few important challenges that our farmers are facing while implementing IPM. Firstly, in my opinion our farmer's knowledge is a major limitation due of their poor educational background which makes them difficult to understand the concepts of IPM components. Secondly, small holdings of the farmer and their economic constraints prevent them in implementing IPM. Thirdly, availability of IPM components particularly bioagents on credit basis is limited due to the poor economic status of our farmers. In addition to these there are few more which however can be overcome by the farmers with little efforts. But the major challenges needs to be overcome by the Government with the help of State Agriculture Departments and Agricultural Universities by educating farmers through field visits/ demonstrations/trainings. Facilitating availability of IPM components on subsidy basis along with subsidizing Greener / Safer pesticides and more importantly continuous monitoring of pest population and recommendation of suitable IPM strategy is need of the hour. This should help the farmers to get higher yields with higher net profit,then only farmers accept the IPM strategy.


Dr.AP in conversation with Dr. BVP

***AP: Other than IPM what are the other areas of entomology you have worked?***

**BVP:** As I said earlier in addition to IPM, I have worked on insect ecological studies in paddy and groundnut, insecticide resistance in *Helicoverpa* populations collected from different cotton ecosystems of south India.

***AP: Finally what valuable suggestions you would like to give for the younger generation seeking specialization in agricultural entomology?***

**BVP:** The interest in entomology should come from M.Sc. (Agri.) level wherein student should focus on learning basics of entomological research right from the experimental layout to biological studies, sampling of insect's population, estimation of pest incidence and yield loss with good interpretation of data statistically. During Ph.D. programme one should have in-depth information on the problems that he/ she wants to work, review the latest information, finalize the methodology for various studies and come out with at least one new information which should be of first record from their research with good publications in high impact journal. In my opinion young Entomologists should develops their own interest in a particular field of entomology and get trained in that area under expert entomologists and expose themselves in attending entomology related Seminars/ Conferences and involve in discussion with experts. Another important area is effective implementation of a research programme with *out of box* thinking. Writing a project with at most cares with reference to for-

*The interview was conducted by Dr. A. Prabhuraj (AP). He is working as Professor at Dvision of Entomology, College of Agriculture, University of Agricultural Sciences, Raichur, Karnataka, INDIA. His research interests are insect ecology with special reference to migration and reproductive biology.*
*Email: prabhusha2014@gmail.com*

# IN CONVERSATION WITH DR. (MRS.) SUDHA NAGARKATTI, A PIONEERING BIOCONTROL RESEARCHER OF GLOBAL REPUTE

Dr. (Mrs.) Sudha Nagarkatti, one of the pioneers in biological control and the first Project Coordinator of AICRP on Biocontrol in India, is known for her inspiring leadership qualities and significant contributions to biocontrol of weeds and insect pests and also taxonomy of Trichogrammatids. She shares glimpses of her career journey with Dr. Kolla Sreedevi, Associate Editor, Indian Entomologist.

Dr. (Mrs.) Sudha Nagarkatti (nee Dr. V. Sudha Rao) born on 23rd January, 1937 in Bengaluru (then Bangalore), Karnataka, is the second child of late Dr. V. Prabhaker Rao (more popularly known as Dr. V. P. Rao) and Mrs. V. Premalata Rao. Dr. Sudha has two brothers and a sister. She did her SSLC at Kamala Bhai School, Bengaluru and then joined Mount Caramel College, Bengaluru and obtained her B. Sc. degree (with CBZ as optional subjects) from the then Mysore University. After her graduation, Dr. Sudha joined Commonwealth Institute of Biological Control (CIBC), Indian Station, Bengaluru where her father, Dr. V. P. Rao, who is considered as the 'Father of Biological Control in India,' was the Director. CIBC, a part of Commonwealth Agricultural Bureau (CAB), London, established its Indian Station in 1957 at Hebbal, Bengaluru, in the same premises where ICAR-NBAIR is presently located. Dr. Sudha had an opportunity to work on several biological control projects, most of them being of pioneering in nature, and gained tremendous experience. Later, she took a break and went to the USA where she joined the University of California, Riverside, California, for Ph.D. (1962-67) in Entomology/biological control and obtained the degree in 1967. Subsequently, she returned to Bengaluru and rejoined CIBC. She got married to Mr. Ashok Nagarkatti, an electrical engineer.

During her time at CIBC, Dr. Sudha Nagarkatti held a leadership position and was associated with several biocontrol projects on weeds and insect pests. These projects were national in stature and explored the potential of biological control which was barely known then. She published several papers. Dr. Sudha also worked on the taxonomy of Trichogrammatids when a separate project on it was initiated at CIBC and path-breaking contributions came from her along with late Dr. H. Nagaraja. They provided new species descriptions and authentic species identification keys. This strengthened the taxonomy of Trichogrammatids and also placed CIBC, (thanks to Dr. Nagaraja and Dr. Sudha) as a dependable center for the authentic identification of the species in this group. Later, as the CIBC was heading for closure, Dr. Sudha Nagarkatti joined ICAR-Indian Institute of Horticultural Research (IIHR), Bengaluru, in 1977 as the Project Coordinator of All India Coordinated Research Project on Biological Control (AICRP

BC). With her vast knowledge and experience, she provided exemplary leadership in the early years, overseeing biocontrol operations across India. Thus, she laid a strong foundation for this all-India project. Initially, the programme was funded by the Department of Science & Technology (DST), Govt. of India, but from 1979 onwards, it received funding from ICAR alone. In addition to being the Project Coordinator, Dr. Sudha headed the Department of Entomology and Nematology at IIHR from 1980-1982. She resigned from ICAR-IIHR in 1983 and moved to USA to join her husband who has taken up a job there. While in the U.S., she continued her research in the field of Entomology, working on grape berry moth at the Grape Research Institute in Erie, Pennsylvania State University, and published several research papers until her retirement in 2001. She worked on several aspects of grape berry moth, including biological control with releases of native *Trichogramma minutum*, phenology, diapause induction and carbaryl resistance in populations of grape berry moth and also historical aspects and projected interactions between climate change and insect voltinism in a multivoltine species. Dr. Sudha returned to India along with her husband in 2020 and got settled in Bengaluru.

***Dr. K. Sreedevi (KS): What motivated you to take Entomology as a profession?***

**Dr. Sudha Nagarkatti (SN):** It was my father, Dr. V. P. Rao's work that motivated me to take up Entomology and Biocontrol as my profession. I was deeply inspired by him, who worked on several aspects of agriculture in various locations, including the biological control of apple pests in Sikkim. During my student days, my father worked as a Plant Protection Officer and also as a Fumigation In-charge at the Delhi centre of PPQ&S, Govt. of India. In 1955, he joined CIBC and established the Indian Station of CIBC at Bengaluru. At that time, CIBC, with its headquarters being at Trinidad, had only two other centres, Rawalpindi (Pakistan) and Switzerland. After joining CIBC, my father travelled a lot on biocontrol assignments

*The staff of CIBC, 1970: Seated L-R: Sundari, Apitha, Victor Karunan*, Dr. T.R.Nagaraj*, Dr. P.R.Dharmadhikari*, Dr.V.P.Rao*, Dr.F.J.Simmonds* (Global Director who was on a visit), Dr.Sudha Nagarkatti, Sumithra Manjunath*, Dr.T.Sankaran*. Standing, 1st row,3rd from right: Dr. H. Nagaraja* (*late). Dr. T. M. Manjunath is in the back row wearing a tie. He has been associated with Dr. Sudha Nagarkatti since 1961 and, at 85, is still active in biocontrol and IPM. Photo courtesy: Dr. T. M. Manjunath.*

and worked in Ghana, West Africa, Cyprus, Fiji, Phillipines, Malaysia, etc.

***KS: What inspired you to take biocontrol as your specialization and as a career option?***

**SN:** As I said, besides my father's work, the indiscriminate and overuse of chemicals in agricultural fields which caused undesirable side effects on the environment and also destroyed a lot of beneficial insects including biological control agents had strongly influenced me to pursue this field. So, I wanted to do something that can encourage people to use biologicals and hence chose biological control as my career option.

***KS: Can you please elaborate your experience during the career?***

**SN:** When I started my career at CIBC, India had not carried out any extensive surveys for natural enemies of major pests and weeds and made any systematic research on the potential of biological control. This provided an opportunity to do some pioneering work and strengthen the areas where BC can percolate to all corners of the country. Weed control in India was not explored fully and it is a tricky area where the released insect should be target specific and should not affect the other non-target organisms. I was associated with the Parthenium weed control and enjoyed my weed control work at CIBC station, Bengaluru. I had worked on species descriptions of Trichogramma along with my colleague, Dr. H. Nagaraja, a very talented artist who worked on Trichogrammatids. I am highly grateful for all his help in drawing the illustrations for scientific publications.

*Dr. Sudha Nagarkatti working in biocontrol lab at CIBC station, Bangalore*

***KS: Having known that you have described several species of Trichogramma, what's your opinion on taxonomy and biocontrol?***

**SN:** I have worked on the taxonomy of *Trichogramm*a along with biological control. For biological control, correct identification of natural enemies is crucial and essential. I worked on the identification of the *Trichogramma* species through morphological characters and in the process was able to describe a few new species too. I feel biocontrol and taxonomy will go hand in hand as many of the insect resources are utilized as biocontrol agents and will supplement and complement each other.

***KS: Which one would you give priority when both family and profession demand your presence?***

**SN:** My parents' support to my family was immense. So, I was able to work with full concentration as long as I was in India with CIBC and IIHR. But, once my husband had decided to leave for the US for work, I thought I should give priority to family and moved to US along with him. He, being an electrical engineer, had better opportunity there and I supported him and also thought that we can provide better opportunities for our 12-year-old daughter and we settled in US. There I joined California Institute, which was way ahead in biological control and joined Grape Research Station and worked on biological control of insect pests and weeds. This has allowed me to pursue my career in biological control. I feel that though I have given priority to my family, I never left my passion for biological control. There comes the balance of personal and professional lives. Balancing family and profession is not so easy. Luckily, I had my family support and thanks to my sister, Mrs. Shyamala Nirodi, who used to take care of my daughter, Sona during my touring time when I worked with CIBC and IIHR and helped me a lot during my official tours and ventures.

***KS: Any tough time, you can recall during this journey?***

**SN:** In December 1983, when I was all set to leave for the US, my father passed away two days before my scheduled departure. He dropped me at the bus stop to go to IIHR to submit my resignation and while driving back home, he collapsed in the car due to cardiac arrest. That was a big shock for me. At the same time, my sister Shyamala suffered temporary limb paralysis due to shock and it added to the woes. It was a very tough time that I ever faced. I postponed my travel and moved to California in January 1984.

***KS: What is the most satisfying and proud moment in your career?***

**SN:** I am happy and proud that I worked on biological control at a time when it lacked adequate professional expertise in this area. A lot of touring within India and abroad has given me a lot of exposure and experience to take forward biological control. I am highly satisfied with the job done and career pursued.

*Dr. Sudha Nagarkatti standing to the left of Dr. V. P. Rao (person in tie at the centre)*

**KS: Can I have your message to youngsters?**

**SN:** Pursue your Passion! No fun in being at one place and stuck to a place. Avail opportunities to tour going all over the country and world and gain lot of experience with the people and knowledge around. Dr. Sudha did a lot of touring in India and abroad and enjoyed her career.

***KS: Can I hear about your hobbies other than your profession?***

**SN:** I enjoy cooking and people say that I am a very good cook (and smiled), I do a lot of gardening and singing is my greatest hobby.

Smt. Shyamala, sister of Dr. Sudha while conversing supplymented saying that Dr. Sudha along with her husband Shri Ashok used to sing duet songs several times during various Indian Gathering in US.

*Dr. Kolla Sreedevi, Associate Editor, IE with Dr. Sudha Nagarkatti*

***Dr. Kolla Sreedevi expresses sincere thanks to Dr. Sudha, Smt. Shyamala, Mrs. Sona (daughter of Dr. Sudha Nagarakatti) for all their cooperation and support in conducting this interview. Also thanks are due to Dr. T. M. Manjunath for his valuable inputs.***

# Sterile insect technique and area wide integrated pest management

*Sridhar V.*

**Abstract:** The known fact of resistance development towards the insecticides by majority of the insects has developed a consensus of requirement of the alternative approach for the efficient management of the insect pests. An approach of species specific, sustainable and nonpolluting serves to be a better approach. Quite, among the several approaches, Sterile Insect Technique (SIT) turns to be an outstanding option. SIT is defined to be an autocidal approach wherein the target insects are mass reared, exposed to gamma/x-rays followed by the field release. Many scientists studied and experimented with the idea, but it wasn't until E.F. Knipling succeeded in controlling the screwworm fly, Cochlomia homnivorax Curacao and Florida. Following the success, other dipteran insects were prioritised and successfully managed, thus efficient protocol was standardized against the insect of same order. The application of the SIT for the management of lepidopterans tends to be challenging due to its cytogenetic and cytological characters that differs from the dipteran insects. It includes achaismatic mode of female meiosis, holokinetic structure of chromosomes and dichotomous spermatogenesis. The complications concerned led to the upraisal of the Inherited Sterility (IS) where F1 off springs exhibit a higher level of sterility than the parents following the irradiation with sub sterilizing doses of ionizing radiation. The concept proves to be an efficient and provides ample scope for exploiting SIT against the insects of order Lepidoptera. SIT includes the strategies such as local suppression, eradication, containment and prevention of invasive pest establishment for the management. On behalf of its nature of being pest specific and autocidal, this forms to be efficient component for Area-wide Integrated Pest Management Strategy (AW-IPM). Additionally, this technique found to be compatible with other management strategies viz., biological control etc and hence could potentially stand out as a efficient, sustainable approach

Insects predicted to be conquerors over 350 million years ago from Devonian period had set out to be the most evolutionary successful group on the Earth and are successfully present in all ecological niches. Among these, majority serves to provide ecological services in the ecosystems while few of them represent a group that threatens the agricultural production. In view of the management, insecticides are considered to be the most important resort. Unfortunately, the irrational and erratic use of insecticides have aroused in the genesis of resistance to each and every class of insecticides, additionally impacting negatively on the human health, food chain and environment. This has resulted in the failure of the efficient management system. The current scenario demands the needs of environment-friendly, species-specific and sustainable approach such as Sterile Insect Technique (SIT) for the control of insect species and disease vectors. SIT is an autocidal control method which is based on the mass rearing, radiation-based sterilization and release of the same species that is targeted for population control. The principle includes sterilizing the mass reared insects with suitable doses of γ-radiations that induces sterility without impairing the ability of the insects fly and mating ability followed by its release in sufficient numbers in order to achieve sterile-to-wild insect over flooding ratios resulting in the reduction of fertile matings proportion in wild population which in turn reduces the population. This approach serves out to be a component of area-wide integrated pest management (AW-IPM) to suppress contain, prevent

| Insect | Place | Year of application/ reference |
|---|---|---|
| Dipterans | | |
| Screw worm,Cochliomyia hominivorax | Florida | 1957-1958 |
| | South-Western USA | 1964-1966 |
| | US-Mexico Border | 1974 |
| | Central America | 1986 |
| | North Africa | 1988 |
| | Caribbean | 1999 |
| Melon fly, Bactrocera cucurbitae | Mariana Islands | 1963 |
| | Japan | 1980 |
| Mediterranean fruit fly Ceratitis capitata | Mexico | 1970 |
| | Guatemala (Mexico) | 1980 |
| | Chile | 1995 |
| | Western Australia | 1985 |
| | Japan | 1993 |
| | California (Preventive release) | 1994 |
| | Florida (Preventive release) | 1998 |
| Mexican fruit fly | South California | 1964 |
| Anastrepha ludens | Rio Grande valley | 1974 |
| West Indian fruit fly Anastrepha obliqua | | |
| Queensland fruit fly Bactrocera tryoni | Western Australia | 1990 |
| Onion maggots | Netherlands | 1981 |
| Tsetse fly, Glossina sp. | Sub Saharan Africa | 1960s |
| Mosquitoes | El Salvador and India | 1960s |
| Coleoptera | | |
| Field Cockchafer, Melolontha vulgaris F. | Switzerland | 1959 |
| | | 1962 |
| Sweetpotato Weevils, C. formicarius | Kume Island | 2013 |
| Lepidoptera | | |
| Codling moth | Okanagan Valley of British Columbia | 1994 |
| Pink bollworm | San Joaquin Valley of California (Preventive release) | 1967 |
| False codling moth | South Africa | Boersman,2021 |
| Painted apple moth | New Zealand | Suckling et al.,2007 |
| Cactus moth | Mexico | Bello-Rivera et al.,2021 |
| Gypsy moth | Mexico | Simmons et al.,2021 |
| Sugarcane borer | South Africa | Conlong and Rutherford, 2017 |
| Navel orange worm | California | Klassen et al., 2021 |
| European grapevine moth | Chile, | Klassen et al., 2021 |
| Carob moth | North Africa | Klassen et al., 2021 |

Table 1. Success of SIT in curacao and in other places

the introduction and eradicate the populations of insect pests and disease vectors (Vreysen et al., 2021). This technique is termed out to be species-specific, nonpolluting and resistance-free.

## History of SIT

The concept of impairment of the fertility in insect's dates back to 1916 when Runner observed that cigarette beetle, *Lasioderma serricorne* (F.) exposed to large doses of X-rays resulted in the incapability of reproduction. Further, in 1927 H. J. Muller showed that ionizing radiations induced larger number of dominant lethal mutations in *Drosophila* which was expressed through reduction in hatching of eggs laid by treated females. Later, in due search of chemicals that induce sterility, Charlotte Auerbach discovered that Mustard gas was mutagenic in *Drosophila* and affected fertility (Auerbach et al., 1947). With this, much research was done over 125 pest species of public health and agricultural importance. The negative impacts due to these alkylating agents against higher animals, including humans and bioaccumulation in natural food chain led to the discontinued the application of chemosterilants. Besides, the means of achieving sterilization in the insects, the idea of releasing sterile insects into wild population and control them was independently conceived in 1930s and 1940s by A. S. Serebrovskii at Moscow State University, F. L. Vanderplank at a tsetse field research station in rural Tanganyika (now Tanzania), and E. F. Knipling of the United States Department of Agriculture (USDA).

Serebrovskii moved ahead with an idea of translocation of segments between two chromosomes resulted in the formation of gametes with lethal genetic duplications and deficiencies in heterozygotes due to an abnormal association of four chromosomes during meiosis which was considered to be partial sterility. In this line, he started the work on translocations in *Musca domestica* L. and *Calandra granaria* L., practically but presumably was impossible to continue due to catastrophic conditions during World War II and death of Serebrovskii in 1948.

In the 1930s and 1940s, Vanderplank and his colleagues attempted to control the insect pests based on the sterility in the hybrids from the crossing over of species. Complete and partial sterility was achieved in males and females of hybrids that resulted from crossings of *Glossina morsitans* and *G. swynnertoni.* The field release of *G. morsitans* pupae in an area with *G. swynnertoni* virtually eliminated the less numerous *G. swynnertoni* population. Besides, the arid climate supported the non-establishment of the *G.morsitans* to establish permanently. The lack of publicity of this remarkable trial for longer periods resulted in the failure of further trials and its establishment.

Fig.1 Edward F. Knipling

Further, the successful debut of development and practical applicability of the SIT occurred in the 1950s in the USA under E. P. Knipling's leadership (Fig. 1). The basis of mass rearing of insects and sexually sterilizing the insects with radiation-induced dominant lethal mutations, proposed by H. J. Muller helped him to transfer the concept into reality. Through these ideas, Knipling and his colleagues achieved success in sterilization of the screwworm flies by radiation without damaging their mating ability or diminishing their longevity. The first decisive test that confirmed the feasibility of SIT was implemented in 1954 on the island of Curacao, close to Venezuela. It is culminated to be the most successful AW-IPM Programme integrating the SIT till date. Following the success of SIT in curacao, this approach was applied in various places (Table 1).

**Dose levels for sterilization in insect orders**

Selection of the dose for the irradiation acts to be critical factor in SIT. Doses ought to be chosen by minimizing somatic damage (allowing normal insect behavior), normal mating performance, flight ability, longevity, fertility, and fecundity levels. As an effort of wide number of studies, radiation doses to achieve sterility in insects belonging to various taxonomic orders are predicted. The mean dose for sterilization ranges from 130 to 400 Gy in Lepidoptera, 30 to 280 Gy in Acari, 40 to 200 Gy in Coleoptera, 10 to 180 Gy in Hemiptera, 20 to 160 Gy in Diptera, 20 to 150 Gy in Araneae, 5 to 140 Gy in Dictyoptera, 100 Gy

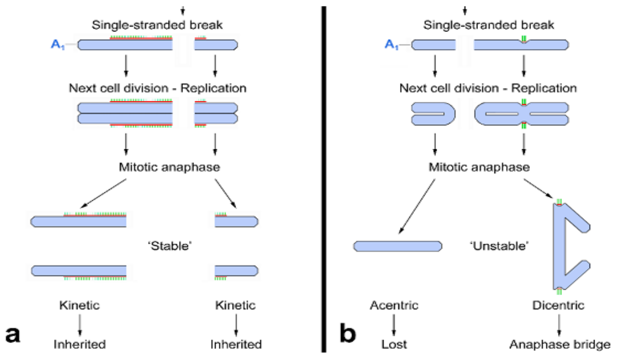

Fig. 2: Comparison of structure of holokinetic and monocentric mitotic chromosomes and consequences of chromosome breakage

in Thysanoptera, and 4 Gy in Orthoptera. Acrididae (Orthoptera) and Blaberidae (Dictyoptera) were the most radiosensitive (<5 Gy) (Bakri et al., 2005).

## SIT in Dipterans and Lepidopterans

Research activities towards different insect orders displayed differences in radio sensitivity. Many have considered that SIT is less effective for Lepidopterans in comparison to the other insect orders (much exploited Dipterans) given their high resistance to ionizing radiation requiring higher doses of γ-rays or X-rays to induce complete sterility. These higher doses result in genetic damage and various physiological defects which reduce the ability of sterile moths to compete with wild ones. The genetic studies on this aspect revealed specific cytogenetic and cytological features of Lepidoptera about SIT. The main differentiating features of Lepidoptera are (i) female heterogamety, which is associated with the achiasmatic mode of female meiosis, (ii) the holokinetic structure of chromosomes, which significantly contributes to the radio resistance, and (iii) dichotomous spermatogenesis (apyrene and eupyrene), which is closely related to the competitiveness of males. Hence, the designing of SIT for Lepidopterans should be done with the consideration of these points.

## Genetics of SIT differentiating Dipterans and Lepidopterans

The main feature of SIT is Dominant Lethal Mutations (DLMs) in the sex chromosomes upon irradiation. The primary event leading to DLMs is a break in the chromosome induced by radiation. In the series of events of fusion and division, the broken chromosome undergoes normal replication during early prophase, but during metaphase the broken ends can fuse leading to the formation of a dicentric chromosome and an acentric fragment. The acentric fragment is frequently lost, while the dicentric fragment forms a bridge at anaphase leading to another chromosomal break. This whole process then repeats itself, leading to the accumulation of serious imbalances in the genetic information of the daughter cells. The accumulation of this genetic damage finally leads to the death of the zygote (Fig. 2). While in Lepidopterans, it doesn’t follow classical breakage fusion bridge cycle which is a characteristic of dominant lethal. The kinetochore plates are large and cover a significant portion of the chromosome length, ensuring that more radiation-induced breaks will not lead to the loss of chromosome fragments in comparision to monocentric chromosomes (Fig. 2). The holokinetic chromosomes possess special character wherein the fragments could persist for a number of mitotic cell divisions and even transmit through germ cells to the next generation. The plates also reduce the risk of lethality due to formation of dicentric chromosomes, acentric fragments and other unstable aberrations.

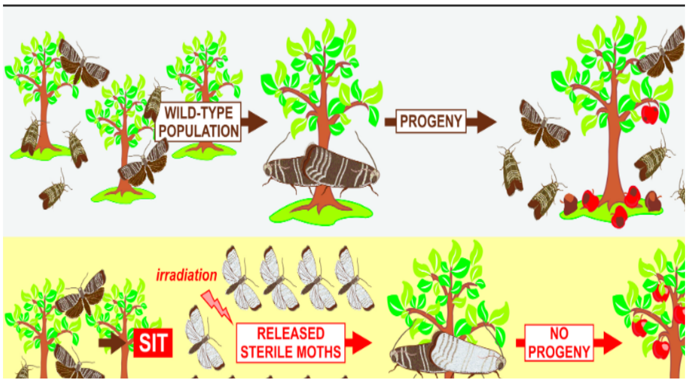

Fig. 3. Illustration of SIT

## Inherited Sterility in Lepidopterans

The term ‘inherited sterility’ (IS) or ‘$F_1$ sterility’ refers to the phenomenon where $F_1$off springs exhibit a higher level of sterility than the parents that are irradiated with sub sterilizing doses of ionizing radiation. Additionally, radiation-induced deleterious effects can be inherited for several generations. IS was first reported in the silkworm, *Bombyx mori* L., and then confirmed in the wax moth, *Galleria mellonella* (L.) but due to the lack of publication, the concept was completely forgotten. Much later, the phenomenon of IS was rediscovered in the codling moth, *Cyadia pomonella* (Proverbs, 1962). The radio sensitivity nature of the females than males make IS very appropriate for pest control programs, because lower doses of radiation increase the quality and competitiveness of the released insects. The studies by Marec et al., 1999 reported the translocations as the main chromosomal mechanism of IS. The study also suggested modified Synaptonemal Complexes in the achiasmatic meiosis of females and the ability to invert the order of the main meiotic events in males. Both the modified SCs and the so-called inverted meiosis facilitate proper chromosome segregation and hence rescue the fertility of heterozygotes for chromosomal aberrations, as recently demonstrated in wood white butterflies of the genus *Leptidea* (Lukhtanov et al., 2018).

### SIT as Area Wide Integrated Pest Management Strategy (AW-IPM)

AW-IPM is defined as the Integrated Pest Management applied within a delimited geographical area against an entire pest population with a minimum size large enough or protected by a buffer zone so that natural dispersal of the population occurs only within this area. Suppressing highly mobile pests on an area-wide basis is usually more benign environmentally, more effective, and more profitable, than on a farm-by-farm basis because of economies of scale. Area wide programmes to be effective, can take an advantage of power and selectivity of specialized methods for the management of the insect pests unlike farm-by-farm basis. The SIT turns out to be pest specific autocidal method and hence can form the component of AW-IPM and also AW-IPM serves to critical approach for SIT to be effective. The SIT requires the mass rearing of the large numbers of the target pest species followed by exposing them to ionizing radiation to induce sexual sterility and releasing them on area wide basis at appropriate proportions for the pest suppression. The major pest management strategic options include suppression, eradication of well-established pest populations, containment (exclusion) and prevention of invasive pest establishment. SIT being pest-specific play a role in implementing all of these area-wide strategies (Fig. 3).

### Local Suppression of pest populations

Since 1981, a trial on local suppression of the Onion maggot fly, *Delia antiqua* (Meigen) has been carried out on an area of ca.10000 ha in Netherland through SIT. But indeed the free riders (growers in the release area who benefit but do not pay) has weakened the programme leading to only 40 % of extension in onion producing area. Additionally, as the onion fields receiving sterile flies do not form a contiguous block the success of the programme is hindered (Everaarts, 2016).

### SIT and Total population suppression

The SIT could be applied for population suppression than the eradication. AW-IPM programmes using the SIT for suppression were established against the Mediterranean fruit fly in some fruit-producing areas of Israel, Jordan, and the Territories under the Jurisdiction of the Palestinian Authority. These programmes benefitted in terms of net returns than the SIT with eradication as the eradication programme would have payback period of 4 years. Codling moth in Canada was successfully reduced with the SIT suppression programme and it also reduced the number of insecticidal sprays. Similar success was achieved in South Africa (Bloem et al., 2001; Boersma 2021; Nelson et al., 2021).

### Eradication of well established populations

Eradication of the pest refers to the sustainable removal of every individual of the pest species in an area surrounded by natural or man-made barriers sufficiently effective to prevent reinvasion. An AW-IPM containing SIT was successfully implemented to eradicate New World screwworm in its native range in the southern USA, Mexico, and Central America. Similarly, using the programme ,pink bollworm in southern USA and northern Mexico, Mediterranean fruit fly in areas of Argentina, Chile, USA, and Mexico and the melon fly *Zeugodacus cucurbitae* (Coquillett) in the Okinawa archipelago of Japan was eradicated using the SIT as area wide programme (Staten and Walters, 2021; Kuba et al. 1996; Enkerlin,2021). Successful eradication of tsetse population from the Island of Unguja, Zanzibar, Niayes area of Senegal (Vreysen et al., 2000; Vreysen et al., 2021).

## SIT and Containment and prevention of invasive pest populations

For containment strategy, examples include barrier development for sterile New World screwworm flies is maintained to contain the screwworm at the Panama-Columbia border (Vargas-Terán et al., 2021) and sterile Mediterranean fruit flies is maintained to exclude this pest from Mexico (Enkerlin et al., 2017). Sterile pink boll worms were released in California's San Joaquin Valley to prevent the pest from establishing on cotton. Similarly, preventive releases of the male-only strain of the Mediterranean fruit fly over the Los Angeles Basin in California and major metropolitan areas in Florida was carried out (Hendrichs et al., 2021)

## Misconceptions and Constraints of SIT

SIT though applicable against wide variety of invertebrate pests, it is practically exploited against few major pests. This may be due to persistence of some common misconceptions but mainly due to some constraints. Some of the common misconceptions include: (1) released insects retain residual radiation (2) females must be monogamous (3) released males must be fully sterile (4) eradication is the only goal (5) the SIT is too sophisticated for developing countries and (6) the SIT is not a component of an area-wide integrated pest management (AW- IPM) strategy. The two most evident constraints include reduced competitiveness of releasing sterile males and the perceived high expenses of the SIT. The high up-front costs and limited private investments serves to be serious constraints. Apart from that, insufficiently trained, funded or committed managers and limited support hinders the success of SIT application. Further, SIT compels the strategic research in ecology, genetics, population dynamics and insect behavior. Studies on the increasing the competitiveness of released sterile males remains the major research objective.

## Future developments of SIT

Applicability of the SIT technology in the AW-IPM program is increasing and will continue to increase due to burgeoning negative impacts of the chemical pesticides' usage and public's concern towards the cleaner environment and residue free food. In this view,efforts for the improvement of overall effectiveness and efficiency of the technique and research for the expansion of the technique for the new key pest species are necessary. The story line of development and application of the technology against many insect species aroused few concerns that needs to be addressed *viz.,* artificial rearing systems or obligate diapauses *etc*. Increased globalization has and will inevitably lead to a further rise in the invasion of non-native or invasive insect pests into new areas and increased survivability due a changing climate. These situations and identified technical bottlenecks in the mass rearing, sterilizing and releasing of the sterile insects provides the avenue for newer opportunities to integrate the SIT into the process of creating pest free or low prevalence areas under a systems approach. Modern biotechnological approaches such as transgenesis and gene editing and paratransgenesis will contribute in improving SIT efficiency in terms of strain marking, genetic sexing, molecular sterilization and disease refractoriness. Exposing male insects to hormonal, nutritional, microbiological, and semiochemical supplements appears to hold great potential for enhancing sterile male performance. Furthermore, there will be significant improvement of mother colony management to reduce the effects of colonization and to slow down mass-rearing effects on key behavioral parameters that often result in rapid colony deterioration. Progress pertaining to the cost-effectiveness of all components of SIT implementation, from cage design to facility design, and from programme planning to evaluation will be made. The concept of sterile insects for pest suppression rather than the eradication, particularly in commercially important commodities will favour the involvement of the private sector and hence accelerate these improvements. *i.e*. Considering the benefits of sterile insects, their expertise with managing live creatures, and their knowledge of the biological control industry, commercial producers of beneficial insects will likely be the natural investors. As the program for the pest control is logistically complex, management plays to be a critical factor for determining the success and failure of any area wide approach. Hence, spite of the many successes achieved and to be expected, in many least-developed countries the SIT may be a technology that is “ahead of its time”.

## Conclusion

The public’s concern towards the residue free produce, less aggressive pest control methods emphasize the need of target specific, biologically based and sustainable suppression methods. Additionally, Globalization has resulted in more incursions and outbreaks of invasive pests. In current scenario, SIT turns out to be a potential management tool for the need. This approach functions as a component of AW-IPM. Several insects have been successfully targeted and suppressed or eradicated by the application of SIT. This technology is quite successful on Dipteran insects while less effective on the Lepidopterans due to the special cytological and cytogenetic characters. IS plays an eminent role in case of Lepidopternas than SIT. Few studies regarding the IS has proved its potentiality in management of the Lepidopterans. Finally, this approach turns out to be excellent tool for the insect management in the future days.

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# Recent invasive insects in vegetable ecosystems: threats, impacts, and strategies for sustainable management

*Satyapriya Singh, Rudra Gouda M. N. and Gobinda Chandra Acharya*

**Abstract**: Horticulture plays a pivotal role in ensuring food security, healthy diets, and environmental sustainability. This article explores the importance of horticulture, particularly in vegetable production (including underutilized and exotic crops), highlighting its contributions to diverse diets, biodiversity preservation, and economic growth. However, invasive insects substantially threaten horticultural ecosystems, causing significant damage, economic losses, and disruptions. The article delves into the traits that make invasive insects successful in new environments, emphasizing the need for comprehensive management strategies. A detailed understanding of invasive insect species in India, such as the rugose spiralling whitefly, pinworm, and black thrips, reveals their detrimental impact on vegetable crops. The article underscores the urgency of implementing effective pest management strategies and emphasizes the importance of constant vigilance to prevent and manage future outbreaks, ensuring the long-term sustainability of vegetable ecosystems.

Horticulture plays an important role in food security, healthy diets, and environmental sustainability. It involves cultivating various plants, including fruits, vegetables, herbs, and ornamental plants, which contribute to promoting diverse and nutritious diets. Horticultural practices contribute to biodiversity preservation, reduction in soil erosion, rural livelihood empowerment, and economic growth through agribusiness opportunities, as highlighted by the International Society for Horticultural Science (ISHS). Vegetables are essential to a balanced diet because they provide essential vitamins, minerals, and dietary fibre, contributing to overall health and well-being (Kovačević et al. 2020). The high nutrient content of these foods supports immune function, lowers disease risk, and enhances digestion, making them crucial for a healthy lifestyle. Production of vegetables is anticipated to increase to 204.61 million metric tonnes from the 200.45 million metric tonnes reported in the 2020–21 timeframe (Second Advance Estimates, 2021–22). At this juncture, underutilized vegetable crops play a vital part in the Indian diet and are closely associated with traditional cuisine. The increasing recognition of the diverse range of underutilized species is important for environmental health and particularly relevant for climate change mitigation. Therefore, improving the cultivation of these vegetables could potentially replace other commonly consumed vegetables without compromising the availability of essential nutrients and phytochemicals in the agricultural and food industries. Endemic underutilized vegetables resist abiotic and biotic stresses, including drought, high temperatures, pests, and diseases, while maintaining productivity (Palanivel and Shah, 2021). These interventions can potentially improve a nation's food and nutritional security with stability in agricultural income. On the contrary, invasive insects pose a significant challenge for many growers, hindering the potential outcome.

Invasive species refer to any species, subspecies, or lower taxon introduced outside its natural historical or current distribution. This includes any part, gametes, seeds, eggs, or propagules of such species that can survive and reproduce. Invasive insects (non-native) pose risks to human well-being, imperil food production, threaten valued species, jeopardize economic stability, and disturb the functioning of ecosystems (Venette and Hutchison, 2021). In the context of horticultural ecosystems, invasive insects play a significant role by causing considerable harm to crops, resulting in reduced yields, heightened production expenses, and the disruption of agricultural systems. Pests and pathogens, lacking natural predators, can quickly spread, resulting in substantial economic losses, food security risks, and the necessity for enhanced pest management strategies. This situation affects local economies and global trade. The economic cost of biological invasions is estimated to be at least US$ 1.288 trillion in Brazil (Adelino et al. 2021), US$4.52 trillion in the USA (Fantle-Lepczyk et al. 2022), US$ 432.6 billion in Asia (Liu et al. 2021). This article aims to understand their damage symptoms and the potential attributes behind their invasiveness. Additionally, studying invasive insects allows for developing effective management strategies to mitigate the negative consequences of their presence.

## Potential traits of invasive insects

Invasive insects possess traits that facilitate their successful establishment and proliferation in new environments. These traits, such as rapid growth and reproduction rates, allow them to thrive and reproduce even in unfavourable conditions, giving them an edge over native species in population growth. Moreover, their ability to thrive in adverse ecosystems is enhanced by their phenotypic plasticity and wide tolerance to environmental fluctuations (Jardeleza et al. 2022). Invasive insects commonly display adaptable feeding behaviours, allowing them to exploit various food sources. Moreover, the ability of these organisms to travel long distances, often with the help of human activities, enables them to spread to different regions quickly. These attributes enhance their competitive ability against native species, contributing to ecological disruption and economic impact. Their ability to adapt to urban environments, agricultural systems, and trade networks allows them to take advantage of human activities, unintentionally facilitating their spread. Comprehensive management strategies are crucial for effectively addressing the challenges posed by invasive insects. Early detection, monitoring, and rapid response measures are crucial in preventing and mitigating the establishment of invasive species, thereby reducing their potential far-reaching consequences on ecosystems, economies,

| Sl. No. | Common name | Scientific name | Host | Entry to India (Place) | From/ Native | Biological control | References |
|---|---|---|---|---|---|---|---|
| 1 | Potato tuber moth | *Phthorimaea operculela* Zeller (Lepidoptera: Gelechiidae) | Potato | 1906 (East Bengal- Now in Bangladesh) | Italy | Copidosoma koehleri, an egg - larval parasitoid; Chelonus blackburnii - exotic parasitoid | Lefroy, 1907 |
| 2 | Serpentine leaf miner | *Liriomyza trifolii* (Burgess) (Diptera: Agromyzidae) | Tomato | 1991 Hyderabad, Telangana | Florida | Chalcidoidea, Pteromalidae and Braconidae -Diglyphus begina, D. intermedius | Viraktamath et al. 1993 |
| 3 | South American tomato pinworm/ Tomato leaf minor | *Tuta absoluta* (Meyrick,1917) (Lepidoptera: Gelechiidae) | Tomato | 2014 Pune, Maharashtra | South America | Nesidiocoris tenuis Reuter; Neochrysocharis formosa (Westwood); Habrobacon sp.; Goniozussp. Trichogramma achaeae | Shashank et al. 2015 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 4 | Black thrips | *Thrips parvispinus* (Karny) (Thysanoptera: Thripidae) | Chilli | 2015, Bengaluru, karnataka | Indonesia | Beauveria bassiana @ 4.00 g or ml/L (spore load - 1x108 cfu/g or ml), Pseudomonas fluorescence – NBAIR-PFDWD @ 20g/L or Bacillus albus – NBAIR-BATP @ 20 g/L | Tyagi et al. 2015 |
| 5 | Rugose spiraling whitefly | *Aleurodicus rugioperculatus* Martin (Hemiptera: Aleyrodidae) | Coconut | 2016, Tamil Nadu | Central America | Encarsia guadeloupae | Sundararaj and Selvaraj (2017) |
| 6 | Cassava mealybug | *Phenacoccus manihoti* | Cassava | 2020, Kerala | African continent | Apoanagyrus lopezi | Joshi et al. 2020 |

Table 1. List of invasive insect pests on vegetables

and society.

**Impact of invasive insect species on vegetable ecosystem**

Invasive insect species can have significant direct and indirect impacts on vegetable ecosystems, affecting both native species and the overall ecological balance (Table 2).

| Direct consequence | Indirect Consequence |
|---|---|
| 1. Predation on Native Species | 1. Changing Food Webs |
| 2. Competition for Resources | 2. Decreasing Biodiversity |
| 3. Disease Transmission | 3. Altering Ecosystem Conditions |
| 4. Reproductive Interference | |
| 5. Altered Trophic Interactions | |
| 6. Displacement of Native Species | |
| 7. Genetic Introgression | |
| 8. Ecological Imbalance | |

Table 2: Direct and indirect impact of invasive insect pests on vegetable ecosystem

Status of some recently invaded insect species in vegetables including underutilized and exotic crops

The Aleurodicus rugioperculatus, or rugose spiralling whitefly (RSW), is a highly harmful species that causes significant losses in agricultural and horticultural ecosystems. This insect's rapid and extensive spread across the nation has caused concerns among millions of horticultural growers. While the species can infest numerous crops, it is important to acknowledge its significant impact on underutilized vegetable crops (Singh et al. 2022). The attack on two new host crops, Amaranthus tricolor (L.) and Solanum torvum, demonstrates the robustness of the species at CHES (ICAR-IIHR), Bhubaneswar (Fig 1). Additionally, there have been reports of infestation on minor cucurbits (Coccinia grandis, Momordica dioica). The Tuta absoluta, also known as the pinworm, has significantly reduced the market value of tomatoes in several states since 2014 (El-Shafie, 2020). Larvae cause feeding damage by penetrating the leaf and consuming mesophyll tissues, creating irregular mines on the leaf surface and adversely affecting the plant's photosynthetic capacity. Consequently, affected leaves wither, reducing overall photosynthetic efficiency and potentially compromising the plant's ability to defend against other harmful agents. The galleries and mines formed in the leaves disrupt the plant's normal development, leading to potential necrosis (Biondi et al., 2018). In severe infestations, leaves may exhibit a scorched appearance. Additional common signs and symptoms of T. absoluta damage include puncture marks, abnormal shapes, exit holes (pin size), rot from secondary infections, and larval excrement on fruit. Mature larvae, particularly in the third to fourth instar, can feed on various plant parts, causing substantial harm to the plant.

The most recent surge of the invasive pest, Thrips parvispinus (Karny) (Thysanoptera: Thripidae), on chili (Capsicum annuum L.) in the southern states of India (Andhra Pradesh, Karnataka, and Telangana) resulted in damage ranging from 70% to 100%, regardless of the chili cultivars cultivated by farmers (Sridhar et al., 2021). In India, the presence of T. parvispinus was initially documented by Tyagi et al. (2015) on papaya, Carica papaya (Caricaceae), in Bengaluru. They underscored the importance of consistently monitoring its presence in other regions of India due to the likelihood of it becoming a pest of concern. Damage symptoms induced by T. parvispinus in chili included profound punctures and scratches on the underside of leaves. The infested lower surface of the leaf exhibited a reddish-brown hue, while the upper side displayed a yellowish appearance. Common symptoms encompass distorted leaf lamina with necrotic areas and yellow streaks. Severely infested leaves showed upward curling. Brownish streaks emerged on petals on floral components due to thrips' scraping. The consequential damage led to the drying and withering of flowers, resulting in a diminished fruit set (Sridhar et al., 2021). The plant's growth was adversely affected by severe infestation, as thrips fed on the growing portions of the plants. Numerous adults, both males and females, were observed congregating in significant numbers, feeding and concealing themselves in the nectar-producing regions of chilli flowers, causing extensive flower drop and substantial crop losses.

a: RSW infestation on the fruit of Solanum torvum; b: RSW infestation on leaf of Amaranthus tricolor (L.);

Fig. 1. Rugose spiralling whitefly (RSW) infestation on underutilized vegetable crops

c: RSW infestation on the leaf of minor cucurbit

The swift proliferation, substantial damage, and capability to impact multiple crops and plant varieties emphasize the importance of implementing effective pest management strategies and maintaining constant vigilance to prevent and manage similar future outbreaks.

## Management

A holistic management strategy is the key to tackling invasive species in the long run. It can be addressed at three different levels of invasion of pests.

## Conclusion

Vegetables are crucial for achieving food security, promoting healthy diets, and supporting environmental sustainability. Those crops promote diverse and nutritious diets, preserve biodiversity, and mitigate soil erosion. The introduction and spread of invasive insect species have significant negative impacts on vegetable ecosystems. These impacts include the disruption of native species, alteration of food webs, reduction in biodiversity, and creation of ecological imbalances. The outbreak of T. parvispinus, T. absoluta, and A. rugeoperculatus in India exemplifies the significant impact of invasive pests. The swift dissemination and significant harm inflicted by this species underscore the pressing requirement for efficient pest management strategies and proactive measures to avert and manage comparable outbreaks in the future.

| Preventive measures | Post quarantine measures | Curative measures |
|---|---|---|
| The pest has not been introduced | Species introduced but not spread to a nearby area | Introduced invasion has established |
| Pest risk analysis (PRA) Quarantine and monitoring | Rejection of the consignment from which the pest has been introduced<br>Eradication using fumigation of the consignment lot | Cultural<br>Biological<br>Chemical |

Table 3. Invasive insect pest management strategies

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# Artificial intelligence in crop protection

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**Abstract:** Artificial intelligence can be deployed effectively to leverage massive data sets to produce environmentally friendly crop protection products. The use of AI techniques can help to automate and speed up the process of providing farmers with timely and accurate decision-support on critical aspects of pest management such as pest identification, pest monitoring, selection of an appropriate pest management strategy and AI-based pesticide application. This new technology can safeguard biodiversity, including pollinators such as bees, which are vital to grow crops and also several beneficial insects such as ladybird beetles, which are a natural way to control pests. Additionally, the AI-based applications help to maintain soil health, enhances capacity of the soil to absorb carbon and thereby lowering the greenhouse gas emissions caused by agriculture.

According to the United Nations Food and Agriculture Organization, the global population will grow by two billion by 2050, while only 4% of additional land will be under cultivation by that time. Farmers face an increasing challenge in maintaining farm productivity in the face of rising agricultural debts and unpredictable weather patterns, as evidenced by the recent spate of farmer suicides. Biotic factors such as insect pests and diseases are major contributors to decreased farm productivity wherein reducing crop losses is the key way to enhance farm productivity. The use of emerging technologies such as Artificial Intelligence (AI) can certainly aid in the efficient and successful management of crop pests. The adoption of cognitive solutions is crucial for the future of farming.

AI is a branch of computer science that deals with computer systems simulating human intelligence processes. AI is rapidly becoming pervasive due to its robust applicability to solve a variety of problems that traditional computing and human efforts cannot solve. John McCarthy, an American computer scientist, coined the term artificial intelligence (AI) in 1956 at the Dartmouth Conference. Artificial intelligence is a subfield of computer science that seeks to develop intelligent machines. AI can identify patterns in data more efficiently than humans, allowing researchers to gain more insight into their data. Natural language processing, speech recognition, robotics, sensor systems, and computer vision are major applications of AI. Learning, reasoning, and self-correction are descriptions of these processes.

Artificial intelligence (AI) is a new technology in agriculture. AI-based technologies have the potential to strengthen crop production by more effectively managing pests and diseases in farmers' fields. Machine learning, a type of artificial intelligence that is trained on massive data sets and then learns on its own, can assist farmers in pest identification and monitoring, providing timely support for pest management decision-making. Machine learning is a subset of artificial intelligence in which supervised learning uses classification and regression algorithms to identify patterns in data and unsupervised learning uses clustering and association algorithms. Classification determines which category an object belongs to, whereas regression deals with obtaining a set of numerical inputs and discovering functions that enable the generation of appropriate outputs from respective inputs. AI-enabled agricultural solutions assist farmers in increasing crop productivity by reducing crop loss. AI, along with other digital technologies, will play an important role in modernising agricultural activities. Artificial intelligence has a wide range of applications in pest management, a critical area of agriculture. Plant protection is a critical aspect of agriculture in the face of numerous challenges. Plant protection challenges can be met with AI-driven techniques and tools. AI can learn from data and thus identify patterns in data more efficiently than humans, allowing researchers to gain more insight from their data.

Identification of specific pests in the field is critical for successful pest management. Growers must distinguish between beneficial and harmful insects in order to implement effective pest control measures. Another critical aspect of pest management is regular pest monitoring, which assists in determining the level of occurrence and the appropriate time to initiate pest management intervention. Following a thorough examination of the level of pest incidence, the appropriate pest management strategy must be chosen from among various pest management strategies such as biological, chemical, physical, quarantine, or cultural methods. Artificial intelligence (AI) has already been used in plant protection all over the world. Deep learning for pest identification, Artificial Neural Networks (ANNs) for pest modelling, and Internet of Things (IoT) for efficient farm management are some of the AI techniques used in plant protection. Researchers have also used AI approaches such as Fuzzy logic and Bayesian Network in the development of a pest management Decision Support System. Although the use of AI is promising, there are challenges in plant protection. Two major challenges in the process of developing AI-based plant protection tools and techniques are the development of innovative AI algorithms and the non-availability or limited availability of data for data learning. Pest prediction is still complex and elusive. The process of plant protection in agriculture is slowly becoming digital with AI showing promising potential.

**Status of research in the subject and advancement:** The application of ICT in agriculture for information transmission began in the 1990s, particularly with the development of stand-alone and web-based applications. Many web-based agricultural databases, information systems, and expert systems have already been developed in India. Web-based expert systems were developed in plant protection to diagnose diseases and pests of various crops and provide management information. Web-based systems are now widely used in agriculture in many countries. This aided farmers in obtaining accurate information on crop varieties, pest identification, and pest management. CUPTEX, an application for managing cucumber disorders; NEPER, a web-based application used for managing the production management aspects of wheat crops; USDA developed an expert system for cotton crop management to provide appropriate management recommendations to cotton growers. Some of the web-based systems developed nationally are: eSAP (Electronic Solutions against Agricultural Pests) for crop health management, detection and advisories for insect pests, microbial diseases, nutritional deficiencies, and weed problems; AGREX, an expert system developed by the Center for Informatics Research and Advancement, Kerala for providing timely and accurate information. Mobile based information apps from ICAR-National Research Centre for Integrated Pest Management, New Delhi such as Pest Management Information System (PMIS) on Brinjal, PMIS on Tomato, PMIS on Okra, PMIS on Chilli, Rice IPM, Groundnut IPM etc.

The recent years have seen a significant amount of research on automatic pest identification. The majority of the time, computer vision, machine learning, or deep learning technologies are chosen and employed to identify plant diseases, but typically just one approach is chosen without comparing the other potential approaches in the same job. Numerous studies on the automatic detection and identification of pests concentrate on a single technological approach, while alternative technical approaches are not explored. In recent years, object recognition and computer vision have made significant progress. Prior to now, image classification challenges have been traditionally approached using features detection methods as DoG, Salient Regions, SURF, SIFT, MSER, etc.

Some learning methods are employed with the features after they have been extracted. Predefined features affect how well the approaches perform. The process of feature engineering itself is challenging and must be redone whenever the problem or dataset changes. This issue arises in all attempts to detect plant diseases using computer vision since they rely on manually created features and algorithms for image augmentation. Deep learning techniques can be used to resolve the problem of manual feature extraction because feature extraction is done automatically. Recent advances in deep learning enable significantly greater object recognition and detection accuracy. Deep learning techniques have been used, on the one hand, to find and cure the disease. Many of these techniques, including Artificial Neural Networks (ANNs), Decision Trees, K-means, and K-nearest Neighbours, have been used in agricultural research projects. One of these techniques that have been widely applied in the field of illness diagnosis is Support Vector Machines (SVMs). However, deep learning, a recent development in machine learning, advances the state-of-the-art in a number of areas, including the capacity to work directly with images without relying on manually derived characteristics. As shown in various applications, both machine learning and deep learning can increase computer vision accuracy. Deep learning may learn and make intelligent decisions using structured algorithms in layers, as opposed to machine learning, which bases its decisions on what it has learned from the incoming data.

AI companies use the new satellite images against pictures of the same using historical data and AI algorithm detects that the insects had landed at another location and farmers use such information after confirmation and timely eradicate the expensive pests from their fields. A deep learning-based programme called Plantix, created by German tech startup PEAT, can find probable flaws and nutritional deficits in the soil. You can use your smartphone to take a picture of the plant and check for faults thanks to this app’s image recognition capabilities. On this app, you will also find short movies with advice and various ideas for soil restoration. Drone-based aerial photography was made possible by VineView, a business that acquired SkySquirrel Technologies. A round of data collection from the grape field is done using a drone, and all the data is then downloaded through a USB drive from the drone to a computer and examined by the experts. As these plants are highly susceptible to grapevine diseases like moulds and bacteria, the company uses algorithms to analyze the captured images and provides a detailed report with the current health of the vineyard, generally, the condition of grapevine leaves, helping farmers to timely control using pest control and other methods.

## Artificial Intelligence (AI) and its role in agriculture

The most valuable sector in the world *i.e.,* Agriculture, is experiencing a tremendous influence from artificial intelligence (AI), which is growing its ground-level footprint. Agriculture is gradually moving digital. Predictive analytics, agricultural robotics, and soil and crop monitoring are the three main areas where AI in agriculture is now being used.

Robots for agriculture: Many companies are creating machines to perform crucial agricultural chores, such harvesting crops more quickly and in greater quantities than people can.

Crop and soil monitoring: To analyze data obtained from drones or sensor-based technologies in order to monitor crop and soil health, organizations use computer vision and deep learning algorithms.

Predictive analytics: Machine learning models are being created to forecast how changes in the weather will affect crop productivity. Public and corporate organizations throughout the world have created numerous AI-based solutions for agriculture. The use of sensors and soil sampling by farmers is expanding, and the data they collect is stored on farm management systems for easier processing and analysis. The accessibility of these data and related data is opening the door for the application of AI in agriculture.

### Practical application of AI and its role in agriculture

1. AI-based crop rotation and farm management: The majority of the UN sustainable development goals may be resolved globally with the help of straightforward AI-based expert systems assisting farms' decision-making for maximizing crop rotation. Crop rotation and agricultural management based on AI essentially work with nature rather than against it (Schoning and Richter, 2021).
2. Integration of Computer Vision and Applied Artificial Intelligence in Postharvest Storage Systems: An intelligent postharvest storage system can be created that is profitable, sustainable, and simple to deploy using vision-based adaptive controls in the storage chamber and vision-based quality grading of fruits and vegetables (Concepcion et al., 2021)
3. AI in agriculture for optimization of irrigation: The development of smart irrigation technology enables farmers to boost production without using a lot of labour by monitoring soil temperature, fertilizer content, water level, and weather forecasts. Turning the irrigator pump ON/OFF maintains the microcontroller to conduct the actuation. By creating remote sensors using Arduino technology, an automated watering system can enhance productivity by up to 40%. The placement of sensors is crucial to the effective application of irrigation robots. Multiple irrigation zones in the fields can be controlled by a single sensor (Shekhar et al., 2017; Jha et al., 2019; Savitha and Uma Maheshwari, 2018, Varatharajalu and Ramprabu (2018).
4. Unmanned aerial vehicles (UAVs) powered by AI: UAVs interact with the GPS and other sensors that are mounted on them. Drones are being used in agriculture for weed identification, cattle and animal monitoring, crop health monitoring, irrigation equipment monitoring, disaster management, and weed identification (Veroustraete, 2015; Ahirwar et al., 2019; Natu and Kulkarni, 2016). Agriculture is being greatly impacted by remote sensing using UAVs for image capture, processing, and analysis (Abdullahi et al., 2015)
5. Yield mapping and monitoring: A tone or shaded guide is often used to depict the ranges of yield within a field (Talaviya et al., 2020).
6. Yield calculation and calibration: Harvest weight or volume reaped per unit region, which is indirectly calculated by yield sensor while harvesting with combined harvesters or reapers (Talaviya et al., 2020).
7. Real-time crop and soil monitoring
8. Crop yield prediction and price forecast
9. Making resource allocation wiser
10. Improving food and environmental sustainability
11. Analysing market demand and managing risk
12. Protecting, feeding and harvesting the crops

### Role of Artificial Intelligence in pest management

The use of AI-based technology helps to increase productivity across all industries and manages the difficulties faced by numerous fields in the agricultural sector, including crop monitoring, pest control, irrigation, and soil content sensing. Artificial intelligence (AI) has the potential to provide Agriculture with a much-needed answer, particularly in the area of pest management. By allowing farmers to produce more while using fewer plant protection inputs and even improving output quality, AI-based pest management technologies can ensure higher market prices for crop production. In addition to accelerating the process of pest detection, Application of AI approaches such as deep learning, in ICT based systems of decision support in pest management has started which not only speeds up the process of pest identification but also greatly facilitates pest surveillance and provides pest management advisories.

**There are different ways of AI in pest management, which are described as follows.**

1. A simple way for field scouting: AI can assist scouts by giving precise descriptions of pests and their locations in fields (Niranjan et al., 2022). The cost of crops lost each year will be greatly reduced by automated crop field surveillance utilizing computer vision, and the security of the field can be fully automated (Khare and Phadke, 2020).
2. Addressing challenges of pest diagnosis: Effective pest management depends on accurate field identification of a particular pest. Regular pest monitoring, which aids in determining the frequency of an infestation and the best time to start a pest control intervention, is another crucial component of pest management (Fig. 1).
3. Predicting pest issues in advance: Using AI approaches, farmers can receive timely and accurate decision-support on crucial areas of pest management, such as pest identification, pest monitoring, and the choice of an effective pest management strategy (Niranjan et al., 2022). AI is essential for increasing crop productivity and identifying plant diseases (Upadhyay and Gupta, 2021).
4. Spraying of pesticides with AI-powered drones:

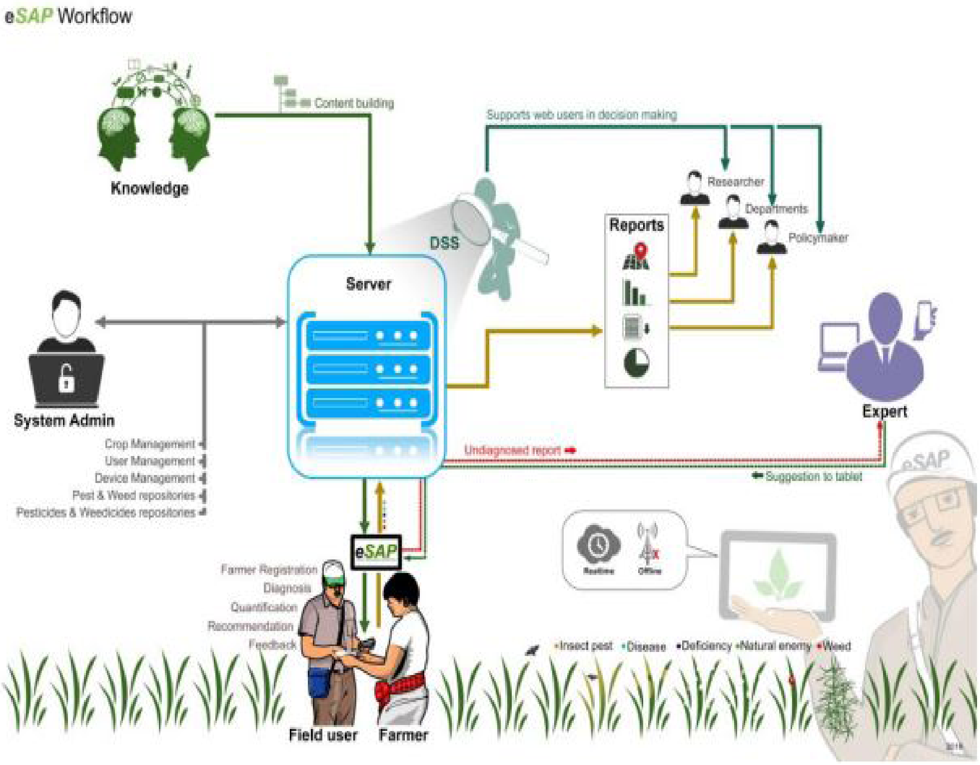

Fig. 1 Workflow of Electronic Solutions against Agricultural Pests (Aralimarad Prabhuraj, 2020)

Spraying pesticides with drones helps to manage pests effectively over a broader region by ensuring that crops are completely covered. Crop protection products are applied at the proper time, only where they are required, and at the best rate by utilising current breakthroughs in AI-aided spray timers, zone spray, buffer zones, and product recommendations. This improves the productivity and financial success of the farmer while also lessening the impact on the environment. The combination of AI-driven spray timing, variable rate application maps, and product recommendations in Europe has resulted in a 30% decrease in the use of fungicides on field trial cereal crops and a 72% decrease in tank residue, minimising environmental pollution. In Brazil the zone spray weed maps solution created using computer vision techniques resulted in a 61% average savings, cutting back on almost two-thirds of herbicide and water consumption (Shankar et al., 2020) (Fig. 2 and 3).

5. Large-scale pest monitoring and surveillance: AI-based drones are employed for pest monitoring

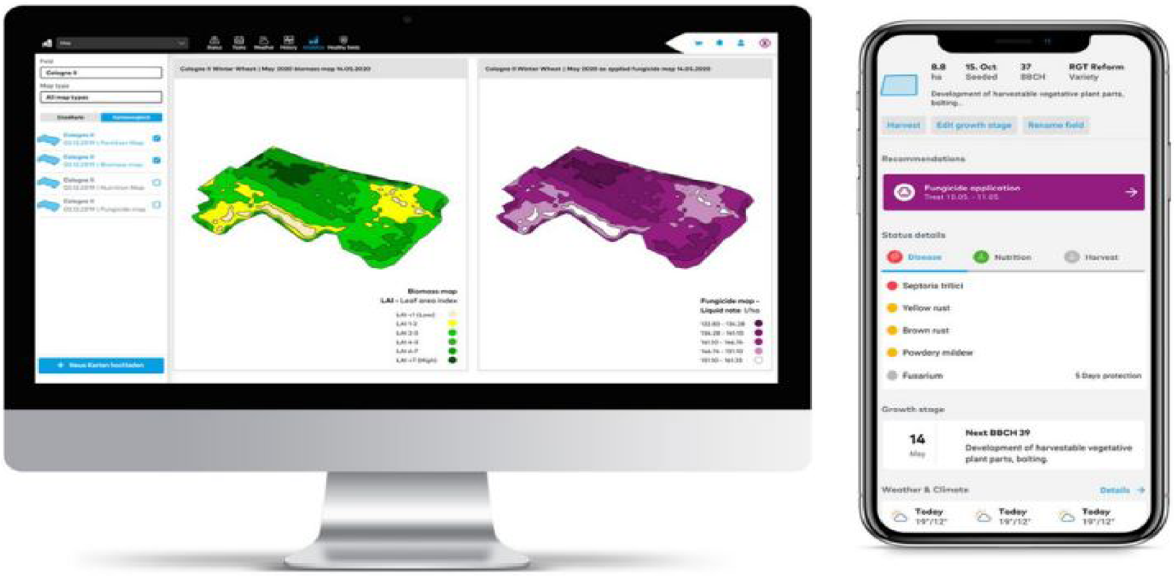

Fig. 2 Illustration of AI based xarvio Zone Spray and Spray Timer (Shankar et al 2020)

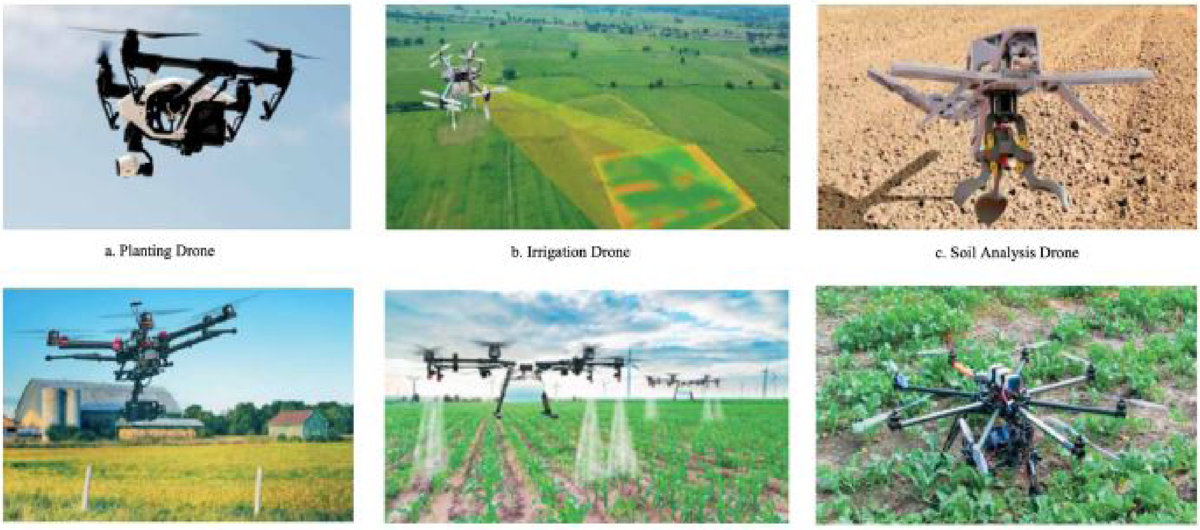
a. Planting Drone
b. Irrigation Drone
c. Soil Analysis Drone
d. Crop Monitoring Drone
e. Crop Spraying Drone
f. Health Assessment Drones

Fig. 3 Various applications of modern agriculture drones (Unpaprom et al., 2018).

and security (Fig. 4).

## AI techniques for crop protection

1. *Machine learning:* Algorithms that can learn on their own from a set of input data in order to accomplish a certain goal are the subject of machine learning. New agricultural opportunities are made possible by its powerful computer. Machine learning and statistical pattern recognition have drawn a lot of interest in the agriculture sector because they have the potential to increase the sensitivity of disease identification and diagnosis. Farmer decision-making and action are aided by the plethora of recommendations and insights provided by machine learning-enabled technologies. Example: Classification of diseased or healthy leaves, fruit, plants, etc.
2. *Artificial Neural Network (ANN):* Among the several techniques used, artificial neural networks (ANNs) are one of the more reliable methods of recognising plant diseases. Neural networks are combined with various image pre-processing algorithms to enhance feature extraction. The biological neurons of the human nervous system are the foundation of ANN. Contrarily, ANN can extract meaning from complex data and identify patterns that are difficult for humans or conventional computers to find. Other advantages of ANNs include adaptive learning, self-organization, real-time operations etc.

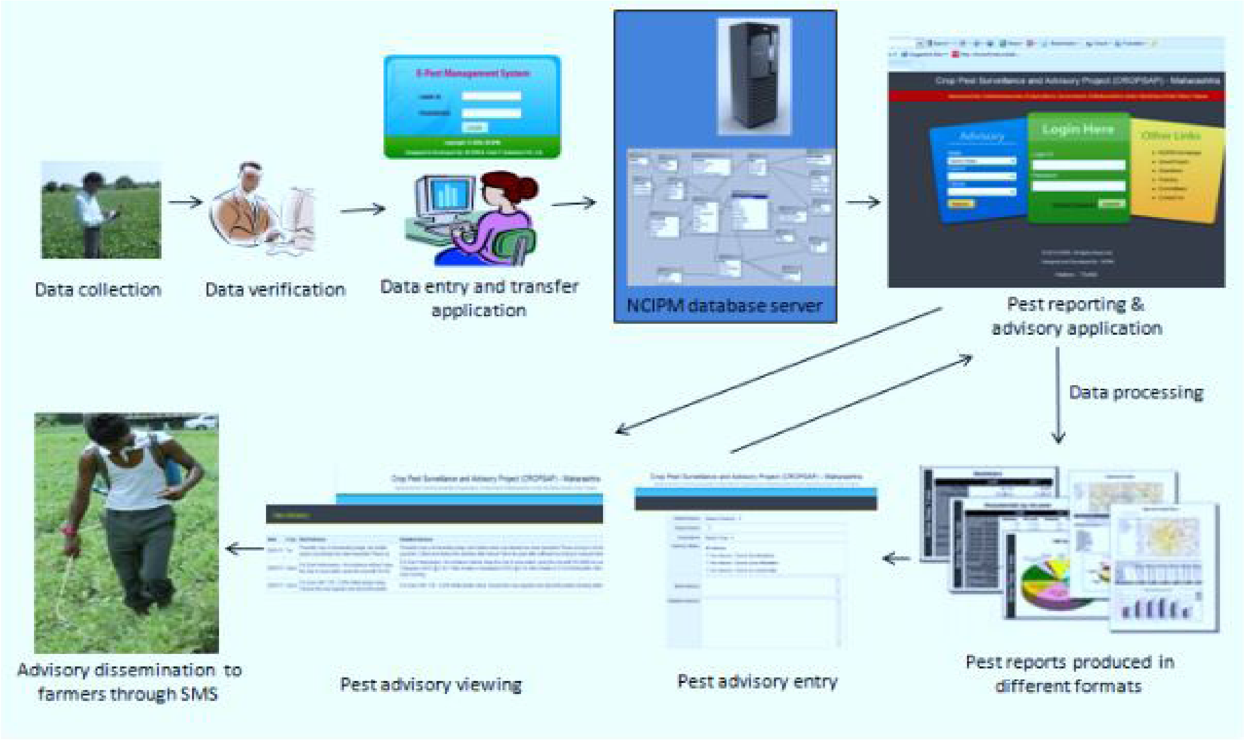

Fig. 4 Structure of ICT-based pest surveillance (https://ncipm.icar.gov.in/NCIPMPDFs/successstories/PestSurveillance.pdf

3. *Image processing techniques:* Image processing techniques were successfully and widely used for plant detection and classification. The data is organised into categories using a two-dimensional taxonomy. One dimension includes the following processes: object detection, data reduction/feature extraction, pre-processing, segmentation, optimization, and image interpretation. At several levels, such as the level of a pixel, an object set, and so on, inputs are received and tasks are carried out in a certain dimension. Several pre-processing techniques, including picture clipping, image smoothing, and image enhancement, are employed to increase the effectiveness of sickness diagnosis. A number of methods, such as the Otsu

method, k-means clustering, and converting RGB images to HIS models, can be used to segment images. Fourier filtering, edge detection, and other image pre-processing techniques were also used. Example: Image-based disease and weed identification.

4. *Support Vector Machine (SVM):* Support vector machines are supervised learning systems that are used to handle classification and regression issues. In SVM, the hyperplane is utilised to separate the classes. A hyperplane in N-dimensional space is analogous to a line in two dimensions. This hyperplane divides the plane into two halves, with each class on one side, in two dimensions. The SVM approach finds the best hyperplane for classifying new samples using labelled training data. As a result, SVM determines the hyperplane to classify each data point separately. For accurately diagnosing leaf diseases, the Support Vector Machine (SVM) has also been found to be very promising.
5. *Internet of Things (IoT):* Internet of Things (IoT): The internet of things, also known as IoT, is a network of interconnected computing devices, mechanical and digital machines, objects, animals, and people who are given unique identifiers and the capacity to transfer data over a network without the need for human-to-human or human-to-computer interaction. IoT includes robotics and sensors. Example: Robotics (Drones) helps to take the view or infestation survey of the field within a short span of time without manual power.

## Conclusion

The foremost application of artificial intelligence is pest detection, identification, and timely recommendation of plant protection measures. It is the latest direction for farmers to adopt new technology in order to meet global food demands by managing insect pests using artificial intelligence techniques, thereby contributing to increased food security. Many mobile apps based on artificial intelligence have been developed by various ICAR research institutes for several crops to efficiently identify and manage crop insect pests. Although the use of AI is promising, there are challenges in plant protection. Two major challenges in the process of developing AI-based plant protection tools and techniques are the development of innovative AI algorithms and the non-availability or limited availability of data for data learning. Pest prediction is still complex and elusive. The process of plant protection in agriculture is slowly becoming digital with AI showing promising potential.

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# Good agricultural practices in insect pest management of field crops

***Rajna, S. Raghavendra, K. V., Reshma, R., and Arya, P. S.***

With the increasing demand for food and improvement in the disposable income of the consumers, the concepts like food safety and nutritional security, natural resource degradation and environmental sustainability etc., started gaining more attention from health and trade perspectives. Consumers' understanding of food safety has recently increased and the agriculture industry must adjust to the changing demand. To achieve this, strategies must be modified along the entire value chain, from the fields to the customers. Globally, Good Agricultural Practices (GAP) have become a crucial strategy in this direction. Several nations have included GAP in their future plans of action, making its acceptance and promotion through legislative measures necessary (Rodrigues et al., 2004). Good Agricultural Practices GAPs are a set of guidelines for growing and handling agricultural products including cereals, pulses fruits, vegetables and other agricultural produce. Food and Agriculture Organization defined GAP as practices that address environmental, economic and social sustainability for on-farm processes, and result in safe and quality food and non-food agricultural product. These guidelines help to ensure that the food produced is safe, of high quality, and grown in an environmentally sustainable manner. GAPs cover a wide range of topics including: crop management, water and soil management, pest management, worker safety and training and food safety. Implementing GAPs can help farmers to reduce risks associated with food safety, improve yields, and increase the marketability of their products. GAPs can be voluntary or mandatory, and are often required by retailers and food service providers as a condition of doing business with them.

The criteria/requirements for GAPs have been categorized, based on their importance, as critical, major or minor;

1. Critical: They are necessary to preserve the quality of the produce, and failure to follow them could result in significant food safety issues leading to product integrity (100 per cent compliance shall be compulsory)
2. Major: these are mandatory and must be followed (90 percent compliance shall be compulsory)
3. Minor: These are important but may not be essential depending upon the produce category (50 per cent compliance shall be compulsory)

According to FAO, to minimize the harmful effects of production and post-production practices, good agricultural practices for controlling food safety hazards are grouped into eleven elements.

The pertinent Food Security Modules (FSMs) are:

- Site history and management
- Planting material
- Genetically modified organisms
- Fertilizers and soil additives
- Chemicals (Plant protection products or other agro and non-agrochemicals)
- Water (Irrigation/Fertigation)
- Harvesting and handling produce
- Traceability and recall
- Training

- Documents and records and
- Review of practices (FAO, 2016)

One important aspect of GAPs is the management of insect pests in field crops. Insect pests are a major problem for farmers as they can cause significant damage to crops and reduce yields. In order to effectively manage insect pests, farmers must adopt a holistic approach that incorporates various techniques and strategies. Among the 11 Food Safety Measures listed by FAO; site history and management, planting material, genetically modified organisms, chemicals, and harvesting and handling produce are relevant in plant protection perspectives of all crops, including field crops.

1. Site history and management: Site history shall be assessed to identify the risks of contamination to crops grown, from the previous use of chemical and/or biological hazards on the site or adjoining sites, and the risks shall be documented.

2. Planting material: One important aspect of GAP is the use of high-quality planting material. High-quality planting material is more likely to be free from pests and diseases. Crops grown from high-quality planting material are less likely to be affected by infestations or outbreaks of pests and diseases, which can cause significant damage to crops and lead to economic losses for farmers. High-quality planting material is more likely to have the right genetic makeup and characteristics to thrive in the specific growing conditions of the farm. This results in crops that are more resistant to environmental stresses, such as drought or extreme temperatures, and biotic stresses like pests and diseases and thus reduces the need for chemical inputs. Moreover, high-quality planting material also reduces the risk of chemical residue in the products, making it safer for consumption (Adhikari and Thapa, 2023).

3. Genetically modified organisms (GMOs): Genetically modified organisms (GMOs) can revolutionize agriculture by increasing crop yields and reducing the use of pesticides and herbicides. However, the success of GMOs depends on the implementation of good agricultural practices. Good agricultural practices (GAPs) refer to the methods and techniques used to grow crops and raise animals sustainably and responsibly. GAPs include crop rotation, soil conservation, and appropriate fertilizers and pesticides. When these practices are implemented, they can lead to increased yields, improved soil health, and reduced environmental impacts (FAO, 2016). In the case of GMOs, GAPs are particularly important because they can help to mitigate the potential negative impacts of these crops on the environment and human health. For example, genetically modified crops are grown in monoculture, they can lead to the destruction of natural habitats and the loss of biodiversity (Dale et al., 2002). However, if GAPs such as crop rotation and soil conservation are used, the negative impacts of GMOs can be minimized. Furthermore, GAPs can also help to ensure that GMOs are grown safely and responsibly. For example, using appropriate pesticides and herbicides can help prevent the development of resistance in pests and weeds, which can lead to increased use of these chemicals in the long run. Farmers, policymakers, and researchers need to work together to promote and implement GAPs for GMOs. Planting or trials with GM crops shall be done if permitted by the applicable legislation in the country. This shall be documented if a producer is growing GM crops, as permitted by the country's legislation.

Even though growing genetically modified crops is a controversial issue, these have been adopted in several countries worldwide. The most widely grown genetically modified crops are; soybean, corn, cotton, canola, alfalfa, sugar beet, papaya, squash, tomato and potato. These crops have been genetically modified for traits such as pest resistance, herbicide tolerance, improved nutritional content, and drought tolerance. The cultivation of GM crops varies widely by country, with the majority being grown in the United States, Brazil, Argentina, India, and Canada.

In developing countries, GMCs are promoted as a means of increasing food security, although their adoption is still limited due to concerns about their impact on human health and the environment.

4. Chemicals (Plant protection products or other agro and non-agrochemicals): Chemicals used on the farm can be categorized as agrochemicals that are applied on the farm or produce such as fertilizers, pesticides, seed treatment material, plant growth regulators and additives, and non-agrochemicals such as grease, fuels, and oils that are required for other purposes. Pesticides for managing insect pests are important in GAP in insect pest management. The critical requirement here is the use of pesticides permitted under a country's regulations. Some major regulations are; purchase of chemicals from registered/licensed suppliers; the dosage as recommended by competent authorities; disposal of surplus chemicals to avoid contamination of the produce; maintaining pre-harvest interval mentioned on the label claim of the pesticide; proper maintenance of plant protection equipments; proper disposal of equipment washed water to avoid contamination to produce; storage of chemicals in the original container with a legible label and according to label directions; avoid reusing empty chemical containers and should be properly disposed of according to the country's regulations and in a manner to avoid contamination of produce and the environment; Obsolete or expired chemicals shall be clearly identified and kept in a secure place till disposal. A record of application for each crop shall be maintained giving details of chemical, reason for application, treatment location, dosage, method, date of application and name of operator; A record of chemicals held in storage shall be maintained detailing chemical name, date and quantities procured and date of complete use or disposal; If chemical residues in excess of maximum residue limits (MRL) are detected in the market where the product is traded or exported, the marketing of the product shall cease and the cause of contamination shall be investigated (FAO, 2016). Corrective actions shall be taken to prevent recurrence and a record kept of the incident and the actions taken; Non-agrochemicals shall be handled, stored and disposed of in a manner to avoid any risks to food safety; Integrated Pest Management (IPM), if implemented, shall require careful consideration of available pest control techniques and the subsequent integration of appropriate measures to discourage the development of pest populations, while keeping the use of plant protection chemicals at minimal level.

Minor requirements are, mixing of two or more chemicals should not be done, unless recommended by technically competent personnel/institutions/authorities; chemicals should be stored in a well-lit, sound and secure structure, which is located and constructed to minimize the risk of contaminating produce and equipped with notices and emergency facilities in the event of a chemical spill; A record of chemicals obtained should be maintained, detailing the chemicals used, name of the supplier, date and quantity obtained, date of manufacture and expiry.

5. Integrated pest management:

Integrated pest management (IPM) is an effective GAP for insect pest management. IPM is a holistic approach that combines multiple techniques and strategies to manage pest populations. IPM aims to reduce pest populations to a level that does not cause economic damage to crops. This is achieved by using a combination of cultural, biological, and chemical control methods. By using IPM, farmers can reduce the need for chemical insecticides, which can help to protect the environment and maintain biodiversity. Effective insect pest management in field crops is essential for achieving sustainable and high-yielding agriculture.

One of the most important GAPs for insect pest management is crop rotation. Crop rotation is the practice of growing different types of crops in a specific field in a recurring sequence. By rotating crops, farmers can disrupt the life cycle of pests and make it more difficult for them to establish populations in a field. For example, if a farmer grows corn in a field one year, and then switches to soybeans the next year, the insect pests that are specific to corn will have a difficult time finding a suitable host plant. This can reduce the overall pest pressure on the soybeans, and increase the chances of a successful crop (Nain et al., 2020).

Another GAP for insect pest management is the use of cultural control methods. Cultural control methods are practices that farmers can use to create an environment that is less conducive to pest outbreaks. These methods include things like proper irrigation, fertilization, and soil management. By providing crops with the right amount of water and nutrients, farmers can help keep them healthy and strong, making them more resistant to pest damage.

Biological control is another effective GAP for insect pest management. Biological control involves the use of beneficial organisms, such as predators, parasites, and pathogens, to control pest populations (Jeffers and Chong, 2021). These organisms can be either naturally occurring or introduced. For example, ladybugs and lacewings are beneficial insects that feed on a wide range of pest insects, and can help to keep populations in check. By rotating crops that attract these beneficial insects into a field, farmers can create a more balanced ecosystem that is less conducive to pest outbreaks.

Another GAP for insect pest management is the use of insecticides. Insecticides are chemicals that are used to kill or control pest populations. While insecticides can be effective in controlling pest populations, they also have the potential to harm beneficial organisms and the environment. Therefore, farmers should use only insecticides when necessary and choose the least toxic option. They should also follow the label instructions and safety precautions when applying insecticides.

6. Harvesting and handling produce

Post-harvest insect pest management is crucial to ensuring the quality and safety of stored agricultural products. Insects are major pests that can cause significant damage to stored grains, fruits, and vegetables, leading to economic losses for farmers and reduced food security for consumers. The key to effective post-harvest insect pest management is understanding the biology and behavior of the pests, as well as the characteristics of the products being stored. post-harvest insect pest management is essential for ensuring the quality and safety of stored agricultural products (FAO, 2016). By understanding the biology and behavior of pests, properly cleaning and preparing storage facilities, monitoring for pests, and using a combination of chemical and non-chemical control methods, farmers and storage operators can effectively manage insect pests and reduce the risk of economic losses and food insecurity. One important step in post-harvest insect pest management is to properly clean and prepare storage facilities before use. This includes removing any debris or old stored products that may harbor pests, as well as thoroughly cleaning and sanitizing the facility. This can help to reduce the number of pests that are present in the facility and make it less attractive to new pests. Another cultural control method is to use good agricultural practices (GAP) for crop production. This includes regular monitoring of crop growth, identifying and removing pests, and using pest resistant varieties of crops. GAP also includes proper crop rotation, and maintaining field sanitation to reduce the risk of pest infestation.

## Conclusion

We need defining certain minimum standards with a well-defined certification and accreditation mechanism for effective GAP. Agriculture being subjected to so much diversity in crop, soil, water, climate, etc. across the country, this does not easily render itself to regulation in order to implement specified Standards. Therefore, there is a need to have a voluntary certification scheme for implementing Standards for GAP. GAPs such as crop rotation, cultural control methods, biological control, use of least toxic insecticides and integrated pest management (IPM) are crucial in reducing pest populations and minimizing the damage caused by pests while maintaining biodiversity and protecting the environment. By implementing these GAPs, farmers can improve the sustainability, safety, and quality of their crops, and ultimately, increase their yields and profits. By implementing strict sanitation protocols, using an integrated pest management approach, and using proper storage conditions, it is possible to effectively manage pest populations and reduce the risk of pest infestation.

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# Exploring the Secrets of Insect Biodiversity

***Madesh K.***

Insects are the most diverse group of animals on Earth, with millions of species inhabiting nearly every terrestrial and aquatic habitat. However, the exact number of insect species remains a mystery, with estimates ranging from 5.5 million to 7 million. As stated in the Convention on Biological Diversity's Secretariat report (2020), approximately 1 million insect species have been formally described and named by scientists. This represents only 20% of the estimated total insect population. Insects perform vital roles in the ecosystem like pollinators, decomposers, and a source of food for other animals. Insect biodiversity is genuinely unique due to the wide range of causes that contribute to their amazing variety. Despite their importance, most insect species remain poorly understood and understudied (Footit and Alder, 2009). To fully grasp the complexities and importance of insect biodiversity, it is essential to delve into the fascinating world of these small creatures.

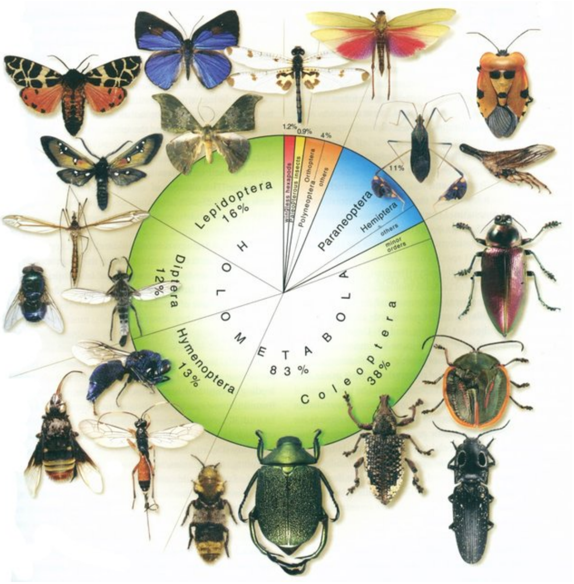

Fig.1: Insect diversity (Grimaldi and Engel, 2005)

### The Significance of Insect Biodiversity: Unveiling the Hidden Ecological Gems

The world of insects is often overlooked and overshadowed by larger, more charismatic animals. However, beneath their tiny exteriors lies a world of immense ecological significance. Insect biodiversity plays a crucial role in sustaining the delicate balance of ecosystems around the globe. Insects, despite their often-underestimated stature, play a fundamental role in the intricate web of life, especially as pollinators, with approximately 75% of flowering plants relying on them for successful reproduction (Klein et al., 2007). These tiny creatures, ranging from the tiniest bees buzzing between blossoms to the mesmerizing butterflies fluttering through meadows, act as nature's diligent workers, diligently transferring pollen between flowers. This process allows plants to flourish, contributing to the diverse ecosystems in which they thrive.

Recent studies further highlight the critical importance of insect pollinators in various aspects. For global food security, research by Potts et al. (2016) estimates that insect pollinators contribute to the production of 35% of the world's food crops, underscoring their vital role in ensuring the stability of global food supplies. In terms of plant diversity, insect pollination promotes the diversification of plant communities, leading to richer and more resilient ecosystems (Ollerton et al., 2019). Additionally, the economic benefits of insect pollination are estimated to be in the trillions of dollars annually, highlighting the immense financial impact of these tiny creatures on agriculture and food production (Gallai et al., 2009). Therefore, safeguarding and preserving insect populations is crucial for maintaining healthy ecosystems, ensuring biodiversity, and safeguarding global food security.

Fig. 2: Pollination by bees (https://www.milgro.eu)

Fig. 3: Flightless Dung Beetle (www.shamwari.com)

Besides, insects also serve as efficient decomposers. Wood-boring beetles, dung beetles, and termites are just a few examples of insects that break down organic matter, recycle nutrients, and maintain soil fertility. Insects play a crucial role in the Earth's natural decomposition process, ensuring the efficient breakdown of organic matter and preventing the accumulation of waste, a vital function that would be severely hindered without their presence. Quantifying the impact of waste accumulation without insects is challenging due to the complexity of ecological systems, but insights from various studies provide valuable perspectives. Estimates suggest that the Earth's terrestrial ecosystems produce around 200 billion metric tons of dry plant matter annually, and a significant portion of this biomass requires decomposition to return nutrients and energy to the ecosystem (Bar-On et al., 2018). Studies have demonstrated that insect-mediated decomposition is significantly faster than decomposition driven by other factors like fungi and bacteria, with invertebrate detritivores accelerating the process by up to 20 times compared to microbial activity alone (Gessner et al., 2010).

Based on these estimations, the potential annual accumulation of undecomposed organic matter in the absence of insects could reach tens or even hundreds of billions of metric tons, significantly impacting the global carbon cycle and disrupting nutrient availability in ecosystems. The consequences of such waste accumulation would be profound, including disrupted nutrient cycling as undecomposed organic matter locks up essential nutrients like nitrogen and phosphorus, limiting their availability for plant growth and overall ecosystem productivity. Furthermore, the increased accumulation of organic matter without insects could lead to higher methane emissions during decomposition processes, contributing to climate change.

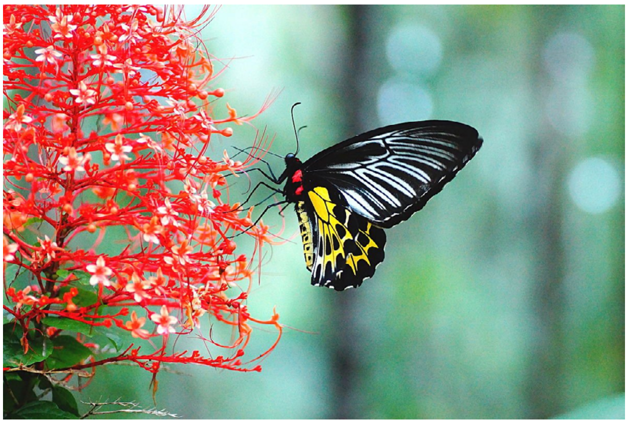

Fig. 4: Southern Birdwing Butterfly (https://twitter.com/amabirdman/status/1666644316759130112)

The ripple effects of insect absence would extend to reduced biodiversity, as a decline in nutrient availability and altered ecosystem functioning could negatively impact various species dependent on decomposed organic matter, ultimately leading to a potential decrease in biodiversity (Ghosh, 1996). Thus, insects emerge as essential components of healthy ecosystems, playing a pivotal role in decomposition processes crucial for waste prevention and nutrient cycling. Their absence would have devastating consequences for the environment, affecting biodiversity, nutrient availability, and potentially contributing to climate change. Therefore, conservation efforts aimed at protecting insect populations are imperative for maintaining a healthy and balanced planet.

In addition to their vital ecological roles, insects are also a vital food source for countless other animals. Birds, reptiles, amphibians, mammals and even other arthropods rely on insects as a primary source of nutrition. From the captivating aerial displays of insectivorous birds to the agile leaps of insect-eating frogs, it is clear that these tiny creatures are essential for sustaining the wider web of life.

## Unraveling the Mysteries: What Makes Insect Biodiversity So Unique?

Insect biodiversity is influenced by a variety of variables, making insect biodiversity genuinely unique. One key factor is their ability to adapt and thrive in diverse habitats, from the depths of oceans to the highest mountaintops. This adaptability allows insects to occupy various niches, resulting in an astounding array of forms, colors, and behaviors. From the brilliantly colored beetles to the velvety wings of moths, each insect has evolved distinct adaptations that enable them to survive and thrive in their specific environments.

Fig. 5: Termite Colony (https://www.istockphoto.com)

Furthermore, the remarkable reproductive capabilities of insects contribute to their incredible biodiversity. Insect colonization is a triumph of rapid reproduction, facilitated by several fascinating adaptations. Another fascinating aspect of insect biodiversity is their incredible range of ecological interactions. Insects have evolved complex relationships with plants, other animals, and even with each other. These complicated relationships contribute to the general stability and functioning of ecosystems, ranging from mutualistic partnerships in which insects give significant services to their host plants to predatory interactions in which insects play an important role in regulating populations of other animals.

Moreover, the study of insect biodiversity with surrounding nature has led to exciting discoveries of new chemical compounds with potential applications in medicine, agriculture, and industry. Insects produce a vast array of bioactive compounds, some of which have been found to possess antimicrobial, antitumor, and anti-inflammatory properties. By delving into the secrets of insect biodiversity, scientists unlock new possibilities for developing innovative therapies, sustainable farming practices, and eco-friendly technologies.

Insect Powerhouse: Exploring adaptability, reproduction, ecology, and potential applications:

Insects, as the undisputed powerhouses of the animal kingdom, showcase a remarkable combination of adaptability, reproductive prowess, intricate ecological interactions, and diverse potential applications. They are survival masters, demonstrating their ability to thrive in diverse environments, from scorching deserts to frigid tundras (Gibbs and Van Der Leeuw, 2018). Furthermore, their evolutionary marvels contribute to their exceptional success, allowing them to adapt to changing environments and evolve rapidly, maintaining their long reign as Earth's dominant life form (Futuyma, 2013).

These survival skills are complemented by the exquisite innovations displayed by insects, ranging from camouflage and mimicry to the development of complex social structures and communication systems, all of which enhance their survival and reproduction (Wilson, 1979). In terms of reproductive prowess, insects possess exceptional capabilities that lead to exponential population growth, allowing them to quickly repopulate and recover from environmental disturbances (Chapman, 2013). The diversity in their reproductive strategies, including parthenogenesis and complex mating rituals, ensures the continued existence of various insect species (Gullan and Cranston, 2010). This prolific reproduction, in turn, plays a vital role in food webs and ecosystem balance, supporting diverse predator populations and influencing plant dispersal (Price, 2012).

Many insects exhibit high reproductive potential, with some species laying hundreds or even thousands of eggs at once. For instance, termite colonies can reach millions of individuals as a single queen lays up to 30,000 eggs per day (Vargo, 2007). Additionally, the short life cycles of many insects, such as houseflies completing their entire life cycle in as little as 10 days (Krafsur, 2009), enable them to swiftly increase their populations. Some insects further benefit from multiple reproduction cycles within a year, allowing them to adapt quickly to changing environmental conditions and exploit newly available resources; mosquitoes, for example, can go through several generations in a single summer (Gubler, 2012). Moreover, non-sexual reproduction mechanisms contribute significantly to insect colonization. Certain species can reproduce asexually through parthenogenesis, establishing new populations even without a mate.

Several intriguing examples highlight the diversity of insect reproductive strategies. Aphids, tiny insects capable of giving birth to live young without mating, can reproduce asexually for hundreds of generations, enabling them to swiftly take over new environments (Simon, 2016). Social insects like army ants form massive colonies with millions of individuals, capable of travelling long distances and quickly depleting an area of its food resources. Additionally, locusts, as swarming grasshoppers, can reach massive numbers, posing a threat to agriculture by consuming crops and causing widespread devastation. Ultimately, the remarkable reproductive abilities of insects contribute to their status as the most diverse and abundant group of animals on Earth, playing a crucial role in maintaining the health and balance of ecosystems worldwide. This output ensures genetic diversity within populations and allows for rapid evolution and adaptation to changing conditions.

Fig.6: *Ephydra hians,* commonly known as the alkali fly
(https://en.wikipedia.org/wiki/Ephydra_hians)

Intricate ecological interactions further define the significance of insects in the natural world. They act as vital pollinators for countless flowering plants, ensuring their reproduction and maintaining the diversity of plant life (Klein et al., 2007). Additionally, as decomposers, insects play a crucial role in breaking down organic matter and returning nutrients to the soil, contributing to overall ecosystem health (Bardgett and van der Putten, 2014). Occupying diverse positions in food webs as both predators and prey, insects contribute to the complex balance and dynamics of ecosystems (Price, 2012).

Beyond their ecological roles, insects offer a plethora of potential applications. They serve as biocontrol agents, playing a valuable role in controlling agricultural pests and offering a sustainable alternative to chemical pesticides (Van Lenteren et al., 2003). Moreover, insects present a promising food source, with potential implications for providing sustainable and environmentally friendly options for the future (Van Huis et al., 2013). In the realm of medicine, insect-derived compounds are being explored for their potential use, showing promising results for various diseases (Lee et al., 2010). This exploration underscores the profound importance of insects in the natural world and highlights the pressing need for their conservation.

## Exploring the Richness: Where to find Insect Biodiversity:

Now that we have delved into the unique aspects of insect biodiversity, it's time to embark on a journey to explore the richness of these fascinating creatures. Insects can be found in a wide range of habitats, each offering a unique array of species and ecological niche. The tropical rainforest is one of the richest and most diverse habitats for insect biodiversity and it harbor a staggering number of insect species. Estimates suggest that there could be 10 million or more insect species in these forests, although only a fraction of them have been described (Mora et al., 2011). Insects are ectothermic, meaning they rely on external heat sources to regulate their body temperature. The consistently warm temperatures in tropical rainforests provide an ideal environment for them to thrive. These lush and dense environments are home to an incredible variety of insects, from colorful butterflies to camouflaged stick insects. The diverse vegetation provides abundant food sources and diverse microhabitats for insects to thrive and evolve (Erwin, 1982).

However, the wonders of insect biodiversity are not limited to the rainforest. Insects, with their astonishing ability to adapt and thrive in diverse and often extreme environments, have a global presence, spanning from the scorching deserts of the Sahara to the frigid tundras of the Arctic (Capinera, 2011). This adaptability is exemplified by remarkable species such as the Ephydra fly, which thrives in the seemingly uninhabitable environment of petroleum wells, showcasing the incredible limits of insect resilience (Horodyski et al., 2014). Noteworthy adaptations include the production of cryoprotectants by some insects, like the Alaskan beetle, preventing their body fluids from freezing in subzero temperatures (Zachariassen, 2002).

Additionally, certain insects, such as the desert locust, exhibit desiccation tolerance, surviving long periods of dehydration by entering a state of diapause where their metabolic processes significantly slow down (Chown and Nicolson, 2004). Furthermore, some insects, like the Pompeii worm, demonstrate extreme heat resistance, withstanding temperatures exceeding 100°C, enabling them to thrive in volcanic environments (Cui et al., 2017). Even in our backyards, a world of insect diversity is waiting to be discovered. Observing and documenting insects in our local environments can contribute to citizen science initiatives (kosamala et al., 2016) and help build a better understanding of insect distributions and population trends, with platforms like iFoundButterflies.org (Kunte et al., 2023) providing valuable opportunities for individuals to contribute to the collection of information. This data

Fig. 7: Butterflies of India website (https://www.ifoundbutterflies.org/)

significantly aids in the broader effort to enhance our understanding of insect distributions and population trends, ultimately supporting initiatives for their conservation.

In addition to natural habitats, certain man-made environments also harbor significant insect biodiversity. Urban areas, often perceived as concrete jungles devoid of life, can surprisingly harbor a rich diversity of insects, with parks, gardens, and green spaces providing essential habitat for these tiny creatures, offering them food, shelter, and breeding opportunities (Beninde et al., 2015). These urban oases contribute significantly to maintaining insect populations and fostering a healthy ecosystem, even amidst the built environment. Studies have highlighted the importance of urban green spaces for insect biodiversity, showing that urban areas support a remarkable variety of insect species, as demonstrated in a 2019 review published in Biological Conservation (Wenzel et al., 2019). Additionally, urban green spaces can act as stepping stones, facilitating the movement of insects between fragmented habitats and promoting the exchange of genetic material (Gilbert-Norton et al., 2010). Furthermore, insects play a vital role in pollinating urban plants, contributing to the production of fruits, vegetables, and flowers, thereby enhancing the aesthetics of the urban environment (Frankie and Ehler, 1978). To actively promote insect biodiversity in urban environments, adopting sustainable gardening practices such as choosing native plants, avoiding pesticides, providing nesting sites, and minimizing water use can significantly enhance insect populations in urban gardens (Baldock et al., 2015). Creating insect-friendly habitats, such as establishing green roofs, meadows, and other features with diverse vegetation, can provide a range of habitats for different insect species (Frankie and Ehler, 1978). Additionally, educating and raising awareness about urban insects can foster community-based conservation efforts and encourage individuals to contribute to their protection (Crutzen, 2017). Thus, exploring insect biodiversity expands our knowledge and appreciation of the natural world and raises awareness of the importance of conservation efforts.

Fig.8: Monarch Butterfly Biosphere Reserve, Mexico (https://whc.unesco.org/en/list/1290/)

### Preserving and Protecting: Giving insect biodiversity the platform it deserves:

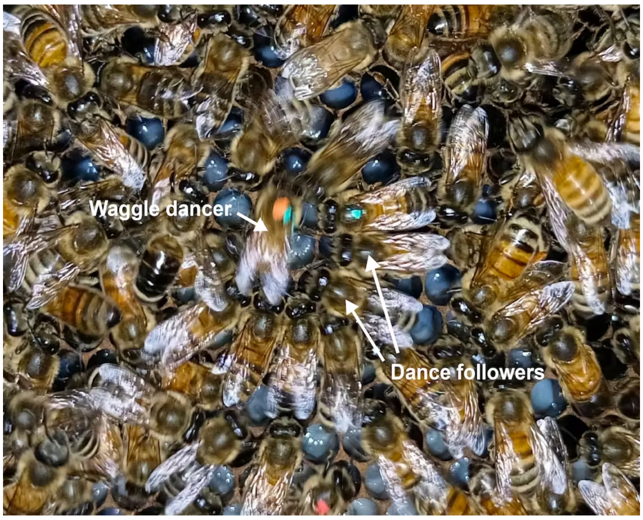

Fig. 9: Waggle dance of Honey bee (https:/theconversation.com)

Now that we have explored the vast riches of insect biodiversity and discovered the incredible wonders that lie within, it is time to shift our focus towards preserving and protecting these extraordinary creatures. As we continue to uncover the secrets of their intricate ecosystems, ensuring their continued survival is becoming increasingly important. Insect biodiversity faces numerous threats primarily driven by human activities, including habitat destruction, pollution, climate change, and pesticide use, all of which pose significant challenges to these delicate creatures on a daily basis. Without intervention, there is a considerable risk of losing countless species crucial to the natural world, as they provide invaluable ecosystem services such as pollination and decomposition. The alarming rate of land-use change, primarily for agriculture and urbanization, leads to the destruction and fragmentation of insect habitats, disrupting populations and diminishing their ability to disperse and find resources (Dirzo et al., 2014). The use of pesticides, herbicides, and other pollutants has a devastating impact on insect populations, either directly causing their death or harming their reproductive systems, ultimately resulting in population decline (Goulson, 2013). Furthermore, rising temperatures and changes in precipitation patterns disrupt insect life cycles, pushing them to their limits and causing range shifts, population declines, and even extinctions (Parmesan, 2006).

One of the most effective ways to conserve insect biodiversity is through the establishment of protected areas. These designated spaces provide a safe haven for insects and serve as important research sites for scientists to study these often-overlooked creatures. By advocating for creating and maintaining these protected areas, we can ensure that future generations can marvel at the beauty and importance of insect diversity.

Fig 10: Conservation of Insect Biodiversity (https://www.istockphoto.com)

Furthermore, individuals need to take action in their own lives to support insect conservation efforts. Small changes, such as reducing the use of pesticides, creating insect-friendly habitats in gardens, and practising sustainable agriculture, can significantly impact be promoting and protecting insect biodiversity. Addressing the multifaceted challenge of preserving insect biodiversity requires more than individual actions; governments and policymakers play a crucial role in creating a supportive framework and implementing effective conservation strategies that impact vast landscapes, agricultural practices, and public awareness. Policy-driven solutions include habitat protection through the designation of protected areas, restriction of harmful land-use practices, and implementation of restoration projects (Fischer et al., 2021). Governments can also address the issue by implementing stricter regulations on pesticide use, promoting alternatives, and supporting research on safer methods of pest control (IPBES, 2019). In addition, policymakers can incentivize sustainable agricultural practices, such as crop diversification, organic farming, and reduced tillage, to benefit insect populations (Garibaldi et al., 2020). Furthermore, governments can play a vital role in raising public awareness about the importance of insects and promoting actions for their conservation (Crutzen, 2017). For instance, in India, the government has launched initiatives like the National Mission for Sustainable Agriculture and the National Biodiversity Action Plan, which promote organic farming, biodiversity conservation, and research on pollinator-friendly practices. In the European Union, the Pollinators Initiative has been implemented, encompassing measures to improve habitat quality, promote sustainable agriculture, and support research on pollinator health.

By implementing and enforcing regulations that prioritize conservation, we can create a harmonious balance between human activities and the needs of insect populations. Education and awareness campaigns can also help shape public opinion and generate support for insect conservation efforts. In Insects, often overlooked and underestimated, play a crucial role as the cornerstone of healthy ecosystems, providing vital services such as pollination, decomposition, and pest control; however, these essential creatures face numerous threats, including habitat loss, climate change, and pesticide use. Nearly 41% of insect species are threatened with extinction, with some regions experiencing declines exceeding 75% (Dirzo et al., 2014), and the State of the World's Biodiversity for Food and Agriculture report in 2019 emphasizing the critical role of insects in food production and warning of potential food insecurity due to pollinator decline (FAO, 2019), underscores the urgency of taking action to conserve insects.

Fortunately, there are various ways individuals can get involved, such as supporting citizen science initiatives like iFoundButterflies (Kunte et al., 2023) and Bumble Bee Watch (Vanbergen et al., 2015), which provide valuable opportunities to contribute data vital for understanding insect populations and trends. Additionally, creating insect-friendly habitats by planting native flowers and avoiding pesticide use in gardens, balconies, or window boxes can offer crucial resources and shelter for diverse insect species. Advocating for policy change to support sustainable land management practices, reduce pesticide use, and protect critical habitats is another impactful step, as is educating others about the importance of insects and the threats they face. By raising awareness within your community and inspiring collective action, we can work together to create a future where insects are valued and protected, unlocking the mysteries and marvels of these incredible creatures for generations to come.

## Success Stories in Insect Biodiversity Conservation in India and Beyond:

Insects, vital components of healthy ecosystems due to their crucial roles in pollination, decomposition, and pest control, are globally facing significant threats from habitat loss, pollution, and climate change. Fortunately, there is hope for the future as various successful regulatory programs have emerged to protect and strengthen insect biodiversity. In India, the National Mission for Sustainable Agriculture (NMSA), launched in 2014, actively promotes sustainable agricultural practices beneficial to pollinators and other insects. It encourages the adoption of organic farming techniques, provides financial assistance to farmers implementing pollinator-friendly practices, and raises awareness about the importance of insect conservation, resulting in increased pollinator populations and crop yields in participating regions. Beyond India, the European Union's Pollinator Initiative, initiated in 2018, addresses pollinator decline in Europe through measures like research, habitat restoration, and awareness campaigns, funding successful projects such as pollinator-friendly corridor creation and innovative pest control methods. Furthermore, the Monarch Butterfly Biosphere Reserve, established in 1980 as a UNESCO World Heritage Site in Mexico, protects the monarch butterfly's overwintering grounds and has successfully stabilized their population after a significant decline through strict regulations and conservation efforts.

Advocates of the Unseen: How Insect Biodiversity enhances our understanding of the Natural World

Insects, with their incredible diversity and abundance, are not only fascinating creatures in their own right but also serve as vital indicators of the health of ecosystems. Their intricate relationships with plants, animals, and other insects provide valuable insight into the functioning of the natural world. One of the key ways in which insect biodiversity enhances our understanding is through its role in pollination. Bees, butterflies, and other pollinators transfer pollen from one flower to another, enabling plant reproduction and the production of fruits and seeds. This process is not only essential for the survival of numerous plant species but also for the production of a significant proportion of the world's food crops. By studying the interactions between insects and plants, scientists can gain insights into how to manage and protect these crucial pollinators.

Insects also play a crucial role in nutrient cycling and decomposition. They break down organic matter, such as dead plants and animals, and return nutrients to the soil. Without insects, these processes would significantly slow down, impacting the overall health and productivity of ecosystems. Understanding the intricate relationships between insects, microbes, and plants in these decomposition processes is key to maintaining healthy soil and sustainable agricultural practices. Furthermore, the study of insect behavior can offer valuable insights into complex ecological interactions. Communication and mating rituals to predator-prey relationships and territorial behavior, insects display a wide variety of fascinating behaviors. By observing and understanding these behaviors, scientists can further unravel the intricate web of life that underpins our ecosystems.

In addition to their ecological significance, insects offer remarkable promise for medical and technological advancements. These tiny creatures harbor a vast array of unexplored compounds with potential applications in various fields, waiting to be discovered and harnessed. In the realm of insect-derived pharmaceuticals, their constant exposure to pathogens has led to the development of potent antimicrobial defenses. Compounds such as defensins and cecropins isolated from insects exhibit promising activity against bacteria, fungi, and viruses, providing alternatives to conventional antibiotics (Zasloff, 2002). Moreover, research indicates that insect-derived compounds possess anticancer properties, with potential anti-cancer drugs identified in bee venom and firefly luciferase (Chassaing et al., 2018). Additionally, venom from various insects, including scorpions and wasps, contains peptides and proteins with analgesic effects, offering alternatives to traditional pain medications (Berenbaum, 2017).

Beyond the realm of pharmaceuticals, insects contribute to technological applications as well. Insect silk, known for its strength and elasticity, holds potential for bioengineering applications such as sutures and tissue scaffolds (Altman et al., 2012). Insects' highly sensitive olfactory and gustatory receptors can be harnessed for developing biosensors capable of detecting explosives, drugs, and environmental pollutants (Leal et al., 2013). Moreover, the remarkable agility and adaptability of insects inspire the development of biomimetic robots, with potential applications in search and rescue operations and environmental monitoring (Zhang et al., 2015). Furthermore, their unique adaptations, such as the ability to fly or walk on walls, have inspired innovations in engineering and robotics. By studying the vast array of insect species, researchers can unlock new possibilities for human well-being and technological development. In conclusion, the unseen world of insect biodiversity provides us with a wealth of knowledge about the natural world. By investing in the study and conservation of insect biodiversity, we protect these incredible creatures and pave the way for a deeper understanding of the ecosystems that sustain us all.

## Concluding Thoughts: Embracing the wonder and importance of Insect Biodiversity:

As we conclude our exploration of the untold wonders of insect biodiversity, it becomes evident that these small creatures hold immense significance in our understanding of the natural world, from their pivotal role in pollination and nutrient cycling to their intricate behaviors and potential for medical and technological advancements. In recognizing their wonder and importance, it is essential to embrace the need for conservation and protection of these incredible creatures to ensure the continued functioning of ecosystems and the sustainability of our planet.

Participating in volunteer programs involving habitat restoration, native plant planting, and invasive species removal offers hands-on support for insect habitats. Transforming your garden or balcony into an insect haven by planting native flowers, shrubs, and trees that provide food and shelter for various species is a practical approach to creating habitat spaces. Additionally, minimizing the use of harmful pesticides, opting for organic pest control methods, and creating a compost bin to recycle food scraps and yard waste contribute to a healthier environment, attracting decomposer insects like beetles and worms (Footit and Alder, 2009).

Educating others about the importance of insects and the threats they face is a crucial aspect of promoting conservation. This can be achieved through spreading awareness on social media, participating in community events, or giving talks at schools and local organizations. Inspiring the next generation of conservationists by engaging children in insect-related activities like butterfly watching or building bee hotels helps build a lasting commitment to environmental stewardship. So, our collective actions, no matter how small, can have a significant impact on the future of insect biodiversity, actively supporting conservation initiatives, fostering insect-friendly environments, and raising awareness all contribute to ensuring the continued survival of these vital creatures and to a healthier planet for all. By becoming advocates for the unseen world of insects, we can make a difference in supporting and protecting the wonders of insect life, appreciating and safeguarding their incredible diversity, and unlocking the secrets they hold for the benefit of our planet and future generations.

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# Sustainable management of soil-dwelling pests

***Devaramane Raghavendra, Ramesh, K. B., Meena, P. N., Bhagyashree, S. N., Ranjith H V and Subhash Chander***

Sustainable agriculture is undoubtedly one of the most important concerns nowadays, considering both human population demography and evidence depicting that crop productivity which relies on chemical control is plateauing. Since conventional agriculture poses increasing environmental and health risks, ecological research is providing promising solutions for crop protection against herbivore pests. Whereas most research has concentrated on above-ground systems, several major crop pests feed exclusively on roots (Kergunteuil et al., 2016). Many of the insects spend at least a small part of their life cycle in contact with the soil whereas, true soil-dwelling pests spend most of their developmental time in this medium. Soil-borne pests are often difficult to monitor and control due to the logistical chore of sampling their populations or the use of control tactics on them. Widespread use of soil insecticides is inevitable despite their non-targeted effects and environmental impact. This results from a lack of information about the actual impact of the target pests on crops and a lack of practical and cost-effective methods for identifying infested fields. A commonly used tactic to control soil pests namely, insecticide application to soil can be very disruptive and negatively impact the functional diversity of soil communities. As a result, a comprehensive approach is required to keep these often-invisible pest populations under control and below economic thresholds. Agricultural land accounts for 25% of the earth's terrestrial surface and is a major contributor to global ecosystem health (Landis, et al., 2000). Annually, around 2 million tonnes of pesticides are being used worldwide, with China being the largest consumer, followed by the United States and Argentina, which is rapidly increasing. However, global pesticide use is expected to increase up to 3.5 million tonnes by 2020 (Sharma et al., 2019). Annual crop losses resulting from insect damage could exceed 15%. Root pests have always caused extensive crop damage and are still responsible for a large portion of global yield loss. The grape phylloxera, the root-feeding aphid Daktulosphaira vitifoliae, had nearly wiped out the entire European grape production. Wireworms (Coleoptera: Elateridae) feed a variety of crops, including cereals, potatoes, carrots, sugar beets, and fruit orchards. The annual cost of the damage caused by the western corn rootworm (*Diabrotica virgifera virgifera*) in Europe and the United States could be much higher than $1 billion. Damage caused by cane grubs (*Dermolepida albohirtum*) cost sugarcane producers by more than $10 million in the southern hemisphere. In comparison to above-ground herbivores, developing sustainable solutions to reduce below-ground herbivores is scarce. One of the main reasons is undoubtedly their ambiguous life cycle, which leads to the "out of sight, out of mind" paradigm (Hunter, 2001). The two pillars of agroecosystem health optimization are habitat manipulation and soil fertility enhancement. These two include several strategies for dealing with soil arthropods and are discussed below.

## Cultural methods

1. Reduce and/or disrupt pest habitat in and around crop
2. Field sanitation, which includes burning previous crop debris and destroying non-crop pest habitat, reduces insect pests that overwinter on plants growing near field edges. Tillage can disrupt

the life cycle of insect pests, and expose them to predators, which overwinter in the soil as eggs, pupae, or adults. Excessive tillage can hasten the decomposition of organic matter in the soil and deplete the food source. Subterranean and foliar insect pests are both affected by tillage practices. In natural systems, infrequent disturbance of soils preserves food webs as well as the diversity of organisms and habitats. Regular disturbance of agricultural soils disrupts ecological linkages, allowing adapted pest species to proliferate without being dampened by natural controls.

3. Crop planting can be adjusted in both space and time to limit the growth of large pest populations.
4. Divert pest populations away from crops.
5. Reduce yield loss due to insect damage: Planting genetically resistant and tolerant crop varieties can improve host tolerance to damage.
6. Resistant cultivars: Breeding cultivars and rootstocks resistant to specific pests and diseases have long been used to control below-ground pests. Rather than directly breeding for disease resistance, another strategy is to breed crops for root exudate characteristics that suppress pests, either by producing bioactive compounds or by recruiting disease-suppressive microbes.
7. Planting practices: In the case of potatoes, planting depth is important because the potato tuber moth is unable to lay eggs through soil cracks and thus prevents infestation.
8. Mulches: Farmers use organic, synthetic or plastic and natural materials for mulching. Straw mulch can reduce Colorado potato beetle activity in the early season by creating a micro-environment that increases the number of predators such as ground beetles, lady beetles, and lacewings. Mulching helps to keep weeds at bay.
9. Habitat diversification: Many pests prefer to feed on particular host plant species. This preference can be used to reduce pest pressure on the crop. Crop rotation, intercropping, trap cropping, and strip cropping can significantly reduce pest load. Cover crops are typically planted to sequester soil nutrients while also adding organic matter, preventing erosion, and adding nutrients. Beneficial insects can find food and shelter in cover crops. Trap crops draw pest species away from the main crop into a defined site where they can be destroyed.
10. Water management: Irrigation can suppress soil-inhabiting pests by suffocating them or exposing them to bird predation on the soil surface. When high-humidity microenvironments are created, several naturally occurring insect pathogens, particularly insect-pathogenic fungi, provide effective pest suppression. Irrigating potato crops during tuber formation can help to reduce potato scabs. Furrow irrigation, rather than sprinkler irrigation, can control anthracnose of beans, early blight, and charcoal rot of potatoes.
11. Soil organic matter: The ability of host plants to resist or tolerate insect pests and diseases is linked to optimal physical, chemical, and, most importantly, biological soil properties. Soils with a high organic matter content and active biological activity have good soil fertility, as well as complex food webs and beneficial organisms that prevent infection. Several studies have also found that farming practices that cause nutritional imbalances can reduce pest resistance (Magdoff and van Es, 2000).

## Ecologically-based pest management (EBPM) strategy

**The goal** of EBPM is to create soil and above-ground conditions that encourage healthy plant growth, suppress pests and promote beneficial organisms. Fertility practices replenish and maintain a high level of soil organic matter while also increasing the number and diversity of soil macro and microbiota (McGuiness, 1993).

## Pest suppressive mechanisms

1. Competition: High levels and diversity of soil microbes reduce soil-borne pathogen populations or infectivity. Microbiota-rich soil reduces the risk of

epidemic outbreaks caused by soil-borne pathogens (Campbell, 1994).

2. Induced resistance: Plants can develop resistance to a wide range of soil-borne and airborne pathogens when treated with compost, compost extracts, or certain microbes (both pathogenic and non-pathogenic) (Kuc, 2001).

3. Natural enemies: Feeding the soil encourages the growth of soil mesofauna, which can serve as alternate prey for natural enemies like carabid beetles and spiders, allowing them to build large populations that can respond quickly to pest outbreaks (Purvis & Curry, 1984).

4. Nutrient supply buffering: Humus and microbial biomass provide a more gradual and balanced release of nutrients than synthetic fertilizers. Crops are more resistant to pests and diseases when their mineral nutrition is more balanced.

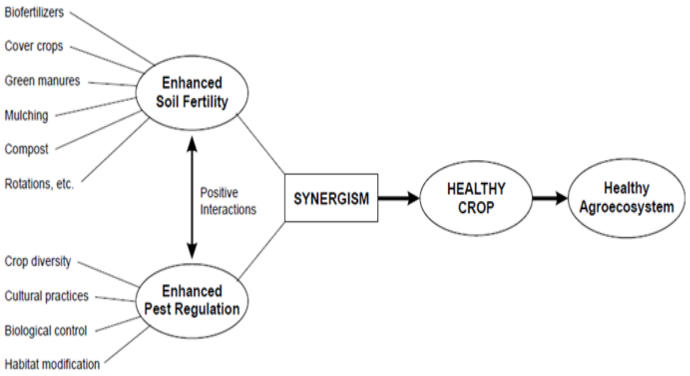

Fig.1 The potential synergism between soil fertility management and IPM

5. Reduced stress: Soils with high humus and biodiversity have a greater capacity to absorb and store water, reducing water stress. Probably due to regulated C and N metabolite release from hairy vetch decomposition. Cover-cropped tomato plants displayed distinct expression of selected genes, resulting in more efficient utilization and mobilization of C and N, improved disease resistance, and increased crop longevity.

6. Soil solarization: Natural solarization or Ultraviolet-protected plastic is recommended in some crops. Certain types of organic matter can be also added. Residues from brassica crops such as broccoli and mustard in the solarization process release plenty of volatile compounds that are toxic to many pests. Soil solarization can provide good pest control up to 8 to 10 inches deep.

7. Pheromone traps: Mainly used for monitoring, mass trapping and mating disruption.

8. Bio fumigation: The process of growing, macerating, or incorporating specific Brassica or related species into the soil, resulting in the release of isothiocyanate compounds (ITCs) from the hydrolysis of glucosinolate (GSL) compounds found in plant tissues (Kirkegaard et al., 1997). To control soil-borne pests and diseases, use biologically active plants as green manures, cover crops, or rotation crops. Glucosinolates are organic compounds found in broccoli, cauliflower, mustard, rapeseed, and horseradish. ITCs are general biocides that behave similarly to commercial pesticides at high concentrations. Mustard and sorghum are two common bio-fumigant crops. The fumigation effect is caused by glucosinolates (GSLs) or cyanogenic glucosides, which are found in Brassicas and specialized sorghums. When the biofumigant crop is macerated, the enzyme myrosinase breaks down GSLs and produces isothiocyanates (ITCs) immediately. Many soil-borne pests, diseases, and weed seedlings are highly susceptible to the toxicity of ITCs. To keep ITCs in the soil, the biofumigant crop must be finely macerated, directly incorporated, and the soil surface sealed with irrigation, rain, or rolling. Potential benefits include soil erosion prevention, nutrient recycling, improved soil structure, and soil organic matter preservation. Mustard can also be used to repel many insects (wireworms) and pests.

9. Biological control: Because the distribution of root herbivores in soils is relatively limited, they are more persistent locally than above-ground pests, favoring

constant and localized applications of bio-control agents in the field. Biological pest control is based on two primary forces:

a) Bottom-up (i.e., the effect of plants on herbivores)

b) Top-down pest control (the effect of predators and parasites on herbivores) (Hairston et al.,., 1985; Price et al.,., 1980)

The inability of microbes to persist in habitats exposed to ultraviolet radiation or desiccation is a key constraint of microbial control, but soil, which affords a conducive habitat for microbes and a reservoir for entomopathogens, should be a better environment for microbial control Hochberg and Holt (1997). Approach used to optimize the isothiocyanate-related biofumigation potential of incorporated Brassica green manures. (Matthiessen and Kirkegaard, 2004).

10. Botanical pesticides

Azadirachtin-treated soil was repellent to wireworms for up to 17 days after application (Cherry and Nuessly, 2010). Commercially available botanical pesticides are derived from plants such as pyrethrum (*Tanacetum cinerariifolium*), neem (*Azadirachta indica*), sabadilla (*Schoenocaulon Officinale*), tobacco (*Nicotiana tabacum*), and ryania (*Ryania speciosa*). Garlic (*Allium sativum*), turmeric (*Curcumalonga*), rosemary (*Rosmarinus officinalis*), ginger (*Zingiber officinale*), and thyme (*Thymus vulgaris*) are other plants with pesticidal properties (Arnason et al., 2012).

**Conclusion and future directions**

More research comparing soil arthropod pests on plants treated with synthetic versus organic pesticides and fertilizers along with several environmentally friendly integrative control options is specifically required. Understanding the underlying effects of extensive agriculture on plant health may result in the development of new and improved integrated pest management and integrated soil fertility management programme designs. If achieved with a clear-cut knowledge about the relationships between soil fertility and insect pest attack, we will be better positioned to convert conventional crop production systems to those that incorporate agro-ecological strategies to optimize soil organic fertilization, crop diversity management, and more natural pest control systems without incurring yield penalties.

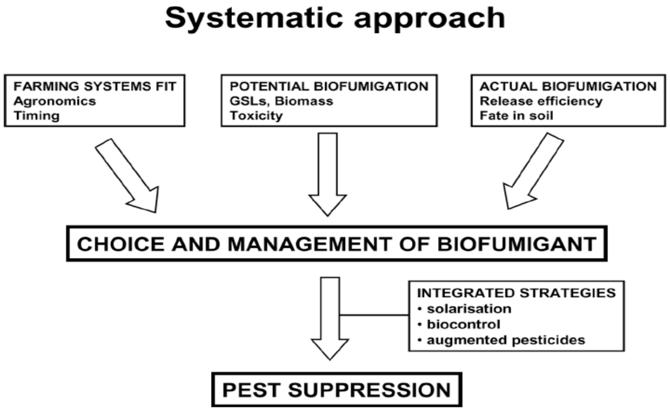

Fig. 2. Diagrammatic depiction of the systematic

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# Molecular Mechanisms of Phase Change in Desert Locusts

*Rudra Gouda, M. N., Sachin, S. Suroshe, and Subramanian, S.*

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Locusts, a type of short-horned grasshopper in the Acrididae family, usually exhibit solitary behavior but can transform into gregarious swarms under specific conditions. In English, the term "locust" refers to grasshopper species that, when crowded, undergo density-dependent phenotypic plasticity, forming swarms from groups of immature hoppers (Shrestha et al., 2021). Boris Uvarov, a pivotal figure in the foundation of the Anti-Locust Research Centre, introduced the concept of phase polymorphism in 1921 to elucidate the changes observed in locusts. Uvarov focused on the migratory locust, demonstrating that the previously considered separate species, *Locusta migratoria* and *L. danica* L., actually represented two phases termed solitaria and gregaria. Charles Valentine Riley and Norman Criddle played significant roles in understanding and controlling locusts, as documented by Egerton in 2013.

Solitary locusts prefer isolation, while gregarious locusts thrive in swarms, exhibiting social behaviour. Swarms in locusts are a response to overcrowding, with heightened stimulation of the hind legs leading to increased serotonin levels. This hormonal shift results in notable changes such as alterations in coloration, intensified feeding, and enhanced breeding. The transition to the swarming form occurs after multiple contacts per minute sustained over four hours. Massive locust swarms can reach staggering numbers, comprising billions of individuals and covering extensive areas, with population densities reaching up to 80 million per square kilometre (200 million per square mile). The release of serotonin during contacts among desert locusts induces mutual attraction, a crucial factor in the formation of swarms. The initial bands of gregarious hoppers are termed "outbreaks." When these bands merge into larger groups, it's referred to as an "upsurge." Continued aggregation of upsurges from separate breeding locations on a regional level is known as a "plague." During outbreaks and early stages of upsurges, only a portion of the locust population becomes gregarious, with scattered bands of hoppers spread across a wide area. Over time, the insects become more cohesive, and the bands concentrate in a smaller area.

During the desert locust plague spanning Africa, the Middle East, and Asia from 1966 to 1969, locust numbers surged from two to 30 billion over two generations. However, the affected area decreased significantly from over 100,000 square kilometers (39,000 sq mi) to 5,000 square kilometers (1,900 sq mi). In 1980, a substantial African locust outbreak impacted over 360,000 hectares in northern Senegal (Walsh 1986). The historically significant desert locust has invaded 31 million square kilometers across 52 countries in Africa, the Near East, and Southwest Asia (Anonymous, 1968). Australia faced a major outbreak in 1998 (Hinton and library, 2007). In 2001, locusts affected southern Russia and concurrently plagued China's Yellow River basin, Bohai coast, and northern Xinjiang. From 2003 to 2004, China experienced a vast locust impact, resulting in substantial crop losses. In 2010, New South Wales saw an extensive locust-infested area of about 390,000 square kilometers, causing significant economic losses (Miao et al., 2015). In 2013, locusts from Egypt reached Israel, covering 800 hectares of desert, affecting half of Madagascar, and causing food shortages (Marei et al., 2015). The 2020 locust outbreak, identified by the Food and Agriculture Organization (FAO) as the most severe in 70 years, devastated 70,000 hectares of land in Somalia and Ethiopia, highlighting the global and varied impacts of locust outbreaks on agriculture and food security (FAO, 2020)

### What triggers them to form a swarm

Guaiacol, a compound found in the gut of desert locusts, is produced through the breakdown of plant material by the gut bacterium *Pantoea agglomerans*. This process contributes to the production of pheromones that are involved in causing locust swarming (Dillon et al., 2002). Research conducted by Guo et al. (2013) has shown that serotonin plays a role in promoting the transition to the solitariness phase in migratory locusts. During swarming, gregarious adult locusts exhibit migratory behaviour where they move in the direction of the wind. They can cover distances of approximately 150 km per day. The wind direction determines the displacement of the adult locusts and swarms.

### Phase polyphenism and its evolution in locusts

Changes in locusts' adaptive traits are closely linked to shifts in their environment. For instance, gregarious locusts typically demonstrate reduced fecundity and engage in more extensive migratory flights compared to their solitary counterparts. Gregarization also impacts other traits, including development, longevity, lipid accumulation, and the size of eggs or offspring. This shift towards allocating energy to flight rather than reproduction is a consequence of the gregarious phase. A recently reported example of an adaptive phase trait is the cold hardiness of locust eggs. Solitary locust eggs with enhanced cold hardiness have a better chance of surviving winter, contributing to the maintenance of their population size in the subsequent year. Changes in body colour and behaviour are common responses to fluctuations in population density. Recent research, utilising phylogenetic analyses, theoretical models, and population genetics, has provided insights into the evolutionary history of locusts and the mechanisms driving their adaptations. Phase-related characteristics exhibit significant similarities among different locust species within each monophyletic group. The evolution of swarming behaviour in locusts has independently occurred multiple times in various lineages globally, indicating that phase change is a convergent phenomenon. Theoretical studies suggest the roles of interspecific interactions, such as predation, and intraspecific interactions, like cannibalism, in the evolution of density-dependent phase polyphenism. Genetic variation between non-outbreaking and outbreaking populations of *Locusta migratoria* indicates that historically outbreaking populations display a higher degree of parentally inherited density-dependent phase changes and greater gene flow. Mitochondrial genomic evidence indicates that *L. migratoria* exhibits lower genetic differentiation, with two lineages displaying similar degrees of phase polyphenism, likely contributing to the maintenance of the south-north cleavage pattern. However, the specific genetic factors responsible for the evolution of locust-phase polyphenism remain unknown. The availability of genomic resources has opened up new avenues for future investigations into the genetic basis of locust phase change.

### Omics of Locust Phase Change

#### Genetic Analysis of Locust Phase Change

The conditions that trigger a phase transition in locusts may vary from those that sustain it, and the apparent disparities between the extreme phases may be a consequence of the phase shift rather than being the cause of it. Consequently, the task of identifying biochemical and molecular markers of locust phase transition becomes increasingly intricate. Recent studies have utilised advanced methods in functional genomics, including transcriptomics, microarrays, proteomics, differential displays, and metabolomics, to investigate the biochemical and molecular alterations linked to locust phase transition. Nevertheless, these investigations have offered only restricted understanding of their molecular roles, although providing vital information regarding the genetic pathways that regulate alternate phenotypes.

### Genes and Transcriptomic Profiles

The study of phase-related gene expression in *Schistocerca gregaria* involved analysing brain tissue using differential display reverse transcriptase polymerase chain reaction. This technique detected eight distinct bands, one of which displayed an 80% similarity in sequence with the SPARC protein found in Drosophila melanogaster. The precise contribution of SPARC to locust phase transition is still unknown, despite its established significance in nematode worm motility and shape, as noted by Rahman et al. in 2003. At the same time, a separate Expressed Sequence Tag (EST) database was created for *S. gregaria*. A study identified and categorised 214 Differentially Expressed Genes (DEGs) into five Gene Ontology (GO) terms: multicellular organismal development, neurological system processes, stress response, precursor metabolite and energy generation, and cellular macromolecule biosynthesis. Individual locusts that were alone showed improved resistance to the ageing process, as indicated by the increased activation of genes related to antioxidant mechanisms, detoxification, and the renewal of anabolic processes. Conversely, sociable desert locusts exhibited a greater number of transcripts associated with sensory processing, nervous system development, and plasticity. An analysis of data from *S. gregaria* and *L. migratoria* showed that solitary and gregarious locusts had comparable patterns of differential gene expression. These findings indicate that there are shared molecular pathways that drive locust phase shift, even among distinct evolutionary lineages, as explained by Badisco et al. (2011).

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### Proteins and Peptidomes

Several studies have examined the protein and peptidome profiles linked to the transformation of locusts between different phases. Researchers employed 2D gel electrophoresis to produce polypeptide maps of hemolymph extracted from fully developed adult male locusts (*S. gregaria*) in a specific investigation. A total of 238 polypeptide sites were discovered, out of which 20 locations showed differential expression between solitarious and gregarious locusts. Significantly, three sites were exclusive to solitarious locusts, whereas 17 were exclusive to gregarious locusts. Field observations of solitary and social locusts confirmed the phase-specific manifestation of these 20 polypeptide spots. After 15 days of treatment with a juvenile hormone (JH) analogue, nine out of the 17 polypeptide spots related to gregarious behaviour were suppressed. Nevertheless, there was a scarcity of data on the molecular weight and isoelectric point of these proteins, and their actual identities remained unknown, as described by Wedekind-Hirschberger et al. in 1(999).

Researchers combined high-performance liquid chromatography (HPLC) with matrix-assisted laser desorption/ionization time-of-flight mass spectrometry (MALDI-TOF MS) to analyse the peptidomes of the solitarious and gregarious phases of *S. gregaria* in a separate study. From this study, two primary proteins were identified: a 6-kDa peptide and a serine protease inhibitor called SGPI-2. These proteins showed varying levels of expression in the two stages. The 6-kDa peptide, provisionally designated as PRP (phase-related peptide), was found in large quantities in the hemolymph of adults raised in a group, with a concentration of 0.1 mM. As the locusts shifted from being social to solitary over multiple generations, the level of PRP gradually declined. Despite thorough study, the exact role of PRP remained uncertain. It had no protease inhibitory, antibacterial, or antifungal properties, and had no effect on yellow protein expression, cuticle pigmentation, or the synthesis of the pheromonal chemical phenylacetonitrile. The eggs absorbed PRP, and gregarious females had higher PRP concentrations than eggs from solitarious *S. gregaria*. Immunocytochemistry and mass spectrometry analysis demonstrated robust positive immunostaining in the follicle cells of the ovary and the seminal vesicle tubes of the male accessory gland complex in *S. gregaria*. The findings indicate that PRP may act as a maternal factor in defining the phase state of the offspring. However, additional trials are needed to determine its exact role, as reported by Rahman et al. in (2008).

## Metabolites and Metabolomics

Metabolomics, when used alongside transcriptomics and proteomics, is a valuable method for studying metabolic patterns in living organisms. This approach offers important insights into biological processes and the function of genes. Metabolomic analysis encompasses the utilisation of several analytical instruments, including gas chromatography/ mass spectrometry (GC/MS), high-performance liquid chromatography (HPLC), nuclear magnetic resonance (NMR) spectroscopy, mass spectrometry (MS), and optical spectroscopic techniques.

A particular investigation employed high-resolution NMR spectroscopy to reveal the metabolic patterns in the hemolymph of gregarious and solitarious *S. gregaria* locusts. This approach enabled the detection of more than 20 naturally occurring substances, such as trehalose, ethanol, lipids, amino acids, organic acids, and the polyamine putrescine. Lenz et al. (2001) reported that solitarious nymphs had higher concentrations of putrescine, trehalose, and lipids, whereas gregarious nymphs showed increased amounts of acetate and ethanol.

### Molecular Regulation of Body Coloration

During the phase transition of locusts, noticeable fluctuations in body colour are noticed. Gregarious locusts exhibit a conspicuous coloration pattern of black and orange, which remains uniform within the same group. On the other hand, solitarious locusts have camouflaged hues that span from green to brown, which are controlled by external conditions including humidity and temperature. Extensive research has been conducted on the endocrine regulation of phase colour polyphenism in locust species, such as L. migratoria and *S. gregaria*. Juvenile hormone (JH) is essential for the initiation of green body pigmentation. The introduction of extra corpora allata, which are responsible for the generation of juvenile hormone (JH), or the injection of synthetic JH or JH analogues might induce the development of green pigmentation in gregarious nymphs of *L. migratoria*. Nevertheless, the green coloration in solitarious nymphs is eliminated following allatectomy with precocene III, and the body pigmentation found in gregarious nymphs fails to develop (Tawfik et al., (1999).

Researchers produced an albino version of *L. migratoria* in *S. gregaria* and discovered a neuropeptide called [His7]-corazonin, which is composed of 11 amino acids, in the corpus cardiaca of both *S. gregaria* and *L. migratoria*. This neuropeptide causes dark pigmentation, but it does not produce the bright yellow body colour that is typical of last-instar gregarious nymphs in S. gregaria. Although the connection between JH and [His7]-corazonin has been investigated, the precise variables that regulate yellow coloration remain incompletely comprehended (Tawfik et al., (1999).

During the phase transition of adult male *S. gregaria*, the outer layer of the body undergoes a transformation and becomes a vibrant yellow hue within a span of 10 days, which occurs simultaneously with reaching complete sexual maturity. The yellow colour is caused by the presence of the yellow protein, which attaches to beta-carotene and is synthesised by epidermal cells that are part of the cuticle. The yellow protein is composed of 250 amino acids and has a molecular mass of 25,682 Da, without any chromophore present. Notably, the protein does not have cysteine residues and has low concentrations of methionine and tryptophan. The transcription of the yellow protein gene in adult males raised in crowded environments commences on day 5 and reaches its highest level on day 12 (Tawfik et al., 1999).

Molecular Regulation of Disease Resistance

Higher population density frequently corresponds to elevated rates of parasitism and disease, causing organisms to allocate greater resources towards disease resistance mechanisms that span immunological, behavioural, chemical, and physical defences. The statement is consistent with the density-dependent prophylaxis (DDP) hypothesis, which is based on three fundamental assumptions: (a) parasite transmission typically thrives in denser populations; (b) potential hosts can modify their physical characteristics in response to signals associated with population density; and (c) defences against parasites incur a cost. Species that display density-dependent phase polyphenism, such as the gregarious adult *S. gregaria* or *L. migratoria*, are likely to demonstrate density-dependent plasticity. Studies have shown that sociable locusts display higher levels of resistance to the fungal disease *Metarhizium anisopliae var. acridum* when compared to solitary locusts. The gregarious locusts have increased antibacterial activity and somewhat greater hemocyte numbers. Nevertheless, no noticeable disparities have been detected between the different stages in terms of phenoloxidase activity, encapsulation, or behavioural fever responses. Pacifastins, a group of serine protease inhibitors present in the hemolymph and CNS of arthropods, are thought to play a role in the preventive immunity of gregarious locusts. Pacifastins have a function in the innate immune system where they hinder the activation of the prophenoloxidase (PO)-activating mechanism or hinder the entry of fungi. Researchers have discovered eight pacifastin-like precursors in locusts, which contain 22 distinct peptides. Research has shown that the levels of the pacifastin SGPI-2 in the hemolymph are elevated in adult S. gregaria that were raised in solitary conditions, as opposed to those raised in crowded conditions. The levels of SGPI-2 rise in subsequent generations of locusts that have been raised in isolation. Furthermore, the influence of SGPIs on the activation of prophenoloxidase in the hemolymph of adult S. gregaria that were grown in a group has been investigated. SGPI-1 and SGPI-2 failed to suppress the initiation of PO activity in reaction to the immunological elicitor laminarin. Nevertheless, the fat bodies of locusts that were injected with laminarin 20 hours prior exhibited elevated transcript levels of two pacifastin-like peptide precursors (SGPP-1 and SGPP-2), which encode SGPI-1, SGPI-2, and SGPI-3 (Ramhan et al., 2003).

## Regulation of Behavioral Phase Change

Solitarious and gregarious locusts exhibit contrasting behaviours while adjusting to alterations in their social surroundings. A behavioural test has been created by researchers to measure the behavioural phase state. This allows for the investigation of stimuli and the underlying neurophysiological, ecological, and molecular mechanisms involved in locust phase transition (Roessigh et al., 1993).

A comprehensive model for behavioural phase shift at ecological and physiological levels has been suggested, mostly based on research conducted on *S. gregaria*. When solitarious locusts are exposed to crowded environments, their behaviours rapidly shift towards those exhibited by gregarious locusts, a phenomenon known as gregarization. The shift is triggered by two sensory pathways: (a) a combination of visual and olfactory detection of other locusts; and (b) repetitive activation of hindleg mechanoreceptors by physical contact with other locusts. The temporal patterns of behavioural phase shift differ among locust species. *S. gregaria* exhibits swift gregarization and gradual solitarization, while *Chortoicetes terminifera* undergoes comparable temporal patterns for both phenomena. Conversely, the process of gregarization *in L. migratoria* is far less rapid when compared to solitarization. Moreover, the particular process of phase transition reported in *S. gregaria* may not necessarily have general applicability to other species of locusts. In the case of *C. terminifera*, the process of behavioural gregarization is triggered by touching the antennae rather than stimulating the hindlegs (Roessigh et al., 1993).

Extensive modifications in the architecture, circuits, and physiology of both the central and peripheral neural systems can impact the path of behavioural phase shift. Ultrastructural examinations have demonstrated that solitarious locusts generally have a greater abundance of sensilla on their antennae, frons, and outer hind femur in comparison to gregarious locusts. Solitarious locusts exhibit heightened sensitivity to olfactory responses and touch stimuli associated with aggregation pheromones compared to gregarious locusts. The cerebral mass of sociable *S. gregaria* locusts is almost 30% more and has a larger central complex compared to solitary individuals, despite having smaller primary visual and olfactory neuropils. The neurons that are responsible for phase-related behavioural responses exhibit significant differences between the two phases. For example, there are several phase-dependent changes observed in descending contralateral movement detectors (DCMDs), tritocerebral commissure giants (TCGs), and slow extensor tibiae (SETi).

Alterations in the concentrations of different possible neurotransmitters and/or neuromodulators in the central nervous system (CNS), including octopamine, serotonin, dopamine, GABA, glutamate, acetylcholine, tyramine, and citrulline, could have a crucial impact on the restructuring of the CNS during phase transition. Hormones such as juvenile hormone (JH) also play a role in regulating phase-related behaviour and the activities of key neurons (Roessigh et al., 1993).

## Serotonin's Role in Gregarious Behavior

Research has investigated the function of serotonin in triggering and maintaining social behaviour in the locust species *S. gregaria*. The study revealed a positive correlation between the amount of serotonin in the thoracic ganglia and the level of gregarious behaviour caused by different durations of crowding. This establishes serotonin as a crucial trigger for behavioural gregarization. Nevertheless, its contribution to the preservation of social behaviour in the long run was restricted, since the levels of serotonin in long-term social locusts were less than 50% of those in long-term solitary locusts.

Serotonin injections in *L. migratoria* were found to elicit gregarious behaviour to some extent. However, when paired with crowding treatment, they resulted in a greater tendency towards solitarious-like behaviour compared to serotonin injection alone. There were no notable disparities in serotonin levels detected in the brain tissues during both phases of *L. migratoria*. A recent study investigated the impact of single and multiple serotonin injections, administered at different doses, on the attraction and avoidance behaviour of *S. gregaria*. The results indicated that serotonin had transient effects on particular locomotor activities and did not have a role in regulating gregarious behaviour. The specific processes via which serotonin affects this behaviour are not yet well understood, as previous studies have typically concentrated on individual behavioural factors to describe the overall phase state, using binary logistic regression models. The investigations emphasise the fact that the regulatory mechanisms in the central nervous system (CNS) that control the start and continuation of phase change are particular to each species. They also emphasise the complex interaction between neurotransmitters (Tanaka & Nishide, 2013).

## Macromolecule Kinases in Phase Transition

The investigation focused on the role of two macromolecule kinases, cyclic adenosine monophosphate-dependent protein kinase A (PKA) and, cyclic guanosine monophosphate-dependent protein kinase (PKG) in the phase transition of *S. gregaria*. The use of drugs and RNA interference techniques showed that PKA, not PKG, is essential in influencing the tendency of locusts to display gregarious behaviour. Administration of the PKA inhibitor KT5720 or double-stranded RNAs specifically targeting the PKA regulatory subunit C1 gene led to a decrease in sociability in solitarious locusts following a one-hour period of forced exposure (Ott et al., 2010). On the other hand, using RNAi to target the inhibitory R1 subunit resulted in a greater degree of gregarization. The involvement of adenylyl cyclase/PKA signalling has been shown to be crucial in multiple types of plasticity, such as sensitization, fear extinction, learning and conditioning, and addiction. While there has been a hypothesis suggesting a correlation between serotonin and PKA, the study failed to show any data supporting this association. Furthermore, although the contribution of PKG to the short-term transformation of locusts into swarming phase has not been verified, there was an observed increase in PKG activity in the brains of gregarious desert locusts. This implies that PKG may play a role in other behavioural characteristics such as regulating foraging and feeding (Ott et al., 2010).

## Epigenetics of phase change

A recent study has revealed a correlation between DNA methylation and phenotypic plasticity in eusocial insects. DNA methylation is involved in the regulation of alternative splicing and gene expression. DNA methylation is the process of adding a methyl group to the C5 position of cytosine residues, specifically at CpG sites where cytosine is followed by a guanine nucleotide. Unlike plants and vertebrates, insect genomes typically have minimal levels of DNA methylation. CpG methylation is mostly observed within gene bodies or transcriptional units, rather than non-genic regions. For instance, when the DNA methyltransferase 3 (Dnmt3) gene is suppressed in honey bees, worker larvae who are not fed royal jelly can nevertheless mature into adult bees resembling queens, with fully formed ovaries. This suggests that DNA methylation plays a role in determining the caste of bees. Regarding *S. gregaria*, the application of liquid chromatography-mass spectrometry study has unveiled that around 1.3–1.9% of cytidines undergo methylation. Upon searching the locust EST databases of *S. gregaria* and *L. migratoria*, two DNA methyltransferase genes, namely Dnmt1 and Dnmt2, were identified, however Dnmt3 was not detected. In addition, the levels of Dnmt1 and Dnmt2 varied in a tissue-specific manner during different phases of *S. gregaria*. In a study conducted by Falckenhayn et al. (2013) using genome-scale bisulfite sequencing, it was found that locusts have higher overall methylation levels compared to other invertebrates. A significant fraction of locust transposons, which are movable genetic elements, were found to be methylated, as reported by Falckenhayn et al. in 2013. This research highlights the importance of DNA methylation in influencing the ability of certain insects, such as *S. gregaria*, to adapt to different environments and regulate their biological processes. It offers valuable insights into the intricate relationship between epigenetic changes and environmental signals in controlling the development and characteristics of these insects.

## Conclusion

In conclusion, the phase change in desert locusts is governed by intricate interactions among genetic, biochemical, and physiological factors. Extensive studies have elucidated the involvement of genes, proteins, metabolites, and neurotransmitters in orchestrating the shift from solitary to gregarious behavior. Notable findings include the role of specific genes like SPARC, the differential regulation of metabolic pathways, and the influence of serotonin as a key neurotransmitter in initiating gregarious behavior. However, uncertainties persist, including the exact functions of phase-related proteins and the genetic factors propelling the evolution of density-dependent phenotypic plasticity.

Prospects involve delving deeper into these intricacies using advanced genomic and proteomic techniques. Unravelling the precise functions of phase-related proteins and understanding the genetic drivers of density-dependent phenotypic plasticity will contribute to a comprehensive grasp of locust phase polymorphism. This continued research promises to unveil additional layers of complexity in the molecular basis of phase change, offering valuable insights into the evolutionary adaptations of locusts and the potential development of targeted strategies for pest control.

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REVIEW ARTICLE

# Pesticide formulation testing: importance and protocols

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## Abstract

Analyses of pesticide formulations is critical in the backdrop of availability of quality pesticide market for ultimate benefit of farmers and ecosystem health. This article highlights the significance of comprehensive pesticide formulation analysis protocols, encompassing methods for determining active ingredient concentrations and assessing physical and chemical parameters. Employing advanced analytical techniques such as spectroscopy and chromatography for pesticide formulation analysis will eventually maintain the quality of pesticides for the sustainable management of pests.

**Key words:** Pesticide formulation, instrumental analysis, volumetric analysis, pest management

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In India, over 330 pesticides are registered of which includes insecticides, fungicides, herbicides (DPPQS, 2023). The current market of non-genuine pesticide is INR 3,200 Cr (USD 525 Million) which constitutes 25 per cent by value and 30 per cent by volume of the total domestic market of agrochemicals in India as per Industry reports, primary interviews, news articles and Tata Strategic analysis (FICCI, 2015). Monitoring registration and regulation of pesticides is governed by the Pesticide Management Bill 2020, which replaced the Insecticide Act 1968 (DPPQS, 2023). The Insecticide Act of 1968 established the Central Insecticide Laboratory, Faridabad, under section 16 with two regional pesticide testing laboratories at Chandigarh and Kanpur (DPPQS, 2023). Current Quality Control of Pesticides in States/UTs during the last five years shows that 68078 pesticide samples were analysed (DPPQS, 2023).In the beginning, these laboratories involved in analysing pesticide samples drawn by any officer or the body authorized by the Central or State Governments and submit certificates of analysis to the concerned authority. Regional Pesticide Testing Laboratories (RPTLs) had a huge target of analysis of 1550 samples per annum that necessitated the establishment of 71 State Pesticide Testing Laboratories (SPTL) spread across India of which 14 are NABL accredited (DPPQS, 2023). As per the Pesticide Management Bill 2020, the routine process of pesticide formulations monitoring includes drawing of pesticide samples randomly from the market by and send it to SPTL for quality analysis. At SPTL, the insecticide analyst (Agriculture Officer/ Asst. Director of Agriculture) will perform the test and issue the certificate (Dileep Kumar and Narasimha Reddy, 2021). If the sample fails to meet the required standard, the manufacturer faces the consequences in a court of law (Dileep Kumar and Narasimha Reddy, 2021).

Pesticide formulation analysis main moto to find the substandard pesticide in the pesticide market. Substandard definition according to insecticide act, 1968 states that it does not conform to the active ingredient test approved for it by the Registration Committee and its active ingredient is within five percent of the nominal value when applied beyond the

| S.NO. | PESTICIDE FORMULATION TESING | |
|---|---|---|
| 1. | Instrumental | Volumetric |
| 2. | HPLC | Precipitation Titration |
| 3. | GC | Gravimetric Analysis |
| 4. | MS | Emulsion Stability |
| 5. | FTIR | Cold test |
| 6. | NMR | Heat stability test |
| 7. | UV-Vis. Spectroscopy | Persistent Foam |
| 8. | Particle Size Analyser | Suspensibility test |
| 9. | Thermal Analysis (DSC, TGA) | |
| 10. | X-ray Diffraction (XRD) | |
| 11. | Automatic Potentiometric Titrator | |
| 12. | Karl Fischer Titrator | |
| 13. | Sieve shaker | |
| 14. | pH meter | |
| 15. | Flash point apparatus | |

Table 1: Types of pesticide formulation testing

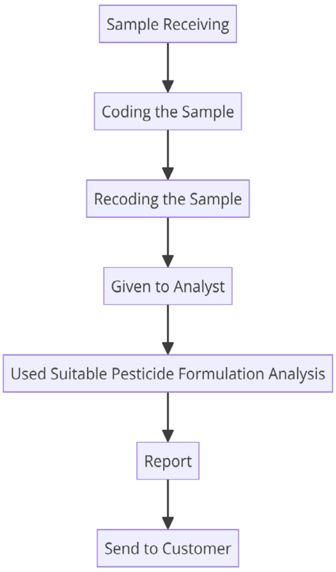

Fig. 1: Series of pesticide formulation analysis in the laboratory

upper and lower limits prescribed for conforming to the test, provided that no tolerance limit shall apply in case of pesticides, which are registered on minimum purity basis (FICCI, 2015).

Pesticide formulations can be analysed in two ways viz., Instrumental pesticide formulation analysis and volumetric pesticide formulation analysis (Table 1).

## 1. **Pesticide Formulation Analysis**

### 1.1 **Instrumental Pesticide Formulation Analysis**

Instrumental pesticide formulation analysis involves the use of advanced analytical techniques and instruments to evaluate the composition, properties, and quality of pesticide formulations. These techniques provide highly accurate and sensitive measurements, allowing researchers, regulators, and manufacturers to gain insights into the chemical and physical characteristics of pesticide products. Here, we'll delve into some of the key instrumental methods commonly used in pesticide formulation analysis:

1.1.1 **High-Performance Liquid Chromatography (HPLC):** HPLC is a versatile technique used to separate, identify, and quantify individual components within a pesticide formulation. It is especially effective for analysing active ingredients, impurities, and degradation products. HPLC employs a liquid mobile phase to transport the sample through a stationary phase, and detectors like UV provide information about the separated compounds.

Eg: Acetamiprid 20 % SP (IS 16328: 2017), Imidacloprid 17.8 % SL (IS 15443: 2004).

**1.1.2 Gas Chromatography (GC):** GC is employed for the analysis of volatile and thermally stable compounds. Pesticide formulations often include volatile solvents and certain active ingredients that can be effectively separated and quantified using this technique. GC utilizes a gaseous mobile phase to carry the sample through a stationary phase, and detectors like flame ionization detector (FID) or mass spectrometry are used to detect and quantify compounds.

Eg: Chlorpyrifos 20 % EC (IS 8944: 2005), Fenpropathrin 10 EC (IS 15161: 2002), Fenvalerate 11 % EC (IS 11997: 1987), Organochlorine, Organophosphorus, Pyrethroids *etc*. can be analyzed by GC

**1.1.3 Mass Spectrometry (MS):** Mass spectrometry is a powerful technique for identifying and quantifying compounds based on their mass-to-charge ratios. MS can be coupled with various instruments (such as GC-MS or LC-MS) to analyse metabolites from parent compounds, complex mixtures in pesticide formulations and identify unknown compounds.

Eg: Fipronil and its metabolite fipronil sulfone (Metabolite will be form after spraying of pesticide on plant leaf, soil, insect)

**1.1.4 Fourier-Transform Infrared Spectroscopy (FTIR):** FTIR spectroscopy measures the interaction of molecules with infrared light, providing information about functional groups present in the sample. It's useful for identifying different chemical groups in pesticide formulations and can help detect changes due to degradation or formulation changes.

Eg: Ethion (IS 10319: 1982)

The nominal value for pesticide active ingredient decided by the bureau of Indian standards as if percent pesticide formulation up to 9 % the range should be between + 10 to -5 and above 9 and below 50 the range should be + 5 to -5 and 50 and above it should be +5 and -3.

**1.1.5 Nuclear Magnetic Resonance (NMR) Spectroscopy:** NMR provides detailed information about molecular structure and composition by analysing the interactions of nuclei with a magnetic field. It's particularly useful for elucidating the structure of complex molecules, confirming the identity of active ingredients, and studying the interactions between different components in the formulation.

**1.1.6 UV-Visible Spectroscopy:** UV-Vis spectroscopy measures the absorption of ultraviolet and visible light by molecules. It's used to quantify the concentration of active ingredients and assess the stability of formulations by monitoring changes in absorption spectra over time.

Eg: Cartap hydrochloride (IS 14184: 1994), Monocrotophos, Glyphosate (IS 12502: 1988), Malathion EC (IS: 2567: 1978)

**1.1.7 Particle Size Analyser (Dynamic Light Scattering, Laser Diffraction):** Pesticide formulations often come in various forms, such as suspensions or emulsions, where particle size plays a critical role in stability and effectiveness. Techniques like dynamic light scattering and laser diffraction provide insights into particle size distribution, allowing manufacturers to optimize formulation properties.

Eg: DP/WP/Granular formulations

**1.1.8 Thermal Analysis (DSC, TGA):** Differential scanning calorimetry (DSC) and thermogravimetric analysis (TGA) provide insights into the thermal properties and stability of pesticide formulations. These techniques help identify melting points, decomposition temperatures, and potential thermal degradation pathways.

**1.1.9 X-ray Diffraction (XRD):** XRD is used to analyze the crystal structure of solid components in pesticide formulations. It's valuable for studying the arrangement of particles and assessing crystallinity changes that may occur during formulation or storage.

These instrumental methods offer a comprehensive understanding of pesticide formulations, including the identification, quantification, and characterization of active ingredients, inert components, and additives. The integration of these techniques ensures the quality, safety, and efficacy of pesticide products while aiding regulatory compliance and environmental protection efforts.

**1.1.10 Automatic Potentiometric titrator:** This instrument is used to find the acidity/alkalinity of pesticide formulation.

Eg: Chlorpyrifos – ≤ 0.05 percent by mass ((IS 8944: 2005)

**1.1.11 Karl Fischer Titrator:** This instrument is used to find the moisture of pesticide formulation.

Eg: Majority of technical formulations and some of formulations (Imidacloprid Technical moisture content should be ≤1 % (IS 15443: 2004)

### 1.1.12 Sieve shaker with test sieves of 2 mm, 1.7 mm, 1.4 mm

**Sieve test:** wet sieve test is a critical analytical technique in pesticide formulation because it ensures that the particle size distribution is controlled and consistent.

Eg: WP and Granular formulations

### 1.1.13 **pH meter: pH meter is an equipment to find the formulation pH**

Eg: Acetamiprid pH (Between 7.0-9.0) (IS 16328: 2017), Fipronil pH (Between 4.0-8.5) (IS 16145: ***2013)***

### 1.1.14 **Flash point apparatus (Abel)**

A flash point apparatus is a laboratory instrument used to determine the flash point of a flammable substance. The flash point is the lowest temperature at which the vapour of a substance can ignite in the presence of an open flame or spark. It is an important safety parameter for handling and storing flammable materials (IS 1448: 1960)

Here's how a flash point apparatus typically works:

**Sample Preparation:** A small quantity of the substance being tested (usually a few millilitres) is placed in a cup or container designed for the apparatus.

**Test Procedure:** The cup containing the sample is positioned in the apparatus, and it is typically exposed to an open flame or an electrical spark in a controlled environment.

**Temperature Control:** The temperature of the sample is gradually increased at a controlled rate (usually 1 or 2 degrees Celsius per minute) using a heating element.

**Observation:** An ignition source, such as a pilot flame, is directed towards the surface of the sample. The operator carefully observes the sample during the temperature ramp-up. The flash point is reached when a small flame or spark occurs at the surface of the sample, indicating that it has reached a temperature at which it can ignite.

**Recording Data:** The temperature at which the flash occurred is recorded as the flash point of the substance. The flash point of the material shall be above 24.5 °C

Eg: EC and SL formulations

### 1.2 Volumetric pesticide formulation analysis

Volumetric analysis is a branch of analytical chemistry that involves measuring the volume of a solution of known concentration (titrant) required to react completely with a solution of the analyte, thus allowing for the determination of the analyte's concentration. In the context of pesticide formulation analysis, volumetric methods are often used to quantify the concentration of active ingredients or specific chemical components within the formulation. Volumetric analysis methods are widely utilized due to their simplicity, accuracy, and relatively low cost. Here, we'll elaborate on some of the key volumetric techniques used in pesticide formulation analysis:

**1.2.1 Precipitation Titration:** Precipitation titration involves the formation of an insoluble precipitate when a titrant is added to the analyte solution. This method can be used to determine ions that form insoluble compounds with specific reagents. In pesticide formulation analysis, precipitation titrations might be used to quantify certain ions or to detect impurities that form precipitates.

**1.2.2 Gravimetric Analysis:** While not strictly volumetric, gravimetric analysis is closely related. It involves the determination of the mass of a compound, which can then be used to calculate its concentration. Gravimetric methods are based on the principle that a specific compound can be separated and weighed to determine its concentration in the original sample. This technique can be used to analyse specific active ingredients or impurities in pesticide formulations.

**1.2.3 Emulsion Stability:** Emulsion stability is typically assessed using a 100 mL Crow receiver. The desired outcome is the observation of any phase separation, such as creaming at the top or sedimentation at the bottom, in a 100 mL emulsion created in standard hard water (342 ppm) with an EC volume not exceeding 2.0 mL (IS 6940: 1982).

Eg: EC and EW formulations (Chlorpyrifos 20 % EC, Fenpropathrin 10 % EC, Fenvalerate 11 % EC)

**1.2.4 Cold test:** Put 50mL of pesticide formulation in a 100mL transparent glass container and close it with a thermometer-equipped cork or stopper. Put the container in ice water to cool it to 10°C.When the pesticide in the container reaches 10°C, apply a little pesticide seeding crystal with minimal stopper opening in the shortest time. The formulation made from technical liquid pesticide does not need crystal seeding. Stir the material in the container gently at short intervals for one hour at 10°C. After one hour, check for turbidity or solid/oily matter separation (IS 6940: 1982).

Eg: All liquid formulations (Chlorpyrifos 20 % EC, Fenpropathrin 10 % EC, Fenvalerate 11 % EC, Imidacloprid 17.8 % SL)

**1.2.5 Heat stability test**: Place the 50 g of the sample in a bottle and if sample is volatile use sealed bottle. Seal the sample container hermetically and keep it in the oven at 55±2□C for 14 days. Remove the sample container from the oven, cool down to room temperature.

Eg: All liquid formulations

**1.2.6 Persistent Foam**: The sample mass is the mass needed to make 200 mL of a suspension with the concentration suggested in the product's instructions. When multiple concentrations are advised, choose the highest. Put 180 mL of standard hard water in the 250 mL measuring cylinder on a top pan balance and weigh in 1g of suspension concentrate. Fill to 200 mL with regular hard water. Stop the cylinder and invert 30 times. Start the stop watch after placing the stoppered cylinder upright on the bench. Read foam production and remaining after 1 min.

Eg: Fipronil 5 % SC (IS 16145: 2013)

**1.2.7 Suspensibility test:** The dry pesticide is slurred into 50 ml of test water in a 100 ml beaker. The slurry is quantitatively transferred to a 250 ml mixing cylinder is stoppered and inverted in 15 complete cycles. The mixing cylinder is allowed to stand for 30 minutes. After 30 minutes the top 225 ml is drawn off and the remaining suspension is dried. The residue weight will determine the percent suspensibility.

Eg: WP and SC formulations

**Conclusion:**

Pesticide formulation analysis (PFA) is a vital part of modern agriculture, assuring the efficacy, stability, and safety of the products. By employing advanced analytical techniques such as chromatography and spectroscopy, regulatory bodies can make decisions according to the act elimination of inferior quality pesticides and make use of quality pesticides to the farmers. It is important to note that though volumetric methods are valuable for many analyses, they might not be suitable for all types of pesticide formulations or analyses. For complex formulations with multiple active ingredients and additives, more sophisticated instrumental techniques like chromatography, spectroscopy, and mass spectrometry might be necessary to achieve accurate and comprehensive analysis. The substandard pesticides can be detected by PFA, which gives farmers the right to take compensation from the company according to consumer protection act, 2019. Therefore, the future implications of pesticide formulation analysis are significant and safeguarding the crop health. PFA ensures production of quality pesticides from industries, which in turn helps scientists to carry out quality research while evaluating pesticides against insect-pests before shortlisting them in university package of practices. It also creates trust among dealers and boosts their business.

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## AUTHORS

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# Navigating the Buzz: Challenges and Opportunities in Beekeeping During Dearth Periods

*Gautam Kunal, Rakesh Das and Chandra Shekhar Prabhakar*

Beekeeping, often celebrated as a harmonious dance between humans and nature, encounters a distinct challenge that tests the mettle of beekeepers: the dearth period. In this period of the apicultural journey, when floral landscapes transform into barren expanses, beekeepers face a complex set of hurdles that demand skill, vigilance, and a profound understanding of the bee colonies. This article embarks on a journey through the dearth period, exploring its nuances, the challenges it poses, and the strategies that beekeepers employ to not only survive but thrive in the face of scarcity.

The dearth period, characterized by a conspicuous reduction in the availability of blooming flowers and nectar, is a temporal chasm in the usually vibrant and symbiotic relationship between bees and their environment. As the once abundant sources of sustenance dwindle, bee colonies are thrust into a precarious dance of survival, requiring beekeepers to become adept navigators of this challenging terrain. The challenges that unfold during the dearth period are multifaceted, each posing a unique threat to the well-being of bee colonies. Floral scarcity stands as the foremost adversary, as the lifeblood of bees—nectar and pollen—becomes a rare commodity. The consequences reverberate through the hive, manifesting in nutritional stress that weakens the immune systems of the colonies, rendering them more susceptible to insect pests and diseases. A simultaneous consequence of the dearth is the decline in honey production, a core aspect of beekeeping livelihoods. The very essence of the sweet liquid gold, so meticulously collected by bees, becomes elusive, challenging the economic sustenance of beekeepers and the availability of honey for consumers. It's a delicate balance of ecological interconnectedness and economic viability, with the dearth period acting as a disruptor on both fronts.

Furthermore, the dearth period triggers a fascinating yet challenging phenomenon of queen supersedure. As resources dwindle, colonies may decide to replace their reigning queen, altering the dynamics within the hive. This natural response, though essential for the long-term health of the colony, requires a nuanced understanding from beekeepers to navigate potential disruptions effectively. However, within these challenges lie remarkable opportunities for innovation and resilience. Beekeepers, armed with knowledge and a commitment to sustainable practices, can not only weather the dearth period but emerge stronger and more adaptable. Diversification of bee forage emerges as a crucial strategy, a proactive approach to mitigate the impact of floral scarcity. Beekeepers can strategically introduce a variety of bee-friendly crops and flowers, creating a more resilient ecosystem for their colonies. Supplementary feeding becomes a lifeline, offering a nutritional bridge during times of scarcity and ensuring the health of the hive. Beyond the hive, dearth periods present a unique opportunity for beekeepers to diversify their income streams. By offering pollination services to local farmers, beekeepers not only contribute to agriculture but also establish stronger ties with their communities.

## I. Understanding the Challenges

### 1. Floral Scarcity

In the delicate ecosystem of beekeeping, the dearth period stands as a significant challenge, casting a shadow over the usually vibrant and symbiotic relationship between bees and their floral surroundings. Central to this challenge is the phenomenon of floral scarcity, a crucial factor that shapes the fate of bee colonies during these lean times. To comprehend the intricacies of this challenge, we delve into the multifaceted aspects of floral scarcity and its implications on bee health, honey production, and the overall dynamics within the hive. At the heart of floral scarcity lies the dwindling availability of nectar and pollen. Bees, meticulous foragers, rely on these resources for sustenance, energy, and the production of honey. When the usual abundance of flowering plants diminishes, bee colonies face a nutritional vacuum, triggering a cascade of effects that reverberate throughout the hive.

### 2. Nutritional Stress

During dearth periods in beekeeping, nutritional stress emerges as a critical challenge. The scarcity of blooming flowers leads to a limited diversity of nectar and pollen sources, compromising the essential nutrients required for bee health. Colonies that suffer from nutritional deficiencies are more vulnerable to pests and diseases. The complex equilibrium of a diverse diet, which is essential for bee health, is upset, making beekeepers' struggles more intense. Nutritional stress during dearth periods underscores the urgency for proactive measures such as supplementary feeding to ensure the well-being and resilience of bee colonies in the face of floral scarcity.

### 3. Honey Production Decline

A direct consequence of reduced forage is a critical decline in honey production. For beekeepers, this translates into not only a financial challenge but also a potential strain on the availability of honey for consumers. Understanding how to navigate this dip in productivity becomes paramount.

### 4. Queen Supersedure

Queen supersedure poses a unique challenge in beekeeping during dearth periods. As floral resources dwindle, colonies may initiate the replacement of their reigning queen. This natural process, while crucial for long-term hive health, introduces instability and disruption. Beekeepers must navigate the intricacies of queen supersedure, recognizing signs and managing the transition to maintain colony harmony. The impact of dearth periods on foraging and nutritional stress often triggers this phenomenon, emphasizing the importance of beekeeper vigilance during lean times to ensure a seamless transition and continued vitality of the hive.

## II. Embracing Opportunities

### 1. Diversification of Bee Forage

In the realm of beekeeping, diversifying bee forage emerges as a transformative opportunity, particularly during dearth periods. This strategic approach involves expanding the range of bee-friendly crops and flowers within the foraging landscape of bees. By planting a variety of floral sources, beekeepers create a resilient ecosystem that sustains colonies even when traditional resources are scarce. Diversification mitigates the impact of floral scarcity by offering a broader palette of nectar and pollen options. It not only supports the nutritional needs of bees but also enhances the overall health and vitality of the hive. Furthermore, a diverse forage environment contributes to increased biodiversity, benefiting not only honeybee colonies but also native pollinators.

Beyond immediate benefits, embracing diversification presents a sustainable solution to challenges faced by beekeepers. It aligns with ecological principles, fostering a balanced and resilient ecosystem. Beekeepers who strategically diversify their forage contribute to the preservation of biodiversity, promote ecosystem health and position themselves as stewards of sustainable apiculture. This approach not only addresses the challenges posed by dearth periods but also underscores the interconnectedness of beekeeping with broader environmental conservation efforts. Ultimately, the act of embracing the opportunity in the diversification of bee forage becomes a proactive step towards a more resilient and sustainable future for both bees and their keepers.

### 2. Supplementary Feeding

Supplementary feeding stands as a pivotal opportunity in beekeeping, particularly during the challenging dearth periods. As and when the floral resources diminish, beekeepers can step in to provide essential sustenance through supplementary feeding. This strategic intervention involves offering bees alternative food sources, such as sugar syrup or protein supplements, ensuring the nutritional needs of the colony are met. Embracing supplementary feeding is a proactive measure that not only helps sustain bee health but also mitigates the impact of nutritional stress during lean times. By understanding the specific dietary requirements of colonies and tailoring supplementary feeding accordingly, beekeepers contribute to the resilience and well-being of their hives.

This opportunity extends beyond crisis management, presenting a chance for beekeepers to actively engage with their colonies. Regular monitoring during supplementary feeding allows beekeepers to assess the health of the hive, identify potential issues, and intervene as needed. It becomes a dynamic aspect of beekeeping that empowers keepers with a deeper understanding of nutritional dynamics of bees. Moreover, supplementary feeding opens avenues for innovation, encouraging beekeepers to explore sustainable and locally-sourced alternatives. By embracing this opportunity, beekeepers not only navigate the challenges of dearth periods but also foster a more adaptive and resilient approach to beekeeping, ensuring the vitality of their colonies in the face of fluctuating floral resources.

Fig. 1 Training on management of honey bees during dearth period

### 3. Pollination Services

Pollination services is a transformative opportunity for beekeepers, especially during dearth periods. Beyond honey production, beekeepers can offer their colonies as essential pollinators to local farmers. This dual role not only diversifies income streams but also strengthens the crucial link between bees and agriculture. By actively participating in pollination services, beekeepers contribute to increased crop yields, fostering a symbiotic relationship with their communities. This opportunity highlights the broader impact of beekeeping, positioning beekeepers as key players in both environmental stewardship and sustainable agricultural practices, demonstrating the profound impact that bees can have beyond their role as honey producers.

### 4. Educational Outreach

Engaging in educational outreach during dearth periods can be a proactive strategy. Raising awareness about the importance of bees, the challenges they face, and the role of beekeepers fosters community

Fig. 2 Hive Inspection and Monitoring

support and encourages sustainable practices.

## III. Mastering Management Strategies

### 1. Hive Inspection and Monitoring

During dearth periods, increased vigilance is essential. Regular hive inspections allow beekeepers to monitor the health of the colony, identify signs of stress or disease, and take prompt corrective actions.

### 2. Queen Management

Understanding and managing queen supersedure is critical. Beekeepers should be adept at recognizing the signs of this natural process, ensuring a smooth transition that minimizes disruptions within the hive.

### 3. Beekeeper-Community Collaboration

Collaboration with the local community is an often-underestimated management strategy. Establishing relationships with farmers, sharing knowledge, and collectively addressing challenges can create a symbiotic relationship that benefits both beekeepers and the broader community.

### 4. Sustainable Practices

Dearth periods highlight the importance of sustainable beekeeping practices. From hive design to forage management, adopting environmentally conscious approaches ensures the long-term health and viability of bee colonies.

## Conclusion

In the delicate dance between bees and their keepers, dearth periods emerge as a significant chapter. Yet, within the challenges lie opportunities for growth, adaptation, and community building. By embracing the complexities of the dearth period and implementing proactive management strategies, beekeepers can not only navigate the lean times but also contribute to the broader narrative of sustainable apiculture. In the end, the resilience of the hive is a testament to the collective efforts of beekeepers who, through challenges and opportunities, safeguard the invaluable role of bees in our ecosystems.

## AUTHORS

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# 9TH INDIAN ENTOMOLOGIST PHOTO CONTEST

The Indian Entomologist Photo Contest aims to promote insect photography among photographers, professionals, amateur entomologists, and laymen. The theme for the ninth edition of the photo contest was “Insects and aspects related to insect life.” The contest was open from the 9th of November until December 8th, 2023. Each participant was asked to submit one good photograph that meet a few specified formats, as well as a filled-in application form in which he or she must include his or her details, caption, description, photograph specifications, and a declaration of the ingenuity of the photograph. We received an overhelming response from 144 participants, who submitted a total of 189 images. The photos were initially screened by BigStudio associate editors for the prescribed standards and overall image quality and further sent to three independent and anonymous external reviewers to judge the best three photos. Based on the reviewer results, the final evaluation was done by a committee of independent members under the oversight of the three editorial board members. During the complete review process, the entries were assessed based on the following criteria: quality (clarity, lighting, depth of field, composition), relevance of the subject matter (theme, rareness of subjects), creativity and originality. To ensure a blind review, the details of the photographer were hidden, and the evaluators were only presented with the photograph, caption, description and technical specifications.

The following are the winner for 9th Indian Entomologist photo contest

- The first place was won by Hemant Kumar (B105, The Ledge, Jakkur Yelahanka Road, Nehru Nagar, Yelahanka 560064), who captured incredible photo of nymphs of Jumping plant lice excreting honey dew.

- The second place was won by Ajeesh Ajayakhosh (Ajayabhavanam, Neeravil Perinad PO Kollam, Kerala 691601) for his incredible photo indicating Tri trophic food chain hanging from spider thread wherein a Lynx spider predating on damselfly while damselfly predating on mosquito.

- The third place was won by Muralidhar Talla (MIG-152/1/G1, Sri Vigneshwara Enclave, Kukatpally, Telangana) for capturing A tiny explorer ant attempts to engulf a drop of water stuck to the coiled tendril of a plant.

Congratulations to the winners, and we acknowledge all the participants who took an interest in 9th Indian Entomologist photo contest and sent their entries!!

## BUG STUDIO ASSOCIATE EDITORS

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ICAR-IARI, New Delhi

First place: Nymphs of jumping plant lice

Second place: A tri trophic food chain hanging from spider thread. Lynx spider predating on damselfly while damselfly predating on mosquito

Third place: A tiny explorer ant attempts to engulf a drop of water stuck to the coiled tendril of a plant

### DARAPUREDDY NAGA SAI SATYA SWAROOPA
### DEPARTMENT OF ENTOMOLOGY
### ACHARYA N.G. RANGA AGRICULTURAL UNIVERSITY, BAPATLA, ANDHRA PRADESH

Darapureddy Naga Sai Satya Swaroopa is currently pursuing Ph.D. in Entomology at Acharya N.G. Ranga Agricultural University, Bapatla, Andhra Pradesh. She is working under the supervision of Dr. T. Madhumathi, Professor of Entomology, on "Studies on the behavioral ecology and management of the cigarette beetle *Lasioderma serricorne* (F.) (Coleoptera: Anobiidae).She is conducting an extensive survey on the incidence and host range of the cigarette beetle from different geographical locations to explore the molecular basis of diversity. Furthermore, she is investigating the growth, development, ovipositional preference, and damage parameters on different hosts. The main emphasis is given to the isolation and identification of the potent kairomones in the potentially attractive hosts. She is also concentrating on the management of *L. serricorne* on turmeric and other hosts with selected botanicals, minerals, microwave radiation, and hermetic storage. She worked on "Insect species diversity and the evaluation of insecticidal spray requirements in soybean" under the guidance of Dr. D. G. More, Assistant Professor at Vasantrao Naik Marthwada Krishi Vidyapeeth, Latur. She recorded insects from 8 orders, spiders, and millipedes, and standardized insecticidal sprays to manage the insect pests of soybean for optimum yield. Swaroopa graduated from the Agriculture College, Acharya N.G. Ranga Agricultural University, Bapatla. Swaroopa is interested in exploring various molecular tools and techniques for insect pest management in the future

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### ARAVINTHRAJU K
### DEPARTMENT OF ENTOMOLOGY
### TAMIL NADU AGRICULTURAL UNIVERSITY, COIMBATORE, TAMIL NADU

Aravinthraju K is pursuing a PhD in Entomology at Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu. He is working under the chairmanship of Dr. M. Shanthi, Director, Centre for Plant Protection Studies, TNAU. Recently, he was selected for the 'Golden Jubilee Scholarship Program' by the World Vegetable Centre in Taiwan. He will conduct his dissertation research collaboratively in Taiwan for 12 months. Currently, he is working on "Assessing the direct and plant-mediated impacts of new fungal bio-control agents against tomato whitefly, Bemisia tabaci and onion thrips, Thrips tabaci". Aravinthraju graduated from the Faculty of Agriculture, at Annamalai University, Tamil Nadu. His rationale for selecting Entomology as a career stem from his inspiration drawn from Dr. S. Arivudainambi, his undergraduate professor, who imparted to him a profound understanding of the subject. He was awarded a master's degree from Agricultural College and Research Institute, TNAU, Madurai. For his master's degree program, he worked on the "Management of Tea Mosquito Bug, *Helopeltis antonii* Signoret (Hemiptera: Miridae) on Guava, *Psidium guajava* L.". He recorded the peak incidence of the tea mosquito bug during December, January and February in different hosts like guava, neem, and moringa. In the future, he plans to carry over research in the applied aspects of entomology to benefit the farming community. He is also interested in getting involved in teaching.

## STUDENT CORNER

### SUBRATA GOSWAMI
### DEPARTMENT OF ENTOMOLOGY AND AGRICULTURAL ZOOLOGY
### INSTITUTE OF AGRICULTURAL SCIENCES, BANARAS HINDU UNIVERSITY

Subrata Goswami is currently pursuing a PhD at the Department of Entomology and Agricultural Zoology, BHU, Varanasi. He is a recipient of the DST-INSPIRE fellowship for a doctoral degree program by the Ministry of Science and Technology. Currently, he is working on the "Development of novel nanotechnology-based chemoecological approaches for pest management" under the supervision of Prof. M. Raghuraman, Professor of Entomology. He is characterizing the neurophysiological and behavioural response of selected lepidopteran pests to semiochemicals, followed by the identification and characterization of the nano matrix for the controlled delivery of the semiochemicals. The development of a controlled-release nano matrix for better spatiotemporal release of pheromones and using the sex pheromone with some other plant volatiles in tandem will provide a groundbreaking avenue for the management of noxious agricultural pests. Subrata completed his postgraduate studies at Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur, Madhya Pradesh, under the mentorship of Dr. S.B. Das, Professor and Head. In collaboration with ICAR-National Rice Research Institute, Cuttack, he studied the gut bacterial microbiota of rice stem borers and their functional significance. He comparatively assessed the culturable gut microbiota among different species of stem borers (yellow, pink, and striped stem borers) collected from the same host plant and time based on 16S rDNA sequences. He found that the gut bacterial composition of the three stem borer species is markedly diverse. Moreover, all the isolated gut bacterial strains were capable of degrading Chlorpyrifos, Chlorantraniliprole, and Thiamethoxam in vitro. Subrata graduated from Visva-Bharati University, West Bengal and aspires to be in the field of academia and conduct translational research for the development of green alternatives for the management of agricultural pests. Specifically, he is interested in insect olfaction and is looking for international collaborations to further hone his research skills to cater to the needs of the nation.

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### NANG SENA MANPOONG
### DEPARTMENT OF ENTOMOLOGY
### ASSAM AGRICULTURAL UNIVERSITY, JORHAT, ASSAM

Nang Sena Manpoong is currently pursuing her doctoral degree from the Department of Entomology, Assam Agricultural University, Jorhat, Assam under the brilliant counsel of her major advisor, Dr. Sahidur Rahman, Principal Scientist & Principal Investigator, ICAR-AINP on Agricultural Acarology, Department of Entomology, AAU, Jorhat. Since there is a dearth of substantial work on termite diversity in the Northeastern part of India (namely, Assam and Arunachal Pradesh), her research work is meant to fill up the research gaps which exist. The objective of her research work is to study the biodiversity of termites and to explore the role of their gut bacteria in plant biomass degradation. She believes that her research could introduce new research methods and lead to the discovery of novel microorganisms from the gut of termites that could degrade plant biomass. Hailing from the picturesque state of Arunachal Pradesh, where insects not only form a part of the local fauna but also carry a great significance in local cuisines and traditional folklores, insects have always fascinated her. A firm believer of perseverance, a keen sense of observation and versatility, she credits her childhood experiences to moulding her future aims. She says "Being from Arunachal Pradesh where cultivation is done almost organically using traditional practices, I would like to integrate these traditional practices in today's advanced agricultural technologies especially in pest management, enhancing the potency of these practices while eliminating their obsolete aspects to develop a sustainable pest management strategy which is environmentally friendly, based on traditional knowledge and having the efficiency of today's modern technology, because I think the key to the solution of a problem lies in the problem itself and nature has bestowed us with an abundance of these solutions which needs to be identified, effectualized and amplified".

## SOURAV SEN
## DEPARTMENT OF ENTOMOLOGY
## BIDHAN CHANDRA KRISHI VISWAVIDYALAYA, WEST BENGAL

Sourav Sen, Ph.D. scholar from the Department of Entomology, Bidhan Chandra Krishi Viswavidyalaya, West Bengal, believes that as an agricultural researcher, it is his responsibility to bridge the gap between agricultural research and adoption by farmers. He received his Master's degree from Assam Agricultural University, Jorhat, under the guidance of Dr. Shimantini Borkataki, Assistant Professor in the Department of Entomology, AAU, Jorhat. During his master's, he worked on the "Brood rearing and foraging activity of the stingless bee, *Tetragonula iridipennis* in cucumber under protected conditions." Conclusively, his research work found that the stingless bee was an effective pollinator of cucumber under protected conditions. His current work is primarily concentrated on the field of biological control, which includes some toxicological aspects related to egg parasitoids of the yellow stem borer. His study mainly comprises the diversity, seasonal occurrence, and insecticide compatibility of hymenopteran egg parasitoids (*Trichogramma* sp. and *Telenomus* sp.) of the rice yellow stem borer (*Scirpophaga incertulas*) in East Burdwan district, West Bengal, India. Rice is a staple food in India, and the yellow stem borer is its most dominant and destructive pest. Studying the potentiality of egg parasitoids for managing the yellow stem borer pest in insecticide-treated fields will help assess the possibility of egg parasitoid utilization and insecticide application in integrated pest management systems. Additionally, his study will elucidate the proper timing for the biological control of the mentioned pest based on the seasonal occurrence of the egg parasitoids. Under the skillful guidance and expertise of Dr. Lakshman Chandra Patel, Assistant Professor in the Department of Entomology, BCKV, Sourav will be working on the multiplication mechanism of some critical egg parasitoids that are not yet properly reared under laboratory conditions. He will be trying to release them successfully under field conditions to control a wide group of pests. He cleared ICAR-AIEEA (PG) in 2019, ICAR-AICE (Ph.D.) in 2021, and ASRB NET in 2021.

***Mr Naveen., Miss Nandhini D, and Miss K Sindhura Bhairavi, Student Associate Editor of IE Compiled the informationfor this section.***

# CRISPR: Tools and application in plant protection

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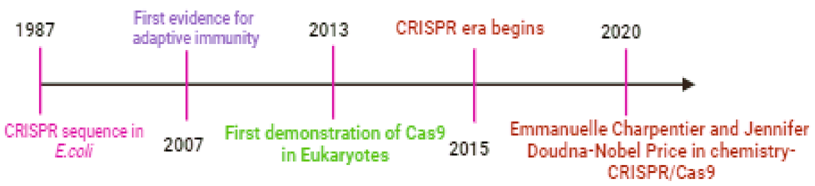
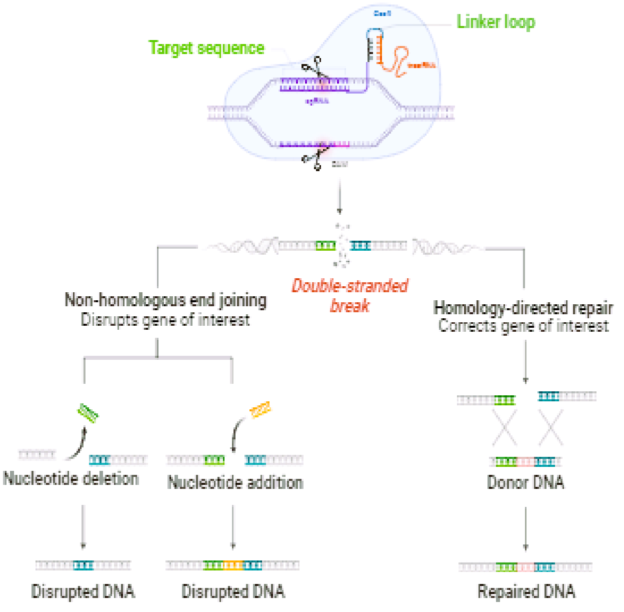
- Clustered Regularly Interspaced Short Palindromic Repeat
- Short, partially palindromic repeated DNA sequences - genomes of bacteria
- Bacterial adaptive immune system (***Streptococcus pyogenes***)

## History

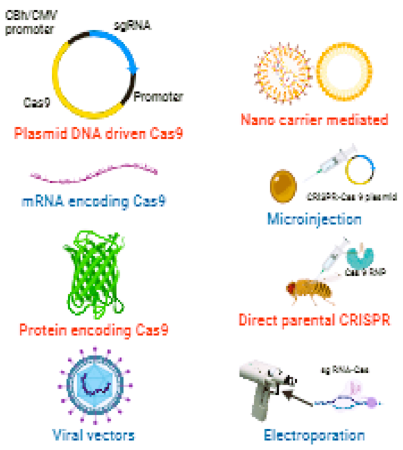

1987
First evidence for adaptive immunity
2013
CRISPR era begins
2020
CRISPR sequence in *E.coli*
2007
First demonstration of Cas9 in Eukaryotes
2015
Emmanuelle Charpentier and Jennifer Doudna-Nobel Price in chemistry-CRISPR/Cas9

## Components and gene editing process



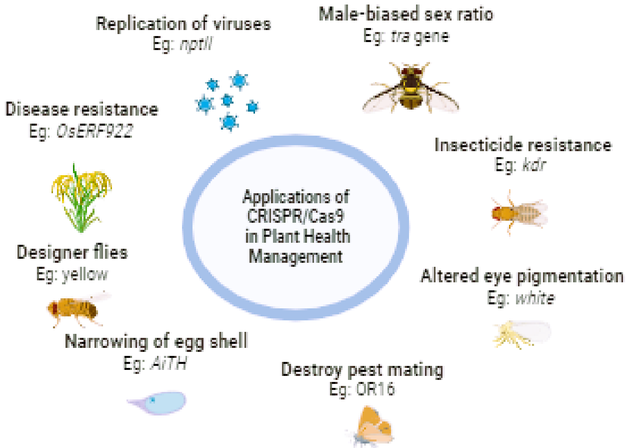
Target sequence
Linker loop
Double-stranded *break*
Non-homologous end joining
Disrupts gene of interest
Homology-directed repair
Corrects gene of interest
Nucleotide deletion
Nucleotide addition
Donor DNA
Disrupted DNA
Disrupted DNA
Repaired DNA

## Delivery methods



Plasmid DNA driven Cas9
Nano carrier mediated
mRNA encoding Cas9
Microinjection
Protein encoding Cas9
Direct parental CRISPR
Viral vectors
Electroporation

## Applications


Replication of viruses
Eg: *nptII*
Male-biased sex ratio
Eg: *tra* gene
Disease resistance
Eg: *OsERF922*
Insecticide resistance
Eg: *kdr*
Applications of CRISPR/Cas9 in Plant Health Management
Designer flies
Eg: yellow
Altered eye pigmentation
Eg: *white*
Narrowing of egg shell
Eg: *AiTH*
Destroy pest mating
Eg: OR16

### *Further Readings:*

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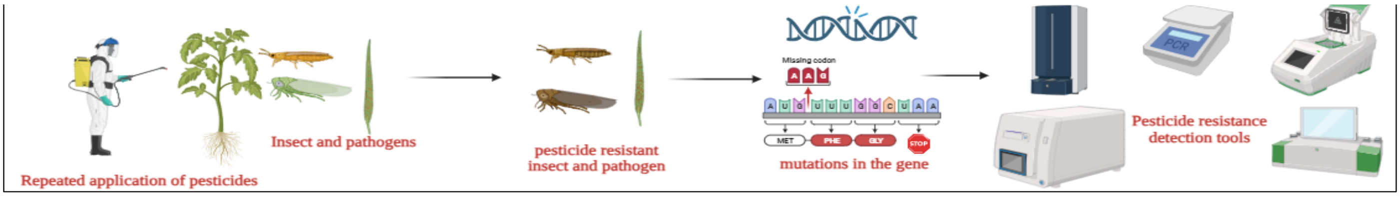
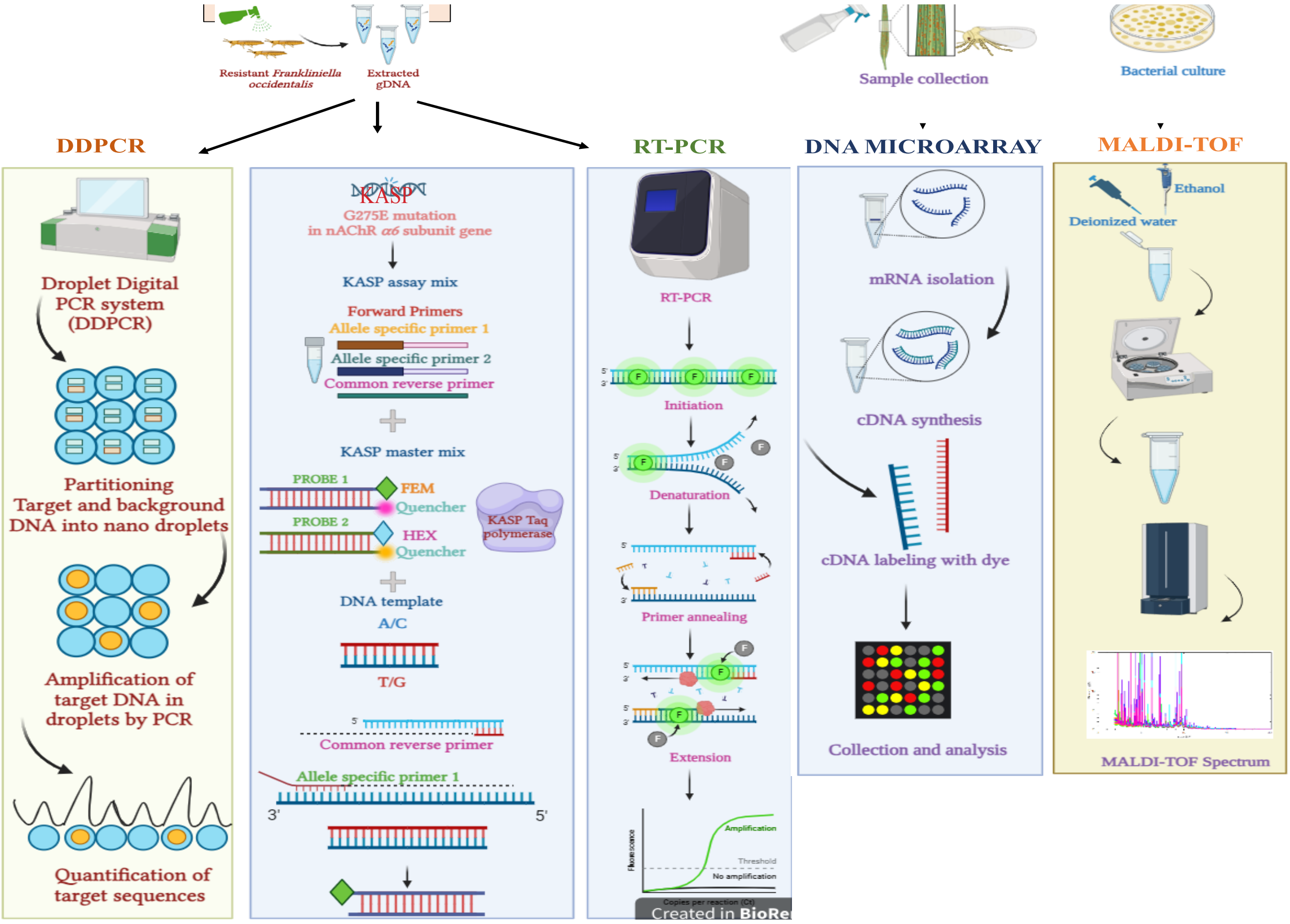
# Molecular tools for detection of pesticide resistance





## Further Readings

- Anjum MF, Zankari E, Hasman H. Molecular Methods for Detection of **Antimicrobial Resistance. Microbiol Spectr. 2017 Dec;5**(6).
- Trends and Challenges in Pesticide Resistance Detection. Trends Plant Sci. 2016 Oct;21(10):834-853.

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## Notes for Contributors

Articles submitted should not have been published elsewhere and should not be currently under consideration by another journal/ magazine. Interested authors are advised to follow the author guidelines of Indian Journal of Entomology for reference citations and to follow as closely as possible the layout and style, capitalization and labelling of figures. All papers are subject to peer review and may be returned to the author for modification as a result of reviewers reports. Manuscripts are acknowledged on receipt and if acceptable proofs are sent without further communication. Minor editorial alterations may be made without consulting the author. Make sure to submit the photographs of high quality in .jpg format. For those who want to contribute commentary and feature articles please contact editors before submission.

## About articles

IE is intended to publish following categories of articles

Commentary – We encourage opinions or critical analysis of current entomological happenings. Submissions should be no more than 5,000 words in length.

Reviews – two types of reviews will be published a. invited review (editorial team will contact eminent entomologists to contribute) and b. peer reviewed review (any author/s can submit a comprehensive reviews on modern entomological developments).

Feature articles – these must be of broad interest to biologists, amateur and professional entomologists. These articles should be no longer than approximately 5,000 words. Articles should contain high quality photographs.

Natural histories & short research articles with focus on insect life cycle, occurrence etc. and have the same requirements as feature articles. Submissions should be up to 5,000 words in length.

Field notes – on unusual observations entomologists encounter during fieldwork (Invasive insects, outbreaks, behaviour etc.). Submissions should be no more than 2,000 words in length.

Bug studio – "Indian Entomologist Photo Contest" will be conducted for every volume of the magazine and best three winners will be announced in the magazine. Images should be submitted as high quality (300 dpi TIFF, jpeg files) files with a detailed photo caption. The announcement for photo contest will be made on our website www.indianentomologist.org

Student corner – students working on interesting topics of entomology to share their views and opinions about their research work. Can submit with personal photograph; it should not be more than 1,000 words in length. We encourage entomologists to contact us if you have any interesting story to share about insects. Contributions to be sent to the Managing Editor, in digital format (MS Word) as an e-mail attachment to indianentomologist@gmail.com

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