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INDIAN ENTOMOLOGIST

ONLINE MAGAZINE TO PROMOTE INSECT SCIENCE

Featuring

A dialogue with Dr. R. C. Joshi

In conversation with Prof. Renee Maria Borges

Termites as source of sciences

Drone application in pest management

INDIAN ENTOMOLOGIST

JULY 2023/VOL 4/ISSUE NO. 2

Editorial Board

***Cover page image: Sriram Murali and Anamalai Tiger Reserve Forest Department, showing the firefly activity and star trails as a result of stacking 50 photos with 19-second exposures at Anamalai Tiger Reserve Forest.**

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EDITORIAL

Will Artificial Intelligence change entomology research and education?

It is a known fact that Artificial Intelligence (AI) is revolutionising various aspects of human life, especially research and education. The AI is changing the way humans approach their critical aspects of daily life. Today we hear that AI along with ChatGpt and other such online information management tools are imbibed in the critical aspects of our life. OpenAI's ChatGPT, the AI powered chatbot has crossed one million users in less than a week since it was officially made available to the public. ChatGPT was made available for public testing on Dec 15, 2022. Many of us have at least started discussing it, while the few futuristic ones have by now started using it for many day-to-day academic and research activities. There are more AI-based chatbots like GPT4, and BioGPT, which many of our younger generation computer savvy entomologists/ academics are aware of. The front runners amongst us, who are using these for many of the routine requirements of teaching and research, also unfortunately deploy these many times in an undesirable manner.

In life sciences, especially in the frontier areas of crop protection, from toxic material discovery, and pest and disease diagnosis/ IPM to education, AI has started showing great promise. It helps us in being more objective and more so in specific tasks like improving IPM decisions, strategies and their impact assessment. It is also changing the dimensions of teaching in entomology and other crop protection components, and the research endeavours thereupon. It enhances learning and provides more authenticity and accuracy in addition to saving time and efforts. Considering challenges like lack of generalisation, risk of over-reliance and other similar aspects, utmost caution is required in their application. Lot of standardization and thoughtfulness will be required for their efficient and successful integration. There will be a need to shun hurry and over board adoption, as it envisages diligent and effective handling of AI to accomplish the right and incremental dividends. Many times it might even boomerang with undesirable outcomes, if not deployed correctly.

Especially in life sciences like in entomology, there are multiple tiers of interactions between organisms, their ecology and evolution. Artificial intelligence can change the way we approach these intricate interactions and their complex scientific aspects. Academicians and researchers have been using AI-based approaches over the last two decades. The emergence of ChatGPT, GPT4, and BioGPT has provided a new handle. We as researchers and educators are exploring these emerging systems. It requires a lot of brainy efforts to effectively leverage these for our essential logistics and workflow, especially when we are building a learning framework around these tools. Many areas of entomology and their essential and core disciplines have started witnessing widespread adoption of AI. These have been initiated to a large extent mainly in the critical aspects of pest and disease diagnosis, genetic basis of multitrophic interactions, analysing images, toxic material discovery, chemical profiling etc. These enable fast tracking of many of the essential components of IPM, especially the decision-making processes, designing of strategies, and their evaluation. Such a development of relevant essential knowledge and its application have resulted in the required fastness compared to the traditional methods that rely on labour-intensive and expertise-reliant processes. The image analysis and diagnosis to aid IPM have been given an impetus of unseen magnitude with the adoption of these AI based tools especially through expedited and accurate image analysis and diagnosis.

I wish to end this editorial note with a note of caution. It is for the front runners amongst us, who are using these for daily requirements in an undesirable manner. Yes, I mean it becomes "undesirable", when these tools are used for circumventing the deployment of intellectual components of human intelligence, and the associated hard work and time that is inherently required in such endeavours.

Dr. V.V. Ramamurthy
Editor in Chief, Indian Entomologist

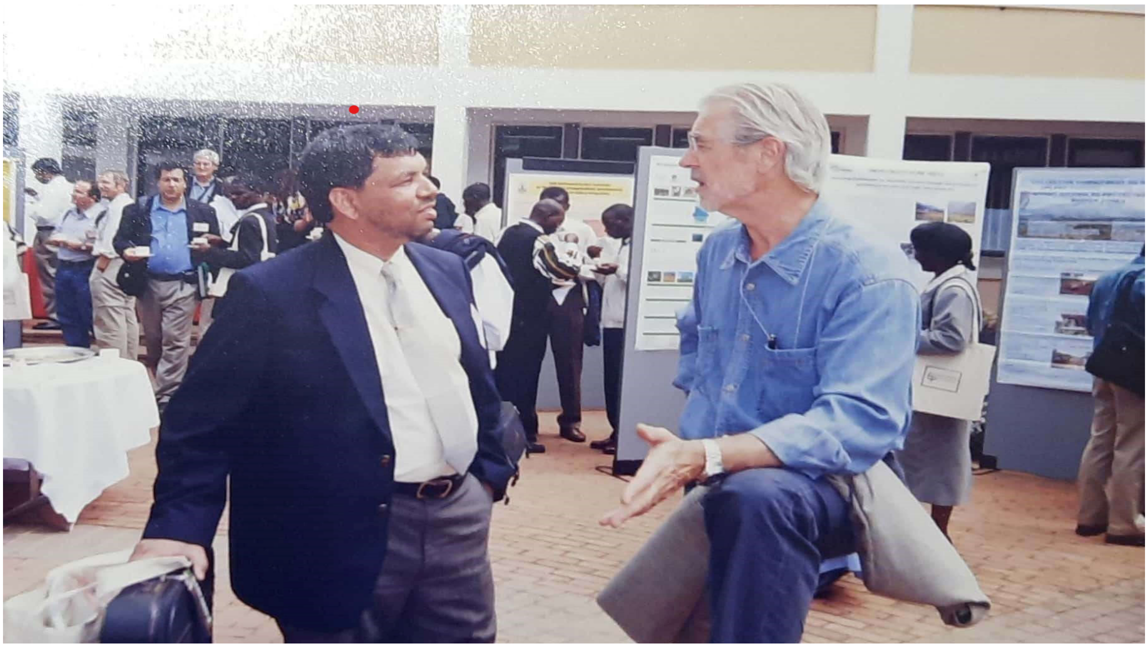
A DIALOGUE WITH DR. R. C. JOSHI

A magnanimous and an incredible journey of a village boy to Scientist at an International Institute. A determined mind and a strong will take you to greater heights. Dr. Ravindra Chandra Joshi, an overseas scientist shares his thoughts and experience with IE associate Editor Dr. Sagar D

Dr. Ravindra Chandra Joshi born on 26th September 1958 in the village Chitai, Almora, Uttarakhand. He had his earlier education in India, completed B.Sc. (Ag.) in 1980 from the Andhra Pradesh Agricultural University, Hyderabad, and M.Sc. (Ag.) in 1982 (Agricultural Entomology) from Tamil Nadu Agricultural University, (Madurai Campus), Coimbatore. His passion in rice entomology blossomed during his thesis research on Rice Gall Midge which paved way to work at the International Rice Research Institute (IRRI), Philippines, and obtained Ph.D. (Entomology) from the University of Philippines at Los Baños (UPLB), Philippines in 1988. Dr. Joshi is currently serving as Senior IPM Consultant, Philippine Rice Research Institute (PhilRice), Department of Agriculture, Philippines who has four decades of rich experience in research, teaching and extension in sustainable agriculture across Asia (Cambodia, India, Japan, Philippines, Vietnam, Japan), in Africa (Nigeria), in the Pacific Islands (Fiji, Solomon Islands), in Europe (Spain), in South America (Ecuador), and in the Caribbean (Haiti, Suriname, Trinidad and Tobago).

Dr. Joshi has made great strides in the integrated management of Asian Rice Gall Midge and the African Rice Gall Midge during his tenure at the International Institute of Tropical Agriculture (IITA), Nigeria. His work has spanned the breadth of national, regional and international organizations, research and government institutions. He served as senior adviser to the Ministries of Agriculture in both Fiji and The Solomon Islands. In each country he developed National Agriculture Sector Policy, assisted in international cooperation, worked in national research, and advised and assisted the senior directors to translate the sector policy into corporate plans. Dr. Joshi is considered as most knowledgeable persons on rice insect pests (gall midges, stem borers, planthoppers, black bugs, invasive apple snails, and rice field rats) and serpentine vegetable leaf miners in highland vegetables (cabbage, potatoes, and others), in the Philippines. In fact, his expertise on the invasive apple snail is recognized internationally as evidenced by his being consulted by other national programs in Asia, Africa, Europe and Pacific Islands.

In Fiji, Dr. Joshi revived the Fiji Agricultural Journal and the Fiji Institute of Agricultural Sciences that had previously been inactive for more than 17 and 20 years, respectively. He is a Visiting Professor in many national and regional universities in Fiji and Philippines, and examiner for universities in the South Pacific, Philippines, Australia, India and Thailand. He has edited 4 books, and published over 150 research articles with students and collaborators on crop protection, particularly regarding invasive species affecting food and nutrition security. He is a fellow of 17 professional societies, and holds



Dr. R. C. Joshi with Dr. Hans R. Herren (World renowned Biocontrol expert), Former Director General, ICIPE, Kenya

honorary positions in a number of academic, and professional networks and associations.

Dr. Joshi is well decorated scientist with many awards, he is recipient of the **Executive Director's Award** from the Secretary of Agriculture during the 18th Anniversary of Philippine Rice Research Institute in 2003, he is Fellow of Royal Entomological Society (FRES) of London, United Kingdom, Fellow of the Royal Society of Biology (FRSB), London, United Kingdom, Fellow, Entomological Society of India (FESI), India and Fellow, Plant Protection Association of India (FPPAI), India.

Dr. Sagar D (SD): Sir, on behalf of Indian Entomologist Magazine, I profusely thank you for accepting our invitation to share your thoughts and ideas with the magazine. Sir, you are the first overseas scientist we are interviewing for Indian Entomologist.

B. Sc (Ag) in Hyderabad, M. Sc (Ag) in Coimbatore and PhD in Philippines what inspired/motivated to do PhD overseas?

Dr. R C Joshi (RCJ): As early as my undergraduate and graduate student days, I was always interested in rice entomological research especially on biocontrol and integrated pest management. Therefore, I used to read lots of International Rice Research Institute (IRRI) publications: research papers, research projects highlight in annual reports and books where IRRI scientists and visiting scientists published their excellent research findings. The rice entomological researches of famous rice IRRI principal entomologists/ visiting scientists starting from Dr. John A. Lowe, Dr. Peter E. Kenmore, Dr. E. A. Heinrichs, Dr. J.A. Litsinger, Dr. B. M. Shepard, Dr. K. L. Heong, Dr. O. Mochida, Dr. M. D. Pathak, Dr. R. C. Saxena, Dr. M. S. Venugopal, Dr. S. Chelliah, and many others had influenced me. I had a big dream to be like them and to work at IRRI as a crop protection specialist one day, and therefore I was determined and joined the Ph.D. programme at the University of the Philippines at Los Baños (UPLB) without any scholarship. IRRI is housed in the UPLB Scientific Community Campus and this proximity and as a UPLB Student it helped me to attend free IRRI weekly seminars every Thursday and Saturday seminars, and learn about the new research directions in the rice world from the world-renowned rice scientists.

SD: What was the special thing that attracted to this field of tiny creatures? What initially sparked your interest in studying insects and becoming an entomologist?

RCJ: During my undergraduate days, I used to collect many crop insect pests (various stages) and their damage symptoms to rear them individually in big glass jars in my house (originally those big glass jars were used by my mother to make pickles), to understand their life cycle (way of life). From my field collections, I kept few individuals (adults and their immature stages) for my entomology course requirements (insect collection that we had to submit). I have borrowed all the glass big jars from my mother to rear those insects and my mother has volunteered to change the plant foods and clean each jar every day while I am at Andhra Pradesh Agricultural University (APAU) attending my classes. To my surprise, she would even observe changes in insects reared in those glass jars. On my return home every day in the evening, she would ask me to check the glass jars. One day she alerted me that some small black insects were emerging in one of the glass jars instead of the usual big adults. This caught my attention and made me interested, then I consulted my APAU Professor (Dr. P. Kameswara Rao) who was teaching us one of the entomology courses, and after few days he showed me that what I have reared is interesting and probably new. So he asked me to rear some more. While rearing them, I already started to look at CAB host-parasitoid catalogues, CAB Abstracts, and published references, and even contacting many Parasitic Hymenoptera experts like: Dr. V. K. Gupta, Dr. H. Nagaraj, Dr. S. Nagarkatti, Dr. T. C. Narendran, and many others from British Museum (London) for any information. My aim was to publish this with my mentors at APAU.

To sum up, basically it is my mother to whom I owe the most for the start of my entomological career (biocontrol), and of course to my earliest most mentors in Entomology at APAU. I published few short research papers in well renowned Journals during my B. Sc. (Ag) studies at APAU, Rajendra Nagar, Hyderabad with my APAU mentors who were renowned Indian entomologists.

Joshi R C, Rao P K, Ali M H. 1981. Preliminary studies on Jamun leaf miner (*Antispila anna* Meyr.) with two new parasite records. Current Science 50(8): 373-374.

Joshi R C, Rao P K, Rao B H K. 1982, New record of a chalcid pupal parasite *Brachymeria (Matsumurameria) criculae* (Kohl) on *Metanastria hyrtaca* Cr. (Lasiocampidae: Lepidoptera). Entomon 7(4): 499.

This sparked my interest to continue my future research in entomology with focus on IPM and biocontrol agents.

SD: You have gained recognition for your knowledge of invasive apple snails on a global scale; could you kindly narrate us how interest in snails has grown?

RCJ: The invasive apple snail (formerly referred to as the golden apple snail), was introduced in the Philippines between 1982 and 1984 to supplement sources of food protein of low-income Filipino farmers. However, in 1986, it began to damage heavily rice farms in northwestern Luzon. In 1986-1988, I was still a Ph.D. student at UPLB and also IPM Consultant at the Philippine Rice Research Institute (PhilRice). One of my professors, Dr. B. M. Rejesus was invited by Plant Quarantine and Training Institute (PLANTI), Malaysia to present a paper on the current status of this invasive snail, and so I volunteered to help her with the related literature collection. She saw the extensive information I provided and she included me as one of the coauthors.

I remember, the first Executive Director of PhilRice, **Dr. Santiago R. Obien** gave me excellent support when I told him that I want to help Philippines to manage the invasive apple snail problem as rice is the staple crop in the Philippines and rice is eaten by every Filipino. He provided me with the modest budget to kick start the snail management research, when no other agency even the International Rice Research Institute (IRRI) and Food and Agriculture Organization of the United Nations (FAO) consider snails as problem in rice. Without Dr. Santiago R. Obien and PhilRice subsequent Executive Directors (Dr. Leocadio S. Sebastian, Dr. Sailila E. Abdula, and Dr. John C. de Leon) solid support, I and my team at PhilRice would have not reached this far. Today, PhilRice is globally recognized for the invasive apple snail research especially on its integrated management. It is because of innovation and consistent hard work that makes our invasive apple snail research important to other countries either experiencing its new invasions or recurrent invasions or spreading its distribution. Invasive apple snail is one of the 100 of the World's Worst Invasive Alien Species listed in the Global Invasive Species Database that was developed and is managed by the Invasive Species Specialist Group (ISSG) of the Species Survival Commission (SSC) of the International Union for Conservation of Nature (IUCN), and our research on invasive apple snail is well documented in the GISD, CABI Invasive Species Compendium and other databases globally. This work still continues to bring me around the globe, wherever this snail has invaded and continues to cause havoc.

SD: Since a few decades ago, invasive species have severely affected the environment and the economy across the globe. In terms of integrated pest management, how important is the research of invasive species?

RCJ: As I considerably worked on invasive apple snails, I could say that the negative impacts of these snails are at regional, national and international levels on agricultural yields (rice and many other aquatic crops), farm income, human health, biodiversity, natural ecosystems, and pesticide misuse and abuse during their management are enormous and irreversible. With the climate change, invasive apple snails are able to proliferate faster, accelerate growth rate and invade rapidly new areas because of their ability to acclimatize to winter temperatures, extreme high temperatures during summer, prolonged drought, flooding and tolerate high salinity and polluted water conditions, and other mortality factors. Based on climate models, higher temperatures from global warming will favor invasive apple snail colonization, feeding, growth, sexual activity and egg laying in many of the rice-producing countries. Thus, the research on invasive alien species and their ecological dynamics is critically important in the context of integrated pest management (IPM) to prevent, detect, and control invasions, and also for developing sound policies for decision-makers.

SD: As you have worked in different capacities in many international organizations, how was your experience working in international institutes?

RCJ: I have more than 30 years of rich experiences in research, teaching and extension in entomology in several Asian, African, Pacific Islands, Europe and Caribbean countries, with national, regional and international organizations, including private sector. In each organization, I learnt something new as their way of working, mandate, vision, mission, areas of focus and goals are different. So, I was lucky to be exposed to diverse work cultures and this made me resilient. The two international organizations (IITA, Nigeria and IRRI, Philippines) that I worked with helped me strengthen global networking, collaboration and partnerships, improved my problem-solving skills, and made me a better team player because of associating with experts from diverse backgrounds, culture and perspectives. However, in my opinion after gaining enough international experience at international centers, one must go back and help national research and academic organizations. This is what I am currently doing, it is time to pay back and share your skills, knowledge and experience.

SD: As an overseas scientist, working away from the motherland, what are the biggest challenges you've came across in your professional life?

RCJ: Like any other international student, I have faced many challenges but one must not forget the unique opportunities that come with it. When I came to Philippines as a Ph.D. student, that was my first time to fly in a airplane, being a strict vegetarian was a big challenge in the Philippines, education system was totally different from India, wide cultural diversity, language barriers were not too much as many Filipinos speak English, away from immediate family members especially when I was hospitalized, navigating to find scholarship and renew visa was a long journey. All of this required resilience, adaptability and an open-minded approach to navigate and make meaningful contributions to the scientific community in the host country. It was because of research breakthrough, finally IRRI for the first time gave a scholarship to a student who is not employed in his home country. This paved the way for other international students who were not employed in their country. The international student experience made me stronger to work anywhere in the world as an overseas scientist. In addition, because of this I am the only foreigner working with the Philippine Rice Research Institute (PhilRice), Department of Agriculture, Philippines. Also I am one of the two foreigners as the Honorary Member of the National Research Council of the Philippines (NRCP), Philippines. The only foreigner as Fellow of the Philippine-American Association of Science and Engineering (PAASE). In short, though there were many challenges as an international scientist but it offered me unique opportunities for personal and professional growth, expansion of scientific horizons, cross-cultural collaboration, etc.

SD: What are the opportunities for young brigade of entomologists in international institutes?

RCJ: Nowadays it is easy for the young scientist (entomologist) to get connected with any international scientist (entomologist) globally because of global connectivity and access, unlike our time when there was no emails and other digital communication platforms. Currently many international institutes have funding constraints and so one needs to have innovative ideas and cutting-edge science that is interdisciplinary, high impact, novel and must address food and nutritional security, climate change, biodiversity loss and many of the UN Sustainable Development Goals. I see there are more opportunities for young entomologists now as they are more exposed to interdisciplinary innovation researches, and are able to push the boundaries of scientific understanding, knowledge and multi-skill sets. I always say if one has an innovative research project proposal, funding is never a constraint!!

SD: Whom do you admire as a role model in your personal and professional life?

RCJ: My parents and my sister have played a big role in my personal and professional life. Especially my mother played a significant role to kick start my entomological career as early as at the undergraduate level (though she was not a scientist). I consider my father a famous plant pathologist/weed scientist. Thus, I decided to take entomology because you know in India, people would associate my success because of my father. I wanted to excel like him but in entomology. My sister was far more serious with her studies than me, and she always helped me to become better in my school years. My deepest gratitude to my wife, Elaine E. Joshi, and my two children: Ranee E. Joshi and Ranjeet Chandra E. Joshi, and my sister's family members for their suberb support.

Before B. Sc. (Ag) Days: Aside from Professor Dr. M. S. Swaminathan, there were many entomologists (Indian and Overseas) that I look-up from the start of my entomological professional. I will name them in the chronological manner (earliest one's only) during my entomological journey. Some of them are still mentoring me and I have been very fortunate and grateful to them. Dr. Raymond C. Smith (Father of IPM)- I remember as a small child accompanied my father with Dr. Smith to visit Taj Mahal, Agra in a Mercedes Car.

During B. Sc. (Ag) Days: Dr. B. V. David (First Indian entomologist who influenced me to become an entomologist), during my B.Sc. (Ag) days at APAU, Dr. D. Bap Reddy, Dr. P. Kameswara Rao, Dr. K. M. Harris (Former Diptera expert on gall midges, Commonwealth Institute of Entomology, Retired as Director of International Institute of Entomology, UK)- First paper on gall midge on Jamun), Dr. N. C. Pant (Director, International Institute of Entomology, UK), Dr. V. V. Ramamurthy (IARI, New Delhi), Dr. John Whitman (ICRISAT), Dr. W. Reed (ICRISAT)

During M. Sc. (Ag Entomology) Days: I had the thesis adviser, Professor Dr. M. S. Venugopal, who had just returned from IRRI, Philippines finishing his tint as Post Doctoral Fellow in Entomology with Dr. J. A. Litsinger, IRRI Entomologist. He has been my mentor even till today. I worked on rice gall midges for my thesis at TNAU, Madurai and I published papers with him. I worked closely with world renowned rice gall midge entomologist, Dr. T. Hidaka and also published papers with him

During Ph.D. (Entomology) studies at University of the Philippines at Los Banos/ International Rice Research Institute, Philippines: I worked with famous rice entomologists at IRRI and UPLB and published papers with them. I am in active touch with them even till to date (retired from IRRI and FAO) with Drs. B.M. Shepard, O. Mochida, J. A. Litsinger, E. A. Heinrichs (all from IRRI).

SD: How do you see the future of entomology evolving, and what potential breakthroughs or advancements do you anticipate?

RCJ: I see digital diagnostic tools, and real-time surveillance and monitoring tools, molecular taxonomy, understanding tritrophic relations, dynamics in the climate change regimes, use of remote sensing, climate models will all play a key role in future IPM programs. In addition, many countries are resorting to citizen science to collect data to identify the spread of invasive species and distribution. The science of Entomology especially the beneficial social insects (Honey bees, Stingless bees), pollinators, butterfly gardens, insects as food, etc. are introduced to high school students to create interests in insects in many countries.

SD: How do you inform the public and decision-makers about your study findings in order to raise awareness and advance conservation?

RCJ: I collaborate with Developmental Communication specialists / Science writers in the organization I work and also with media networks (TV/Radio) in the Philippines and abroad, to develop knowledge-based information materials in simple and easy to understand language for non-specialists. I use lots of photos, cartoons (science comics), infographics, short video clips, story-telling "show and tell", short drama clips, and through online *via* social media, contribute to websites, blogs, and sharing through networks, etc. to reach public and policy/decision -makers.

I volunteer to give free presentations in training programs, workshops, conferences, symposiums, webinars, scientific societies, and community programs about invasive species, management and ecological restoration and conservation. I have introduced a special course on invasive species in the undergraduate and graduate programs at the University of the Philippines, Baguio which is now offered on a regular basis. I also prepare policy briefs for policy makers, and scientific papers to publish in referred journals.

SD: Lastly, any suggestions or specific advice you would like to give for the improvement and wider reach of 'Indian Entomologist' magazine?

RCJ: "Indian Entomologist Magazine" is a good source of information to young entomologists and one way of remembering and recognizing the pioneering Indian entomologists. India has produced eminent entomologists and some of them have settled abroad, some have retired, some are still active and many have gained global recognition. I think in my opinion, we should feature them, as their stories will motivate young generations of entomologists to be like one of them and excel. We can also request the featured entomologists to disseminate the "Indian Entomologist Magazine" -- one of the goals should be is to create more awareness of the success stories of Indian Entomologists both at home and abroad!!

The interview was conducted by Dr. Sagar D. He is working as Senior Scientist at Division of Entomology, ICAR-IARI, New Delhi. His field of specialization is insect reproductive physiology in relation to heat stress. He is one of the Associate Editors of IE.
Email: garuda344@gmail.com

IN CONVERSATION WITH *CRÈME DE LA CRÈME* OF INDIAN SCIENCE: PROF. RENEE MARIA BORGES

Dr. Renee M. Borges, Professor at Centre for Ecological Sciences, Indian Institute of Science, Bengaluru, known for her significant contributions to ecology and evolutionary biology shares her experience with Dr. Ankita Gupta about her journey in the field of science.

Professor Renee M. Borges is an evolutionary biologist and professor at the Centre for Ecological Sciences, Indian Institute of Science, Bengaluru, India. Professor Borges holds a lushly illustrious career with an h-index of 31 and 2441 citations (as on May 2023) which one can set one's heart on! Her publications have a synergistic impact on the readers as, apart from the great scientific content, they possess a unique and a catchy title which adds to the insatiability and inquisitiveness of the readers. Possessing great oratorial skills in combination to a pleasing demeanour, it's unlikely for the audience to not get swayed by Dr Borges's scientific talks!

To start with her education, Professor Borges obtained her bachelor's degree in Zoology and Microbiology in 1979 from St. Xavier's College, Mumbai. Later she did her master's degree in animal physiology from the Institute of Science, University of Bombay in 1982. She received her doctorate degree from the University of Miami, Florida, with a thesis entitled "Resource heterogeneity and the foraging ecology of the Malabar Giant Squirrel, *Ratufa indica*".

Professor Borges has worked on the visual ecology of predation in flower-visiting crab spiders, chemically-mediated mate location strategies in ant-mimicking spiders, the visual ecology of nocturnal carpenter bees and the nutritional ecology of herbivorous giant squirrels. She currently deals with figs and fig wasps, ant–plant mutualisms, fungus-growing termites and pollination systems in the Western Ghats, besides collaborating with engineers on animal architecture such as the mud nests of termites and potter wasps. Her research focusses on mutualistic, symbiotic, and parasitic interactions between species. She is instrumental in guiding an array of students on these research aspects.

Apart from being a scientist of international repute, Dr Borges attained many accomplishments and to name a few of them: Secretary General of the International Union of Biological Sciences; Fellow, Indian Academy of Sciences; J. C. Bose National Fellow; Fellow, Indian National Science Academy; Chairperson of the DST-Program Advisory Committee on Animal Sciences, and Organismal & Evolutionary Biology (2016–2021); Member, Western Ghat Ecology Expert Panel (WGEEP), Government of India, 2010–2011; and the list goes on.

Dr. Ankita Gupta (AG): Thank you for speaking to Indian Entomologist magazine. You are considered as the cream of the crop and an inspiration for thousands of budding researchers, so I would like to know whom do you consider as your inspiration or a driving force?

Prof. Renee M. Borges (RMB): I cannot think of one person as my inspiration. If I have to pick someone, I would say my father, who was a renowned cancer surgeon, whose biography I have just published. And my mother, who was a botanist and an amateur horticulturist. Both my parents were perfectionists, and I have strived to meet their expectations. I am inspired by the work of great scientists, especially polymaths, and often feel that I would have enjoyed the company of Erasmus Darwin, Charles Darwin's grandfather.

AG: Which moment do you consider as "the turning point" of your life?

RMB: I do not have a specific turning point; I have always known that I wanted to be a student of nature; this for me has been as normal as breathing.

AG: You being an alumna of the University of Miami, Florida, what differences did you feel while starting and establishing your scientific career in India.

RMB: I have been fortunate in that I was offered a job right away at the Wildlife Institute of India, at Dehradun, after my PhD. However, I did not accept the position and continued my work on giant squirrels after I returned from Florida with a project that I obtained through the United States Fish and Wildlife Service. I then joined the Bombay Natural History Society as Deputy Director (Research). I did not think much about differences between academia in Florida and in India. I just knew that to become a scientist one had to do research even in India that could compete with the rest of the world.

AG: Did working on fundamental research ever put you down on any of the platforms? What were your challenges?

RMB: Strangely enough, I have not felt put down on any research platform. I think it depends on how one presents one's work and one's passion. These are traits that are easily recognisable and what we look for in our potential students and collaborators. A commitment to excellence and passion are the two key ingredients that make for success.

AG: Amongst all the scientific discoveries you have made, which ones you feel have made a big impact or have seen the light of day.

RMB: I am proud of the work which demonstrated that the insect ovipositor is an olfactory organ, just like the insect antennae. We were able to demonstrate this by rigging up an electroantennogram apparatus to take readings from the ovipositor; we refer to this as an ovipositogram (EOG). We found that the ovipositor of parasitoids was sensitive to volatiles of the fig (*Ficus*) inflorescence and it was also sensitive to carbon dioxide. We believe that this sensitivity to volatiles aids parasitoids in egg-laying decisions within the fig inflorescence which is guided solely by the sensilla at the tip of the ovipositor.

I am also proud of the collaborative work that I have done with a granular physicist on the structure and stability of the soil nest mounds of fungus-farming termites. Through this collaboration, I have learned to think like an engineer and have enjoyed making fundamental discoveries about how termites are able to achieve strength in their architecture by exploiting the properties of soil in the presence of adequate amounts of water. Our findings have important implications for heat dissipation and ventilation in human architecture.

AG: Considering feminism in practical sense, did you ever experience hurdles in accomplishing your milestones? Being a woman, was it difficult for you to achieve your goals? Do you feel that woman have to go the extra mile to prove their worth at work place?

RMB: I have never thought about my gender during my career. This is perhaps because of an upbringing in which high achievements were expected irrespective of one's gender. In this I have been fortunate. I have been spared the anxiety that many budding female researchers have experienced. Having said this, I have also made a conscious decision to ignore gender in my lab; males or females are treated as equals and there is no task that is considered male- or female-biased. Every researcher is unique, with their own strengths and weaknesses, and we must celebrate this diversity. As I have mentioned earlier, for me there has always been a striving towards excellence. Whether I have reached excellence is immaterial; what is important is the effort towards it. In that sense, my greatest critic is myself, and therefore it doesn't matter if I am male or female.

AG: You have served as a Chairperson of the DST-Program Advisory Committee on Animal Sciences in that context what advise you would like to give to the Indian researchers to keep in mind while formulating the projects for competitive grants.

RMB: As Chairperson of several funding committees, I have sometimes despaired when I see that young researchers fall into the trap of jumping onto current research bandwagons rather than following their own interests and passions. Some of the bandwagons in recent years have been the obsession with nanoparticles, bioprospecting or biodiversity surveys. Most of these projects get rejected right away and do not even get sent for review. A project must have a good and focussed question, must make some predictions, must have a thorough literature review, and a comprehensive and doable work plan. Above all, the project must indicate the sincerity and commitment of the researcher. A good proposal must also be candid about its weaknesses, or areas of uncertainties, and must show how if Plan A does not work, what will Plan B deliver. By writing a good proposal, the researcher is showing her/his philosophy and approach towards science. It is not a mere exercise that ticks some boxes. Writing a good proposal is like performing on the stage, except that the stage is a piece of paper, and the words are in the proposal writer's mind and in the reviewer's eye.

AG: In the course of time, what changes you expect/ suggest for the Indian Scientific Organizations or major scientific funding bodies for attaining higher standards in Indian research.

RMB: Indian research needs adequate funding. For Indian research to be globally competitive, the funding for research must increase to at least 3% of GDP from its current value of about 0.7%. Failing this, Indian research, except in some favoured sectors such as space research, will always remain at a low level. Even in the so-called Institutes of Excellence (IoEs) with my institute falling in that category, funding for research is woefully inadequate. There is money for sophisticated equipment but no money to maintain such equipment and no cadre of trained technical personnel. Therefore, most often, equipment stops working after its warranty period is over. This is a great loss to science. Mission-mode research must be discontinued; *i.e.* as when a few scientists decide what subjects will be given priority over the next few years. While it is important for research to have a focus, allowing just a few scientists to take decisions on where and how the limited money will be spent is improper. The newly announced National Research Foundation which is supposedly modelled on the National Science Foundation of the USA will hopefully use the best global practices in place to prioritise research and also to reward maverick science, since it is sometimes from harebrained ideas and seemingly impossible dreams that great discoveries are made.

AG: You have guided many scholars but some would have aspired to seek your mentorship but somehow would have missed the chance. So, I wish to know what road map you suggest for the researchers to follow?

RMB: The best roadmap is to follow one's heart. Research is a vocation; it is a calling; just as becoming a doctor or a healer is a vocation with the goal to cure the sick and soothe the afflicted. Doing research in a mechanical way is merely engaging with technology; it is not doing science. The quest for answers to scientific questions is the goal. The moment research loses its meaning and the ultimate goal is not in sight, that is the point to stop and ask oneself: Am I in the right profession?

The interview was conducted by Dr. Ankita Gupta. She is working as Senior Scientist at Division of Germplasm Collection and Characterisation, ICAR-NBAIR, Bengaluru. Her field of specialization is insect biodiversity, systematics, host-parasitic wasps association/interactions and molecular characterization.
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FEATURE ARTICLE

Termites as source of sciences: An untold tale of termite mounds and beyond

Kalleshwaraswamy C.M.

Abstract: Imagine how thousands of termites respire through the thick-walled mound? How they construct the mound? Social life and Collective behaviour of termites can be utilized as 'Biomimetics' for human well-being. The article explains the biological and behavioural aspects of termite life, and tries to unravel the possible opportunities which the human beings can exploit in various branches of science. The need for research investment and technological advancement to use the knowledge of termites for the benefit of humans is discussed.

Key words: biomimetics, diversity, ecosystem service, stigmergy

Termites usually carry the reputation as enemies of human beings. However one who closely observes and work with them, surely would fall in love with them, as there is a lot to wonder about and learn from termite life and behaviour. Their nest, generally called a mound, is an architectural marvel made of soil and saliva and appears to be like a thick-walled structure, but the gaseous exchange occurs. The social life, long-living queen, foraging strategy, cellulose digestion, symbiotic relationship with microbes, and inquilines they support provides a wealth of information for the benefit of humans. Termites are a classic group of insects which inspires humans as '**biomimetics',** an area of science that is advancing more than ever. It is intriguing to know how termites communicate and inform other members to collaborate and make group decisions.

Winston Churchill, one of the greatest orators of all time, once said, "We shape our buildings, and after that, they shape us". The story goes like this. In October 1943, following the destruction of the Commons Chamber by bombing during the Blitz (a German bombing campaign against the United Kingdom), parliamentarians debated rebuilding the chamber. With the approval of Winston Churchill, the then prime minister, they agreed to retain its rectangular pattern instead changing to a semi-circular or horse-shoe design favoured by some legislative assemblies. Churchill insisted that the shape of the old chamber was responsible for the two-party system, which is the essence of British parliamentary democracy. The design of the section was such that it helped to keep debates lively and robust but also intimate. Termite mounds, with thousands to millions living inside, have long practised the design of their house wherein a unique combination of physical contact and behavioural communication keep the colony intact and robust. Lesson human beings can take in this developed world, where group living is on the wane. The house we live in impacts us; hence, we must construct and manage sustainably without severely hurting natural resources. Each nest has characteristic structures which allow ventilation and cooling. Nests of termites are architectural wonders of the living world, built by the worker's collective performance. Generally speaking, each nest will have a queen, a king, several workers and a few soldiers (Fig. 1), although slight variation occurs in some species. Although known for damaging the wood and wood-based materials in the houses (Fig. 2) and economically important trees in fields, the ecosystem service they provide outweighs the harm they cause. Many soil-feeding species of termites (Fig. 3) add a lot of organic matter to the soil and reported to have enhanced wheat yields by 36 per cent (Evans et al., 2011).

Termites and how they construct mounds can be a source of wisdom. Let us assume a situation where direct sunlight falls on our home that leading to an increased temperature inside the house. We must shell out a lot of money and arrange materials to avoid this direct sunlight. Termite mounds may also face the same problem, which eventually leads to hot air flowing inside the mound. How do termites correct the situation? As the temperature increases in a part of the mound, hot air flows into the mound,

Fig. 1. Different stages and castes of termites

Fig. 3. Soil feeding *Dicuspiditermes*

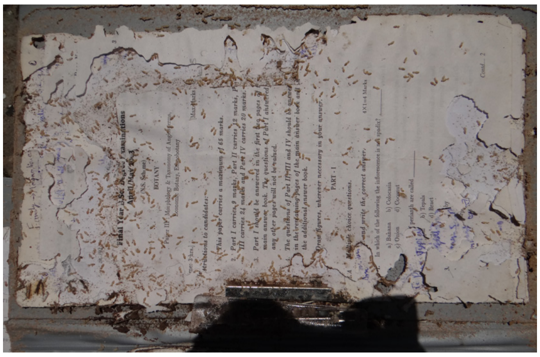

Fig. 2. *Coptotermes* damage on paper

Fig. 4. The dealate male and female imagoes finding a site for starting a new colony

coupled with increased production of metabolic gases such as carbon dioxide, changing the behaviour of termites. If one section of the mound is too warm, that temperature change will trigger a change in airflow, which will carry construction cues to nearby workers, informing them where to adjust the mound to reduce temperature. The termites will follow their senses to that section and adjust the mound to reduce temperature. Why money and materials? Science helps!

Very little is known about how individually these minute and blind insects come together to construct their mounds. The question is how they achieve this; the term '**Stigmergy**'coined by French biologist Pierre-Paul Grassé in 1959, referring to 'stimulation of workers by the performance they have achieved' explains this phenomenon better. In this behaviour, one worker modifies the environment inducing a change in others. Stigmergy, meaning in simple terms, 'leaving a sign on work in progress,' is a characteristic behaviour that forms basis of termite biology and social life.

The very basic of gathering soil particles and building a mound is stigmergy. When a queen and king start a new colony, initially queen identifies a suitable place (Fig. 4) in the soil and lays fewer eggs. The workers coming from these make their random walks. They

Fig. 5. Variation in head characters which forms the base for taxonomy of termites

Fig. 6. *Neotermes viraktamathi* Ranjith and Kalleshwaraswamy (Kalotermitidae) which the author described from Western Ghats

pick up and drop soil particles, leading to variations in the density of soil particles. During the process, the termites leave a pheromone scent on the soil particles they have carried around, increasing the drop chances of another loaded termite randomly passing by. This behaviour leads to a self-amplification of soil particles, a pile that depletes the free soil grains. The process of amplification and depletion leads to a regular pattern of sand pillars forming their nest's starting point. This explains how the indirect communication among termites via soil particles leads to a collective behaviour in building a mound. In turn, the termite queen communicates with this self-organizing termite-soil system by emitting a pheromone gradient. Now, the same stigmergic principles of termites have been exploited in cellular morphogenesis. A team of interdisciplinary researchers led by Philippe Bastiaens, Director at the Max-Planck-Institute of Molecular Physiology in Germany, have created a life-like proto-cell energized by chemical potential, which is capable of translating external signals into shape changes in dependence on its own self-organized morphology. The scientists idea were confirmed when their lifelike proto-cells showed that the cytoskeleton and signalling system both interact with the membrane to self-organize into various patterns, following the same stigmergic principles as the termite-soil particle system. A clear-cut example of 'Termite based biomimetic exploited in Science' to understand cell to cell interaction.

Does the number of people in the room affect the Air conditioner's performance or cooling effect? We assume that the AC's cooling efficiency depends on the size of the room and the appliance capacity. But the number of people in the room also affects the cooling. Now think of termites, millions of termites respiring and releasing CO_2 from the body. In addition to temperature increase, What if a large quantity of CO_2 accumulates in the mound? Carbon dioxide and an elevated temperature would drastically impact the life of termites inside. Although the temperature of open ventilator mounds and closed ventilation systems differs, most termite species maintain a mound temperature of around 25 degree Celsius. But how do they manage? The termites could achieve this remarkable feat by constantly opening and closing a series of heating and cooling vents throughout the mound over the day. The air enters the lower part of the mound, and they can control the flow of air by adjusting the location and size of tunnels and the height of the mound. Controlling airflow also allows the termites to adjust the temperature and humidity inside the nest. The industrious termites constantly dig new vents and plug up old ones to regulate the temperature. Termites have learnt how to construct their nest efficiently, keeping them ventilated and maintaining the temperature for survival.

Inspired by David Attenborough climbing inside the chimney of a termite nest in Nigeria, Zimbabwean architect Mick Pearce rightly said that evolution had already solved the air conditioning problem. The story began in 1992, when Zimbabwean architect Mick Pearce and his Arup group received a commission to build Eastgate Centre, a two-building office complex and shopping mall, in the country's capital city of Harare. Pearce, however, wanted to do more than build a new building. Eastgate costed 10 per cent less to build than a similarly sized building with air conditioning. The building also used only 35 per cent of energy consumed by comparable buildings in Harare and saved $3.5 million in energy costs in first five years. The Eastgate Centre, made mainly of concrete, has a ventilation system that operates similarly to the termite mound. Depending on which is hotter, the building concrete or the air, the outside air that enters is either warmed or cooled by the building mass. The air thus enters vented into the building's floors and offices before exiting via chimneys at the top. The east gate complex also consists of two buildings separated by an open space covered by glass and open to the local breezes. Fans on the first floor continuously draw air from this open space. Air is then pushed up vertically through the ducts located in the central spine of each of the two buildings. The fresh air replaces stale air that rises and exits through exhaust ports in the ceilings of each floor. Ultimately it enters the exhaust section of the vertical ducts before flushed out of the building through chimneys. Can't we think of building such biomimetic architecture in India, which reduces electricity consumption? Can't we construct climate-responsive buildings which naturally cool down when the ambient temperature is high?

Taxonomy and diversity of termites in India

It is worth remembering two of the greatest termite taxonomists of India who contributed to Indian and world fauna. Dr Mithan Lal Roonwal was the pioneering termite taxonomist in India whose two faunal volumes cover termites of India and adjoining countries. His student Dr Kumar Krishna moved to USA for his Ph D under Dr Alfred E Emerson and contributed to world termite fauna. He published the definitive systematic treatment of the termites of the world in a seven volume *Treatise on the Isoptera* *of the world* in 2013. India has a high diversity of termites, but the Indian termite fauna shares a tiny portion of the global fauna, *i.e.*, approximately 295 species, 52 genera, and six families (Rajmohana et al., 2019; Ranjith and Kalleshwaraswamy, 2021). Among the 295, 188 are endemic to India (Rajamohana et al., 2019). Termites evolved from social cockroaches of the family Cryptocercidae (Blattodea: Blattoidea) (Inward et al., 2007). Hence, termites are now classified under Isoptera, Epifamily Termitoidae within the order Blattodea. There are about 2,937 species of extant termites worldwide (Krishna et al., 2013). Few characters of termites used in termite taxonomy are shown in Fig. 5 for the benefit of readers which represent great diversity among termites.

Ecosystem services of termites

Termites (Isoptera) play essential roles in ecological systems. They are decomposers, especially of a variety of cellulose-based resources, and thus ensure the cycling of organic matter in ecological habitats. The magnitude of ecological role termites play in a habitat is a function of their population density and biomass (Evans et al., 2011). Although both microbes and termites are decomposers, microbes require relatively high amount of water to grow and consume wood, termites can function at relatively low moisture levels, making them an important organisms in tropics. Conservation of beneficial fauna is the need of the hour. Deforestation and urbanization or any other anthropogenic activities could decrease the diversity of termites (Kalleshwaraswamy et al., 2018). Termite species diversity and abundance are linked to historical usage of the land and human activities that alter the landscape and the ecosystem. Ants and termites have similar functional roles to earthworms and provide valuable ecosystem services (Evans et al., 2011). In Addition, they have both direct and indirect benefits to other organisms living in natural systems. But the question is how to balance the agriculture/ urbanization and conservation of termites. Studies need to be initiated to understand the species decline due to human activities and, at the same time, efforts for conservation.

Termites as pests

Many species of termites are serious nuisance organisms, inflicting damage to the wood used in both human-made structures and agricultural and forest environments (Kalleshwaraswamy et al., 2018). The ecology of these termites and ecosystem service they provide must need to be understood. Termites can be grouped into four ecological types: drywood, damp wood, harvester, and subterranean termites. Subterranean termites are comprising of 80% of the economically important species. Unlike drywood termites that are easily transported from region to region, most subterranean species are restricted to their native habitats. In India, the economically important species of termites, *Coptotermes* spp. and *Heterotermes* spp., caused significant damage to timber - in storage and in service. Less than 35 to 40 species have been reported to damage crops and timber in buildings in India (Kalleshwaraswamy et al., 2022).

With the increased trade of wood, more termites are becoming invasive in different countries; India is no exception. Therefore, anticipating this potential mega problem, strict policy measures are vitally necessary (Kalleshwaraswamy, 2022). Termites are identified based on the measurements of body parts of conserved characters such as head length, mandible length etc. which may not be completely correct. Development of molecular tools and automated systems for identification using artificial intelligence may provide better tool for accurate identification.

Termite nest/mound diversity

The species belong to Kalotermitidae (Fig. 6), and some Rhinotermitidae build nests in dead, decaying or living wood (Fig. 7 and 8). The carton nests of *Microcerotermes* (Fig. 9) are common in Parts of Kerala and Karnataka. Most *Nasutitermes* construct arboreal nests on tree trunks (Fig. 10) or in crevices of tree trunks (Fig. 11). Few *Nasutitermitinae* build galleries on the tree trunk, which connect the arboreal nest to soil *Grallatotermes* (Fig. 12) or a few species nest in soil *viz*., *Trinervitermes biformis* (Fig. 13). Few other groups constructing nests underground are common *viz*., *Psuedocapritermes* species (Fig. 14). Most species forage by making earthen galleries; however, few are open foragers, *viz*., *Trinervitermes biformis* (Fig. 15) and *Macrotermes convulsionarius.*

In India, the true mound-builders are mostly belonging to Termitidae family where several species of *Odontotermes* construct earthen mounds. The mound size depends on the colony's age, but the structure of the mound is characteristic. For example, *O. redemanni* (Fig. 16) and *O. brunneus* (Fig. 17) construct multilocular mound with buttresses open to outside, whereas *O.*

Fig. 7. *Coptotermes* species (Rhinotermitidae)

Fig. 8. *Coptotermes* species construct nest in a piece of wood

Fig. 9. A carton mound of *Microcerotermes pakistanicus*

Fig. 10. Arboreal nest of *Nasutitermes*

Fig. 11. Nest of *Nasutitermes* in a crevice of a tree

Fig. 12. Galleries of *Grallatotermes* (Nasutitermtinae) on the tree trunk

obesus construct, unilocular mound without any openings (Fig. 18). However, few African and Australian species make huge mounds and are very characteristic. For example, *Cubitermes,* endemic to Africa, construct gigantic mushroom shaped mounds (Fig. 19). *Nasutitermes triodiae* are known for their "cathedral" shaped giant mounds, often more than 15 feet in height (Fig. 20) found in Australia.

Termites nests horbour inquilines

Many inquilines called termitophiles, live in termite nest, which include a wide range of morphologically and behaviourally specialized organisms. Some species cohabiting in close association with the host colony or occupying nest cavities without direct contact with the host. The strategy of termitophile organisms to become integrated into termite societies include appeasement through chemical, morphological and/or behavioral mimicry. They may be beetles, flies, bugs, caterpillars, mites and millipedes. However, it is not clear whether they are parasites or symbionts. For the reason unknown, many termite species harbour

Fig. 13. Nest entrance of *Trinervitermes biformis*

Fig. 14. Underground nest of soil feeding *Psuedocapritermes* species

Fig. 15. Nest entrance and open foraging of *T. biformis*

Fig. 16. Mound of *O. redemanni*

Fig. 17. Mound of *O. brunneus*

Fig.18. Mound of *O. obesus*

Fig.19. Mushroom shaped Cubitermes nest found in Africa (Photo courtesy Dr Jan Sobotnik)

Fig. 20. Cathedral shaped mound of *Nasutitermes triodiae* found in Australia (Photo courtesy Dr Jan Sobotnik)

numerous parasitic arthropod species, few none. Termite nests provide ideal condition for the survival and resources for these termitophiles. There are no detailed studies in India, the species of termitophiles associated with termites. Among the termitophiles, considerable work has been done on rove beetles (Staphylinidae) which are belong to subfamily Aleocharinae which includes most termitophilous species among arthropods (Mizumoto et al., 2022). Other termitophilous insects are silver fishes, phorids and scarabaeids, but termitophily is advanced in rove beetles (Fig. 21). Most termitophilous rove beetles are associated with foraging termite species. So, there is a necessity of understanding time, stage of entry into termite mound and biology of these insects associated to with termites.

Termite nests are super communities

In any ecosystem, termite activity and their mound support particular species belonging to several kingdoms, notably fungi, plant and animal kingdoms. These organisms in turn act as producers such as phanerophytes, chamaephytes, hemicryptophytes, bulbous, rhizomatous and geophytes. In the second tropic level, consumers such as herbivores, includes leaf-eaters, flower-eaters, fruit-eaters, and even stem-parasites, and carnivores are common (like insects, birds, squirrels, reptiles, mollusca and lichens etc).

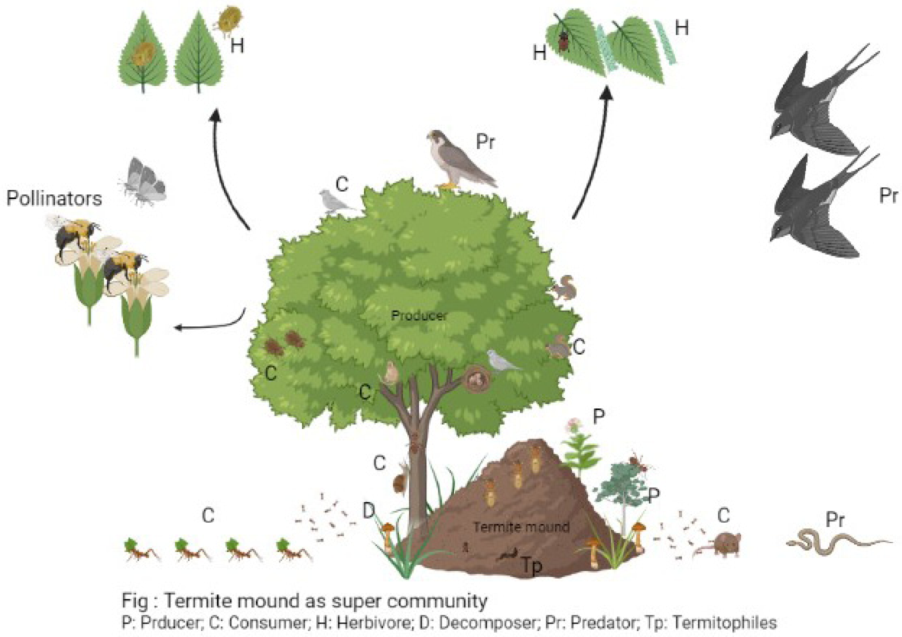

Fig. 21. Supercommunity of termites

Fig. 22. A termitophilic rove beetle in the nest of *Odontotermes* (Photo courtesy Dr Taisuke kanao)

Fig. 23. Defensive secretion from Fontanelle

At third tropic level, decomposers are either animals or fungi (such as mushrooms). Both consumers and decomposers possess their respective predators, which in turn, may be consumed. Parasitism also occurs at different tropic level comprising both endo-parasites and ecto-parasites, such as ticks and insects. Overall, a termite mound supports growth and development of many organisms which are all interlinked forming a complex community, not to forget the microbiota they house inside the gut. The super community of termites is represented in Fig 22.

Termite gut inspired biofuels

Approximately 200 species of microbes live inside the termite hindgut. Their bellies also harbour an array of enzymes which in combination with symbiotic microbes works like bioreactors to produce hydrogen. When termites eat wood and plants, the lignocellulose polymer are broken down into sugars and are transformed into hydrogen. From a small piece of wood, termites while consuming, can produce about a kg of hydrogen which is trapped in the wood. Studies are on the way to use the cocktail of enzymes and gut symbionts for developing efficient renewable energy resources. Genomic studies may further yield efficient way of exploiting termites for commercial biofuel production (Scharf et al., 2011) and hope to exploit this renewable resource through technological advancements.

Termite-inspired Robots

Although human beings are efficient construction engineers, they too face hurdles in the ease of handling materials and the reaching out to difficult terrains where construction work needs to be taken up. Under such circumstances, robots come in handy and can build complex structures without a central controller. Here also, the 'stigmergy' behaviour of termites works without requiring constant human instruction or supervision. A prototype of termite-inspired robots capable of constructing complex structures in remote and hostile locations developed by Harward University in 2014 is a testimony to this area of 'biomimitics' (Gibney, 2014; Korb, 2014). Efforts are underway to use these robots capable of moving sandbags, building leeves in flood-affected areas, carrying food items to the people and so on.

Termites in medicine

Termites are known to have antimicrobial peptides, and in many places worldwide, termites have been used in traditional medicine. In Australia, spinigerin and termicin isolated from *Pseudocanthotermes spiniger*, showed antifungal and antibacterial activity (Coutinho et al., 2008) and are being used in practice known as entomotherapy. They are used to treat various diseases that affect humans, such as influenza, asthma, bronchitis, whooping cough, sinusitis, tonsillitis and hoarseness (Alvae, 2009). The species *Nasutitermes macrocephalus* was the most frequently recorded. It is widely used in Brazil as a therapeutic resource to treat asthma, hoarseness and sinusitis, among other diseases. Another example is *Macrotermes nigeriensis*, used in Nigeria for treating wounds, sickness of pregnant women and as a charm for spiritual protection. In India, there are documents of termites used for treatment of Asthama (Solavan et al., 2006).

Termites as human food

Since time immemorial, India has had many ethno-entomophagic groups restricted to northeast, south and central India. Nevertheless, the diversity of insects consumed is less in south and central India than in the northeast. However, the insect species consumed as food by ethnic people in India are based on availability, palatability, and nutritional values (Chakravorty, 2016). Among insects, around 61 species of termites are considered edible and eaten in many parts of the world (Ramos-Elorduy, 2005). Dewinged termites are considered delicious food in many parts of the world, which may be consumed as a main dish, side dish or snacks (Kinyuru et al*.,* 2009).

Protein-energy malnutrition (PEM) is a significant public health problem in India, especially among young kids. PME affects the child at the most crucial period of development, which can lead to permanent impairment in later life. The underweight prevalence of 42.5% is the highest in the world (Bhutia, 2014). Termites may fulfil the protein requirement, but there is a need for technological intervention where an edible and approved product may fulfil the requirement of young and aged alike. However, until today, a termite-based commercial edible product has yet to be available in India. There is a need to promote termite-based food to serve as an alternative protein source, to remove PEM (De Figueirêdo et al., 2015). Institution-industry collaboration may provide a base for the production of edible dishes such as cookies which could partially support the protein requirement of humans.

Are termites are indicators of ground water?

There are anecdotal stories in villages that farmers' after banking on geologists and native 'dowsers' for finding site for digging bore well have failed, opted for termite mound presence as a cue and found success. As early as 500 CE, Indian astronomer Varahamihira wrote in the *Brihat-Samhita* that termite mounds were indicators of ground water and mineral deposits. There are various literature suggesting a relationship between termite mounds and groundwater. In India, ground water is the most vital and important source for rural livelihood. For farmers, it is costly digging bore wells and any failure is an emotional feeling. In Africa, it is demonstrated that, about 43% of termite mound sites have greater aquifer potential than adjacent areas. One of the primary reasons of enhanced aquifer potential around termite mounds is observed to be the thickness of the weathered layer (saprolite). Termites either have the ability to locate places with deeper weathering horizon or are themselves agents of biological weathering. In Africa, studies have demonstrated that mounds of the genus *Nasutitermes* are usually indicative of promising aquifer potential groundwater reserves compared to macrotermes (Ahmed et al., 2019). Studies of this kind in India need to be initiated, which may identify the potential termite species as an indicator, type of mound and also the success rate.

Termites are critical in natural ecosystems- they help recycle dead wood from trees and plants. Without termites, it would have taken more time for decay or whole world would piled up with dead plants and animals. The benefit accrued from the termites to human beings overweighs the damage they cause. In the recent period, target of termite defensive fluids (Fig. 23) have been tested for household repellents and insecticides (Appalasamy et al., 2021).

Conclusion

Lessons from social insects, especially termites can be applied to solve complex social issues. The super community structural system of self-regulation can be applied to solve complex social issues by understanding the interaction. Individually termite may perform simple behaviour but through collective behaviour they perform complex tasks and have succeeded in the most complex environments. The areas of research are wide and termites provide innumerable opportunities for researchers to understand and use termite biology and behaviour for the benefit of mankind.

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FEATURE ARTICLE

Drone application in pest management: A step towards precision agriculture

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Abstract: Agriculture is the backbone of Indian economy. The profitable crop production depends on several factors of which mechanization and technology advancement are crucial. The advent of artificial intelligence and machine learning technology in the recent past has contributed towards the 'precision farming' or 'smart agriculture'. On these lines, use of unmanned aerial vehicles (UAVs) or more commonly called drones is making rapid strides to ensure efficient resource utilization and enhanced income to farmers. Drone technology in pesticide application is gaining momentum and certainly aids in making better decision towards pest management options for precision agriculture. For effective and efficient use of drones, the knowledge on rules and regulations to fly a drone for the agricultural operations is essential. The Government of India, DGCA to be more precise, has put in place clear guidelines on the use of drones in agriculture and also is taking steps to encourage and popularize drone technology. Several ICAR research institutes and State Agricultural Universities are actively involved in developing crop specific SOPs for drone based pesticide application in various crop ecosystems. An attempt has been made in this article to present the status and scope of using drones for plant protection purpose.

Keywords: Unmanned aerial vehicle, agriculture, bioagents, drone, pesticides, rules and regulations

In this era of artificial intelligence and deep machine learning techniques, use of unmanned aerial vehicles (UAV) or Remotely Piloted Aerial Systems (RPAS), popularly known as drone (dynamic remotely operated navigation equipment), is gaining momentum in various fields. Drone is the popular term often used by the public to denote unmanned aerial vehicle (UAV), which can be an unmanned aircraft or unmanned aerial system (UAS), where the latter refers to a larger system of the airborne portion of the UAV. Drones are controlled/maneuvered by a person located elsewhere through wireless linkages coordinated with the sensor(s) mounted on the UAV, which can be either operated manually, or programmed to operate automatically.

Though development of UAVs was initiated during the early twentieth century for use in military missions, their applications and utilization moved at faster pace in other fields in the recent past. Another important sector where drone application caught attention is agriculture and the first UAV was developed by the Yamaha motor company in 1997 for agricultural purposes (Giles and Billing, 2015).

In tandem with the growing emphasis on smart and precision agriculture, drones emerged as one of the important components of modern agriculture and are being used for different purposes like surveillance, soil mapping, irrigation monitoring, seed dispensing, crop monitoring etc. (Huang et al., 2009). Initially their use was focused towards crop production and monitoring, gradually intensified towards crop protection. Of all the applications, pesticide spraying for crop health management using drones is the fastest growing area to attain accuracy and rapid coverage of larger areas. Certain UAVs are equipped with the cameras and sensors that enable both crop monitoring and pesticide spraying. It ensures saving of time and resources with additional benefits like uniform and thorough coverage in a cost effective manner. Several enterprises in India are working right now on drone technology for delivering food, medicines, and vaccinations. Other industries like agriculture, military and, media entertainment have already adopted drones for various purposes. At present, drones are considered as an essential tool for farmers to accomplish various applications, of which pesticides spraying (Fig. 1) is one of the advantageous and important activities that save their time and labour and ease out the hazardous conventional methods especially in hilly areas (Pathak et al., 2020).

Evolution of drones

Drones are widely used in various sectors of agriculture like mapping and surveying of topographies, surveillance of pest and disease incidence, watershed management and monitoring emergency/ disaster situations.

The first UAVs were developed in Britain and USA in 1917 during the First World War. Subsequently UAVs intended for specific purposes has evolved and the first agricultural drone in the world for aerial spraying was manufactured by Yamaha (Japanese company) during 1990s. These were intended further for use in aerial survey for crop mapping and field analysis. The company introduced Japanese unmanned helicopter Yamaha R-MAX (16 kg payload), which was basically designed for pesticide spraying for agricultural pest management and then crop monitoring. The R-MAX was approved for operation in USA in 2015 by the Federal Aviation Administration. It was extensively used in agriculture for nearly 30 years with proven performance, reliability and efficiency where this unmanned helicopter was fitted with double-acting piston with flat nozzle and impeller (with 300mm diameter) as discharge methods to suit liquid and granular spray application, respectively. The technology became widespread 2010 onwards. Initially it was a fixed wing UAVs, now multi-rotor unmanned aircrafts are into the market. Currently, DJI Agras MG-1S (10 L capacity) (developed for precision variable rate application of liquid pesticides, fertilizers and herbicides), 3WQF120-12 (12 L), 3CD-15 (15L), WSZ-0610 (10 L), HY-B-15L (15 L) are in wide use for agricultural spray operations (Borikar et al., 2022).

In India, in 2022 budget, the Finance Minister of India introduced Drone-as-a-service model naming it as *"Kisan Drones"*. These are intended for use in digitizing the land records, spraying of insecticides, pesticides, nutrients and on whole monitoring and assessing of the crop health.

Regulations and Acts

The Ministry of Civil Aviation (MoCA), Government of India has brought out new Drone Rules, 2021 vide gazette notification CG-DL-E-26082021-229221 dated August 25, 2021 in place of the Unmanned Aircraft Systems Rules 2021 and were subsequently amended by the Drone (Amendment) Rules, 2022 on 15 February 2022 to accommodate and regulate the various drone related activities in India. Recently, the Ministry of Civil Aviation has launched the Digital Sky Platform, a unique unmanned traffic management (UTM) system that facilitates registration and licensing of drones and pilots. The procedures pertaining to issue of Unique Identification Number (UIN), Unmanned Aircraft Operator Permit (UAOP) and related activities are furnished under DGCA RPAS Guidance Manual (DGCA, 2020). It is pertinent to know about the procedures and regulations laid by the Directorate General of Civil Aviation (DGCA) for smooth operation of drones in India.

A license or registration requirement to fly a drone in India

- One should get registered with the DGCA to operate a drone and possesses a license to fly it.

Fig. 1. Pesticide spraying by an agricultural drone in a paddy field

The minimum age limit to fly a drone is above 18 years and should have passed 10th standard along with a completion of training course from a DGCA-approved institution. Upon completion, a written exam need to be passed to receive a remote pilot certificate from the DGCA through the Digital Sky Platform, which comes normally within 15 days or from the Institutions authorized by DGCA. The certificate thus obtained is valid for 10 years.

- Certificate is not required for operating nano drones (weighing less than 250 g) and non-commercial micro drones (weighing less than 2 Kg) under the new rules and the operators should remember not to fly nano and micro drones over 50 ft. above ground level and maintain a speed of 25 m/s.
- The Indian Ministry of Civil Aviation has also deployed an interactive airspace map on the Digital Sky Platform for the convenience of drone operators and all other stakeholders. The map is color-coded into Green, Yellow, and Red zones.
- The drones may be operated freely in the green zones that are earmarked at 400ft above ground level, whereas a special permission is required to fly in yellow zones, which are controlled airspace. Red zones are strictly no-fly zones, which normally include areas such as military bases or nuclear power plants and other sensitive areas that are restricted due to the risk of accidents or national security purposes. The drones are not allowed to be operated near airports or in a densely populated areas.

One can visit https://digitalsky.dgca.gov.in for further more details and get insights into the requirements, criteria, procedures and regulations of UAS operations in India.

Types of drones

Among the different types of drones, especially fixed wing and rotary wing drones, the multi rotor drone especially hexacopter is the widely used one for foliar application of pesticides. The advantage with the multi-rotor drone is propellor turbulence in the crop canopy, that facilitates the better spray droplet penetration into the lower parts of the canopy.

The main categories of UAVs are fixed wing aircraft or vertical take-off and landing rotary wing helicopters or multicopters. A fixed-wing aircraft, require an approach and landing runway and are usually flown in automated mode. It has the advantage of longer endurance and hence can cover larger areas and has a fast flight speed. They can fly at a speed of more than 80 km/h. This makes fixed-wing UAVs ideal for aerial survey, high-resolution aerial photos, mapping and land surveying. In contrast, multirotor UAVs that have lower speed, shorter flight duration and limited payload capacity are easier to pilot manually and need limited space to take off. It's ability to hover around a particular area, and ability to operate in confined areas make them ideal for surveillance and for detecting crop pests, diseases and weeds. The only limitation with the copters is a shorter flight endurance. Hybrids in the form of vertical take-off and landing (VTOL) systems are more versatile operationally as they maintain efficient range without the need for a runway.

UAVs are often dissimilar to conventional aircraft and are obtainable in a range of shapes, sizes, and configurations. The take-off mass of a UAV has been used historically to classify the devices. Frequently used categorizations occur at 2 kg mass, at 25 kg and at 150 kg. The minimum age of the pilot, the expected remote pilot competence, whether the device has to be registered with the CAA or not, the need for electronic identification and installed geo-fencing software are essentially dependent on the category a UAV. The UAVs heavier than 150 kg are generally considered as equivalent to conventional aircraft with obligations to meet analogous airworthiness and certification standards.

UAVs are also classified based on their size – from very small, small, medium to large, the details are furnished hereunder:

Classification based on weight of a drone including payload

(a) Nano drone: Less than or equal to 250 gram;

(b) Micro drone: More than 250 gram and less than or equal to 2 kilogram;

(c) Small drone: More than 2 kilogram and less than or equal to 25 kilogram;

(d) Medium drone: More than 25 kilogram and less than or equal to 150 kilogram; and

(e) Large drone: More than 150 kilogram.

Drone Piloting – a new employment generation platform

The training of drone pilots in flying a drone and also in it's maintenance is an essential component in drone application. The knowledge of the operation as well the management of drone is essential and must undergo training and obtain a certificate to fly a drone to the requisite accurate altitude with precision. In India, the pilot training and the Remote Pilot Certificate has to be obtained from any of the certified training schools authorized by Directorate General of Civil Aviation (DGCA). Initially a few institutes like Indian Institute of Drones, Indian Academy of Drones, Bombay Flying Academy got the DGCA approval for drone pilot training, after which a few more institutes lined up. As the use of drones becoming popular in agriculture especially for pesticidal spraying, the requirement of trained drone pilots and generation of human resource in this direction is very crucial.

Among the State Agricultural Universities, Acharya N G Ranga Agricultural University (ANGRAU), Guntur, Andhra Pradesh is the first one to get DGCA approval for Remote Pilot Training Organization (RPTO) to train the drone pilots to operate the agricultural drones for pesticidal spraying. Developing agricultural drone Pilot human resources with well knitted course curriculum in lines with DGCA and SOP's for drone applications in agriculture is the need of hour and ANGRAU with its established APSARA (A Research Wing of ANGRAU on Drones) proficient in drone pilot coaching has developed 15 days Drone Pilot training curriculum and started imparting training to the agricultural/polytechnic students of ANGRAU as a part of their curriculum to train them as Professional Agricultural Drone pilots (Fig. 2) through its ADITI (Agricultural Drone Incubation and Training Institute) – a RPTO of ANGRAU (Vishnuvardhan Reddy, 2022). Recently the University started Drone pilot training to the farmers facilitated through state agriculture departments. The University has trained 300 pilots in fifteen batches (Fig. 3) till now to fly drones commercially.

Government has taken up a concerted efforts to encourage training institutes and establish courses and programs in the State Agricultural Universities to increase the number of skilled personnel in the industry to promote the drone technology in agriculture.

The drone trainer, drone pilots, software developer will be in great demand in coming future. The Government of India has released a certification scheme for agricultural drones vide gazette notification CG-DL-E26012022-232917 dated January 26, 2022 and now many are the beneficiaries.

Drone requirements for pesticide application/ spraying

The efficiency of agricultural drones in terms of lifting capacity and flight dynamics varies and depends on the following parameters:

1. Number of arms and rotors
2. Rotor positions
3. Location of the nozzles and its configuration
4. Number and type of nozzles
5. Distance between nozzles

Standardizing the above parameters will aid in proper

Fig. 2. Trainee pilots flying an agricultural drone

Fig. 3. A batch of drone pilots trained at ANGRAU, Guntur, Andhra Pradesh

pesticide spray coverage, better penetration of spray droplets into the target crop canopy, with less spray drift or spillage. The latest design for discharge of spray solution uses rotary atomizers positioned under large propellors, which are referred as Controlled droplet atomizers (CDAs). The accurate real-time recognition system of spraying areas for UAVs is of utmost importance for UAV-based sprayers. There is a need for developing the deep learning system that enables the classifier recognition to process the computation time based on the collected images from a UAV for a given spraying area. The developed deep learning system can be deployed in real-time to UAV-based sprayers for accurate spraying.

The flight flying altitude and the velocity are very important in determining the spray droplet density and deposition on the crop canopy, which ensures the proper and uniform coverage. These factors need to be evaluated for each type of drone on specific crop and the pesticidal formulation.

Govt. support to popularize drones in agriculture/ Recent initiatives by NARES to popularize drone application and development of SOPs for pesticide application

To promote and popularize the use of drones for agricultural purposes, the Government of India has recently announced a 100% subsidy or Rs10 lakhs, whichever is less to the Farm Machinery Training and Testing Institutes, ICAR Institutes, Krishi Vigyan Kendras and State Agricultural Universities. Additionally, a contingency fund of Rs.6000/ha will also be set up for hiring drones from the Custom Hiring Centres (CHC). The subsidy and the contingency funds will help the farmers to access and adopt this otherwise expensive technology.

The Government organizations like Indian Council of Agricultural Research (ICAR), State Agricultural Universities (SAUs), several other national organizations have started procurement and operations of drones. The major challenges include training of the pilots and developing standard of procedures for spray operations in different crops.

The Ministry of Agriculture and Farmers Welfare, Department of Agriculture, Cooperation and Farmers Welfare, Directorate of Plant Protection, Quarantine and Storage (DDPQS) and Central Insecticides Board and Registration Committee (CIB&RC) together has come up with the draft Standard of Procedures (SOPs) for use of drones in application of pesticides for crop protection in agriculture, forestry and non-cropped areas. Accordingly a document on “Crop specific standard operating procedure (SOP) for the application of pesticide\s with drones” has been published by Ministry of Agriculture and Farmers Welfare, Department of Agriculture and Farmers Welfare (Mechanization and Technology Division), Government of India, Krishi Bhawan, New Delhi and the document can be accessed at https://farmech.dac.gov.in under 'SOP for DRONE 2023'.

Flight altitude is crucial in determining the spray swath width and the quality of spray deposition into the target canopy. In this direction, ANGRAU was the first SAU to undertake the research and development in drone technology especially in pesticide spraying and development of the crop specific SOPs and evaluated agricultural drone spraying in 10 major crops viz., paddy, blackgram, chickpea, pigeonpea, sugarcane, maize, sugarcane, groundnut, cotton, chilli during 2021-22. They also worked out the drone spraying efficiency with 11 pesticide formulations and the studies revealed that the low volume spraying i.e. 10 L/acre or 25 Litres/ha of the existing formulations @75% of the recommended doses is effective and does not cause phytotoxicity. It works out to a 25% pesticide reduction, which is a definite saving to the pockets of the farmers. The Professor Jayashankar Telangana State Agricultural University (PJTSAU), Hyderabad, Telangana has come up with the SOPs for drone based pesticide application in rice crop. It is pertinent to follow the appropriate rules and regulations while adopting the drone applications in pesticide spraying in agriculture.

Promoting drone industry through 'Make in India'

To popularize the drones in agriculture and especially in spraying operations, the Government has started supporting indigenous drone manufacturing units.

As supported by new regulations and rules in the journey of becoming a global drone hub by 2030, India has banned the import of all drones (with exceptions in defense sector, security purposes and R&D of the technology) to encourage the domestic drone manufacturing industry and push the Indian manufacturing sector to rapidly assimilate technology to cater to the needs of the Indian market.

Fig. 4. A&B: Development of an agricultural drone by the trainees

In line with this Government initiative of Make in India, ANGRAU has developed Drone technology and is the first SAU to start the Kisan Drone RPTO and Kisan Drone production in India through APSARA, which designs and develops its own agricultural drones (24.8 kg all up weight) in the small category called ANGRAU-PUSHPAK with 10L payload (Fig. 4). Several other Institutes and industries have also initiated the manufacture of the agricultural drones to make it cost effective to the farmers, and promote the indigenous drones.

Scope of drone sprays beyond pesticides/ Researchable issues in drone technology

The Ministry of Agriculture, India had released a memorandum on 18 April 2022, which furnishes a list of approved pesticides for spraying by drones on interim basis. The registered pesticide formulations that include fungicides, insecticides, plant growth regulators, botanicals and biopesticides have been provisionally approved for use through drones for a period of two years. The SOPs prescribed by CIB&RC for use of drones in different agricultural, forest and non-cropped areas are to be complied with and the new SOPs may be intimated to CIB&RC for inclusion with the supporting data generation. Another area, which needs to be focused is standardization of macrobial biocontrol agents release through drones.

Release of biocontrol agents using drone technology

In recent years, much emphasis is laid on organic or chemical free farming and hence much focus is given to the biological control that involves release of parasitoids and predators and biopesticide applications in the fields. Here comes another challenge of parasitoid release system by drones. ICAR-National Bureau of Agricultural Insect Resources (NBAIR), Bengaluru is attempting and working to standardize the technique and develop a delivery system to release the parasitoids at appropriate height on the crop or tree canopy to manage the insect pests. For example, the release of parasitoid, *Encarsia* sp. for the management of rugose spiraling whitefly in coconut and oil palm gardens is a big challenge and SoPs are being developed for the application of the same using drones. Efforts are being made at ICAR-NBAIR in developing the SOPs for release of different insect parasitoids and predators in various crop ecosystems considering all parameters like drone nozzle structure, operation, flying height and velocity, etc.

Benefits of pesticide application using drones

1. Wider crop coverage in lesser time, as the drones speed is higher than the human labour and cover the operational delays.

2. Water saving, as the agricultural drones spray application is of ultra-low volume (ULV) and thus save water in comparison with traditional spraying.

3. Secured, as the drones are operated by trained personnel and all computed.

4. High efficiency as the drones can work double the speed of human labor.

5. Drones aid in monitoring and can detect minute signs of pest attacks, and provide accurate data regarding the degree and range of the attack, which help farmers to calculate the required amount of chemicals to be used that would only protect the crops rather than harming them.

6. Cost effective, works out cheaper in long run and require minimum maintenance.

7. Precision in spraying, as SOPs are developed for specific crops and drift hazards are minimum.

8. Drone application reduces the amount of pesticides, insecticides, and other chemicals and thereby avoid excess use, pollution and detrimental effects associated with the pesticidal application.

Limitations of pesticide application using drones

1. Weather dependent - the spraying cannot be taken up in windy or rainy situation.

2. Knowledge and skill - the drone pilot requires a right skillset and adequate knowledge to understand its operational mechanisms, servicing, etc.

3. Net connectivity - the connectivity should be strong for uninterrupted spraying. Often, net connectivity is poor in villages for the farmers to operate.

4. Development of Standard operating procedures (SOPs) for crops - the dosage, droplet deposition, phytotoxicity studies, etc.

5. Payload capacity - its minimal after keeping in view the drone weight to fly at the requisite height.

6. Less flight time due to relatively higher payload where the drones use ranges from 7-30 minutes with every charge depending upon the field geometry, payload and power capacity.

Certain preliminary points to remember with drone spraying:

1. The coverage capacity - on an average an agricultural drone can cover one acre in 5-8 minutes.

2. Altitude of flying - Drones can be made fly at 50-100 m high depending upon the crop height. Above 50m high, a special authorization is required.

3. Drone with payload capacity

4. Balancing with the pesticide tank and spray operations in harsh weather.

Economics of operational expenses

The agricultural operations have to be eased out in a cost effective manner and mechanized in view of labour shortage and in this direction, there is a scope of 40-50% growth in drone usage and application. The estimated value of the drone technology used across all industries including commercial and public applications amounts to nearly $150 billion, which may increase further in coming years.

The wide use and rapid advancement of drone technology in agriculture lead to reduction in cost and the Government also encouraging the drones in farming practices by providing subsidies to farmers to realize good yields and better management of crops. The market for drones is expected to increase to $200 billion in the upcoming years (Puri et al., 2017). According to recent research, the global drone market within agriculture would grow at 35.9% CAGR and reach $5.7 billion by 2025. The cost of the drones range from 5 to10 lakhs per unit but still on higher side for the farmer to procure and hence the Indian Government has come up with subsidies scheme up to 50% for the small, marginal and women farmers and up to 75% to the farmer groups or FPOs.

Conclusions

With enhanced awareness and government support, drone based farm operations are expected to have wider reach in near future. However standaradization of dosage, dilutions, phytotoxocity, efficacy tests to suit to different cropping systems need to be precisely worked out. There is also a need to minimize the drone weight used in pesticide spraying, maximize the drone flight time and more precise autonomous control of drone (Borikar et al., 2022). Since there is a swift and significant growth of drone application in agriculture, we need to be prepared to overcome all challenges to use UAVs widely. The drone industry is going to spike soon and will become a stronger platform providing numerous job opportunities for the youth. If that is achieved, and vital services are provided, then half the battle is won when it comes to becoming world leader in the drone ecosystem.

Looking further into the future, drone technology is going to change the agriculture sector in several folds. Many Indian startups are coming forward to invest in the industry and produce the low-cost drones, which can help farmers substantially.

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Dr. Adala Vishnuvardhan Reddy, a plant breeder by profession, is a well-known name in the field of Oil seeds research since 1992 and presently discharging duties as Special Officer in ANGRAU. He had an illustrious career spanning over 31 years, with 28 years in Agricultural Research and 13 years in Research Management Position as Vice Chancellor, ANGRAU and Director-ICAR-IIOR. His notable research contributions include, but not limited to, development of 18 varieties/hybrids of crops including sunflower, castor, sesame, safflower, rice, pearl millet, blackgram, redgram, and Jatropha. Created 216 inbreds, 45 CMS lines, 63 'R' lines of sunflower; identified 7 GM resistant genes, 20 rice donors, registered 30 Castor markers, 9 parental lines with NBPGR, introduced high oleic safflower genotypes and licensed biopesticides (Bt-1, Trichoderma, Beauveria) to multiple firms. He handled 18 competitive grants of more than 76 Crore INR. Three years in the office as a Vice-chancellor of ANGRAU (2020 -2023), Dr. Vishnuvardhan Reddy brought in a sea of changes in the spheres of both academics and research besides vastly improving the infrastructure of the varsity. A steep jump in ANGRAU ranking from 31st to 11th position among the 74 agriculture universities in the country, obtaining 6 patents and securing highest number of ICAR JRF and SRF seats (2021) was made possible by his tireless efforts. He is instrumental in placing ANGRAU in forefront as the first SAU with drone pilot training capabilities. Dr. Vishnuvardhan Reddy is bestowed with several awards and laurels for his achievements, both as a researcher as well as an administrator, like Jawaharlal Nehru Award (1993), Andhra Pradesh Scientist Award (2008), N Kaverappa Gold Medal (2014), SCOCH silver award for ANGRAU (2021), and several best AICRP centre awards, seed production awards to name a few. He has about 165 research publications and 11 book chapters to his credit and guided around 50 PG students. Email: adalavishnu63@gmail.com.

Discovery of new social behaviour in ant colonies

Anand Harshana

Ants are eusocial insects belonging to the family Formicidae (Hymenoptera: Formicoidea). They are ubiquitous and so abundant that the biomass of all ants is more than the combined biomass of wild birds and mammals, and equals 20% of the human biomass (Schultheiss et al., 2022). They live in colonies of thousands and millions of highly coordinated individuals, that's why they are also known as 'Super Organisms'. However, many individual interactions in social insect societies remain poorly understood or incompletely known, therefore requiring systematic studies on these interactions. Recently, a new social behaviour of ants was discovered based on the experiments of Snir et al., 2022, where they found immobile pupae stage extrudes a nutrient-rich social fluid or moulting fluid which was rapidly consumed by adult ants and young larvae. This nutrient-rich social fluid or moulting fluid of pupal ants is analogous to mammalian milk and it elicits parental care behaviour. This behaviour is crucial for the pupal survival and development of young larvae. Moreover, they found that this derived social function of the pupal social fluid or moulting fluid is conserved across studied ants.

Is pupal social fluid essential for young larvae?

The experiments of Snir et al., 2022 found that the beginning of pupal secretions and larval hatching are tightly synchronized events in the studied clonal raider ant, *Ooceraea biroi* (subfamily: Dorylinae) colonies and proved that pupal fluid serves as a 'milk-like' substance for newly hatched larvae. Larvae with pupae in their colonies have increased larval growth and survival during the first days after hatching, compared to larvae without pupae in their colonies. Based on observations, it was found that *O. biroi* adults will readily place young larvae on pupae, where they can feed on pupal fluid. Overall, their findings suggest that the pupal moulting fluid has a crucial, yet previously unknown, role in the social structure and colony fitness.

How pupal social fluid hinders the survival of the pupa itself?

Based on the experimental studies on *O. biroi* pupae, it was found that a substantial amount of pupal social fluid was secreted toward the end of the pupal stage *i.e.,* secretion begins six days before eclosion and secreted volume increased over time till eclosion. Further, they found that if the social fluid is not removed from the pupae in isolation under a clean environment, they drown in their own secretions. Moreover, ant nest environments are not clean and when the pupae are placed in vacant used nest boxes, the fluid droplets become contaminated with fungi, and these infections spread and ultimately killed all pupae. In contrast, when fluid was removed daily manually, a high rate of pupal survival and eclosion was reported (Snir et al., 2022).

Molecular Composition of the pupal social fluid

Based on proteomic and metabolomic profiling it was found that the pupal social fluid contains a variety of micro and macronutrients *viz.*, all essential amino acids, multiple carbohydrates including N-acetyl-d-glucosamine (GlcNAc), nucleic acids, and vitamins. Proteomic Gene Ontology enrichment analysis identified the processes of protein and chitin degradation, which are respectively represented by activities of peptidase and chitinase. The protein and chitin degradation activities are related to the degradation of the old cuticle, which is one of three major molecular pathways characteristic of insect moulting fluids. Many free amino acids and GlcNAc was found to be increasing as pupae approached eclosion. Further, it was demonstrated that the pupal social fluid possesses the molecular and physiological traits of insect moulting fluids and is rich in a range of proteins and metabolites (Snir et al., 2022).

Is the role of pupal secretions conserved across the ants?

Although Snir et al. (2022) mainly worked on *O. biroi* (Dorylinae), they also explored the same social behaviour in four other species to cover the five major ant subfamilies: *Solenopsis invicta* (subfamily: Myrmicinae), *Nylanderia flavipes* (Formicinae), *Tapinoma sessile* (Dolichoderinae) and

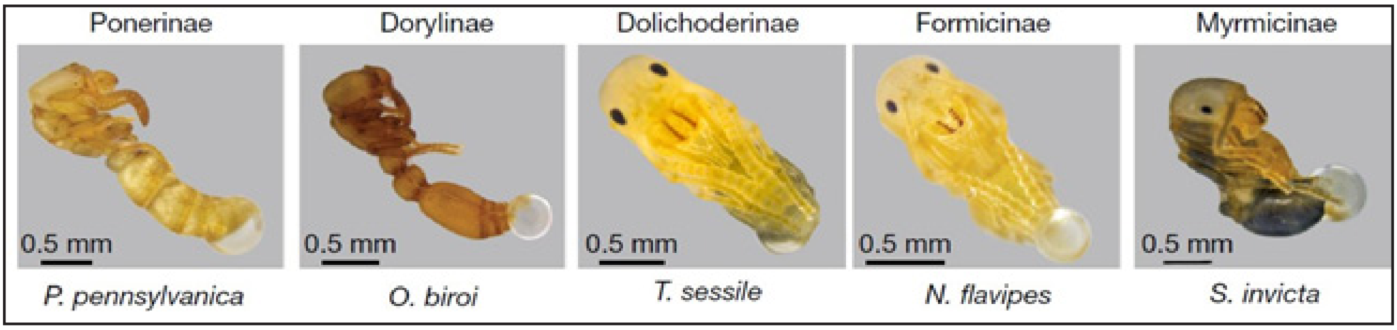

Fig. 1. Ant pupae of different species with secretion droplets at their abdominal tip accumulated over 24 h in social isolation. In species *P. pennsylvanica*, the cocoon has been removed. Source: Snir et al. (2022)

Ponera pennsylvanica (Ponerinae). They observed that melanized pupae of all four species emit liquid droplets from the abdominal tip. The composition of these secretions is similar to that of *O. biroi*, according to metabolomic profiling. This indicated that across the different taxon of ants, pupae secrete a liquid derived from the moulting fluid. Moreover, in species whose pupae are enclosed in cocoons, for those species adults consume the social fluid through the permeable silken fabric.

Conclusions

The ant pupal social fluid or moulting fluid has acquired novel social functions within an ant colony, which was previously unknown. It plays an important interdependence link between pupae, larvae, and adults. It has been demonstrated that pupal fluid is detrimental to ant pupae if not removed and that it is an important food source for early larvae. Moreover, this behaviour is widely conserved in different ant taxon. This milk-like pupal secretion is perhaps having additional far-reaching effects on larvae and other colony members. The evolutionary aspects of pupal secretions across the Hymenoptera and ants will be interesting to see in future investigations.

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Companions of the 'fun-loving' fireflies in the wild: friends or foes?

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The Environmental Management and Policy Research Institute (EMPRI), Bangalore, Karnataka, India initiated a study on fireflies in January 2022. The firefly's team interacted with more than a thousand persons from urban, semi-urban and rural areas on the sightings of fireflies in their backyards. All persons affirmed with conviction that the populations of fireflies have dwindled from the past 4-5 decades. "Earlier, we use to commonly come across these enigmatic beetles in the open but not now", they asserted. In the childhood days, *i.e.* during 1960s, it was fun-catching, collecting and watching these insects glow. Children would collect these beetles in empty match-boxes, plastic containers, pickle-glass bottles and if nothing was accessible / available, fireflies were held in hand-kerchief (hanky) or shirt pockets. Unware of the feeding habits of the beetles, children use to offer grains, leaf-bits as food to the beetles. The glowing fireflies use to raise a great deal of inquisitiveness and the phenomenon eluded everyone- a source of joy and fun! (Sara Lewis, 2016).

At the outskirts of the Bangalore city (12°58', 20.7912"N and 77° 34'50.3148"E, 962m amsl) during 1960s and 1970s quite a few pools, wells, marsh, paddy fields and wetlands existed. A visit to these patches would invariably be accompanied by a chorus of chi…chee….chee, the noisy singing chorus of the male Baya weaver birds, *Ploceus philippinus* Linn. (Ali and Ripley, 1983). These birds in flocks, breed in colonies on bulrush (*Typha sp*.), grass reeds in marsh or on trees at edges of wetlands. Males, year-round engage in nest-building activity. The nest- a dome-shaped purse with a long, down hanging entrance tube is usually made of finely woven strips of leaves from rice plant, weeds or grasses. Stuck inside this dome-shaped structure would be blots of wet clay mud. The Baya would catch the fireflies and glue them on to these clay blots. The glows of firefly would help the mother bird to tend and rear the chicks. Even the Baya streaked weaver birds (*plreceus manyas* Lesson), that co-inhabits with the Bayas were found using fireflies to lit their homes!

Mr. Aiyyappa, a forester in Melkote, Mandya (12°31'270012", N 76°53'44.998E 679m amsl) toward south Bangalore has been observing fireflies for over 20 years in the Melkote wildlife Sanctuary (17 square Km.). He has sighted fireflies during post-monsoon period (i.e. after October- November) in and around paddy fields, marsh and at edges but not deep into the forest in 8-10 numbers at a spot at about 10-20m from ground. He has observed the Indian Jungle Nightjar (*Caprimulgus indicus,* Latham); launching aerial sallies to catch the glowing fireflies. Bills are used to handle the beetles and the birds take the beetles to the nest site- dark crevices in rocky edges or hill slopes. The bird has no nest (Ali and Ripley, 1983). Female lays eggs on the bare stone in a well-hidden niche near or on rock or along stony slope. The dark nest-site gets lit-up enabling the mother-bird to incubate eggs and rear the nestlings. Mr. Aiyappa has also observed the Spotted Owlet (*Athene brama,* Franklin*)* issuing out at dark to associate with the flying firefly to locate and pounce on the unwary insects prey.

During February 2023, the firefly team made explorations at Swarna River, Bramhavara (13°25'41.618" N, 74°44'434796" E 7m. amsl), Mangalore, and coastal Karnataka for presence of firefly. The team sighted eight fireflies at Muddalkatte mangroves surrounded by brackish water- ponds. The team recorded a spider with a large web trapping four fireflies along with a grasshopper.

Generally, fireflies are distasteful to several lizards, birds and mammals. But certain birds like the Nightjars (Caprimulgidae), Spiders (Lycosidae, Araneidae), Potoos (Nyctibiidae) and Anole lizards (Iquanidae) can metabolise and digest fireflies. So, Nightjars not only pick, but also devour the fireflies. Toads and frogs are the prominent predators of fireflies (Lloyd, 1973), while Phorid and Tachinid flies (Diptera), mites and nematodes are proven parasites. Infact in

Fig. 1. Baya weaver bird

Fig. 2. Baya weaver bird nests

Fig. 3. Phorid fly

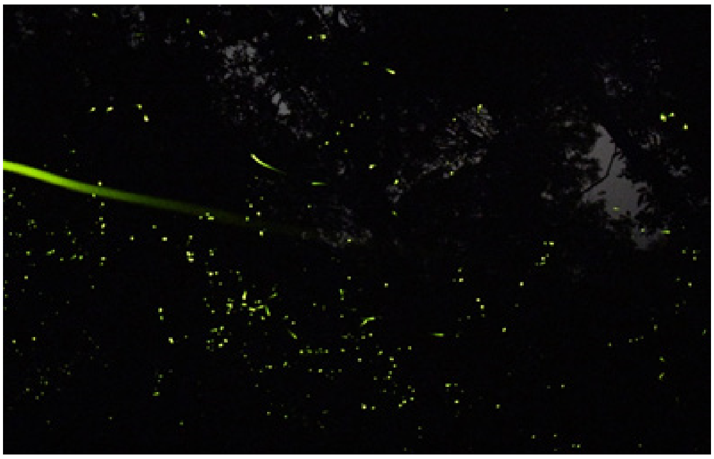

Fig. 4. Its amazing – Congregation of fireflies at Charmadi Ghats- Mudigere, Chikmangalur

Fig. 5. Fireflies in the spider web.

laboratory rearing of fireflies at EMPRI, Bangalore, we recorded phorid flies parasitizing the larvae. As we see there is documentation although largely speculative and anecdotal on natural enemies but not on those that help firefly to thrive. Further research is needed to identify and understand the bio ecology of these fascinating creatures. (See Leslie Ballantyne websites).

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https://lesleyballantyne.com/ (Website of Dr. Lesley Ballantyne)

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Life lessons from social insects

Sunny Maanju and Preeti Sharma

If you want to learn something then learn from the experts because they know how to do it in the best possible way. Insects especially social insects have inspired and motivated many out there, morally as well as scientifically. You can learn from the insects as an individual, group and even as a class (Insecta). Humans originated only a million years ago compared to the insects that appeared at least 250-500 million years ago and surviving since then, rather thriving. They outnumber all the other organisms in terms of diversity. One-third of your meal comes from the pollination services of the bees. So, they know how to do it. There are many lessons we could learn from the insects, apply and inculcate them in our day-to-day life and behaviour which could benefit our society. Diapause in insects teaches us that we should never lose hope, difficult time will pass. The lessons for life we could learn from ants are spirit of sharing, ignoring diversions, discipline, brave attitude, hardworking, preparing ahead, teamwork and adaptation to surroundings. Ants have co-opetition (competition+cooperation) behaviour which teaches us how we can keep our greed aside and help each other to thrive together. It is the result of these behaviours that fire ants (*Solenopsis* spp.) could survive even a flood like condition for almost three weeks by making a fire-ant-raft. Army ant (*Eciton burchellii*) makes living bridge to cover the obstacles which are difficult to pass by a single ant.

The social insects like bees, termites and ants share "eusociality", the highest form of social behaviour with humans. Some ant cities are huge. If ants were human sized, the settlement of ants (*Formica yessensis*) would be much larger than Tokyo. Similarly, if termites were as big as humans, then the height of an African termite mound would be equal to the tallest building on earth, the Burj Khalifa. These social insects show a high degree of sacrifice. The exploding ants (*Colobopsis explodens*) blow themselves up to kill their enemy in order to save their colony. Army abide by a code that no man is left behind when injured inspired by Termite-hunting ants (*Megaponera analis*) after raid on a termite nest. But if ants were severely injured, they themselves refused to cooperate, waving their legs when picked up, forcing the helpers to abandon them. The mortally injured ants choose to die rather than wasting resources and energy on them.

The ants also show leadership qualities guiding others to the food source through trial-marking pheromones. They can lift 5000 times their own weight, motivating us to exploit our true potential within. Trophallaxis is the sharing of food in ants as well as bees because they have social stomach meaning some of them search food out there in the wild and bring it to the colony for those who are taking care of young ones and protecting the colony. Our social stomach is the tax system where we collect money from the public and use it to help the needy ones. "Umuntu-ngumuntu-ngabantu" abbreviated as "Ubuntu", a saying meaning: "I am because you are, and you are because we are." Ants works on the principle of

Fig. 1. A fire ant raft (Source: al.com)

Fig. 2. Army ant bridge (Source: mappingignorance.org)

Fig. 3. A termite mound (Source: depositphotos.com)

Fig. 4. Trophallaxis in ants
(Source: wordpress.com)

Fig. 5. Ants lifting weight heavier than their body
(Source: worldatlas.com)

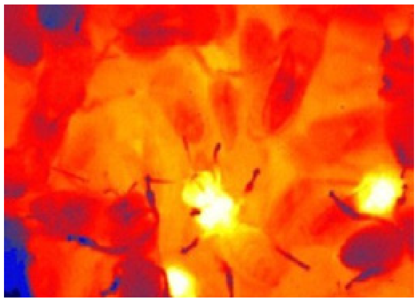

Fig. 6. Temperature regulation in honey bees
(Source: todayifoundout.com)

Ubuntu and inspire humans to realize the importance of Ubuntu which implies that everyone has different strengths and skills, people are not isolated and with mutual understanding they can help each other to support themselves.

I bet, no matter how much time you may spend on any of the social networking sites. You can't be more social than these social insects. Honey bees show "Altruism" which is the behaviour of worker bees who spend their whole lives working for the welfare of the colony, queen and her off springs. One of the best examples of teamwork could be found in bees. Bees are poikilothermic organisms as an individual, also called cold-blooded orectothermic organisms. These are those organisms whose body temperature depends on the temperature of the surrounding. But as a colony they act as homeothermic/warm-blooded/ endothermic organism which congregate around each other to maintain a uniform temperature of about 32-35^{o}C, necessary for their survival. So, we need to see the world from their perspectives to find unique and effective solutions to our life problems.

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Foldscope - a versatile tool in agriculture for on-site and off-site identification of insects and pathogens

Raghavendra K.V., Ramesh K.B., Subhash S., Rajgopal N.N., Rekha Balodi and Subhash Chander

Crops are vulnerable to a variety of biotic stresses during the agricultural production cycle. Few can be spotted visually while infested with insect pests and diseases, whereas others require laboratory diagnosis. In any event, early detection of pest incidence and proper identification of the culprit organism is critical for planning subsequent crop protection activities. Most disease causing pathogens and minute insects (aphids, whiteflies, thrips, mites, scale insects, mealy bugs, leafhoppers, plant hoppers, and other microscopic mites) make detection of the responsible organism difficult and impossible in many circumstances. Alternative identification instruments, such as an advanced lens or a microscope, are required in field conditions under such circumstances for identification and detection. However, in the laboratory, microscopic detection is a frequent practice for pest identification, but in field conditions, it is not practical since a compound microscope is heavy, requires power, and is difficult to transport to the field. As a result, there is a need for an alternate microscope that is easy to transport, small in weight, and economical.

With a philosophy of "microscopy for everyone," a team led by Manu Prakash and his student Jim Cybulski from Stanford University, USA, invented the origami-based optical microscope called foldscope that can be assembled from a flat sheet of paper and lens, as part of the "frugal science" movement that aims to make cheap and easy tools available for scientific use in the developing world. This foldscope's applications are unlimited, and it can be used for study and testing in a variety of industries. Foldscope can be attached to a smartphone using a magnet so that the user can photograph the magnification. When compared to traditional microscopes, it is compact and light (Cybulski et al., 2014). Foldscope microscopy has recently emerged as a useful imaging tool in a variety of sectors, including plant research, pollen studies, insect taxonomy and identification, disease detection, antioxidant testing, and in the medical field. In this article, emphasis has been given to its application in the field of agriculture for on-site and off-site identification of insects and pathogens.

Image acquisition using foldscope

Materials

Foldscope was procured online (Amazon, e-commerce site). The deluxe foldscope kit included paper foldscope sheet (140 x, 2 um resolution microscope) made up of a synthetic material which is waterproof, tear-resistant, and inexpensive, assembly/instruction sheet, lens, the sample-mounting components, a LED torch with a battery for illumination, cell-phone coupler to attach foldscope to smart phone, tardi sticker, unique ID sticker, clear circle sticker -1, double-stick ring sticker, diffuser stickers for light module, Reusable sealable PVC slides with micro-wells and plastic coverslips.

Assembling the foldscope

The foldscope kit is supplied with all the necessary parts and a user friendly assembly sheet with step-wise assemble. Also videos and detailed guidelines are available at https://foldscope.com/pages/user-guide._The total optical path length from the light source to the last lens surface is about 2.7 mm, while that of a conventional microscope is around 300 mm.

Imaging

The prepared slides were placed within the foldscope, and the slides were focused by sliding the foldscope's two scales. LED lights supplied with the kit were used as an external light source. Using magnetic couplers, a mobile phone (Redmi Note 6 Pro) was connected to the foldscope, and photographs were recorded after focusing using the smart phone. The photos acquired

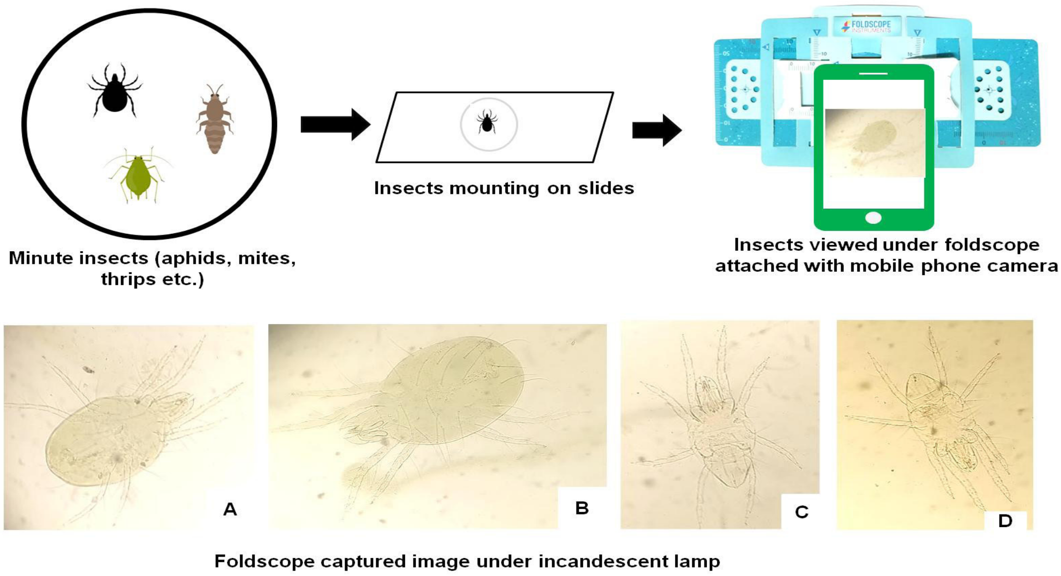

Fig. 1. Foldscope for insect identification: A&B - Female adults of *Tetranychus* sp. on marigold; C & D - Male adults of *Tetranychus* sp. on marigold

were utilized for identification.

Application of foldscope in on-site and off-site identification of insects and pathogens

Insects

Insects are the crucial components of many ecosystems, where they perform many important functions (Raghavendra et al., 2022). Insects are the major group on earth, making up 66% (1,020,007 species) of all animals and 82% of arthropods which includes few minute insects (aphids, whiteflies, thrips, mites, scale insects, mealybugs, leafhoppers, plant hoppers, and other microscopic insects) needs advanced lens or a microscope for identification and detection in the laboratory. Hence, there is a need for alternative tools for on-site and off-site identification of these insects with handy tools. The literature revealed that foldscope can be used as a handy tool for the identification of these minute insects (Figure 1). Prakya (2018) revealed that small pests of crop plants *viz.,* aphids, mites, thrips, and whiteflies and a few scale insects and crawlers of mealybugs can be easily observed under the Foldscope. He also stated that parasitoids (e.g., *Trichogramma chilonis*), predatory mites (e.g., *Amblyseius largoensis*, *Neoseiulus longispinosus*, *N. paspalivorus*) were easily visualized under the Foldscope.

Prakya (2020) conducted demonstration-cum-training workshops for traditional farmers in the states of Tripura and Meghalaya on the use of foldscope to observe microscopic arthropods like aphids, thrips, whiteflies, mites and, parasitoids, there was a remarkable turnaround in their perception of entomology. Through a series of workshops around 100 farmers were involved right from insect collection, sampling, staining, slide-mounting, and examining them through the Foldscope. Kulshreshtha et al., (2022) conducted field explorations of students to identify red spider mite (*Oligonychus coffeae* Nietner) infestations on tea leaves using foldcope and clear images of mites and the features of red spider mites were captured using foldscope. They also provided handson training to students on the visualization of mouthparts of arthropods with a foldscope and they could clearly visualize the ommatidia or compound eyes even with a foldscope.

Pathogens

Early diagnosis in the field is generally important to succeed in eradicating new diseases in modern agriculture to prevent massive production losses. Precision agriculture, using image processing and machine learning algorithms, has enormous benefits in detecting crop diseases at an early stage. There are numerous methods for identifying fungal phytopathogens; Pathogen culture on selective nutritional media and morphology assessment of the fungal colony using optical microscopy are two essential classical approaches for detecting and identifying fungi.

The key elements that affect the acceptability and choice of diagnostic tests are speed, specificity, sensitivity, and cost-effectiveness. Foldscope can be a very useful diagnostic instrument for the detection and identification of disease under field conditions. Wangadi et al. (2019) identified foliar fungal pathogens *viz., Cladosporium cladosporioides*, *Xylaria hypoxylon, Colletotrichum* sp., *Colletotrichum coffeanum, Rhizosphaera oudemansii*, *Alternaria alternata*, *Exobasidium vexans* associated with the leaf spot and leaf blight disease in the tea garden of Sikkim using Foldscope. Maheswari *et al.,* (2018) captured the images of *Alternaria solani,* early blight of tomato using foldscope, and the images were classified using various machine learning algorithms. The quadratic Support Vector Machine (SVM) classifier shows the highest classification accuracy of 89% in the prediction phase when compared to other machine learning algorithms

Chhetri et al. (2019) made an attempt towards on-site identification of plant pathogens infecting crops like rice, maize, ginger, beans, and some vegetables of Sikkim using foldscope. Foldscope was useful for on-site identification of the sclerotial body of sheath rot of rice, urediniospores of french bean, grass and canna rust, false smut of rice, powdery mildew conidia and conidiophore from vegetable crops, conidia of *Helminthosporium turcicum* from maize and *Cercospora beticola* from rayo saag. Additionally, the rhizosphere soils from the infected plants were also used to culture and identify the pathogens *viz.,* Conidia of *Fusarium* spp., and spores of rod shaped bacteria.

Singh et al. (2018) used the foldscope for *in situ* identification of the soft rot complex of ginger and revealed that transverse sections of healthy rhizome showed outer and inner cork, parenchymatous ground tissue, endodermis, a vascular bundle containing xylem, phloem, fibers, and oleoresin cells arranged in a uniform fashion, whereas the section of diseased rhizome showed disintegrated parenchymatous tissue, endodermis, a vascular bundle, and oleoresin. Arora et al. (2020) monitored superoxide production and cell death during pathogen infection in *Arabidopsis* under different nitrogen regimes. Prakya (2018) studied the importance of foldscope in biocontrol research and revealed that foldscope can be used to differentiate between fungal bio-control agents (e.g., plant disease antagonists - *Trichoderma* spp.; entomopathogenic fungi - *Beauveria bassiana*, *Metarhizium anisopliae*, *etc*.) and plant pathogens and nematodes which are easily visualized under the Foldscope.

Conclusion

Foldscope offers a handy and cost-effective tool for on-site and off-site identification of insects and pathogens by the farmers which in turn, facilitates the timely planning and execution of insect pests and diseases management tactics.

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The Calabash connection: *Crescentia cujete* and the preservation of honeybees

Rudra Gouda M.N. and Yogananda M.

Honeybees are crucial pollinators responsible for maintaining the biodiversity of ecosystems and supporting agricultural productivity. However, honeybee populations worldwide have been experiencing significant declines due to various factors, including habitat loss, intensive agriculture & indiscriminate usage of harmful pesticides and reduced forage availability (Ratnieks and Carreck, 2010). To address these challenges, it is essential to explore and utilise plant species that can provide suitable habitats and abundant food resources for honeybees. One such species with great potential is *Crescentia cujete*, commonly known as the Calabash tree or gourd tree. In this article, we will delve into the unique characteristics and contributions of *Crescentia cujete* to honeybee conservation efforts.

Floral resources and forage availability

C. cujete offers an abundance of floral resources with cauliflory flower bearing type *i.e.,* plants bearing flowers and fruits directly on their trunk or main branches, instead of at the branch tips are highly attractive to honeybees (Fig. 1a). Its unique flowers, with distinct shape and fragrance provide a rich source of nectar (Fig. 1b). The nectar composition of *C. cujete* is known to be nutritious, offering essential carbohydrates and other beneficial compounds for honeybee health and vitality. By incorporating *C. cujete* into honeybee-friendly landscapes, we can enhance forage availability, ensuring a diverse and ample food supply for honeybees throughout the year. (Sharma, 2011)

Nesting Suitability and Shelter

In addition to providing floral resources, *C. cujete* offers suitable nesting sites and shelter for honeybees. The trees structural characteristics such as its sturdy branches and dense foliage (Fig. 1c) create ideal conditions for honeybee colonies to establish hives and protect their brood. The presence of *C. cujete* in honeybee habitats can enhance nesting opportunities and contribute to the overall well-being and survival of honeybee populations.

Cultural and community involvement

C. cujete holds cultural and historical significance in many regions where it is native. It has been used by indigenous communities for various purposes, including crafts, utensils, and traditional medicine. Engaging local communities in honeybee conservation by promoting the cultivation and preservation of *C. cujete* not only provide habitat support for honeybees but also foster a sense of pride, cultural identity, and environmental stewardship. By integrating traditional knowledge and practices, we can establish a collaborative approach for honeybee conservation, benefiting both the ecosystem and local communities.

Implementation strategies

For effective utilization of *C. cujete* for honeybee conservation, strategic implementation is necessary. Planting and maintaining *C. cujete* in suitable habitats, such as gardens, parks, and natural reserves can create honeybee-friendly environments for their natural multiplication. Collaboration between beekeepers, conservation organisations, and local communities is essential for maximising the impact of *C. cujete* in honeybee conservation efforts. By raising awareness, providing education, and engaging in habitat restoration initiatives we can create a network of *C. cujete* habitats, which support thriving honeybee populations.

Conclusion

C. cujete, with its abundant floral resources, nesting suitability, and cultural significance offers great promise for honeybee conservation. By incorporating *C. cujete* into conservation strategies, we can enhance honeybee habitats, ensure adequate forage availability, and engage local communities in the preservation of this valuable resource. However, further research and monitoring are needed to assess the long-term effectiveness of *C. cujete* in honeybee conservation and to develop sustainable management practises. With collective efforts and a focus on

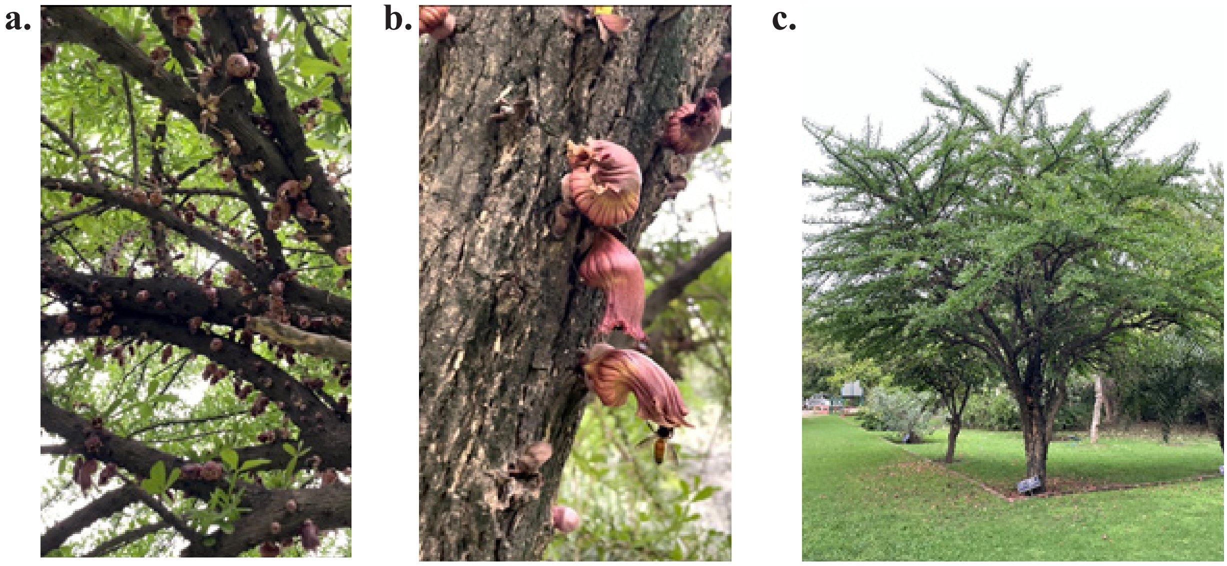

Fig. 1: *Crescentia cujete* (Calabash tree or gourd tree) a. Cauliflory bearing type of flower; b. Individual flowers; c. Tree

preserving biodiversity and ecological balance, *C. cujete* can contribute significantly to the conservation and well-being of honeybees, ensuring their vital role in our ecosystems for generations to come.

To view a video showcasing pollination in a calabash tree, please follow this link:

https://youtube.com/shorts/w0INjvf00SI?feature=share

https://youtube.com/shorts/U2qpzpqM_SI?feature=share

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Weed flora: A blessing in disguise to bees

Samrat Saha, Pushpa Kalla and Riju Nath

Weed, whenever we hear the term it comes to our mind a non-remunerative plant competing with our food production. It is a common mindset of people. But if we say weeds can improve crop yield, then it will seem to be counterintuitive but that is the fact. Presence of weeds can enhance the pollination service that can improve the crop yield. As we all know, majority of our important food crops (35%) rely on pollination services. Among different flower visitors, bees (both eusocial and solitary bees) are the leading pollinators and bee pollination to some extent relies on the diversity and abundance of weed flora (Fig.1).

Pollination is an unintentional activity of bees as their main focus is to collect pollen and nectar from the flowers. Usually in agro-ecosystem with predominance of nectar-deficit plants (particularly cereal crops) bees are rewarded mainly with pollen, whereas natural ecosystems with more abundance of wild flora offer them with ample amounts of nectar. Honey bees process the nectar into honey and store it as food reserve to spend harsh winter days. So, the requirement of nectar is quite seasonal (though still required). However, there are certain plant species having no nectaries. Such plants are not able to offer nectar to bees. In such cases bees collect a profuse amount of nectar from wild flora. On the other hand, bees require a continuous influx of pollen as it deteriorates quickly allowing bees to store it in little quantity. However, it is the pollen that provides different kinds of proteins, vitamins, antioxidants, minerals, carbohydrates and other nutrients to the bees. What if a situation arises when there is no mass-flowering crop (such cropping patterns having short blooming periods separated by a long time gap) in the field to provide pollen then what would the bees do as it would not only affect the colony strength but would also threaten their biodiversity? At this point of time different weed flora would stand for the bees providing all the prerequisites to them and protect them from an enforced extinction. In turn pollination of these wild flowers by bees ensures their reproduction (as 78-94 % flowering species depend on insect pollination service) and aids in their survival. It is for sure, if someone performs melissopalynological analysis of raw honey, then he or she would definitely find the presence of at least one weed palyno taxa in that honey (Fig. 2).

How much do bees depend on crops versus weeds varies according to their taxonomic group (*i.e.*, honey bees, wild bees). Being a generalist forager (less selective in floral selection), honey bees always prefer to visit diverse flora to satisfy their need for proteins, vitamins, fats and other nutrients. Though their abundance is higher in mass flowering crops, but a single floral resource will never be able to fulfil that requirement, hence forcing the honey bees to visit diverse flora that can be as many as two hundred species. On the other hand, wild and solitary bees are specialist foragers (due to short activity period) and more rely on weed flora, indicating a strong correlation between wild bee diversity and wild floral diversity. They are more abundant in sub-natural habitats, grasslands and grassy stripes. For both the groups weeds are a limiting factor but for different reasons: quantitatively for honey bees particularly in between mass-flowering seasons and qualitatively for wild and solitary bees that are more selective foragers with major dependency on weed flora. Bumblebees have an intermediate strategy as their foraging preference consists of both mass flowering crops and sub-natural habitats with fairly uniform and low abundance. For bumblebees weeds are also a limiting factor.

Though there is a marked segregation in habitat requirement between wild and honey bees, still they are interconnected through weed factor both directly and indirectly. Indirectly, wild bees interact with the honey bees by pollinating weed flora making them available to the honey bees in between the mass flowering period. Directly, they interact in two different ways. First, competition for floral resources particularly during the period when honey bees forage on weeds. Second, competition through behavioural

Fig. 1. Different weeds are abundant sources of pollen and nectar and are frequently visited by different bee species. (A) *Megachile disjuncta* visiting *Crotalaria* sp., (B) *Apis dorsata* visiting *Polygonum* sp., (C) *Ceratina* sp. visiting *Mimosa* sp. and (D) *Apis dorsata* visiting *Leucas aspera*.

interference where one's behaviour influences other's activity. Therefore, the interaction between wild and honey bees is much complex. It may be antagonistic or mutualistic and depends on season.

Even weed can improve the crop yield indirectly in two ways. First, weed flora harbour these pollinators during the dearth situation and conserve their diversity for the upcoming blooming season of the main crop and increase its yield through pollination. Second, they increase the yield through behavioural interaction. Studies revealed that if sufficient weed communities are growing near the crop fields, then wild bee diversity will be more and as a result of behavioural interference they will push honey bees away to pollinate the main crop, resulting in higher yield. Similarly, foraging activity of honey bees is found to be more effective in orchards with non-*Apis* bees.

So there is a mutualistic relation between the beekeeper and farmer (growing crops that depend on bee pollination) as pollination improves the yield for the farmer and the honey produced from the nectar generates income for the beekeeper. However, this complex web of crop-weed-pollinator creates a trade-off between the stakeholders. Two scenarios may appear. First trade-off situation between the beekeeper and farmer (particularly a cereal grower that doesn't rely on bee pollination) appears as the farmer always considers the weeds as pests that will compete with his crop but for beekeeper weeds are required for survival of his colonies. Second trade-off situation may appear between two farmers, where the first farmer is an oilseed cultivar (like rapeseed, sunflower) who is hoping for increase in pollination through increase in weed diversity and the second farmer is a cereal grower who never allows weeds in his field as it may reduce his crop yield. In addition to that, another trade-off situation between farmers and the general public may appear as weed abundance ensures the survival of wild flora and fauna and thus improves socio economic value of the landscape. Thus increasing weed diversity can enhance the pollination service by maintaining pollinator populations, generate additional income for beekeepers by improving the honey yield and improve aesthetic value of landscape by ensuring the survival of wild flora.

However, an antagonistic relation may also develop between bee pollinators and wild flora. There are

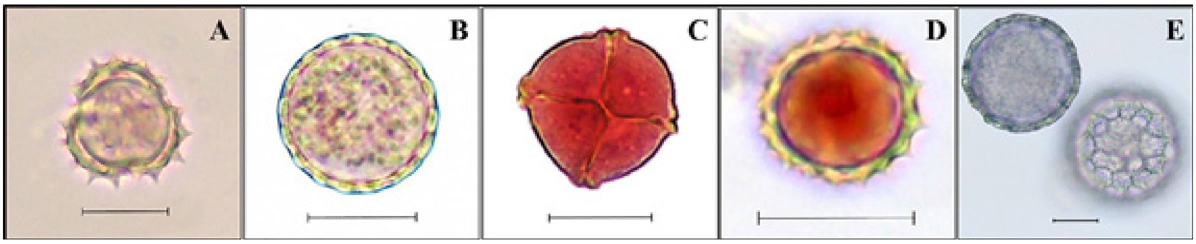

Fig. 2. Light microscopic images of different weed pollens recovered from honey. (A) *Ageratum conyzoides*, (B) *Amaranthus*/*Chenopodium* sp., (C) *Mimosa* sp., (D) *Parthenium hysterophorus* and (E) *Polygonum* sp. Scale bars=10µm

certain cases where flowers trick the visiting bees without providing any kind of reward to them. These flowers mislead the bees by using visual, olfactory, or sexual cues. On the other hand deceptive bee pollinators obtain nectar from the plants without helping them in pollination. Bees may collect the rewards from plant structures (such as extra-floral nectaries) without touching the reproductive parts. Thus nectar robbing without aiding in pollination negatively impact the fitness of the wild flora. Though such cases are very less. So, it is better to focus on the mutualistic pollination relation between wild flora and bees.

However, in the present scenario with agricultural intensification, diversity of many taxa are in a threatened position, especially weeds because of their close association with crop production. Since the middle of 19th century, applications of high amounts of herbicide have reduced the crop-weed competition and eliminated 50% weed diversity in last 70 years. Over the last 30 years there is a significant decrease in weed species like *Chenopodium album, Stellaria media, Sinapis arvensis, Fallopia convolvulus, Polygonum persicaria* and *P. aviculare* which are important food sources for many bees. Moreover, vacancy of that niche may be occupied by certain invasive wild flora that may not have any benefit to bees. It completely shatters the base of agricultural food webs. Decline in weed abundance is strongly linked with decline in wild bee diversity. Statistics revealed that only in Europe, 37-65% of bee species come under conservation concern. In the USA there was 59% decline in honey bees in 61 years. Over the 2021-22 season beekeepers from the USA faced an estimated loss of 39% of their managed bee colonies. In this aspect indiscriminate use of insecticides is a big concern that leads to phenomenon like colony collapse disorder (CCD). Exposure of bumblebees to imidacloprid not only slowed down their colony growth but also resulted in 85% reduction in queen production. With decline in bee population, the economic activity that relies on bees and beekeeping also showed a downward trend.

So from the above perspectives it is fair to say, “weeds are for bees and bees are for weeds”. But intensive agricultural practices make this thought bleary. Standing on the present day, intensive weed management strategies is a matter of question. Conservation of biodiversity is now becoming an agronomic concern as long term enhancement of crop production depends on it. Therefore we need to think over the best compromise between food production and societal benefits, instead of focusing on the sole aim of food production. The diversity of weed visiting pollinators can be enhanced by implementing field margins, wild floral stripes, set-aside fields, no-tillage strategy, or by reducing application of pesticides and inorganic fertilizers, and moving towards organic production. A study suggested that an increase from 5 to 20% in organic cropping can improve the diversity of solitary bees by 60% and bumblebees by 150%. At present we are going through a worldwide bee decline phase that needs to be addressed with immediate action and if it is not addressed then we will have to face a situation which Sir Albert Einstein has already visualized, “If the bee disappeared off the face of the Earth, man would only have four years left to live”.

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Sirens and sailors: collective sexual deception at its finest

Sangeeta Dash

Sirens are the characters from Greek mythology that are half women and half bird and are known to lure sailors to death with their irresistible symphonies. Yet, a similar example can also be witnessed in insect societies wherein the Meloid beetles lure the male solitary bees mimicking their sex pheromones.

The Mojave (Fig. 1) and Oregon Deserts, located in the southwest of the United States of America, is a sizable dry region where summertime highs regularly exceed 50^{0}C and wintertime lows approach -18^{0}C. Additionally, it receives scanty rains and is buffeted by scorching, sandy winds. Even such wilderness supports a range of exotic flora and fauna. *Meloe franciscanus* (Coleoptera: Meloidae), blister beetle, is one exceptional insect that endures this difficult environment. Like all other meloids, it too emit oil droplets from the joints in their exoskeleton, containing cantharidin, a potentially hazardous toxin that causes blistering and boils on the skin.

This beetle's life cycle (Fig. 2) is pretty entertaining. The females (Fig. 3) dig down in the sand to lay their eggs in groups (a maximum of 761 eggs recorded) in region that are comparatively cooler. Triungulins, which have three claws on each foot, are the first instar larvae that hatch; they aggressively seek out food and hosts. The miniature larvae ascend and clamber up onto the closest grass stem, and hundreds of them group together to form a tiny mating ball (Fig. 4) that visually resembles the females of the solitary digger bee, *Habropoda pallida* and *Habropoda miserabilis* (Hymenoptera: Apidae). In addition to their aesthetic similarity, these wriggling balls of beetles vibrate to create a buzzing noise and mimic the female pheromones of bees, which fool their male counterparts (Saul-Gershenz et al., 2007).

The fuzzy male catches the larvae mounting to its body hairs when it tries to mate with the larval aggregation, assuming it to be a female bee. Therefore the male bees unwittingly wear a shiny brown vest of parasitic beetle larvae (Fig. 5). These small larvae switch hosts when the male bee mates with a genuine female bee. The male bees rarely get assaulted and are only employed for phoresy. The female bee then transports the larvae of the beetle to her underground nests. At this point the larvae have finally succeeded to reach their intended destination. These uninvited guests spend the next phase of their lives feeding on the pollen and nectar arranged by the female and also on the eggs and young bee larvae that hatch. With time it progressively deprives the bee's nest of all resources that are needed to develop to adult. The adult beetles finally leave bee's nest, mate with their opposite sex and lay eggs only to repeat the process. Unlike the larval stages of the beetle, the adults are

Fig. 1. Mojave desert

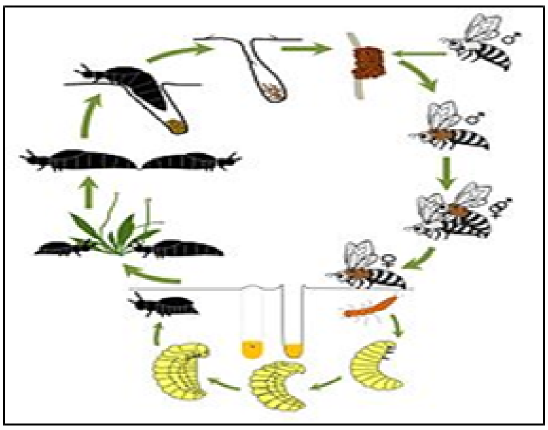

Fig. 2. Life cycle of *Meloe franciscanus*

Fig. 3. Female of *Meloe franciscanus*

Fig. 4. Mating ball of *Meloe franciscanus* triungulins

Fig. 5. Two species of bee from the Mojave (A) and Oregon (B) parasitized by beetle larvae (Saul Gershenz et al., 2018)

flightless and feed on *Astragalus lentiginosus.* Similar case of parasitism of solitary bees *Colletes hederae* (Hymenoptera: Colletidae) by the beetle larvae of *Stenoria analis* (Coleoptera: Meloidae) was reported in western France (Vereecken and Mahe, 2007).

This is probably one of the most remarkable instance of sexual deception in insects wherein these horror beetles faux the female bees to hitchhike over the male. This is also a classical example of cooperation, pseudo-copulation, cleptoparasitism and chemical mimicry portrayed by the beetles.

It should be emphasised that adaptation to scent of the bees is a local behaviour. For example, male bees in Mojave deserts were not lured by the olfactory cues of the triungulins larvae of Oregon implying that the beetles have evolved to produce signals tailored to the sympatric bee species (Saul-Gershenz et al., 2018). Also, the height from ground at which the mating ball is formed is variable in Mojave and Oregon and perfectly matches with the cruising altitude of local bees. Additionally, the tendency and propensity of the larvae to aggregate and cooperate is of utmost significance in luring the sex-hungry bees. Solitary or small groups of larvae can't produce enough scent to lure the male bees. Thus, there is an extremely specific ecological intimacy between these bees and beetles.

Therefore, this story of gangs of beetle larvae luring fathers of their next meal into a sex trap is an existential dread. The beetles can be reputed as "masters of deception" exhibiting visual, olfactory, and auditory mimicry.

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Entomophagy practices among the tribes of Andhra Pradesh

Swapna Rani K.

Tribal lifestyle is closely connected with nature, they protect biodiversity and maintain the balance of nature through their cultural practices. Entomophagy is one such practice by which even adverse insect pests also can be utilized for human well-being by turning them into a tasty delicacy for human consumption. For example, the global pest 'locusts' are considered as absolute delicacy by local tribes in some countries like Nairobi, Israel, Mexico, Thailand and Kuwait where the local tribes catch the desert locust swarms and eat them as kebabs, biriyani, salads and even chocolate coated locusts are served as desserts (Shenoy, 2020). The Australian government encourages people to eat locusts which are regarded as "sky prawns". Dishes like locust dumplings and locust popcorn is prepared and eaten by locals to cope with the locust invasions (Van Huis et al., 2014).

Nowadays, in many countries, insect delicacies are being produced on a commercial scale and are available in markets in several forms like chutneys, powders and pastes along with some spices for additional taste. Energy bars prepared with crickets flour is very famous in United States (Bartrim, 2017). However, in India entomophagy is restricted to tribal communities. People consume insects for their peculiar taste, flavor and nutritional values.

Unlike livestock animals and poultry birds, insects are cold blooded and have more efficiently convert ingested food into body weight hence they are regarded as a source of unconventional protein (Van Huis et al., 2013). Many insect based foods are known for their authentic taste and also for good nutritional value including protein, lipids, minerals, vitamins and salts (Ramos-Elorduy, 2009). Apart from being nutritionally rich, they also have potential medicinal and therapeutic properties (Devi et al., 2022).

In India, about 255 species of insects are consumed as food in various parts by different tribes (Chakravorty, 2014). The practice of entomophagy by ethnic tribes of North Eastern states is well known than other parts of India (Devi et al., 2022). Our present study is to bring into the limelight of the edible insect species and traditional insect based foods consumed by different tribes of Andhra Pradesh.

1. Palm weevil grubs

The tribes *viz.,* Khond, Kuvi, Bagata and Koya are major inhabitants of Araku valley and other parts of Vizag agency in the state of Andhra Pradesh, traditionally practice entomophagy and prefer to eat grubs of silver date palm weevil, *Rhyncophorus* sp. which are locally called "bodengalu". The *Phoenix Sylvestris* commonly called as Indian date palm or

Fig. 1. A. Palm grubs; B. Dish prepared with palm grubs

Fig. 2. Fried wasp grubs

Fig. 3. Roasted termites served as a snack

silver date palm or wild date palm and as khajuri in Hindi, etha chettu in Telugu. During rainy season, the palm species sprout profusely and grown abundantly on the hills of the region. The young shoots are infested by apodous, stout, whitish grubs having a well sclerotized dark red to brownish head (Fig. 1A). The body of grubs are soft and filled with fatty tissue and hide themselves at the center of the shoot where they feed on the succulent portions of palm shoots. The grub infested shoots show rotting symptoms, apical leaves turn yellow and chewed fibrous materials found near the base of the infested shoots. The local tribes are highly skilled in catching these grubs, they spot such rotting shoots and dig at the base to collect the grubs from November to February. Each palm weevil grub contains approximately 23% crude protein content (Opara et al., 2012). The local people regard them as "Agency prawns" and eat in many ways, they collect the grubs, clean them and heads of the grubs are pinched off then mixed thoroughly with salt and chilli paste, placed in a leaf pouch made with *Bauhinia vahli* (addakulu) leaves and tied with fiber for fire roasting. Grubs are also eaten as a curry prepared by boiling them along with some spices for enhanced taste (Fig. 1B) and the locals believe that it is rich in many nutrients, specially fed to patients suffering from anemia (Sudhir, 2017).

2. Wasp grubs

Wasps are carnivores, mainly feed on beneficial honey bees hence they are regarded as honey bee enemies. They usually hunt the bees, caterpillars and also some flies by stinging with their sharp pointed ovipositor to paralyze them with their venom and carried to their colonies to consume as food for themselves and also for their progeny. Wasps are social insects and live as colonies by constructing nests. Wasp nests grow downwards as successive layers are added underneath the existing layers. The brood chamber is constructed in the shape of an inverted umbrella and the brood is reared in hexagonal honeycomb like cells but without any cappings. The wasp comb or nest is called "kandireega pattu/ kandireega putta" by local tribes. They collect this wasp colony by smoking with help of dried palm leaves tied to a long stick. After that, they unopen the nest for collection of grubs and fill them into a leaf basket along with salt and some spices. The leaf basket edges were closed by tying with any natural fibers and then placed in the fire. The roasted wasp grubs are enjoyed as a tasty delicacy by several tribal people of Andhra Pradesh (Fig. 2).

3. Winged termites

Termites or white ants are known as silent destructors that can eat away almost all kinds of woody vegetation. They are subterranean insects, eusocial, form a colony comprises four castes *viz.,* king, queen, soldiers and workers. However, winged termite is another caste that develop within a colony as secondary reproductive adults inside a termitarium. They form once a year during a certain period of time when the colony is longing to spread and multiply. Rainy or monsoon season is most congenial to termites for spreading their colony.

Termites are the most common species for entomophagy and are fondly eaten by many tribes throughout India (Jahnavi, 2020). In Andhra Pradesh, especially tribal people of Tirupati call them as "eesurlu or usillu" and are fascinated to catch swarms of winged termites. The termite swarms are attracted to the light source and are caught during dusk. Wings are removed by rubbing them repeatedly on a cloth or towel, later the de-winged termites are cleaned by washing in water then dried for some time before roasting. The roasted termites in earthen pots are fondly eaten as a snack by children and is regarded as

Fig. 4. Red ant chutney

a seasonal delicacy available during monsoons (Fig. 3).

4. red ants

Red ants are consumed by certain tribes in Andhra Pradesh from the areas adjoining to Odisha and also by adivasis of Cherla and Dummugudem areas of Telangana (Anonymous, 2022). The tribal people collect the ant nests from the trees with bare hands only as they believe that ant bites can cure many diseases. The ants and their eggs are separated, adult ants are crushed into paste with help of a mortar and pestle and used for making soups. These soups are consumed and are known to improve eye sight as well as reduce acidity problem (Patnaik, 2018). Pickle with ant eggs is made by boiling them in plan water, then they are ground by adding onion, green chilli and salt. This pickle is consumed along with rice during summers known to have cooling effects on body. Fried ant eggs are also eaten as a snack.

Insect farming

Insects have rapid growth rate, emit low greenhouse gas and require very less area for their cultivation. Rearing of crickets for human consumption is a widespread commercial activity in countries like Thailand where about 750 kg of crickets in a period of 45 days being produced in farms (Nadeau 2015). In the United States, start-ups based on edible insects *viz.,* Rainbow Mealworms, San Diego Wax Worms, Small Stock Foods are growing rapidly. In Australia a company called "edible bug shop" is producing approximately 800 kilograms of crickets and 400 kilograms of mealworms per month fetching good price in the market where a 200g packet of cricket protein powder being sold for $40 (Bartrim, 2017). Thus, insect farming can be an innovative and profitable alternative for feeding the growing population.

GI tag to insect delicacies

Recently in 2022 GI tag was provided for a traditional insect delicacy i.e., the red weaver ant *Oecophylla smaragdina* chutney (Fig. 4) of Mayurbhanj district of Odisha (Barik, 2022). The dish is locally called as Kai chutney very famous among tribal community for its fiery taste as well as for its medicinal properties. Government support by recognizing traditional food practices such as entomophagy is substantial.

Conclusion

Tribal people practice entomophagy and their knowledge of edible insect species was acquired from generation to generation, and to conserve such precious indigenous knowledge, proper documentation is necessary. Insect based foods are nutrient rich and can be an excellent alternative food option for feeding the growing population. In view of nutritional and ecological benefits, psychological motivation needs to be enhanced among people to adopt entomophagy.

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Bumble bee: The teddy bear of class Insecta

Neha Negi

Bumble bees are the members of the family Bombidae, order Hymenoptera and belong to the genus *Bombus* Latreille. *Bombus* species are annual eusocial insects with short-lived colonies that are found predominantly in temperate climates around the world. These bees are the primary pollinators and the main service providers with more pollinator diversity and play acritical role in ecosystems by delivering key pollination services which are required for all living organisms (Potts et al., 2010; Khan et al., 2018).

Bumble bees have unique physical and behavioural adaptations for collecting nectar and pollen from the flowers they visit. These adaptations include hairy bodies well adapted for pollen gathering, pollen baskets or corbicula on the hind legs of bees, mandibles and lengthy tongues used to retrieve pollen grains from anthers and moistening pollen grains with regurgitated nectar droplets. These insects unlike other species of bees can forage outside in cold and bad weather conditions and are regarded as important and capable pollinators. These bees are largely restricted to high land ecosystems in India, with distinct species confined to elevations ranging from 1000 m to 5500 m amsl. These bees build their nests in the earth, frequently in abandoned rat tunnels or in tall grasses above ground. When the queen finds the nest, she supplies it with a ball of pollen mixed with nectar and a single wax nectar pot. The queen will deposit the first clutch of eggs in the ball of pollen in close proximity to the nectar pot and then incubate them using her body heat. The eggs will mature into larvae and then pupate over the period of 3-5 weeks before emerging as first worker offspring.

Workers who have just taken up foraging and brood care, allowing the queen to focus on egg-laying. Bumble bee colonies in the early spring are made up of a single fertilised queen, female workers, and immature brood. Depending on the species, nests can develop to be rather large (300–400 workers) or reach a peak population of around 100 workers. The colony turns to generate reproductive in late summer and early fall (*i.e*., males and gynes). The male offspring are created first, followed by the female progeny *i.e*., unfertilized queens.

The only caste of *Bombus* that survives the winter is the queens whereas the workers and males die in the late summer and early fall, respectively. The young queens go into diapause after mating while the colony's founder queen, workers and males die. The queens that have survived hibernation give birth to the next generation in the following spring.

In India, bumble bees are mostly confined to the high-altitude regions. These species are so adapted to their specific habitats that many of species that are found in highly elevated areas are not reported from low altitude areas and vice-versa. Bumble bees are closely related to various types of flowers and can be seen foraging in a variety of hilly environments. In comparison to the locked deep and dark forests, bumble bees prefer wide sunshine meadows.

Many plant species have a close relationship with the existence and activity of bumble bees as a result of the adaptation. They are nearly totally reliant on plants for nourishment as social insects. The range and availability of floral resources accessible to bumble bees depend upon the distance from the nests where they forage. In the Himalayas, different species have different host plants depending on altitude. Bumble bees feed significantly on *Cirsium arvensis, Cirsium falconeri, Carduus* spp., *Nepeta* spp., *Prunella vulgaris, Impatiens balsamina, Saussurea* spp., *Trifolium repens* and *T. pratense*.

Bumble bees come in two hundred and sixty-five different species around the world and between species, there is a lot of diversity in reproductive, developmental, behavioural and ecological features. Bingham (1897) compiled a list of 23 species in British India's fauna, which included some data from neighbouring nations such as Myanmar, Bhutan, and Nepal. Following workers added 149 taxa to the list, bringing the total number of species to 172 however due to a lot of synonymies, only 47 species are considered legitimate, according to Williams (1998). Genus *Bombus* is at present represented by

Fig. 1. *Bombus haemorrhoidalis* foraging on onion flower

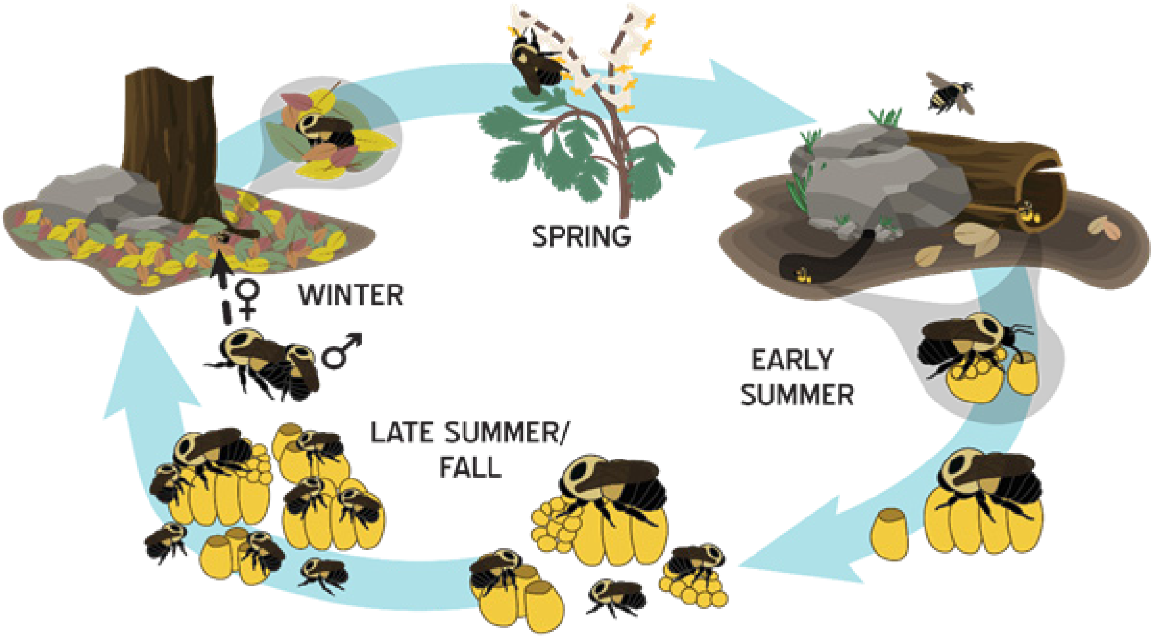

Fig. 2. Life cycle of bumble bees

48 species from India. Several native bumble bee species are present in Himachal Pradesh *viz., Bombus waltoni* Cockerell, *Bombus keriensis* Morawitz, *Bombus asiaticus* Morawitz, *Bombus personatus* Smith, *Bombus rufofasciaticus* Smith, *Bombus haemorrhoidalis* Smith and *Bombus tunicatus* Smith. They are important pollinators of a bewildering variety of cultivated as well as wild flowering plants in the high-altitude regions of Himalayas thereby playing a major role in conserving a fabulous tapestry of plant diversity particularly confined to an inhospitable environment of alpine meadows and snow-clad mountains.

Bumble bee laboratory rearing has a lengthy history, beginning with Sladen 1912, who worked on bumble bees in 1912 and published his findings in his well-known book 'The Humble Bee'. Successful rearing of bumble bees is being tried in some countries like Japan, China, Israel, Turkey, Australia, etc. Worldwide only five species of bumble bees namely *Bombus terrestris* (L.), *Bombus impatiens* (C.), *Bombus occidentalis* (G.), *Bombus lucorum* (L.) and *Bombus ignites* (S.) are commercially reared and used for pollination (Velthuis and Doorn, 2006). Thakur (2002) made the first attempt in India to study and rear bumble bees (*B. haemorrhoidalis*). The studies on biology, domestication and development of the local bumble bee species *B. haemorrhoidalis* in India began in 2004 with the establishment of this species in laboratory conditions (Dayal and Rana, 2004). Despite the fact that the diversity of bumble bees can be used to pollinate a wide range of crops, greenhouse farming, floriculture, fruit trees, vegetables and medicinal plants. There is a limited number of researchers have been working on the diversity and species record of bumble bees and very few attempts have been made on the domestication of bumble bees, keeping all this in view, there is a need of advanced research in this field.

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Potential insect vectors of plant virus diseases

Mayank Kumar and Bijendra Kumar

Every year, plants are affected by many diseases. Most of them are caused by fungi, bacteria and viruses. Among these causal organisms, viral diseases are difficult to control. Majority of plant viruses that cause disease in agricultural crops are transmitted by insect vectors (Whitfield et al., 2015). There are many classes of virus transmitting vectors like insects, mites, nematodes and chytrid fungi. Of these, insect vectors cause significant economic damage to crops. They transmit the virus in two modes *i.e.*, persistent or non-persistent manner. It depends upon the time window of acquisition and its further dissemination. Plant viruses usually rely on their vector for contravention the plant cell wall to be delivered directly into the cytosol. In most cases, there are specific viral capsid or membrane glycoproteins that are required for transmission and determinants of vector specificity (Whitfield and Rotenberg, 2015). Persistent viruses usually take long period of time up to virus life, while non-Persistent virus retained only for seconds to minutes in the insect stylets or foregut and released rapidly during salivation. Today about 94 per cent of animals that transmit plant viruses are arthropods. Of which insects especially whiteflies and aphids share 50%.

At present, the estimated potential yield losses caused by plant pathogens including fungi, bacteria, virus and nematodes is up to 16% globally. Virus disease pandemics and epidemics were estimated to have a global economic impact of >US$30 billion annually (Sastry and Zitter, 2014). Among the major virus diseases that causes high yield losses in different crops are belongs to tobamovirus, tospoviruses, begomoviruses, cucumoviruses, ilarvirus, potyviruses, tungro virus, carlavirus, babuvirus, badnavirus, polerovirus, and allexivirus (Scholthof et al., 2011; Sastry and Zitter, 2014; Mandal et al., 2017). However, the losses caused by plant viruses to agriculture crops may vary from crop to crop and sometimes from virus-to-virus species. At now most researches in plant pathology aims to reduce yield loss in our crops directly or indirectly. Losses by diseases not only affect farmers but also consumers because heavy infections lead to reduction in crop yields, leading to increase in the market prices.

At present there is no permanent solution for virus disease management. At now, they are just managing by some common prevalent techniques and methods like Quarantine, Host plant resistance, cultural and some others like chemical and biological control methods. The major target of these techniques like quarantine and cultural methods is to control the carrier of virus while other some aims to manage disease. Currently, it needs more careful studies on their mechanisms, host-vector specificity and genomic insight for successful management in agricultural crops.

No, Doubt, the largest class of virus-transmitting vectors of plants are insects but other vectors like mites, nematodes and chytrid fungi are also there. For the dissemination of 18 plant virus groups, there are 12 different groups of vectors. of these, 8 groups belong to insects like leafhoppers, treehoppers, plant hoppers, aphids, whiteflies, coccids, beetles and thrips. The major interactions by which these insects transmit the viruses are of four types (Whitfield et. al., 2015; Dietzgen et al., 2016).

a) Non-persistent transmission

Non-persistent viruses are usually retained in the distal tip of the insect stylet and transmit them through two strategies *i.e.*, either capsid-only or helper-dependent. In capsid-only, virion attached to the insect stylet and facilitated by a direct interaction, which is mediated by the capsid protein for example, cucumber mosaic virus (CMV) transmitted by the aphid Myzus persicae. In second strategy *i.e.,* helper-dependent, virion uses several or a single non-structural protein(s) (example potyviruses) for their attachment to the stylet.

b) Semi-persistent transmission non-circulative

These viruses usually retained by viruliferous vectors for longer period of time as compare to those which is transmitted in a non-persistent manner. These vector loose these viruses during molting. Semi-persistent

Table 1. Potential insect vectors of virus group by Bragard et al. (2013)

Vector Insect	Virus family	Virus Group
Leafhoppers	Reoviridae	Phytoreovirus
	Rhabdoviridae	Cytorhabdovirus, Nucleorhabdovirus
	Secoviridae	Waikavirus
	Tymoviridae	Marafivirus
	Geminiviridae	Mastrevirus, Curtovirus
	Caulimoviridae	Tungrovirus
Treehoppers	Geminiviridae	Topocuvirus
Aphids	Alphaflexiviridae	Potexvirus
	Betaflexiviridae	Carlavirus, Vitivirus
	Reoviridae	Raslavirus
	Rhabdoviridae	Nucleorhabdovirus
	Bromoviridae	Alfamovirus, Bromovirus, Cucumovirus
	Secoviridae	Fabavirus, sequivirus, Waikavirus
	Unassigned	Sobimovirus, Umbravirus
	Caulimoviridae	Badnavirus, Caulimovirus
	Closteroviridae	Closterovirus
	Luteoviridae	Enamovirus, Luetovirus,Polerovirus
	Nanoviridae	Babuvirus, Nanovirus
	Potyviridae	Maculavirus,potyvirus
Whiteflies	Betaflexviridae	Carlavirus,
	Secoviridae	Torradovirus
	Closteroviridae	Crinivirus
	Giminiviridae	Begomovirus
	Ophioviridae	Ipomovirus
Plant hoppers	Reoviridae	Fijivirus, Oryzavirus
	Rhabdoviridae	Nucleorhabdovirus, Cytorhabdovirus
	Unassigned	Tenuvirus
Coccids	Betaflexviridae	Vitivirus
	Caulimoviride	Badnavirus
	Closteroviridae	Ampelovirus
Thrips	Bromoviridae	Llarvirus
	Bunyaviridae	Tospovirus
	Tombusviridae	Machlomovirus
Beetles	Bromoviridae	Bromovirus
	Secoviridae	Comovirus
	Tombusviridae	Carmovirus, Machlomovirus
	Tymoviridae	Tymovirus
	Unassigned	Sobemovirus

viruses are internalized in the insect body by binding to chitin of the inner lining of the gut, but do not appear to enter in the tissues. Example: Crinivirus lettuce infectious yellows virus (LIYV), transmitted by whitefly (*Bemisia tabaci*).

c) Non-Propagative Transmission, Circulative

Usually, circulative viruses enter into the insect's body, prior to their transmission to plant and disseminate into the various tissue systems of insects. These virus are of two types i.e. that do not replicate inside insect body (Non-Propagative) while those which replicate inside insect body (Propagative) in different tissues. The entry of viruses inside insect body majorly described through salivary gland. Example: begomovirus by whitefly.

d) Propagative Transmission, Circulative

Circulative, propagative viruses are those viruses that replicate and systemically invade into the several organs and tissues of the vector insects. The primary goal of virus is to enter in the hemolymph or neuronal tissues of vectors in order to reach the salivary glands for transmission. Example; reovirus rice dwarf virus (RDV) in the leafhopper Nephotettix cincticeps.

Potential Insect Vectors

Insects have 29 orders, out of them, order Hemiptera is considered as the most potential group for virus transmitters in plants. However, few other vector species are found in six orders *i.e.*, Thysanoptera, Coleoptera, Orthoptera, Lepidoptera, Diptera and Dermaptera. At now, maximum insect vectors of plant pathogenic diseases are aphids, whiteflies, hoppers etc. (Table1). They have piercing and sucking mouthparts in common. Some most important vectors of plant diseases are described here (Fig 1).

1. Plant hoppers

They are the members of sub order Homoptera, which are distributed worldwide. All the members of this group are plant-feeders, surprisingly few are considered as pests which hamper economic important plants. At present there may be around 10,000 plant hopper species of which the most significant pest species occur within the Delphacidae family. Most of the disease vectors are found among delphacid plant hoppers. Recently the importance of plant diseases and their vectors have highlighted by the papers of Redak et al., (2004) and by Weintraub and Beanland (2006). At present, the potential plant hopper vectors of plant virus disease come under 4 families *i.e.,* Cixiidae (6 species), Delphicidae (4 species), Derbidae (1species) and Flatidae (1species).

2. Leafhoppers

At now, there are approximately 20,000 leaf hopper (Cicadellidae) species, which are already been documented and described but estimates suggest them over 100,000 species (Dietrich, 2005). Most of them belongs to Cicadellidae family under 10 subfamilies. For disease transmission, there are around 71species under these texa that responsible to transmit the viral disease. These vectors species comes under subfamilies Typhlocybinae (3), Scarinae (1), Macropsinae (5), Idiocerinae (2), Iassinae(1), Deltocephalinae (55), Coelidiinae (1), Cicadellinae (1), Aphrodinae (1) and Agalliinae(1).

3. Whitefly

Approximately out of 1,500 species of whiteflies (113), only few species have been shown to vector of plant viruses, and these vectors include the cotton/tobacco/sweet potato whitefly [*B. tabaci* (Gennadius)] and the greenhouse whitefly (*T. vaporariorum* Westwood). By far the most important whitefly in terms of virus transmission is *B. tabaci*. It is typically polyphagous and generally found in tropical and semitropical regions. The main groups of viruses that are transmitted by whiteflies are begmovirus, ipomovirus, crinivirus carlavirus and torradovirus (Navas-Castillo et al., 2011). Some others like *Trialeurodes vaporariorum*, *T. abutiloneus*, and *T. ricini* (Misra) are also potential vector of many viral disease in plants. Recently, *Bemisia afer* sensu lato described as a vector of the crinivirus Sweet potato chlorotic stunt virus (Gamarra et. al., 2010). Generally, whiteflies transmit the virus in two modes *i.e.,* semipersistent and persistent. Semipersistent transmission requires minutes to hours for acquisition and has a retention time in the foregut of hours to days. In contrast, persistent transmission requires hours for acquisition, with a retention time in the haemolymph of days to the entire life of the insect.

4. Aphids

Aphids are the most common vector of plant viruses. The majority of aphid vectors belong to the subfamily aphidinae (Order: Homoptera) (Blackman and Eastop, 2000). Aphid vectors usually found in nine subfamilies, but they account for only a very small proportion of those that are known to transmit

Plant hopper

Leaf hopper

Whitefly

Aphids

Beetles

Fig. 1. Potential vectors of plant disease. Source: https://unsplash.com/s/photos

viruses. At present, aphids are globally distributed and there are more than 200 vector species of aphids have identified, a number that is most likely a gross underestimate (Nj and Perry 2004).

5. Beetles

Beetles are dominant group of insects. At present its 70 species are known to transmit virus diseases that infect economically important vegetables and grain crops. It is an estimated graph that beetles transmit approximately 11% of insect-borne viruses. Most of the beetle vectors of plant viruses belong to Chrysomelidae (flea beetle), Coccinellidae (coccid beetles), Curculionidae (weevils), Meloidae (blister beetles) families and have a unique mode of transmission. The virus group which usually transmitted by these beetles are belongs to six groups of plant virus genera: Machlomovirus, Bromovirus, Carmovirus, Comovirus, Sobemovirus, and Tymovirus (Wielkopolan et al., 2021)

6. Others

Some more insects like thrips, mealy bugs and coccids are their which spread the many economic virus disease to the plants. The major genus of thrips which spread the plant virus belongs to thrips, *Frankliniella*, *Scirtothrips*, and *Ceratothripoides*. The species that are known vectors of viruses are the members of Thripidae family with subfamily Thripinae. It included 1400 species in 230 genera. Plant viruses that transmit by thrips are Tospovirus, Ilarvirus, Carmovirus, Sobemovirus and Machlomovirus genera (Jones, 2005). Likewise, mealybugs that transmit viruses in semi-persistent manner are known to transmit some plant viruses that belongs to genera like *Ampelo*, *Badna* and *Clostero* genera . In case with scale insects and mealy bugs form the superfamily Coccoidea, contains arround 8000 species devided under 30 extant families. In those near about 35 species in the Coccoidea have so far been identified as vectors of 30 virus species, and classify majorly under two families *i.e.* Pseudococcidae (mealybugs) and the Coccidae (soft scales) (Herrbach et al., 2016).

Integrated Management

Presently, it is difficult to manage the plants infected with virus, unlike bacteria or fungi that can be treated with antibacterial or antifungal agents, respectively. So, viral disease management require some preventing measures like quarantine stations or some resistant plants from viral infection, using multiple strategies that must be developed specifically for respective virus, host, and environment. Some basic strategies for the management of vectors and its associated disease are described here as follow

1. Quarantine measures/Germ free planting

material

To stop the entry of any new microorganisms which is non-native, quarantine measures are must. Virus presence in quarantine can be check in the planting material by virus indexing. Many viruses are seed borne and carried by planting material. For them, certified seeds/planting material is necessary to check their initial build-up of infection in the field. So, it is recommended to always use virus free seed or the planting material so that there is no virus source available to the areal vectors to spread the pathogen. Once the source of getting virus is eliminated, the vector would not be able to receive the virus.

2. Host plant resistance (HPR)

HPR is the relative amount of heritable quality of plant which influences the ultimate degree of damage done by insects (Painter, 1951). For such situation resistant and tolerant verities is effective way of managing vectors and vector-transmitted diseases. It is one of the most important tactics by which the population of vector can be reduced on insect resistant cultivar and the pathogen resistant cultivar. Resistance to the pathogen may be the only means of management in some cases, example sugarcane mosaic virus. HPR has three components *i.e.,* antixenosis, antibiosis and non-preference. Non-preference should perhaps be the most effective form of resistance to the vector for control of non-persistent type viruses, whereas antibiosis may be effective for persistent types of viruses.

3. Cultural measures

In cultural management of virus, we may use some basic and effective management practices like isolation, alteration of in sowing and harvesting dates, modifying crop density and plant nutrition, destruction of vectors, barrier crops, traps, mulches etc. they all are useful, in virus vector disease management. Isolation is useful in to avoid the risk of viral infection. It is simplest and effective way of minimizing the number of viruliferous insects that can find the crop for multiplication and disease spread for example potato viruses. Next practices are alteration in sowing and harvesting dates. To avoid invasion of efficient vectors on crop, the sowing and harvesting dates are altered. In many parts of western countries, seed production of potato is found partly on prior haulm destruction before virus is brought into healthy crop by aphids. Another control measure is crop density and plant nutrition. It is practiced in tobacco leaf curl virus. It is more in robust crop when fertilized with excessive nitrogen. Similarly in the reduction of nitrogen dose in onion crop reduced the population of thrips and ultimately reduce vector population of viral disease. One important reservoir of viruses is the plants and weeds. So removal of these can minimize the initial inoculum. In annual crops alate vectors initiate/spread the virus and peak of virus spread coincide with peak of migrant alate vectors. They need to destroy at early stages especially for annual crops. Sticky traps are another way to reduce the vector population in field crops. They are working so well that they are now a standard practice for the control of potato viruses and cucumber mosaic viruses in many countries on various agricultural crops. The attraction of winged aphids to yellow has been utilized for many years in the yellow water pan traps or yellow sticky traps to monitor aphid populations. Sticky traps are used for direct vector control. This is a standard practice for the control of potato virus and CMV in peppers in Israel. Another effective method is by growing the crop under protected cultivation we can keep the vectors away from the crop. For example, covering tomato nursery with nylon nets for 3-4 weeks following by sprays of pesticide delayed the tomato leaf curl incidence for 3-5 weeks. Mulching of tomato and cucumber field with saw dust or yellow polythene sheets reduced the incidence of cucumber yellow vein virus and tomato yellow leaf curl virus and the population of the whitefly vector (Cohen and Melamad-Madjar, 1978). Combined use of mulching and pre-sprouting had a synergistic effect on reduction of PVY incidence (Doring et al., 2005).

Future and Conclusion

Vector-borne disease management represents some of the most economically important and invasive agriculture diseases. At present, many effective control strategies are used by the farmers to thwart the transmission of any insect-transmitted pathogen but most of them have negative impacts on the environment and human health and are unsustainable. Sustainable plant disease management specifically to vector born requires a multi-dimensional consideration for management approaches. Some of the key steps in their management are very important like correct identification. Due to genetic variation, identification is the major difficulty in their management. It can be solved by utilizing new techniques of identification like ELSA, LFA, and isothermal amplification (CRPA and LRMP). But management wants early detection. True detection always decides the management of any vector-borne disease. Systems biology could be another way to led the re-examination of existing paradigms on how pathogens interact with insect vectors, including the bacterial symbionts, and have identified vector-pathogen interactions at the molecular and cellular levels for the development of novel transmission interdiction strategies. Lastly, a brief overall summary is provided concerning how to achieve successful management of global virus disease pandemics and major epidemics that afflict important food crops. Currently, the available strategies that interfere with virus transmission by vectors include host genetic resistance to virus or insect, insecticides and integrated pest management. Finally, Better knowledge of these interactions and mechanisms of transmission will be essential for developing more effective control measures for a better future.

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Social immunity in insects

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Abstract: Social insect colonies have developed a collective immune defence against parasites. These defense systems, known as “social immune systems,” result from individual group members cooperating to combat the increased risk of disease transmission that comes with social living. Traits that reduce the intensity and transmission of pathogens and parasites within the colony are called “social immunity.” While there are several ways in which social insects enhance the overall immunity of the colony to defend against invading pathogens or parasites, they can be broadly classified into different types: maintaining nest hygiene, providing sanitary care for infected individuals, eliminating pathogens from the colony, modifying social interaction networks, and reducing vertical and horizontal parasite transmission. Social immune actions progress from initially protecting individual members to safeguarding the entire colony by preventing disease transmission.

Keywords: Social immunity, defense, disease transmission, vertical parasite transmission, horizontal parasite transmission

Social insects are characterized by their ability to live together in colonies or communities, exhibiting a range of social behaviours such as communication, food sharing, and protection of offspring and eggs (Liu et al., 2019). However, living in social groups also poses challenges, particularly regarding the spread of infectious diseases among group members, which occurs more quickly than solitary individuals (Rosengaus et al., 2011). This is due to the high density and frequent social interactions within the group, and the close genetic relatedness among group members, making them susceptible to the same parasites. Consequently, social insect groups are highly susceptible to transmitting infectious diseases. However, these social groups are expected to have evolved various strategies to counteract this threat.

Immunity refers to the ability of an organism to resist or be protected against harmful agents, particularly pathogens or infectious diseases. Immunity may occur naturally or be produced by prior exposure or immunization. In insects, immunity is of two types 1) individual/ innate immunity and 2) group/ social immunity (Cremer et al., 2019). At individual/ innate immunity, social insects have evolved various mechanisms to combat parasites and pathogens. The first line of defense is the cuticle (exoskeleton of insects) which is a mechanical and biochemical barrier covered by antimicrobial compounds. As a second defense, insects have developed an innate immune system based on cellular and humoral responses. Hemocytes primarily mediate cellular defense and include phagocytosis, nodulation or encapsulation of pathogens such as bacteria, protozoa, or nematodes. Humoral defense is based on the secretion of antimicrobial peptides (e.g., defensin, abaecin or hymenoptaecin in honey bees), using reactive oxygen intermediates as killing molecules and activating enzymatic cascades that regulate melanisation. This immune response is costly to the hosts and can reduce their life span and impair their cognitive functions (Gómez-Moracho et al., 2017; Meyel et al., 2018).

Social insects have developed cooperative behaviours, known as “social immunity,” in addition to individual defense, to combat infections. These behaviours aim to reduce exposure to parasites and colony’s transmission rate. Honey bees, for instance, collect antimicrobial substances from plant resins, which they mix with wax to create a paste called propolis (Lavine and Strand, 2002). They spread this propolis within the nest to control infections and reduce pathogen loads, including bacteria like *Paenibacillus larvae* and fungi like *Ascosphaera apis*. Another critical strategy for preventing infections is spatial segregation within the hive. Bees with higher risks of exposure to parasites and pathogens, such as foragers, have reduced physical contact with in-hive bees like nurses. This segregation helps minimize the chances of transmission. In the event of infection, adult bees detect and sacrifice infested broods to prevent further

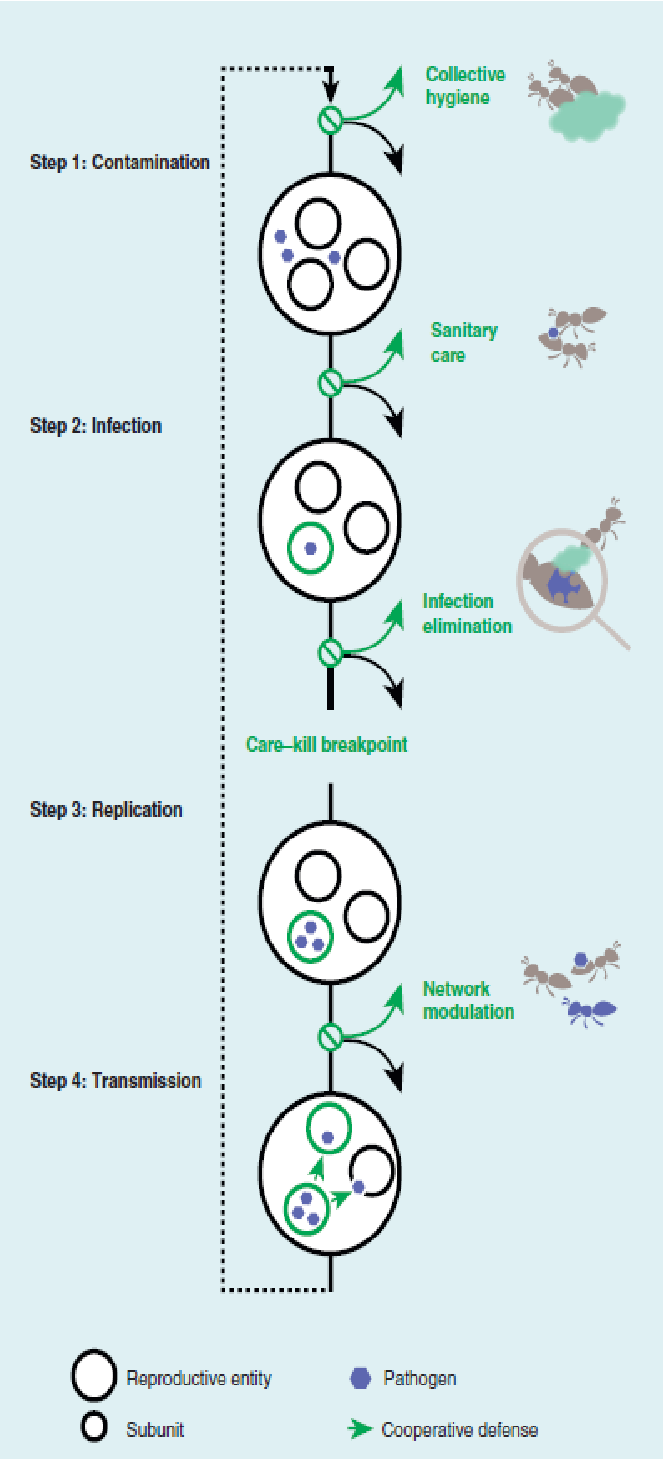

Fig. 1. Disease stage-dependent course of social immunity.

transmission. These hygienic behaviours serve as the central defensive mechanisms of honey bees against parasites.

Different kinds of parasites attacking the social insect colonies and their transmission:

Social insect colonies are susceptible to damage caused by a wide range of parasites, including macroparasites like helminth worms and arthropods, as well as microparasites such as fungi, bacteria, viruses, and certain protozoa (Cremer et al., 2018; Wilson et al., 2003). These parasites can enter the colony actively by searching for suitable hosts or be picked up and transported into the colony by individual members. The social nature of the group can contribute to the risk of an epidemic outbreak. This is because social insects often reside in environments with high microbial abundance, colonies are densely populated with closely related individuals, and there is frequent social contact among group members. As a result, parasite infections can be easily transmitted between individuals. In social insects, the distinction between "vertical" and "horizontal" transmission, referring to transmission from parent to offspring versus transmission among individuals of the same generation, becomes less clear. This is because parents and offspring live together permanently within colonies (Meyel et al., 2018; Patterson and Ruckstuhl, 2013). Therefore, in social insects, "horizontal" transmission refers to transmission within and between groups or colonies. In contrast, while "vertical" transmission refers to the transmission from a mother colony to a daughter colony in the next generation. Regardless of the type of transmission, the invasion of parasites into a colony involves multiple steps. The parasite must either actively approach or passively be transported to the colony. Once inside, it must establish itself within the nest environment and spread among group members. It may then exit the colony either horizontally or vertically, infecting new colonies in the process.

Components of social immunity / Mechanisms of defense in the colony

Social immunity in social insects operates at each stage of disease progression (steps 1-4). Cooperative defense mechanisms protect the reproductive entity, represented by green upward-bent arrows. However, if these defenses fail, the disease advances to the next step (black downward-bent arrows), allowing the pathogen (blue diamonds) to infect individuals (green circles), replicate (multiple diamonds), and transmit to new colony members (small green arrows). In response to disease progression, social immunity employs collective nest hygiene, elimination of infections, and modulation of the social interaction network through behavioral changes of colony members. Initially, the focus is on protecting individual members, but the aim shifts towards protecting the entire colony by preventing disease transmission (Cremer, 2019).

Avoidance strategy

The first and most effective line of defense in protecting insect colonies from infections is to prevent the entry of pathogens. Avoiding direct contact with pathogens is a vital aspect of this strategy. For instance, termites actively avoid areas where fungal pathogens are present. They employ vibratory warnings and seal off contaminated areas to prevent their nestmates from coming into contact with the pathogens. Similarly, while bringing nest mate's carcasses back to the colony for food, ants ensure that they do not come into contact with fungus-contaminated corpses (Liu et al., 2019).

Another important element of the avoidance strategy is careful handling materials brought into the colonies. Leaf-cutter ants exemplify this by having large foragers carry leaves into the colony. At the same time, while specialized workers known as hitchhikers are responsible for removing fungal contaminants from the leaves, akin to the skin immunity observed in vertebrates. Border defense is another significant component, where social insects incorporate antifungal materials into their nests. They collect these materials from the environment or produce them internally to enhance the nest's defense. For example, ants gather tree resin as nesting material to prevent fungal growth. Furthermore, termites, ants, and bees can add certain antifungal chemicals to the nesting materials. Termites and ants also utilize symbiotic microorganisms from their nesting structures to defend against fungal pathogens.

Collective nest hygiene

Nest hygiene serves as the initial step in the social immune response of a colony and is typically employed as a preventive measure in a non-specific manner. It involves the mechanical removal of potentially infectious materials and the application of broad-spectrum antimicrobials. Social insects maintain meticulous cleanliness within their nests, even in without pathogens, to eliminate any potential sources of infection. For instance, when garden ants establish a new nest, they treat the nest material, including the newly constructed brood chambers, with a self-produced disinfectant containing formic acid, which acts as a poison with antimicrobial properties (Evans et al., 2009). Termites incorporate their feces into their nests as they contain a rich microbial community that produces antimicrobial substances, ensuring a clean environment. Corpses and debris are carefully collected and relocated to specific areas called graveyards or middens, located within peripheral nest chambers or outside the nest., When faced with nest contamination, honeybees employ a strategy similar to our own bodies: they raise the temperature. This social fever is achieved by bees vibrating their flight muscles collectively, resulting in an overall increase in hive temperature. This behaviour has been observed to effectively eliminate heat-sensitive pathogens such as *Ascosphaera apis* (Starks et al., 2000).

Sanitary care

Sanitary care acts as the second step in the social immune response of a colony when an individual becomes contaminated with a pathogen, either due to inadequate nest hygiene or foraging outside. In a similar way, how monkeys groom each other to remove ectoparasites, honeybees groom their nestmates to eliminate pests like the *Varroa* mite (Evans et al., 2009). Ants and termites also engage in grooming behaviours to remove fungal spores from contaminated individuals, preventing them from penetrating the cuticle and causing internal infections. Allo-grooming, where individuals groom each other, is particularly effective in preventing infections compared to self-grooming because it allows for the grooming of body parts that may be difficult to reach individually, such as the thorax. Grooming is a common form of sanitary care observed in social insects and is highly effective (Land and Seeley, 2004). However, a question arises as to whether allo-grooming increases the risk of infection for the groomer. Grooming ants, for example, collect the infectious material they remove and store it in pouches within their mouth called infra buccal pockets. The material is then compacted and sterilized using antimicrobial gland compounds. Eventually, the compacted pellets are expelled and have a significantly reduced ability to germinate. Despite these measures, pathogen transfer can still occur from the contaminated individual to its nestmates, although it typically results in non-lethal, low-level infections. Such low-level infections can trigger a protective immunization response in ants and termites. In a study conducted by Neto et al. (2006), the researchers experimentally examined the three main hypotheses proposed to explain hitchhiking behavior in *Atta sexdens* and field colonies of *Atta laevigata*: a) defense against phorid flies, b) defense against fungal contaminants, and c) leaf sap obtention. The results of the study revealed the following findings: a) Limited evidence was found for an increase in hitchhiking in the presence of phorid flies. The presence of phorid flies only led to a slight increase

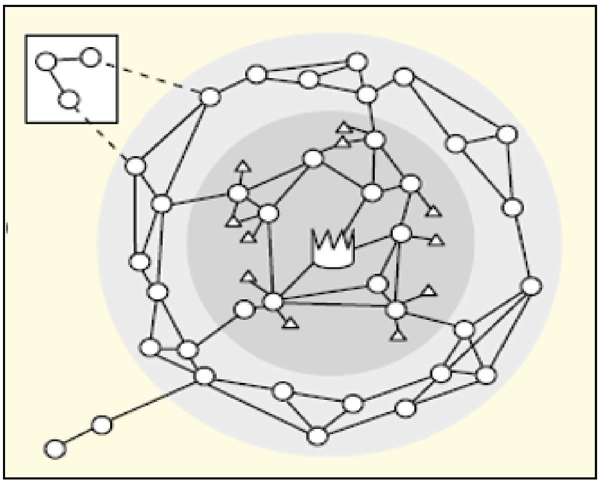

Fig. 2. Interaction network of a generalised social insect colony.

in the number of hitchhikers in *A. sexdens*, and no increase was observed in *A. laevigata*. b) In both species, the proportion of fragments with hitchhikers was significantly higher in fragments obtained from fresh leaves compared to those from dry leaves. This suggests that obtaining leaf sap may be one possible function of hitchhiking behavior in *A. sexdens* and *A. laevigata*. c) The primary function of hitchhiking behavior was found to be a defense against fungal contaminants. The proportion of fragments with hitchhikers was approximately 4 to 6 times greater in fragments experimentally inoculated with moldy bread compared to clean fragments or those inoculated with an inert substance. These findings indicate that hitchhiking behavior in these ant species serves as a defense mechanism against fungal contaminants, with obtaining leaf sap potentially playing a secondary role. Sanitary care, including grooming and removal of infectious material, likely contributes to the defense against fungal pathogens and may be involved in the hitchhiking behavior observed.

Infection elimination

Since the 1960s, it has been known that honeybees can detect infected broods within sealed comb cells and remove them by uncapping and dropping the brood outside the hive. This behaviour has also been observed in several ant species, although their brood is pooled in open piles instead of sealed cells. Unlike bees, ants risk reinfection if they drop infectious brood outside the nest as they forage in the same territories. Garden ants have developed a complex multicomponent behaviour to address this challenge to eliminate brood infections. The process begins with the ants slicing open the cocoon of an infected pupa and biting through its soft cuticle. They bend their abdomen over the pupae and release a poisonous spray containing formic acid. This behaviour allows the poison to enter the infected pupa, disinfecting it from the inside out. Doing so, prevent pathogen replication is before new transmissible stages can be produced. This process, known as "destructive disinfection," serves a function similar to eliminating infected cells in a body and operates mechanistically equivalently (Pull et al., 2018).

The "care-kill dichotomy" is an important aspect of social immunity. Nest hygiene and sanitary care are crucial in preventing pathogens from establishing within the colony. While many studies focus on these early defense mechanisms, they are only sometimes fully effective. When initial defense fails and infection takes hold, social immunity shifts its focus from prevention to combating disease replication and transmission. In such cases, the emphasis shifts to excluding or eliminating infected individuals. Once an infection reaches an irreversible stage, social immunity transitions from a "care" strategy to a "kill" strategy, aiming to minimize the spread of the disease within the colony.

Modulation of the social interaction network

Social insects exhibit structured interaction networks, which are shaped by the clustering of individuals according to their tasks and the spatial organization within the nest. In many social insect colonies, such as ants and termites, the contact rates between individuals are limited due to spatial and behavioural compartmentalization (Cremer et al., 2007; Ament et al., 2008). This compartmentalization is most evident in the division of labour based on age and caste. Young workers, known as nurses, are responsible for caring for the brood and queen in the central area of the nest, while older workers venture outside the nest to forage. This inherent network structure may have evolved, at least in part, as a mechanism to restrict the transmission of infectious diseases, as suggested by the "organizational immunity hypotheses." These compartments within the nest consist of groups of workers arranged in concentric circles, with individuals of the same age and/or caste performing similar tasks. The central region (a dark grey area) houses the queen (represented by a crown) and her brood (triangles), which are attended to by the young workers. On the periphery (a light grey area), older workers engage in nest maintenance and leave the nest for foraging purposes. The disposal of dead bodies and waste occurs in specific locations at the edge or outside of the nest (upper left corner, depicted as a rectangle for the garbage dump workers), with limited indirect contact with the main nest. In response to contamination from foragers, the nurses adjust their behaviour by bringing the brood even closer to the center of the nest. This further separates the foragers from the nurses, reducing the risk of infection for the nurses and queen. Consequently, pathogen transmission is primarily observed among individuals within the same age and task groups, particularly among foragers, while the nurses and queens typically receive only low amounts of pathogens. These lower pathogen levels often result in immunization rather than disease development.

Reducing vertical and horizontal parasite transmission

Once a parasite has established within a colony, it can spread to other groups, including neighbouring independent colonies or daughter colonies. Vertical transmission to daughter colonies can occur when reproducing queens lay infected brood or when the daughter queens or accompanying workers (in the case of nest budding) acquire an infection before leaving the parental colony, either through horizontal or vertical transmission (Wilson et al*.,* 2003) While there may not be strong selection against avoiding horizontal infections between colonies, there is likely intense selection pressure to prevent vertical transmission to daughter colonies. This is because the colony's fitness heavily relies on the successful production of offspring colonies. To prevent vertical transmission, social insects have developed various strategies. Infected honeybee workers may stop tending to the queen, and wasps protect their juvenile stages by rearing them in brood cells impregnated with antimicrobial secretions. Ant queens, while laying eggs, sometimes coat them with venom, and workers can spray venom over the brood to reduce fungal infections. Protective substances, such as royalisin and other antimicrobial peptides, can also be directly fed to the brood, as seen in honeybees. Furthermore, social insects exhibit a "transgenerational transfer of immunity," similar to what is observed in other organisms, where immunity is passed down to the offspring. On the other hand, avoiding horizontal infection between neighbouring colonies is not commonly expected, except in cases where the neighbouring colonies are closely related and/or when it directly reduces the risk of re-infection for their colony.

Conclusions

Social immune systems in social insects serve as functional barriers at every stage of parasite invasion, providing a comprehensive defense mechanism. They have evolved to minimize the energy expenditure associated with individual immune responses by harnessing the power of collective action. Through social immunity, colonies gain significant resistance against generalist parasites, effectively reducing the risk of infection and transmission within the group. However, it is important to note that specialist parasites may have evolved strategies to overcome or circumvent social immunity defenses. Overall, the up-regulation of immunity at the colony level enhances the fitness and survival of the entire social insect colony.

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FIELD NOTE

Oviposition mistake in plain tiger butterfly, *Danaus chrysippus* L.

Kunal Ankola

Insect oviposition (egg laying) is an important reproductive behaviour, essential for the establishment of healthy offspring for the next generation. In herbivorous insects, such as butterflies, the sensory system plays a vital role in this process, helping females to find a suitable host plant for egg laying. This phenomenon is best explained by the preference-efficiency hypothesis (PPH), which speaks of the natural selection of only those females with the ability to choose ideal host plants that further support the growth and development of their offspring. Here, ideal host plants referred to plants of high nutritional value with limited or reduced defence mechanisms against herbivorous insects. Choosing the right host plant is highly recommended, especially when neonatal larvae are sensitive and less mobile than adults. Hence, PPH is also known as 'mother-knows-best' hypothesis. However, appropriate selection of host plant is a challenging task for the females that depends on both external and internal stimuli and is influenced by a series of fluctuating environmental parameters.

A butterfly choosing its host plant is a dramatic episode in which the female uses visual and olfactory cues and get attracted towards their host plants. Generally, butterflies are oligophagous specialist insects prefers a specific group of plants for their larval feeding. These specific groups of plants impart specific chemical signals that are identified by the females prior to oviposition. Mostly, these chemical signals are the secondary metabolites (alkaloids, glycosides etc.) that are identified by the female through a unique method. For instance, few butterflies use their first pair of tarsal claws to scratch the surface of the leaf. This releases the chemical stimulus from the leaf which is conveniently diagnosed by the females. Despite of being specialized to comprehend these chemical stimuli, the females commit some major mistakes during egg laying. Such mistakes are also known as oviposition mistakes, that adversely affects the survivability of the newly hatched larvae.

One of the oviposition mistakes made by the Plain Tiger butterfly (*Danaus chrysippus)* has been documented in this article. The female plain tiger butterfly was spotted ovipositioning on the leaves of its host plant (*Calotropis sps.*) in the Jnana Bharathi campus, Bangalore University. It is extremely uncommon to see a plain tiger butterfly make any sort of oviposition error, but this butterfly's action was remarkable since the female was attempting to lay her eggs on leaves that had fallen away from the plant body.

Fig. 1. Plain Tiger butterfly (*Danaus chrysippus*)

Fig. 2. Plain Tiger (*D. chrysippus*) butterfly trying to identify the chemical cues from Calotropis leaves that are fallen away from the plants

Fig. 3. Oviposition of the Plain Tiger (*D. chrysippus*) butterfly on Calotropis leaves that are fallen away from the plants

D. chrysippus, is a member of the family Nymphalidae, which is widespread throughout southern India. The butterfly is categorised as milkweed butterfly due to its larval feeding habit on toxic milkweed plants. Like any other butterflies, the oviposition of plain tiger is depending on the specific chemical cues imparted by the milkweed plants. Generally, the female wander around its host plant to examine and select appropriate leaves for ovipositioning and lays 10 to12 eggs individually on different leaves within 5 to 6 minutes. Although these butterflies are experts at picking up the chemical stimuli of the leaves, they cannot identify the location of the leaves. In some cases, the females lay eggs on the leaves of their host plants that have fallen out of the plant body. This is one of the serious mistakes in oviposition that might risk the hatchability of eggs and also influence the survivability of newly hatched caterpillar. The eggs laid on the fallen leaves could be damaged or predated by other animals. Conversely, by the time the egg hatches, the fallen leaf may have dried and the new born larvae are very unlikely to migrate in search of their host plant. Such new born non migratory larvae would become easy prey for other insects or may die from starvation.

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Occurrence of a large congregation of synchronous Fireflies and Firefly species diversity at Anamalai Tiger Reserve, India.

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The captivating bioluminescence of fireflies has long fascinated researchers and nature enthusiasts worldwide. Among these enchanting insects, synchronous fireflies, with their mesmerizing, coordinated flashing displays, have become a subject of intrigue. The Anamalai Tiger Reserve (ATR), geographically located between the longitudes 76°E and 77°E and latitudes 10°N and 10°N, falls in the southern part of the Western Ghats in India. Encompassing an extensive area of 958.59 square kilometers, this reserve is a vital biodiversity hotspot, teeming with a diverse range of endemic flora and faunal species, including the captivating fireflies. With an annual rainfall range of 500-4500 mm, ATR provides an ideal and thriving habitat for studying the behavior and ecological roles of these mesmerizing insects.

The research conducted at ATR was focused on unraveling the synchronization patterns of these bioluminescent organisms and investigating their roles in the delicate ecological balance of the reserve. Comprehensive field surveys have been carried out to document the congregation of fireflies and identify the various species present, shedding light on their unique behaviors and interactions within the ecosystem. As an indicator species, fireflies play a crucial role in biodiversity conservation and ecosystem management. Their synchronized flashing behavior serves as a vital ecological marker, reflecting the health of their habitat and the surrounding environment. Understanding their behavior and the factors influencing their flashing patterns can provide valuable insights into the overall health and functioning of the ecosystem. This research manuscript presents a wealth of findings gathered from the field surveys, providing a comprehensive understanding of the firefly community at ATR. The observed congregation and diversity of species highlight the reserve's importance as a thriving

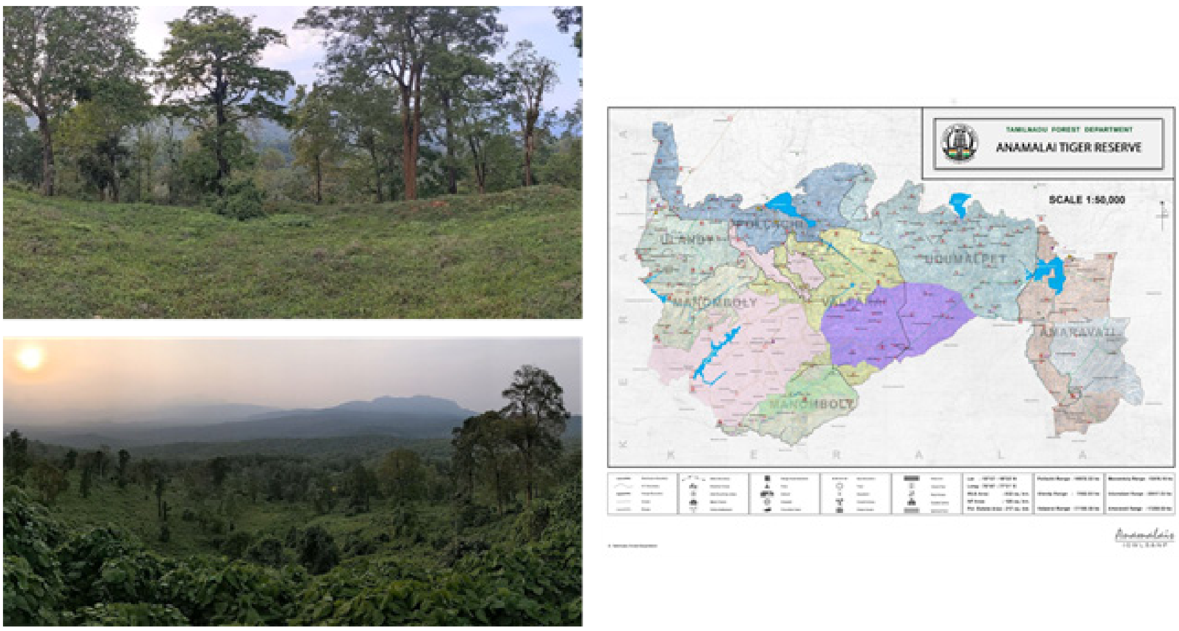

Fig. 1. Study location: Map of Anamalai Tiger Reserve: Depicting the diverse ranges within the protected area

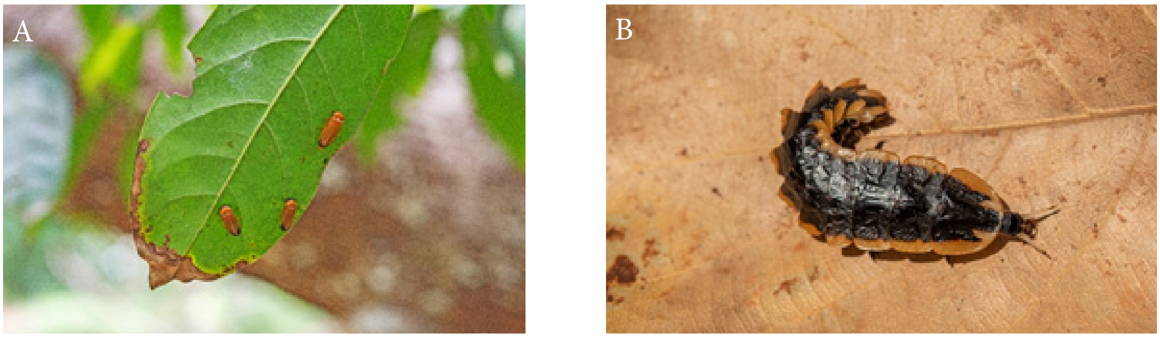

Fig. 2. A. Adult fireflies roosting under the vegetation during the day hours; B. Firefly larva

Fig. 3. These are 15.83-minute exposure reveals firefly activity and star trails. Stacking 50 photos with 19-second exposures, the final image captures the brightest pixel and counts flashes per pixel once. The stationary fireflies during flashing are evident from the absence of flash trails in the trees.

habitat for these captivating insects. Moreover, by studying their behavior and interactions with other species in the food chain, this research underscores the significance of proactive conservation measures to preserve their habitat and safeguard the entire ecosystem.

In the captivating realm of Anamalai Tiger Reserve, billions of synchronously flashing fireflies adorn the landscape with a mesmerizing carpet of yellowish-green brilliance during April. These bioluminescent wonders have long fascinated people of all ages, as they illuminate the darkness to communicate and find mates (Branham et al., 2003, Cladistics, 2019). Through the fascinating process of bioluminescence, fireflies produce their enchanting cool light. Unfortunately, once abundantly present firefly populations are facing drastic decline globally (Kevin et al., 2016; Owens et al., 2022) due to anthropogenic mediated climate change, habitat fragmentation and light pollution. Remarkably, large congregations of synchronous fireflies are a rarity, found in only a few locations worldwide, including the USA (Carlson et al., 1985), Malaysia (Copeland et al., 1995; Razak et al., 2016; Abu Seri et al., 2022), Thailand (Razak et al., 2016), and Brazil (Jaikla et al., 2020; Hagen et al., 2015; Viviani et al., 2001). This study delves into an in-depth study of the synchronous firefly populations dwelling within the breathtaking Anamalai Tiger Reserve in Tamil Nadu, India.

Extensive field surveys were conducted during the firefly mating seasons from 2022 to 2023 in the Anamalai Tiger Reserve (ATR), India (Fig. 1.) to observe and document the behavior and synchronization patterns of fireflies (Fig. 3). The

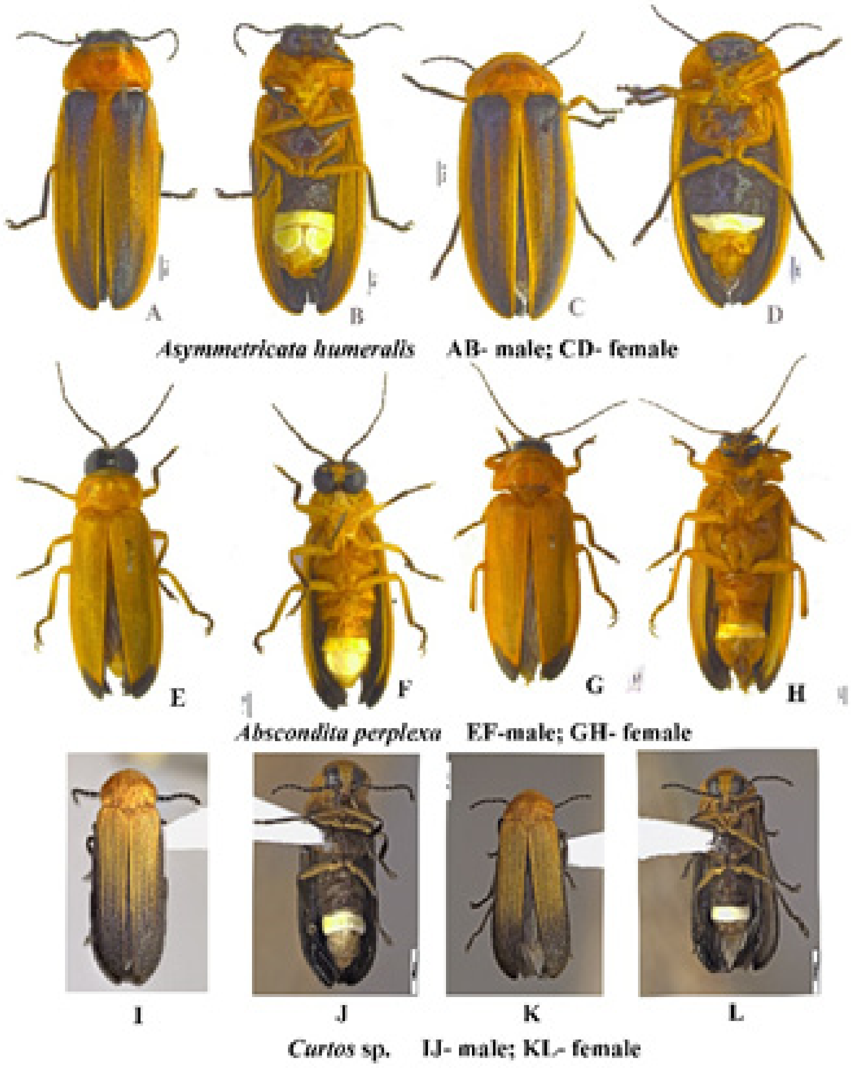

Fig. 4. Firefly species diversity in Anamalai Tiger Reserve

study aimed to understand the ecological significance of synchronous fireflies and identify the diverse firefly species present in this pristine habitat. Observations were made at various locations within the reserve to capture a representative sample of firefly activity. Researchers recorded the flashing patterns of fireflies in individual trees and documented whether the flashes were ascending or descending. The timing of flashing events was noted relative to sunset, allowing for an analysis of the synchronization phenomenon. Mating behaviors, such as rapid pulsations and the duration of flashing sequences, were carefully observed.

Firefly specimens were collected from different locations within the reserve for species identification. Each specimen's physical characteristics were examined, and distinguishing features were noted for species classification. To investigate the potential influence of environmental factors on firefly behavior, data on sunlight intensity, lunar face, wind direction, and weather conditions were recorded during the observation period. Additional surveys were conducted in specific areas with unique habitat characteristics, such as the Anaikundhi valley, which experienced a forest fire in 2017, to understand how such events may impact firefly activity.

The research conducted at the Varagaliyar range of Anamalai Tiger Reserve (ATR), India, unveiled intriguing patterns of firefly synchronization within the observed trees. Each tree exhibited local synchronization, with flashes either ascending or descending. However, not all trees displayed synchronized flashing simultaneously, indicating a degree of individual variability in their behavior. A pivotal moment occurred precisely at 19:30, witnessing a remarkable peak of activity. Flashes initiated in a single tree and propagated like a "Mexican wave" across several adjacent trees. Interestingly, global synchronization was observed in most trees, with one exception. Surprisingly, the top section of one tree displayed its own local synchronization while the rest remained in unison (Fig. 3). This unique behavior hints at a potential influence of moon light on the magnitude of synchronization, possibly indicating a correlation between light intensity and firefly activity. During the day, fireflies concealed themselves under leaves to avoid sunlight. The larvae, around 2 inches long with a glowing rear end, were observed burrowing underground and are predominantly nocturnal like the adults' fireflies (Fig. 2).

Analyzing the timing of flashing events offered further insights into the synchronization phenomenon. On average, flashes commenced 24 minutes after sunset, followed by local synchronization after about 33 minutes, and finally, the wave-like global synchronization after approximately 54 minutes post-sunset. The global synchronization persisted for several hours into the night, providing a captivating spectacle of light. Throughout the night, the wave-like synchronization displayed a consistent pattern, starting from one tree and propagating unidirectionally. However, occasional reversals in the direction of the wave were observed, suggesting a potential relationship with the prevailing wind direction. The findings indicate a complex interplay of environmental factors influencing firefly behavior and synchronization. Further investigation is warranted to understand the precise role of sunlight and wind in shaping these patterns (Fig. 3).

Moreover, the unique observations in the Anaikundhi valley, which experienced a forest fire in 2017, marked it as a hotspot for firefly activity. Each tree in the valley exhibited distinct flashing patterns, with rapid pulsations of 3 to 4 flashes per second, lasting about 4 seconds. Billions of fireflies contributed to the enthralling spectacle in this area. While the tall trees surrounding the Anaikundhi valley displayed typical global wave patterns, the slopes showcased a variety of exceptional flashing patterns, including upward, downward, and outward displays. Such diversity in flashing behavior was not observed elsewhere in the forest. The interspersed arrangement of trees in the valley is hypothesized to facilitate the transmission of firefly flashes across a large area. Additionally, one section of the forest housing rosewood trees demonstrated the highest concentration of global 360-degree synchronization. In contrast, firefly activity near Topslip was scarce, with no evidence of synchronization (Fig. 3).

On a separate observation day, during steady lightning and a slight drizzle, firefly activity was very low. Conversely, more open areas with widely spaced trees showed little activity. The Anaikundhi valley, being an open area, exhibited no activity on this day. Some fireflies continued to flash despite the lightning, while others did not participate, possibly indicating variations in mating behavior and desperation among individuals. Firefly activity was very scarce in the denser forest areas during all the observation periods.

Our research revealed a diverse firefly community within the reserve, with three identified species: *Asymmetrica humeralis* (Walker, 1858), *Abscondita* genus (species unknown), and *Curtos* sp (Fig. 4). All the three species showed variation in size morphology. They shared similar habitat types with overlapping zones. Among the three species *Asymmetrica humeralis* being the most abundant population in all the study areas during this observation period. *Curtos* sp was the smallest among the three species with single segment of light organ in both male and female while males of *Abscondita* sp and *Asymmetrica* had 2 and 3 segments.

***Abscondita perplexa*:** Asian genus, usually pale yellow or brownish yellow, with black elytral apices; males have an entire Light organ in abdomen segment 7 ventrally occupying almost entire segment. Most species of this genus exhibit the very widespread dorsal colour pattern of yellowish-brown dorsum with or without black tipped elytral apices, which is very common in Luciolinae fireflies of South East Asia. Species with pale dorsum and black elytral apices, which both have very dark terminal abdominal tergites, distinguished by the pale terminal abdominal tergites in the male.

***Asymmetricata humeralis*:** Dorsal colouration having paler brown elytra with darker brown markings restricted to base and apex, pronotum entirely yellow. Light organ is bipartite on the abdominal segment 7.

***Curtos* sp.**: The genus is very easy to see distinguish by the yellow colour with black areas on their elytra than other genus.

The documentation of these species contributes to a deeper understanding of their composition and distribution patterns in this specific habitat. Notably, synchronous fireflies are found in various other locations worldwide, including the entire stretch of Western Ghats specifically in Maharashtra, India, mangrove forests in Malaysia, and several places in Southeast Asia, particularly the Smoky Mountains

National Park in the USA. This underscores the global significance of these mesmerizing bioluminescent insects and their captivating natural displays.

In conclusion, the congregation of synchronous fireflies at the Anamalai Tiger Reserve represents a captivating natural spectacle with significant ecological importance. These mesmerizing insects potentially serve as crucial pollinators and bioindicators of the reserve's environmental health. Understanding their ecological functions is vital for effective biodiversity conservation and ecosystem management.

However, the study also highlights the potential threats posed by light pollution to firefly populations. Fireflies rely on bioluminescence for communication and mating, and artificial lights in the buffer zone of the reserve may disrupt their delicate synchronization and mating behaviors. Thus, it is crucial to establish a sustainable tourism model in the buffer area that minimizes light pollution to preserve the firefly population and their unique displays.

Conservation strategies

Conservation efforts play a pivotal role in preserving the habitat of the diverse firefly community within the Anamalai Tiger Reserve. The well-preserved core zone of the reserve, which is a result of decades of conservation efforts, serves as a critical sanctuary for firefly activity, especially during the crucial breeding season in April and May. It is vital to maintain this area undisturbed to safeguard the firefly eggs and larvae from any potential harm caused by soil unrest or the introduction of foreign elements (Abu Seri, 2022; Hagen, 2015).

To ensure a thriving population of fireflies, measures should be taken to minimize the impact of artificial light on their communication and mating behaviors. Introducing lighting within the reserve should be carefully considered, and if necessary, shielded and of lower color temperature than white LEDs to minimize its effect on fireflies (Owens, 2022). During patrolling, field staff should use low luminosity torch lights whenever possible and reserve high-intensity lights for emergencies. Limiting vehicular movement at night, especially during the breeding season, is essential to mitigate disturbances (Abu Seri, 2022; Hagen, 2015).

Additionally, religious festivities coinciding with the peak firefly mating season at the Kozhikamuthi settlement should be regulated to prevent increased foot traffic and light pollution near the firefly hotspot areas. Providing suitable alternative lighting options can help reduce the impact on firefly habitats. Designating a firefly watcher to monitor the population and prevent illegal activities such as vehicle entry, forest fires, or felling can further safeguard the firefly population for the future.

By implementing preventive measures and raising awareness about light pollution's detrimental effects, we can effectively protect the captivating firefly community within the Anamalai Tiger Reserve. Proactively conserving this unique habitat and educating visitors about the ecological significance of fireflies will foster appreciation and ensure the preservation of this natural wonder for generations to come. The delicate balance of nature, exemplified by the reserve's rich biodiversity and the enchanting beauty of synchronous fireflies, serves as a powerful reminder of our responsibility to protect, and cherish these fascinating creatures and their habitat.

Acknowledgement: We sincerely thank the Anamalai Tiger Reserve (ATR), India, for granting research permission and the continuous support of ATR forest staff, officials, and dedicated field assistants. Their contributions were vital to the success of our research. We thank Dr. Yeshwanth H.M, National Centre for Biological Sciences (NCBS) for his support in taxonomic characterization of the firefly species. The mesmerizing fireflies of ATR have inspired us, igniting our commitment to conserve these enchanting insects and their delicate ecosystems.

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Do you know me? I am buzz bee

Jyoti Falswal

What are these colorful, beautiful creatures who keep coming on flowers in our garden? Yes, these are bees. Your daily visitors you do not even notice. Whenever we talk about bees, generally only honey bees come to our mind. Why? Wouldn't other bees feel bad? (Fig.1). If I tell you the truth, Indian Halictid bees have been orphaned after Bingham 1897. Or maybe this would be right to say that nobody had interest in them or even knew them. But now the situation is different. Bees are happy to know that few are studying and knowing them.

Before 3 years when I started my research on bees I found a lot of Halictid bee literature from foreign countries but very less from India. Why so, are not we interested or we are playing hide and seek with our bees? But today, i can say that Halictid bees have taken their flight in India. Soon, the world will be seeing our duet with bees.

"Taxonomy" mostly considered as a horrific word by students in science that frightens them because it's very difficult to remember the scientific name of organisms. Everyone thinks that it's not their cup of tea…only those have interest in taxonomy, which has capability of rote learning and have a lot of patience. Like you, I was one of them and never liked the subject till my post graduation. However, working on little cute Lady Bird beetles during my postgraduate program changed my mind set and I developed interest in taxonomy. And today I don't find any other subject better than taxonomy and I am fond of taxonomy now. Maybe this is the reason my Ph.D. in taxonomy doesn't feel like a headache. Eventually, bees need a pilot in their flight. Do you know in the whole learning process which one could be your favorite part? Sitting quietly in a corner in laboratory, look at the bees under microscope, identifying them and search for new species. Sounds pretty amazing right?

By the way taxonomy is a branch of science in which we identify the living and non-living things based on their features, place them in their family to which they belong and give identity by giving them name by which they would be called tomorrow by everyone. Whenever we find new species, naming them is just like we keep the name of a new born baby at home. Subsequently, we make their complete horoscope, so that after 10 years from today or after 100 years no one forgets them. They become a significant part of the history. Other hand naming them is beneficial for us too like for biodiversity organization and

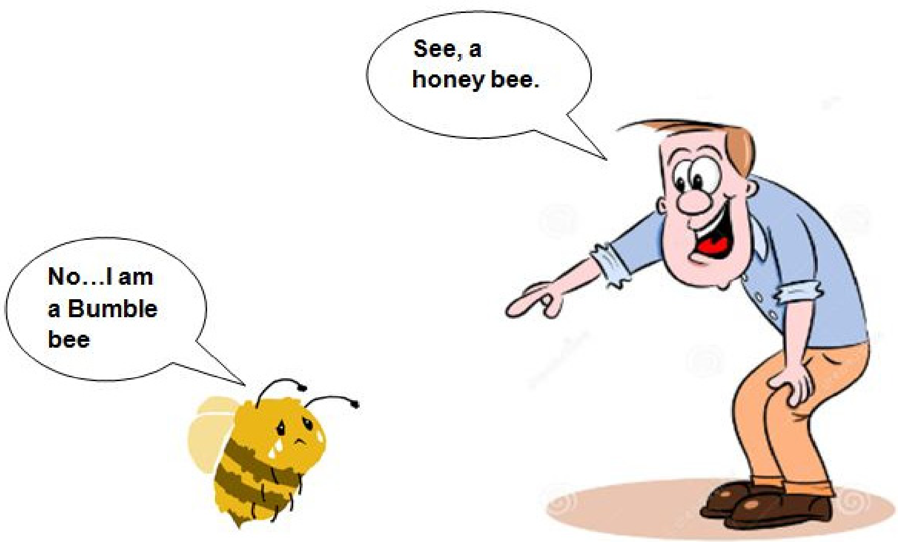

Fig.1. Bombus bee is being misidentified by a common man

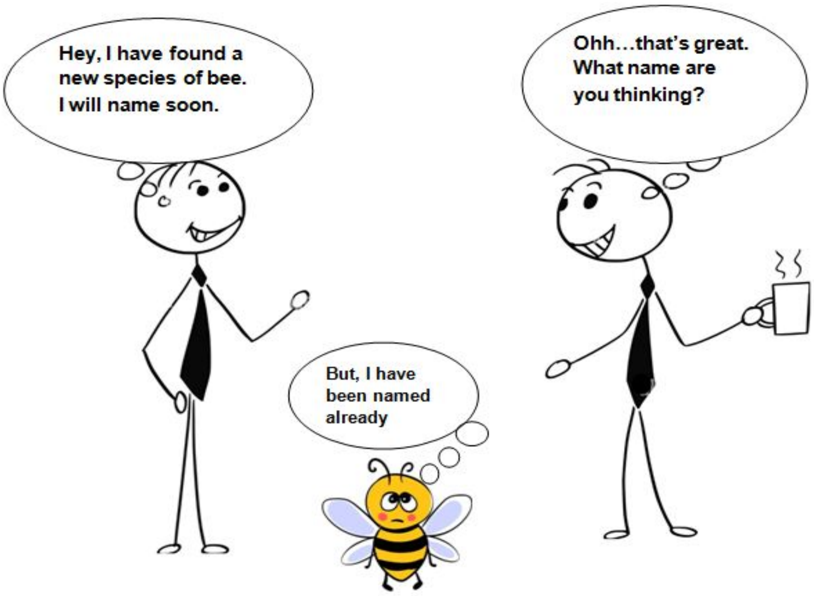

Fig. 2. A bee is upset by being named repeatedly

conservation.

Why is it important to name them? If taxonomists don't take care of, who will remember them tomorrow? How long do the bees live, just a few days? Any organism, any caste will get upset because of different nomenclature again and again (Fig.2). They feel as if they don't have any identity. Here comes taxonomist's role, the taxonomists are *Pandits* in their life who writes down their horoscopes (Fig. 3).

Along with our insecticides issues these bees are also upset as no one knows about them and call them as honey bees. Thus, I thought of taking care of them. When I started working on bees, I developed interest in the Family. Halictidae, which includes bees other than honey bees, is the 2^{nd} largest and most beautiful bee family after Apidae (honey bees) yet with no pride. Simple living creatures, they silently visit the flowers, trade nectar and pollen, and return to their nest with no tension of unemployment, the problem of tax filing and the election period. But their simplicity does not mean that you are allowed to capture or harm them. They will definitely sting to protect themselves. Well, almost all the bee can sting, whether it's honey bee or other bee (except stingless bees from family Apidae). But here is one surprise for you, you have to be careful with only female bee (though, have to be careful with females anyway) because male bees don't sting. As female bees have a sting on the tip of their abdomen which is inserted into the body of enemies. But by just planting a few flowering plants, we can make them our dear friends.

Their family ladder is also similar to ours, it starts from Phylum followed by Class, Family, Subfamily, Tribe, Genus and finally Species. The genus is like our family name and the species is like an individual name. Another striking similarity is that their family is also governed by parents, just like us, who are present in house and propagating their family. For every

Fig. 3. Bees getting their recognition by a taxonomist

work, they have different individuals, some take care of their food, some cleanliness, some do repair work and some do protect them. There are many more like this…Isn't it interesting? Sometimes people found it fascinating and became fan of these beautiful bees.

The bees of my interest belong to Halictidae family which has almost 4500 species worldwide. Sadly, only 215 species love India or we can say that till date only 215 species are reported from India. I have found almost 37 new locality records of the Halictidae family in India in the last 2 years. I am glad to say that I have recorded 04 species for the first time from India and discover 07 new species from this family.

This research has increased total number to 220 in gamily Halictidae. You may find the numbers small but the journey of a researcher is full of hurdles. Taxonomists must wander around day and night and travel great distances in order to capture, research, and provide a family name for these bees. To find these shy creatures, they have to visit different agro-ecosystems. Light traps during nighttime inside the forest area or deep vegetations also important for night out loving bees.

The flight is yet to be completed and it is forbidden to be tired. There are many more bees living in our country, but they do not have Indian citizenship. I believe that they should get their due. They should get their family name and their own Aadhar Card. Apart from bees; there are many other creatures which are still unknown. We have to find out about all of them. This research should be continued. The deeper the search, the more golden will be the result. This study can never end because evolution will continue and our work will too continue.

This is my bee's little story which is comprise many short stories in very simple language so that everybody can easily understand. I hope with your blessings I can make my bees fly higher.

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8TH INDIAN ENTOMOLOGIST PHOTO CONTEST

- The Indian entomologist photo contest aims to encourage insect photography among photographers, professionals, amateur entomologists, and layman. The theme of the 8th episode of the photo contest was 'Insects and aspects related to insect life.' With this objective, entries were invited from 8th June to 10th July 2023. Each participant was to submit one good photograph that met a few prescribed standards along with the filled-in application form in which the participant had to furnish his/her details, caption, description, specifications of the photograph, and also a declaration on the ingenuity of the photograph. We received total 49 entries screened first for the prescribed standards and overall image quality. The final evaluation was done by a committee of independent members under the oversight of the three editorial board members and also by an invited expert, 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 8th Indian Entomologist photo contest

- The first place was won by Kiran Vati K (Faculty, Department of Zoology, St Aloysius College (Autonomous), Mangalore, E-mail: kiranvatik@gmail.com), who captured the ant bridge formed by weaver ants, also known as green ants (*Oecophylla smaragdina*).
- The second place was won by Pradyumna S (#203, Sai Pavithra Residence Anjaneyanagra, Bengaluru-85) for his photograph of mating chaffer beetles.
- The third place was won by Adil Chowdhury (Vill: Karajgram; PS: Katwa, Purba Bardhhaman- 713502) for his photograph on Spittlebug nymph is busy making spittle cover around itself, and another one is giving us "peak-a-boo".

Congratulations to the winners, and we acknowledge all the participants who took an interest in 8th Indian Entomologist photo contest and sent their entries!!

BUG STUDIO ASSOCIATE EDITORS

First place: Ant bridge formed by weaver ants

Second place: Mating chaffer beetles

Third place: Spittlebug nymph with spittle

INSECT PHOTO CONTEST-cum-EXHIBITION (Series I)
(A National Level Event) - May 6. 2023
Department of Entomology, School of Agriculture, Lovely Professional University, Phagwara, Punjab
In collaboration with
ENTOMOLOGICAL SOCIETY OF INDIA (ESI), New Delhi

Objectives of the Event:

- To create an awareness among the students regarding the importance and existence of insects
- To explore the world of insects and the environments they live in for better understanding
- To provide an opportunity to explore new subjects that may be outside of one's comfort zone
- To discover and recognize talented students and others with good photography skills

Details of the Event:

On 6th May 2023 (Saturday), a National level One Day Event on INSECT PHOTO CONTEST-cum-EXHIBITION (Series I) was organized by the Department of Entomology, School of Agriculture, LPU, in collaboration with one of the premier professional societies, the Entomological Society of India (ESI), New Delhi. A total of 87 photo entries were received from UG students, PG/Ph.D. scholars, faculties of LPU and external participants from states like Sikkim, Manipur, Kerala, etc. The photo entries are available at the official instagram page of Department of Entomology @lpuentomology (https://www.instagram.com/lpuentomology/).

The event was graced by three panelists for the evaluation:

1. Dr. Chandra Mohan Mehta, Prof. and Deputy Dean, SAGR, LPU
2. Mr. Niwit Pauly, Assistant Professor, School of Humanities (Fine Arts), LPU @hippieinformals
3. Mr. Ediheilung Jamir, Independent Photographer

The organizers would like to thank The Entomological Society of India for the collaboration, all the participants and the panelists for making this event a grand success.

Event Organizing Committee

Dr. Devina Seram (Organizing Secretary)
Dr. Ankush M Raut
Dr. Haobijam James Watt
Dr. I.Y. Longkumer
Dr. Paramveer Singh

Student Co-ordinators

Mr. Sudhanshu Raikwar
3rd year, B.Sc. (Agri.)
Mr. Abhinash Borah
1st year, M.Sc. (Entomology)

WINNING PHOTOS

UG Category

First place: Mr. Aman Kumar Tiwari
(1st Year - B.Sc. (Agri.)

First runner up: Ms. Cheenglembi Laishram
1st Year - B.Sc. (Agri.)

Second runner up: Mr. Gokul Krishna BS
3rd Year - B.Sc. (Agri.)

Third runner up: Mr. Fuad Zenin P
3rd Year - B.Sc. (Agri.)

Fourth runner up: Mr. Barnik Debnath
3rd Year - B.Sc. (Agri.)

Consolation 1: Ms. Sutapa Ghosh
1st Year - B.Sc. (Agri.)

Consolation 2: Mr. Smit Shah
2nd Year - B.Sc. (Agri.)

PG/Ph.D. Category

First place: Ms. Iddi Nangkar
1st Year - M.Sc. (Ento.)

First runnerup: Mr. Konthoujam Ambedkar Singh
1st Year - M.Sc. (Ento.)

Second runnerup: Ms. Aquiny Befairlyne Mawthoh
1st Year - M.Sc. (Ento.)

Faculty Category

First place: Dr. Devina Seram
Assistant Professor
(Entomology)

First runnerup: Dr. Chetariya Chana Pitha
Assistant Professor
(Genetics & Plant Breeding)

Second runnerup: Dr. I Yimjenjang Longkumer
Assistant Professor
(Entomology)

ARADHANA PANDA
DIVISION OF ENTOMOLOGY,
FACULTY OF AGRICULTURE, Wadura, SKUAST-KASHMIR

Aradhana Panda is currently pursuing her Ph.D. from Division of Entomology, Faculty of Agriculture, Wadura, SKUAST-Kashmir. She is doing her work on molecular studies and organic management of oriental armyworm, *Mythimna separata* on wheat under the guidance of Dr. Ishtiyaq Ahad (Associate Professor-cum-Senior scientist, Division of Entomology, Faculty of Agriculture, SKUAST-Kashmir). Oriental armyworm has been reported to be severely infesting various cereal crops like rice, wheat, oats and maize in Kashmir condition, which keeps on shifting from one crop to the next. She is working on generating DNA barcodes of armyworm and its natural enemies followed by screening of various armyworm infested wheat genotypes. She will also determine the genes responsible for the resistance and susceptibility of wheat against this notorious insect pest. Besides, she is studying the impact of several organic measures taken up against the insect for its timely management. In the future, she is willing to continue her research work on different molecular studies against the herbivorous insect pest along with their natural enemies and their organic management. Shifting nature of the pest, degree of damage and double cropping system in temperate conditions of Kashmir, necessitates organic management of this polyphagous pest for the welfare and sustainability of marginal farmers in the area.

D SAICHARAN
DEPARTMENT OF ENTOMOLOGY
PJTSAU, HYDERABAD

Saicharan is currently pursuing Ph.D. in Entomology at Professor Jayashankar Telangana State Agricultural University in Rajendranagar (PJTSAU), Hyderabad with the research work entitled "Valorisation of organic wastes through Black Soldier Fly, *Hermetia illucens* (L.) (Diptera: Stratiomyidae)" under the guidance of Dr. V. Anitha, Professor of Entomology and Dean of Post Graduate Studies at PJTSAU, Hyderabad. The objective of his research is to upcycle organic waste into a valuable, protein-rich substrate using black soldier fly larvae. These flies have the ability to decompose organic waste and increasingly recognized as a good source of food and feed for poultry and fisheries. D. Saicharan graduated from the College of Horticulture, Rajendranagar, SKLTSHU. Following that, he obtained his M.Sc. in Agricultural Entomology as an ICAR-JRF from the University of Agricultural Sciences, Dharwad, College of Agriculture, Vijayapur. During his master's program, he focused on the sorghum endemic pest, Sorghum Shoot Bug (*Peregrinus maidis*), under the guidance of Dr. S. S. Karabhantanal, Principal Scientist at AICRP on Sorghum, RARS, Vijayapur, Karnataka. Throughout his academic journey, D. Saicharan has been the recipient of various fellowships, including ICAR-JRF, ICAR-SRF, UGC NET JRF, and National Fellowship for Scheduled Tribe. In the future, he is interested in working on Integrated Pest Management (IPM) aspects to minimize the environmental pesticide load in pest management.

STUDENT CORNER

MEGHA
DEPARTMENT OF AGRICULTURAL ENTOMOLOGY, UNIVERSITY OF AGRICULTURAL SCIENCES, DHARWAD

Megha, a Ph.D. student working on management of major insect pests of fodder sorghum and chickpea under organic agriculture systems at Bio resource farm (organically certified since 2006), Institute of Organic Farming, Dharwad, Karnataka. The investigation's objective is to assess the insecticidal properties of locally accessible medicinal flora and compare them to indigenous technological knowledge of farmers. The main focus of the project proposal is the creation of a practical, inexpensive, cost-effective organic plant protection model that is both scientifically sound and practically feasible in farmer's fields. Additionally, the choice of the fodder crop is a positive for the research field that helps in understanding the importance of chemical-free fodder cultivation in safeguarding the health of the livestock. During her M.Sc. program, she worked on effect of climate change on biotic potential of two major insect pests of cowpea *i.e.*, pod borer, *Maruca vitrata* and aphid, *Aphis craccivora* at center for agro-climatic studies, Main Agricultural Research Station, University of Agricultural Sciences, Raichur, Karnataka. Megha is primarily interested in selecting an area of investigation based solely on current agricultural challenges such as climate change and its impact on agriculture, particularly on the insect population, as well as the future scope of conservation agriculture in sustainable development under pesticide-free organic production systems.

Mr. Kishore Chandra Sahoo and Miss. Akshatha, Student Associate Editors of IE compiled the information for this section.

Indian Entomologist is a biannual on-line magazine and blog site that publishes articles and information of general, scientific and popular interest. The magazine publishes letters to the editor, columns, feature articles, research, reviews, student opinions and obituaries. The magazine accepts articles on all aspects of insects and terrestrial arthropods from India and worldwide. Short field notes and observations are also welcome. This magazine is intended to provide a broad view of topics that appeal to entomologists, other researchers interested in insect science, and insect enthusiasts of all stripes.

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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