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FEATURING

Behavioural Genomics in Post Genomic Era

Tête-à-tête with Dr. K.K. Sharma

In conversation with Dr. S. Vennila

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Editorial Board

*Cover page: Egg laying of Desert locust captured on 22.07.2020 during ICAR-IARI, New Delhi locust survey at Gotan, Rajasthan, India
Photo by: Shashank PR, Anooj SS, Naresh NM and Subash Chander

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LOCUST MAYHEM AND NEED FOR A RESURGENCE IN RESEARCH

It is pleasure to pen an editorial for the unique venture "Indian Entomologist", second in the series- of the youngsters actively practicing Entomology in India. When I look back into the few months that passed away, there had been many entomology happenings in the country. Of these, the striking one is that of the "desert locust", the *Schistocerca gregaria* Forskal. In simple terms- "*all locusts are grasshoppers, but not all grasshoppers are locusts*". The one that develops the behaviour of swarming and migration over continents with regular seasonal variations, and effect plague cycles becomes a deadly "*locust*". Of the four or five grasshoppers which acquire this habit of "plague cycles", India is usually afflicted with only *S. gregaria*.

Plague cycles are a period of two or more consecutive years of widespread breeding, swarm formation and crop destruction. In India, such plagues were recurrent in the 19th century, up to 1950s, with the last one being in 1959-62. Subsequently, there have been only isolated 'upsurges'. The one fresh in my mind is of 1973-76, immediately after my entry to IARI, New Delhi. But this fizzled out as an insignificant one in real terms. Then came 2019, with 1,500 swarm attacks, and 27 so far in this year. Fear of "plague" came thus, during summer when crops were few, in Punjab, Haryana and north Rajasthan, with a warning that it will return to Rajasthan in July for breeding. The damage is yet to be assessed in real terms. Fortunately, Delhi just escaped, but not without frightening the Delhiites- I recollect here a frantic call, during end of May, by one Dr Jyoti Chugh, from north Delhi to help save her "potted plants, valuables" on the terrace from this "locust army".

I cannot end this editorial without reminding the need for a resurgence in research, and the way forward. I will cite only few, who dedicated their lifetime for locust research, and we need to introspect, and emulate.

1. Sir Boris P Uvarov (1889 -1970), who pioneered locust research, referred to as "Uncle Boris". Boris gave "phase theory in locust" with his >60 years (1910 onwards) of expertise in taxonomy, and ecology. These stand as testimony of the need for the taxonomy fundamentals in any entomology work. Much of what we find in the "Desert Locust Information Service, the famous "DLIS" of FAO are his contributions, a distinction to remain forever!

2. M.L. Roonwal, a taxonomist, who stay put in Jodhpur, focused on desert and locusts (in addition to his monumental termite's work in the desert regional station, Zoological Survey of India). He established a theory on the 11-year cycle of mass-increase in *S. gregaria*. He confirmed Uvarov's work on the existence of two phases, being produced at will by the process of crowding and thinning (published in Nature way back in 1947). His later (1980) taxonomic finding that eye stripes are indicators of polymorphism/ population flux is a taxonomy marvel.

3. Y. Ramchandra Rao, again a taxonomist, whose work culminated in a ICAR Monograph (No. 21; pp. xix+ 721; 59 plates, published 1960) ."Uncle Boris" while writing a review of this work in Nature (1962) stated that it is an "extensive investigation for nine years, of the biology and ecology of the locust, extending over Pakistan and India"; and "not merely a detailed report but augmented by the abundant data carefully extracted". Boris stated "it is a comprehensive monograph which have no parallel in any other locust-infested part of the world"; yes, indeed, credit goes to ICAR which published it! He added that the intrinsic value of the book is so great that it will always remain a classic example; with work carried out with inspiration and determination resulting in far-reaching conclusions.

There emanates a large number of facts on the current status, as reviewed by one of the experts in 2006- "when such seasonal rains fall sequentially, populations develop into an upsurge and eventually into a plague unless checked by drought, migration to hostile habitats, or effective control"; "Increases in the proportion of gregarious populations as the plague develops alter the effectiveness of control; "As an upsurge starts, only a minority of locusts is aggregated into treatable targets and spraying them leaves sufficient unsprayed individuals to continue the upsurge"; "Spraying all individuals scattered within an entire infested zone is arguably both financially and environmentally unacceptable"; "More of the population gregarizes and forms sprayable targets after each successive season of good rains and successful breeding"; "Eventually, unless the rains fail, the entire upsurge population becomes aggregated at high densities so that the infested area diminishes and a plague begins"; "These populations must continue to increase numerically and spread geographically to achieve peak plague levels, a stage last reached in the 1950s"; "Effective control, aided by poor rains, accompanied each subsequent late upsurge and early plague stage and all declined rapidly"; "The control strategy aims to reduce populations to prevent plagues and damage to crops and grazing. Differing opinions on the optimum stage to interrupt pre-plague breeding sequences remain"

Thus, in its management, facing of these intriguing facts will require inertia, strength and potential, in terms of rigorous exploration of fundamentals in taxonomy integrated with ecology. These were there luxuriously indeed, in the dedication and devotion of BP Uvarov, ML Roonwal, and Y Ramchandra Rao, the stalwarts!

Will there be a revival of such essential action and competence in taxonomy in addressing S. gregaria? Will the desired motivation be in place soon? It is inevitable, if one need to face the challenges, especially in these times of climate change! I am confident it will be, and one has to find ways! After all, where there is a will, there is a way!

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

Behavioral genomics: a way to study insect behavior in the post-genomics era

Kallare P Arunkumar

Abstract: Thanks to recent developments in biology in the last 20 years, the classical genetics mode of studying insect behavior is now being actively replaced by new biotechnologies including massively parallel nucleotide sequencing and genome engineering. These two technologies have changed the way the researchers study insect behavior even in non-model organisms. Owing to the lack of research resources it was once considered a difficult task to study behavior in non-model insects, especially in serious agricultural pests, which is now a possibility due to cost effective sequencing and ease of gene disruption in these species. Several studies are now underway to understand the molecular genetic basis of behavior in several insects. This would provide a large body of information on peculiar behavior of many economically important insects, which would certainly help to address several longstanding questions in entomology.

Key words: Insect genomics, CRISPR/Cas9, phototropism, insect behavior.

The study of the genetic control of behavior is fundamental to an understanding of its evolution (Ewing and Manning, 1967) and we can now make a fairly consistent interpretation of behavioral evolution by comparative genomics approaches. The insects have proved to be an excellent material for the understanding of how genes influence behavior for three main reasons. First, the short generation time and high fecundity of many insect species make them well suited to a variety of quantitative genetic breeding designs. Secondly, many behaviors in male and female insects are highly stereotyped. Finally, insects have relatively simple genomes and many have been sequenced increasing the ease and effectiveness of genomic studies investigating the specific genes that regulate behavior (Hunt et al., 2018).

Previously, the techniques of classical genetics were used to study insect behavior and such studies were complicated by the limitations of classical genetics and the difficulty of detecting segregating units of behavior. Also, classical genetics techniques were mostly useful for comparing insect behaviors that differ at one locus only but became complicated when they differ at more than one locus. Today the scenario has changed. With the tools and techniques available currently, the behavioral genetics can be studied easily through the genomics route. Insect behavior controlled by QTLs can also be identified now and functionally characterized. In this article, I discuss why the current scenario is best suited to study insect behavior through the genomics approach and what are the biotechnologies that come in handy in achieving this? I have given a few examples of how insect behavior can be studied through the application of new technologies.

Several studies have begun to identify the genetic toolbox that controls behavior in insects. Studying insect behavior is one of the very important aspects of insect biology as it is central to developing better management strategies for controlling agriculture pests, medically important insects as well as beneficial insects. Understanding the molecular genetic basis of why some insects behave the way they do will help to develop better insecticides for pest species and aid in improving the productivity of beneficial insects. The new biology heralded by technological advances in cost effective massively parallel sequencing of genetic materials and subsequent development in the field of genome engineering that allows for precise editing of the genome of an organism is leading to unprecedented progress in studies on the genetic effect of insect behavior. Subsequent studies can use methods for complex trait analysis in economically important insects to map behavioral genes, map out gene expression patterns and study gene -gene and gene - environment interactions.

The behavior observed in different animals is the result of the interaction between the genome and the environment. Here the broad view of 'behavior' as the 'response of an individual to a particular stimulus' is considered. Given that the macro-environment will be more or less the same for all the individuals of a species inhabiting a particular location, the differences in the behavior of individuals may be attributed mainly to the genomic makeup of the organism. Understanding the genome would help us in linking the genetic loci to a behavior. Once linked the underlying information will be useful in practical applications. The newly developed DNA sequencing technologies have made the job relatively easy.

NGS and third generation sequencing techniques and their application in insects

Regular advances in sequencing technologies have spurred the rapid accumulation of insect genome sequences, setting the stage for a new era of insect science. The last two decades of decreasing DNA sequencing costs, simplified data analysis and proliferating sequencing services in core labs and companies have brought the de-novo genome sequencing and assembly of insect species within reach for many entomologists. However, sequence production alone is not enough to generate a high-quality reference genome, and in many cases, poor planning can lead to extremely fragmented genome assemblies preventing high quality gene annotation and other desired analyses. Owing to constant improvements in sequencing technologies, numerous insect genomes have been sequenced. More than a thousand insect genome sequencing projects have been registered with the National Center for Biotechnology Information, including 401 that have genome assemblies and 155 with an official gene set of annotated protein coding genes (Li et al., 2019).

Now that a large amount of DNA sequence data is available, the challenge remains to make its sense. Several labs are now working on utilizing this data in various ways. Thanks to inexpensive sequencing technology, currently the researchers are getting representational sequences from whole genome from individuals of mapping population and analyzing to identify the genetic loci responsible for complex traits. This has shortened the research period from many years to less than a year. Global gene expression profiles can be prepared from tissues obtained from different treatments and one can identify the genes linked to specific behavior of the insect.

Differential gene expression studies

Genes influence behavior through the presence or absence of allelic gene variants in the genome or through differential gene expression. The best way to study the effect of genes on behavior is to link the dynamic expression patterns to behavior using different molecular biological studies such as mRNA quantification through massively parallel sequencing of mRNA transcripts. This has been made possible through technological advances that allowed the researchers to simultaneously examine the expression of thousands of genes via RNA-Seq. This kind of global transcriptomic analysis allows for an unbiased view of genes potentially underlying a behavior (Wong and Hoffman, 2010).

Differential gene expression studies help in identifying the genes linked to behavior of insect under study. A research was conducted in Honey bees to study associations between grooming behavior and the expression of selected immune, neural, detoxification, developmental and health-related genes. It was found that the level of grooming behavior may be related to the expression pattern of vital honey bee genes (Hamiduzzaman et al., 2017). These genes may be further studied to find their suitability as bio-marker for behavioral traits and also as genetic markers in marker assisted selection to breed better honey bee strains.

Genome wide association studies

Association studies are presently conducted across the genome usually with Genome wide association studies (GWAS). GWAS searches for genetic associations using many thousands of markers spanning the entire genome. The markers, mainly Single Nucleotide Polymorphisms (SNPs) are single base-pair changes occurring at a higher frequency in a genome. GWAS utilizes many of the same methodologies that were used as classic linkage based QTL studies and they have become highly successful in identifying loci linked to quantitative traits of interest in many insects. Once the linked loci are identified the functional genomics approaches can be used to generate information about possible gene functions and study the genetic interactions between gene complexes and the environment (Hunt et al., 2018).

Using GWAS a few studies have been carried out to understand the behavior and adaptation of insects. The genetic landscape of insect behavior was assessed using GWAS in *Drosophila* (York, 2018). The results of the study provided evidence that different types of behavior are associated with variable genetic bases and suggested that, across animal evolution, the genetic landscape of behavior is more rugged, yet predictable, than previously thought. However, the findings revealed several important caveats and prospects for future behavior genetic studies. The QTL mapping methods possess inherent limitations in detecting the complete genetic architecture of certain traits. Therefore, future studies of the genetic architecture of behavior will thus benefit from integrating QTL methods with results from genome-wide sequencing and genetic interrogations directed by genome editing (York, 2018).

Fig. 1. Negative phototropism exhibited by the Indian Golden silkworm larvae. The late instar larvae tend to move towards ground when there is bright sunlight and less leaves on the trees

CRISPR/Cas9 based Genome engineering in insects

With the development and application of genome editing, both the scope and depth of research on economically important insects were improved. Custom-designed nuclease technologies such as the clustered regularly interspaced short palindromic repeat (CRISPR)-associated (Cas) system provide attractive genome editing tools for insect functional genetics. The targeted gene mutagenesis mediated by the CRISPR/Cas9 system has been achieved in several insect orders including Diptera, Lepidoptera and Coleoptera. Initially, the genome editing was mainly used to confirm some known functions or to verify candidate genes discovered by positional cloning. With the increased applications of genome editing, functional genomics researches in insects have evolved, in which large scale analysis of genes in an entire pathway was conducted. Compared with RNAi technology, which regulates gene expression on the transcription level, the CRISPR/Cas9 system works on the genome level and is more penetrating and heritable, and therefore useful for functional gene analysis.

The CRISPR/ Cas9 technology has captured the imagination of insect scientists. It has been optimized and explored in more insect species beyond Drosophila. Nevertheless, the successful editing of insect genomes using this technology will require careful attention to the design and assessment of the gRNA, the delivery of Cas9 and the gRNA, and the screening for and detection of insects carrying the mutation of interest. Finally, the reassessment of how genetically altered organisms are regulated, based on the latest science will definitely play an important role in the possibility of the future release of CRISPR-edited insects into the environment (Taning et al., 2017).

Studies are now going on that combine the genomics information and gene disruption techniques in economically important insects to address the questions linked to their behavior (eg., Yan et al., 2017).

Negative phototropism in Indian Golden silk moth, *Antheraea assamensis*

The Indian Golden Silkworm, *A. assamensis*, locally known as muga silkworm, is reared outdoors and it completes the larval stage on its host plants. The peculiar behavior exhibited by muga silkworms is negative phototropism towards the end of their larval stage. The larvae mainly in the fifth instar climb down the tree when they sense bright sunlight. This happens at around 10AM-12PM when there is bright sunlight (Fig. 1). This has been observed to happen when there are fewer leaves in the tree, which exposes the larvae to sunlight. This induces the movement of larvae towards the ground. Once they climb down they search for nearby host plants and climb them. This kind of behavior the farmers believe that the larvae sense the dearth of leaves for feeding and then they decide to leave the tree, which in reality is not the case.

When the larvae mature and ready to spin the cocoons, where they metamorphose to emerge as moths, they again climb down the tree and find a specific place to spin the cocoon. But this time they will start moving toward the ground at the time of sunset. This phenomenon is called as positive geotropism. These two behaviors are not observed in closely related Saturniid silkworm species *Antheraea mylitta* and *Antheraea proylei*. These two species of silkworms stay on trees the whole time of their larval duration and also prepare cocoons on the trees.

This peculiar behavior of muga silkworms is not yet studied in detail owing to lack of genomic information and gene editing technologies in this insect species. The ongoing efforts of Central Silk Board, India to prepare a high-quality genome sequence will aid in studying the genetic and molecular basis of negative phototropism and positive geotropism exhibited by muga silkworm larvae. Also, other closely related silkworm species are also being sequenced by different laboratories, the comparative genomics approach would identify the linked genetic factors and thereby help in disrupting them through gene editing.

To study the genetic basis of negative phototropism in muga silkworms, the transcriptomes from tissues of the larvae that climb down the tree maybe compared with those of the ones that do not show this behavior and continue the feeding on the tree. This will provide the information on the expression of the linked genes and such genes may be functionally annotated through transient knockdown via RNAi. The genes identified as linked to the behavior can be disrupted using CRISPR/Cas9 technology and look for loss of behavior. Thus, using the behavioral genomics datasets the causal relationship between gene expression and behavior, and their associations with time can be addressed.

Nocturnal behavior of *Spodoptera litura*

Insect pests cause significant damage to crops and affect agricultural productivity significantly. *Spodoptera litura* is an important polyphagous pest in India, China and Japan. It is a serious pest of various economically important crops such as cotton, groundnut, chilly, tobacco, caster, bendy, pulses, etc. It is a noctuid moth nicknamed 'night thief' in Japan because of the voracious night feeding of the late instar larvae which steal crops and vegetables when farmers are asleep while cryptically hiding in the soil during the day.

A very interesting aspect of the *Spodoptera* study is that *S. litura* is extremely polyphagous and attacks over a hundred important crops, while another moth species well studied the domesticated silkworm, *Bombyx mori*, is strictly monophagous. A comparison between these two species will lead to a deeper understanding of insect-host plant interaction and also the nocturnal and polyphagous nature of *S. litura*. The genus *Spodoptera* constitutes a good model to explore host-plant specialization within phytophagous insect groups and to address exciting questions in phylogeny and ecological adaptation (monocots *versus* dicots or monophagy *versus* polyphagy). *Spodoptera picta,* which is closest to *S. litura*, is found in Japanese southern islands and feeds only on monocots of Liliaceae, whereas *S. litura* feeds mainly dicots. The comparison between *S. litura* and *S. picta* could be very informative to study ecological adaptation. In addition, "Polyphagy" presents an interesting subject to be studied. Since each plant family has its own defense system against herbivores, polyphagous insects such as *S. litura* may have a "master system" to evade a wide-range of defense systems in host plants. The understanding of the molecular basis of behavior and adaptation mechanisms of *S. litura* could provide the required knowledge for devising pest control strategies.

Towards this end, the genome of *S. litura* has been sequenced and a physical map is made available. The genome sequencing project provided strong evidence on how this polyphagous insect has evolved to become a deleterious and powerful global pest through adaptative changes and subsequent selection of gene expansions(Cheng et al., 2017).Additionally, the CRISPR/Cas9 system induced efficient gene mutagenesis has also been standardized for *S. litura* (Bi et al., 2016). Utilizing these two main developments, many outstanding questions in this notorious pest can be studied.

As nocturnal insects like *S. litura* are active and also feed at night but sleep or rest during the day. The dichotomy of the two phases, namely feeding and hiding, possibly by circadian control, may have contributed to make them the most efficient herbivore in the field. Existence of such a mechanism can also be studied using the tools currently available to study this insect.

Foraging behavior in insects and its link to domestication of the silkworm *B. mori*

Population density varies over time and space, and plays a significant role in the evolution of characteristics within populations. Population density affects a number of processes, for example, predator–prey and parasite–host interactions, the spread of disease, competition, population regulation, and territoriality. Population density was one of the main factors that affected the domestication of silkworm *B. mori* more than 5000 years ago. In nature, maintaining lower density will increase the chances of survival of organisms as it leads to the increased availability of food. However, for commercial sericulture, we need a higher density of silkworm larvae per unit area, which is a contrasting requirement. The continuous selection has made possible to rear a very high number of silkworms in the small area thereby increasing productivity. *Bombyx mandarina* and *Bombyx huttoni*, two of the bombycid wild silkworm species closely related to the domesticated silkworm, do not show crowding behavior indicating that crowding behavior was selected for during the domestication process. Studying the molecular basis of this behavior would help in the domestication of wild silkworm species such as Tasar (*A. mylitta*) and muga. Muga silkworms exhibit non-crowding behavior; an adaptation for its survival in limited availability of food. The larvae though feed in groups in the initial larval stage, move away from each other in search of food in late instars.

Fig. 2. Population density was one of the main factors that affected the domestication of silkworm *B. mori*(A). Similarly, the domesticated Saturniid silkworm Eri, *Samia ricini* (C) also can be grown indoors in higher population density. The same is not true for *B. huttoni* (B), a close relative of *B. mori,* and also for the saturniid silkworm *A. assamensis* (D).

The foraging behavior has been studied well in the fruit fly *Drosophila melanogaster*. Normal individual differences in the *foraging*(*for*) gene of Drosophila result in two behavioral types called rover and sitter. Larval rovers show a greater behavioral response to changes in their food environment than sitters. The*for*gene makes an enzyme called PKG, which is found in the head of the fly, as well as in most other organisms, including humans (Kent et al., 2009). As larvae, rovers move more and feed less in the presence of food than sitters, but do not differ in locomotion in the absence of food.

In the case of silkworms *B. mori* and *Samia ricini* larvae stay in groups while feeding and therefore are grown indoors, where the rearing environment can be controlled to get the desired yield (Fig. 2). However, *A. mylitta* and *A. assamensis* larvae tend to move away from each other. Identification of genetic factors linked to such behavior in silk moths through application of transcriptomics, GWAS and genome engineering would help in breeding new strains of tasar and muga silkworms that can be reared indoors in higher density.

Conclusions and future prospects

Almost all behaviors are associated with some form of heritable genetic variation. The interplay between genetic and environmental forces that shape behavior is complex and disentangling it requires an array of research endeavors spanning several disciplines. Previously, owing to limits in data and availability of research methods, the extents to which genetic architectures that vary across a full spectrum of behaviors and animal taxa remained largely unexplored (York, 2018).Now that the tools and data becoming available, behavioral biology in insects may begin to produce a more nuanced and predictive understanding of the interplay of genetic forces governing the evolution of behavior, especially in the economically important insects.

Genome editing has not only accelerated fundamental research but has also shown promising applications in agricultural breeding and therapy. The recent publication of genome sequences even in non-model insects along with the development of CRISPR/Cas9 based gene disruption technique in non-model insects has provided required tricks and tools for behavioral genomics studies in insects including the non-model species. This ease of doing disruption of candidate genes as identified through genomics and transcriptomics approaches will pave new ways of studying insect behavior. Several ongoing studies to analyze the enormous sequence data in many economically important insects will provide deeper insights into genetic manifestations of the peculiar behavior of insects in their habitat. Such studies will be fascinating for basic biology studies in ecology and evolutionary biology as well as in addressing the long standing problems in agriculture and allies fields.

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Insecticide Induced Resurgence in Insect pests

Rajna S and Nikhil Raj M

Abstract: Resurgence is an adverse effect of indiscriminate and non-judicious insecticide use in crop production. As more evidences of increase in pest population appear, resurgence is gaining practical significance in agriculture. Insecticides being the key factor responsible for inducing resurgence, can enhance the target or non-target pest number through direct and indirect effects. In some pest populations, insecticide induced hormesis can also cause stimulatory effects in physiological and behavioral processes. The insecticide application, leading to elimination of natural enemies, and inducing biochemical changes in plants such as change in plant defense chemicals triggers indirect mode of resurgence development. Even though not directly related, and do not occur always, with resistance development, the probability of the population to resurge will be higher.

Key words: Insects, pesticides, outbreaks, pests, resistance

Resurgence is a result of indiscriminate and non-judicious use of synthetic pesticides in field conditions. More than 50 cases of resurgence reported, since the commencement of pesticide application in agriculture (Dutcher, 2007), and we have failed in resolving this problem. Globally, many researchers have proposed various definitions for resurgence. One of the oldest definitions is by Bartlett (1964) which stressed on pesticides and natural enemies to explain that resurgence is an anomalous quick come back to economic abundance of a pest, which was initially suppressed by the application of pesticide and had also destroyed its natural enemies. In order to make the definition better acceptable to the scientific community Heinrichs *et al.* (1984) imparted a statistical dimension and described resurgence as 'statistically significant increase in the pest population or pest damage in insecticide treated plots over that of untreated plots. Other researchers suggested an initial decline in the pest population due to pesticide application for resurgence. Conversely, pesticides having sub-lethal effects on a pest will not show an initial decline of the population. The classification of resurgence as primary and secondary brought in more clarity. The increase in target pest population by insecticide treatment to a level at least as high, or higher than the untreated control is attributed as primary pest resurgence, whereas the increase in non-target pest population as an accidental consequence of the insecticide treatment is the secondary pest resurgence (Fig.1) (Hardin et al., 1995).

Pest resurgence, though depends on a multitude of reasons, is however caused primarily by the insecticides (Cutler, 2013). There is no single group of insecticides free from resurgence inducement. Homopteran insects registered the maximum resurgence cases in field condition, followed by phytophagous mites. The resurgence does not require multiple insecticide applications of insecticides and may happen after even a single spray (Dutcher, 2007). The very first report of insect outbreak post-insecticide treatment was the population abundance in the soft scale (*Coccus hesperidium* L.) in citrus after application of parathion, an organophosphate insecticide. The resurgence phenomenon has come to the limelight in Asian countries after the population explosion of brown planthopper in insecticide-treated rice tracts (Chelliah and Heinrichs, 1980). Nutritional factors such as excessive use of nitrogenous fertilizers can also contribute to resurgence. In addition to these, introduction of high yielding varieties, continuous cropping, staggered planting, and use of some insecticides are reported to cause for increased brown plant hopper populations in rice (Chelliah and Heinrichs, 1980).

For an insect population explosion to be called insecticide induced resurgence, an increase in population must follow the insecticide treatment, response of the insecticide application should be showed as an increase in abundance, and the valid resurgence can be compared only with treated and untreated populations (Hardin *et al*., 1995). This indicates, mere crop loss cannot be designated as resurgence phenomenon in the field. The general response of insects to high and low dose of insecticides differs as *lethal dose* (causing mortality) *and sub-lethal dose* (no mortality). Although growers try to apply pesticides evenly at recommended concentrations to kill target pests, many biotic and abiotic processes will spatially and temporally change the dose of insecticide to which an insect is exposed in the field (Cutler and Guedes, 2017).

Lethal dose/Higher dose of insecticide application in the field: Lethal dose always keeps the susceptible population a level lower than the economic threshold level. Spraying insecticides more than the recommended dose can cause deleterious effects to not only the environment but also to the natural enemies and many non-target organisms. Resurgence increases as the frequency of insecticidal spray increases because insecticides eliminates the natural enemy population and may reduce the chances of predation and parasitization and thus providing a safer place for pests to feed and multiply, resulting in population abundance of pests.

Sub-lethal doses of insecticides: Sub lethal dose of insecticides will not cause mortality to a desirable level in field populations. Sub-lethal dose is categorized into two classes, *viz*. deleterious and hormetic. Deleterious sub-lethal effects cause a reduction in reproduction and longevity, poor behavior of the insect species, whereas hormetic response causes stimulatory effects on pest species including reproduction, longevity, and enhanced behavior. In short, the same chemical which is lethal at high doses can bring in certain biological processes of the same insect species at sub-lethal levels (Guedes and Cutler, 2014). This biphasic dose-response characterized by high-dose inhibition and low-dose stimulation during or following exposure to a toxicant is termed hormesis. Hormesis is defined *as a dose–response relationship characterized by a reversal in response between low and high doses of a stressor, thus characterizing a biphasic relationship.* The stressors can be of different kinds *viz*., pesticides, temperature, ionising radiation, heavy metals, calorific restrictions, exercise, *etc*. and are known as hormetic agents.

Yet another term, 'hormoligosis', coined by Thomas D Luckey in 1968, more accurately pointed towards a phenomenon known as insecticide hormoligosis. The term hormoligosis has derived from two Greek words, *hormo* (= to excite) and *oligo* (= small quantities) and defined it as a *phenomenon in* *which sub-harmful quantities of many stress agents may be helpful when presented to organisms in suboptimal environments* (Luckey, 1968). Insecticide hormoligosis is basically a special case of hormesis in which a biphasic dose–response for an insecticidal compound is observed when the organism is already under stress due to another environmental factor or agent (Guedes and Cutler, 2014).

Insecticide induced hormesis in insect pests

One of the earliest studies reported the increased fecundity of females of bean aphid (*Aphis rumicis)* treated with low concentrations of rotenone, while high concentrations were lethal (Sun 1945). The fruit fly (*Drosophila melanogaster*), house fly (*Musca domestica*), granary weevil (*Sitophilus granaries*) and house cricket (*Acheta domesticus)* were early subjects of study, particularly with exposure to sublethal doses of organochlorine insecticides. Insecticide-induced population stimulation in mites has been observed since the 1970s and has sparked concerns of insecticide-induced pest outbreaks among at least two mite species: the citrus red mite (*Panonychus citri)* and the two-spotted spider mite (*Tetranychus urticae)*. Pyrethroid insecticide also reported to cause hormesis of sucking pests at sublethal doses. A list of pests reported to have evidence of insecticide induced hormesis is enclosed in Table 1.

Resurgence through indirect effects of insecticides

The use of insecticides can cause certain indirect effects that trigger the resurgence of a pest population, *viz*., natural enemy destruction, biochemical changes in host plants, physiological and biological changes in insect pests, and insecticide resistance.

Natural Enemy Destruction: In nature, natural enemies are important in regulating a pest population. It is believed that the elimination of natural enemies by insecticide applications is a strong cause for resurgence phenomenon. The toxic and non-specific insecticides are assumed to destruct natural enemies in the ecosystem, so this can be considered as a reasonable factor for insecticide induced pest resurgence. Even before the use of organic insecticides, non-selective insect control agents including sulfur and petroleum oil formulations induced resurgence. Insecticide application cause both direct and indirect effects on natural enemies. The most important direct effect is the increased mortality of the natural enemies, due to the enhanced susceptibility to insecticides than their herbivore host. This dissimilarity in susceptibility may be due to the rapid concentration of insecticides in natural enemies which feed on contaminated prey, increased exposure of the adult natural enemies to insecticide residues due to their increased mobility compared to its host, differences in detoxification enzyme levels in prey and natural enemy, and even the inability of the natural enemies to develop resistance as quickly as their host insect species (Hardin *et al*., 1995). As a result of the difference in the feeding habits of the natural enemy species, the direct toxic effect may vary between species.

Insecticides can interfere with the quality of its prey by indirectly altering the quality of the host plant, where the herbivore feed. Alternate prey of natural enemies can also be eliminated by insecticide applications. Moreover, alternate food source such as honeydew become unavailable in the absence of prey. Even though all these factors exist, natural enemy population destruction can be called responsible for resurgence when there is an increase in pest population abundance in their absence compared to the situation when they exist. However, natural enemies may not always cause mortality of its prey that is proportionate to the prey population density, and certain populations may not be regulated by natural enemies even when they are present (Hardin *et al*., 1995). So, it can be concluded that the complicated phenomenon of resurgence, may not be solely caused by the removal of natural enemies. Moreover, insecticide induced reduction in the natural enemy population can be due to the shift of the prey from density dependent to density-independent response in unsprayed and sprayed field respectively, which can even lead to the extinction of natural enemy species. Apart from these, the physiological effect of the pest and the natural enemy can also contribute to the resurgence. The higher fecundity rate of the pests helps them to escape from the suppression by natural enemies. Voltinism, dispersal ability, feeding habits, *etc*. of both the pest and natural enemy influence the recovery duration after insecticide application, thereby enhancing or reducing the chances of the pest to resurge.

Biochemical Changes in Plants: The ability of the insecticides to change the biochemical constituents of the plants is well described in the literature. These changes can in-turn alter the physiology of the pests including reproductive behavior. The quality changes in plants include enhanced plant growth, increased nutritive value, and increased attractiveness, but reduced plant defense (Heinrichs and Mochida, 1984). The literature shows that field applications of insecticides results in increase accumulation of total sugar and protein and depletes phenol content in plant species. A synthetic pyrethroid, deltamethrin was found to reduce carbohydrates to nitrogen ratio and increase the amino nitrogen content in brown planthopper susceptible varieties. The phenol content in cotton leaves, which has a major role in imparting defense against insects, was found reduced by the application of synthetic pyrethroids, cypermethrin, and deltamethrin which can be assumed as a primary factor for whitefly and aphid resurgence.

Physiological and Behavioural Changes Caused Due to Insecticides: Insecticides can cause alterations in the physiology and behavior of target pests. Increased longevity and fecundity of females, decreased mortality of progeny are some physiological effects due to insecticides. A high female to male ratio of progenies is observed in some mite species when the adult or nymph gets exposed to sub-lethal doses of insecticides which in-turn help in population builds up in the next generation. Direct application of deltamethrin, methyl parathion, and diazinon to the brown planthopper cause enhanced fecundity in females irrespective of any host plant effects. In addition to direct application, contact with treated surfaces can also act as a basis for change in fecundity. Hyper-excitability of male insects in response to pheromones due to the exposure of sub-lethal dose of insecticides is the behavioral change which in-turn affects the more rapid location of calling females. This cannot be considered as common behaviour, still, it has been reported in some major insect pests such as *Pectinophora gossipiella* and *Trichoplusia ni.* Indirect stimulation of fecundity can also occur due to enhanced nutritional contents of the host plant. However, this insecticide induced behavioral changes will not always be responsible for resurgence

Destruction of Non-Target Species: Insecticide may also kill other non-target phytophagous pests that share the same habitat/niche with the target pests. The reduction in competition for resources could be a reason to facilitate resurgence of a pest population. In the absence of competition, in favourable environmental conditions, pest species may reach maximum reproductive potential, which enables the population to rebound to a level higher than that of spraying (Hardin *et al*., 1995).

Insecticide Resistance Development: It is the need of the hour to think about the development of resistance and resurgence together and in the same direction. Even though there is no direct relationship between resistance and resurgence, it can be mentioned that there is a probability that resistance can enhance the resurgence of a population. Nevertheless, for comparing both, an assumption that, when both susceptible and resistant populations receive the same dose of an insecticide, a higher number of survival will be in a resistant population, can be made. If the insecticide can impart any of the above-said characteristics on the pest or the host plant, there is a chance that resurgence happens only in resistant population, not in susceptible one (Hardin *et al*., 1995). Mironidis *et al*. (2012) reported that the resurgence of *Helicoverpa armigera* in cotton is closely associated with the resistance of the pest to the insecticides, chlorpyriphos, and alpha cypermethrin. It can be concluded that although resistance is not required for resurgence to occur, resistance may enhance resurgence (Hardin et al., 1995).

Conclusion

The persistence of resurgence in agriculture over the years is an indication that we need to deal with it more cautiously. It is not an evolutionary process happening naturally in the biosphere and hence can be maneuvered by meticulous scientific research efforts. For successful resurgence management, it is crucial to recognize it as an ecological phenomenon, occurring as a result of insecticide application, coupled with many other biotic and abiotic factors.

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Table 1. Evidence of insecticide induced hormesis in insect pests

Year	Pest class	Common Name	Insecticide	Author
1	*Aphis rumicis* Linnaeus	Bean aphid, Aphididae; Homoptera	Rotenone	Sun (1945)
2	*Drosophila melanogaster* Meigen	Fruit fly, Drosophilidae; Diptera	Dieldrin	Knutson (1955)
3	*Sitophilus granaries* (Linnaeus)	Stored product weevil, Curculionidae; Coleoptera	DDT	Keunen (1958)
4	*Acheta domesticus* (Linnaeus)	House cricket, Gryllidae; Orthoptera	12 Different insecticides	Lucky (1968)
5	*Spodoptera littoralis* (Boisduval)	Egyptian cotton leafworm, Noctuidae; Lepidoptera	Carbaryl, Methyl Parathion, Deltamethrin	Esaac *et al.* (1972)
6	*Nilaparvata lugens Stal.*	Brown planthopper, Delphacidae; Homoptera	Decamethrin, Methyl parathion	Chielliah *et al.* (1980) Chelliah and Heinrichs (1980)
7	*Choristoneura fumiferana (Clemens)*	Spruce budworm, Tortricidae; Lepidoptera	Fenitrothion, Phosphamidon	Smirnoff (1983)
8	*Myzus persicae* (Sulzer)	Green peach aphid, Aphididae; Homoptera	Azinphosmethyl	Gordon and McEwen (1984)
9	*Tribolium castaneum* (Herbst)	Red flour beetle, Tenebrionidae; Coleoptera	Azadirachtin	Ramachandran *et al*. (1988)
10	*Scirtothrips citri* (Moulton)	Citrus thrips, Thripidae; Thysanoptera	Malathion	Morse and Zareh (1991)
11	*Zabrotes subfasciatus* (Boheman)	Mexican bean weevil, Chrysomelidae; Coleoptera	*Tetradenia riparia* Extract	Weaver *et al.* (1992)
12	*Plutella xylostella* (Linnaeus)	Diamondback moth, Plutellidae; Lepidoptera	Methomyl	Nemoto (1993)
13	*Dysdercus koenigii* (Fabricius)	Red cotton bug, Pyrrhocoridae; Heteroptera	Eucalyptus Oil Volatiles	Srivastava *et al*. (1995)
14	*Blaberus craniifer (*Burmeister)	Death's head cockroach, Blaberidae; Blattaria	Charybdotoxin	Goudey-Perribre *et al*. (1997)
15	*Plutella xylostella* (Linnaeus)	Diamondback moth, Plutellidae; Lepidoptera	Fenvalerate, Methomyl	Sota *et al.* (1998)
16	*Cydia pomonella* (Linnaeus)	Codling moth, Tortricidae; Lepidoptera	Azinphos-Methyl	Abivardi *et al.* (1998)
17	*Myzus persicae* (Sulzer)	Green peach aphid, Aphididae; Homoptera	Bifenthrin	Kerns and Stewart (2000)
18	*Plutella xylostella* (Linnaeus)	Diamondback moth, Plutellidae; Lepidoptera	Fenvalerate	Fujiwara *et al*. (2002)

19	*Bemisia tabaci* (Gennadius)	Whitefly, Aleyrodidae; Homoptera	Fenvalerate, Acephate	Abdullah and Joginder (2004)
20	*Plutella xylostella* (Linnaeus)	Diamondback moth, Plutellidae; Lepidoptera	Spinosad	Yin *et al.* (2009)
21	*Sitophilus zeamais* Motchulsky	Maize weevil, Curculionidae; Coleoptera	Deltamethrin	Guedes *et al*. (2010)
22	*Ceratitis capitate* (Wiedemann)	Mediterranean fruit fly, Tephritidae; Diptera	*Metarhizium anisopliae* Crude Extract	Ortiz-Urquiza *et al*. (2010)
23	*Plutella xylostella* (Linnaeus)	Diamondback moth, Plutellidae; Lepidoptera	Hexaflumuron	Mahmoudvand *et al.* (2011)
24	*Agrotis ipsilon* (Hufnagel)	Black cutworm, Noctuidae; Lepidoptera	Clothianidin	Kullik *et al*. (2011)
25	*Oligonychus ilicis* (McGregor)	Southern red mite, Tetranychidae; Acarina	Deltamethrin	Cordeiro *et al*. (2013)
26	*Zabrotes subfasciatus* (Boheman)	Mexican bean weevil, Curculionidae; Coleoptera	Azadirachtin	Mallqui *et al*. (2014)
27	*Myzu spersicae* (Sulzer)	Green peach aphid, Aphididae; Homoptera	Sulfoxaflor	Tang *et al*. (2015)
28	*Plutella xylostella* (Linnaeus)	Diamondback moth, Plutellidae; Lepidoptera	Chlorpyrifos	Deng *et al*. (2016)
29	*Tetranychus turkestani* (Ugarov&Nikolskii)	Strawberry spider mite, Tetranychidae; Acarina	Biomite®	Mohammadi *et al.* (2016)
30	*Panonychus ulmi* (Koch)	European red mite, Tetranychidae; Acarina	Four Different insecticides	Saritas *et al*. (2016)
31	*Aphis glycines* Matsumura	Soybean aphid, Aphididae; Homoptera	Beta-cypermethrin	Qu *et al*. (2017)
32	*Mythimna separate* (Walker)	Oriental armyworm, Noctuidae; Lepidoptera	Lambda-cyhalothrin	Li *et al.* (2019)
33	*Myzus persicae* (Sulzer)	Green peach aphid, Aphididae; Homoptera	Flupyradifurone	Tang *et al.* (2019)
34	*Rhopalosiphum padi* (Linnaeus)	Wheat aphid, Aphididae; Homoptera	Dinotefuran	Deng *et al*. (2019)
35	*Phenacoccus solenopsis* (Tinsley)	Solenopsis mealybug, Pseudococcidae; Homoptera	Pyriproxyfen, Lufenuron	Idrees *et al.* (2020)
36	*Aphis gossypii* (Glover)	Cotton aphid, Aphididae; Homoptera	Thiamethoxam	Ullah *et al.* (2020)

Utilization of Edible Insects as Food in Northeast India

Loganathan R and Shravan M Haldhar

Abstract: Consumption of edible insects by human being is called as Entomophagy. Insects are traditional food in many parts of the Northeast India. In Northeast India, entomophagy was practiced on a large scale by tribal communities. Entomophagy is not only supporting the nutritional security but also protect the family livelihood of tribal communities during difficult periods of the year. So, edible insects are the good source of supplement food item that could meet the people's present and future need. In India, a total of 255 species of edible insects are recorded so far and it is mostly practiced in North Eastern State of India. Study of entomophagy in Northeast India is explored the uncharted natural resources of the region and medicinal, traditional beliefs of tribal people. This paper reviews most common edible insects consumed by peoples in Northeast India.

Key words: Entomophagy, Northeast India, Food, Edible insects, Tribal communities

Northeast India is one of the primary biodiversity hotspots in India, where a huge percentage of its flora and fauna uncharted. It comprises of seven sister states namely Arunachal Pradesh, Assam, Meghalaya, Manipur, Nagaland, Tripura and Sikkim. The Northeast India is native to many traditionally living indigenous tribes and communities who are in continual touch with nature. The use of edible insects as food is common among ethnic people of Northeast India. The food processed and prepared traditionally by its people is connected to their socio-culture life and health. In Northeast India insects have been using in varied ways such as for edible, medicinal, industrial, cultural purposes. It was observed that various insects used by tribal people as a food it plays a vital role in retaining the nutritive value of food and cause significant impact on health.

Insects are actually rendering to humans priceless services as pollinators, as predators of crop and storage pests, as source of raw materials and as food. Entomophagy is derived from Greek word "*entomon*" means Insect and "*phagein*" means to Eat. The word Entomophagy literally means consumption of insects as food by native human population (Bodenheimer, 1951). Some of the important insects consumed by tribal people include grasshoppers, beetle grubs, termites, bees, ant, wasps, cicadas and a variety of aquatic insects. But it varies with regard to local population and ethnic group (Johnson, 2010). A scientific study revealed that almost 255 insect species are used as food by different tribes of India. Among the edible species of insects, consumption of coleopteran insects was highest constituting about (34%) followed by Orthoptera (24%), Hemiptera (17%), Hymanoptera (10%), Odonata (8%), Lepidoptera (4%), Isoptera (2%) and the least was Ephemeroptera (1%) (Chakravorty et al., 2014). Edible insects are chosen by members of various tribes according to their traditional beliefs, taste, regional and seasonal availability of the insects. Depending on the species, only certain, but sometimes all, developmental stages are consumed. Preparation of the edible insects for consumption involves mainly drying, roasting and boiling. Sometimes spices are added to enhance the taste. This review focuses on Entomophagy practiced in different tribes of Northeast India.

Fig. 1. Bihu festival in Assam

Why Entomophagy?

Health

- Edible insects are healthy and nutritious
- Rich in protein, fat, vitamins and minerals.
- Insects are also used in therapeutic purposes.

Environmental

- Insects emit less greenhouse gases (GHGs) and ammonia than most livestock.
- Require small area of land for rearing and not necessarily a land-based activity.
- Insects can be fed on organic waste streams.
- Require less water for survival than conventional livestock.
- As they are cold blooded, they have high feed conversion efficiency.

Livelihoods (economic and social factors)

- Insect harvesting/ rearing is a low-tech, low-capital investment option that offers entry even to the poorest sections of society, such as women and the landless.
- Insects are easily available in the wild and can be collected directly.
- Processed insects (fried, steam, curry, chutney *etc.*) can be sold in the market as street food which directly provides income.
- Insect rearing can be low-tech or very sophisticated, depending on the level of investment.

Entomophagy Culture in Northeast India

Tribes of Arunachal Pradesh consume many number of insect species compared to other parts of the Northeast India. They mostly choose highest number of insects from the order Orthoptera. Tribe communities of Arunachal Pradesh used nearly 158 species of insects for cooking. The preference of edible insects varies depends upon the different tribe communities and regions. *Nyishi* of East Kameng and *Galo* of West tribal communities of Arunachal Pradesh consume 102 number of species of insects. *Galo* tribes use most of insects from Odonata and Orthoptera and *Nishi* tribes consume more insects from Coloeoptera and Hemiptera.

Six tribes of eastern Arunachal Pradesh namely Nocte, Wangcho, Singpho, Tangsa, Deori and Chakma using 51 insect species for edible purposes (Chakravorty et al., 2014).

In Assam (in Moridhal Panchayat of Dhemaji district), 16 terrestrial edible insect species are eaten belonging to 6 orders. These six orders include Lepidoptera (3 species), Orthoptera (5 species), Hymenoptera (5 species), Isoptera (1 species), Blattodea (1 species) and Hemiptera (only 1 species) (Dutta et al., 2016). In Morigaon district, 15 species of insects belonging to 6 orders and 14 families were consumed by the Tiwa people. Out of these, three species belong to the order Hemiptera, two species from Coleoptera, four species from Orthoptera, three species from Hymenoptera and one species each from Odonata, Lepidotera and Isoptera (Rahman et al., 2018). The Entomophagy among the *Bodos* of Udalguri district recorded from 23 species of edible insects belonging to Orders Hemiptera, Coleoptera, Hymenoptera, Orthoptera, Lepidoptera, Isoptera and Odonata were recorded. The Giant water bug (*Lethocerus indicus*) and Eri silk worm larvae (*Samia cynthia ricini*) were most preferred edible insect species in their community (Hazarika, 2018).

Fig. 2. Insects used as food A. Red ant egg, B. Silkworm larvae, C. Silkworm pupa, D. Crickets

In Manipur, 46 species of edible insects are reported. The ethnic groups of Manipur prefer to consume highest number of Hemipteran insects. Five different tribes of Manipur namely, *Meitei, Tarao, Tangkhul*, *Chothe* and *Thadou* tribes consume the highest number of insect species (28–30) as compared to other communities in Manipur. On the other hand, the Lepidopteran insects are not preferable as food by the *Meitei* community (Shantibala et al., 2012). Aquatic beetles are also popular in Manipur and other parts of Northeast India.

In Nagaland, 82 insect species belonging to 28 families and 9 orders are consumed as food by the tribal communities. The list includes 8 species of Odonata, 17 species of Orthoptera, 2 species of Mantodea, 1 species of Isoptera, 19 species of Hemiptera, 9 species of Coleoptera, 20 species of Hymenoptera, 5 species of Lepidoptera and 1 species of Diptera (Lobeno Mozhui, 2017). Edible insects considered delicacies comprise different kinds of bees, beetles, bugs, cicadas, crickets, grasshoppers, locusts, wasps and various larval forms of insects.

In Meghalaya, termites are mostly used as edible insect and to a lesser extent by the tribes of Mizoram and Tripura. Comparatively this practice is much lower among the ethnic people of other parts of Northeast India. The option of insects as food by tribes depends upon the availability of insect, palatability, nutritional value, customs and tradition.

Preparation of Insects in North East India

Edible insects are prepared in the forms of curry, roasted, fried, raw and chutney. Depending upon the type of insects and form of the consumption, these are prepared with or without other ingredients like spices and oil. Hard bodied insects are eaten in roasted or fried form whereas soft bodied insects are eaten as curry or raw. The method of preparation is mostly traditional and is handed down from generation to generation. Odonates are eaten in nymph stage only but Lepidoptera are eaten in both larval and pupal stages. In Hymenoptera insects, eggs are also eaten along with other stages (Shantibala et al., 2012).

Nutritive and Medicative Feature of Insects

‘**Medicine Is Food and Food Is Medicine’** likewise edible insects are natural inexhaustible resource of food with nutritional, economic, medicinal and ecological benefits to the rural people. Insect food have high protein content with digestibility as well as some minerals, vitamins, fats and carbohydrates make the insects as excellent food. Insects are the cheapest source of protein compared to animal meat and fish (De Foliart, 1992). The composition of unsaturated omega-3 and six fatty acids in mealworms is comparable with that in fish (higher than in cattle and pigs) and the protein, vitamin and mineral content of mealworms is similar to that in fish and meat. Insects have high feed conversion ratios (FCRs) and emit low levels of greenhouse gases. Insects can be used instead of fish meal and fish oil in animal diet. Insects are of a higher calorific value than meats, maize, soybeans, lentils, or other legumes. Recent data show that of the insects, it had 50% caloric value higher than soybeans, 87% higher than corn, 70% higher than fish, lentils and beans and 95% scored higher values than wheat and rye. Caterpillars contain proteins to the extent of 50-60g/ 100g dry weight, the palm weevil grubs contain 23-36g, Orthopterans contain 41-91g, ants contain 7-25g and termites and storage are necessary in order to avoid contamination and to ensure safety levels.

Beliefs in Ancient Food Culture

In Assam tribes of Mishings and Ahom community use red ants (*Oecophylla Smargdina*) as a food at the time of Assamese festival Bohagi Bihu in the month of April. Tribes of Mishings people believe that red ant keep the health safe from infection of disease.

The formic acid of these insects is being used in connection with scabies, malaria, tooth aches, stomach disorders and blood pressure anomalies. In Ahom Community its compulsory to eat red ants (*Myrmica rubra*) during Bohag Bihu festival (Doley and Kalita, 2012).

Some peoples of Northeast India trust to use Muga silkworm (*Antherea assama*) to cure constant itching and soreness of the throat. They also used the pupae and larvae of Eri silkworm (*Samia cynthia ricini*) for curing“Dudmur” or infection of mouth and tongue in young children.

The larvae and eggs of yellow jacket wasp (*Vespa orientalis*, *Vespa magnifica*) and the “nest” of potter wasp (*Eumenus* spp.) were used to treat stomach problems. Egg, larvae of honey bee (*Apis* spp.) and its products (honey) were used to cure whooping cough. Cockroach *(Periplaneta americana*) was consumed for the treatment of asthma problems.

Seasonal Availability of Edible Insects

Edible insects generally occur throughout the year, the availability of insects depends upon their food plants as well as by seasonal conditions. Coleopterans occurred during June to September (pre monsoon and monsoon) and then got reduced during winter and early spring. Seasonal trends were also observed in some Odonata and Orthopterans, which were most abundant in September and October (late summer). Insects belonging to the Hemiptera and Hymenoptera were found to be restricted to the period lasting from November to February (winter). Some edible insects like certain bugs and ants were found to be available (and used) throughout the year.

Conclusion

Worldwide more than 2000 insects are consumed by local people on a regular basis. Edible insects are an important component in the diet of the different tribal communities of Northeast region. It will play important role in future generations. It has more vitamins, amino acids, fat and proteins compared to other animal meat and plants. Some of edible insects are pest of agriculture and horticulture crops, entomophagy practices reduce the pest population as well as pesticide application. According to recent data, world population is increases year by year. We have to create awareness about insect food to rural people. Again, we should continue the research in other parts of Northeast India to explore the uncharted edible insect species. In future we may get some more new insects which will be used as food and also, they can be used as medicine for different diseases. Molecular work about insect nutrition and medicinal properties of insects also enhance the Entomophagy culture in future.

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Table 1. Nutritive value of different insects

Insects	Protein (g)	Fat (g)	Carbohydrate (g)	Calcium (g)	Iron (g)
Giant water beetle	19.8	8.3	2.1	43.5	13.6
Red ants	13.9	3.5	2.9	47.8	5.7
Silk worm pupa	9.6	5.6	2.3	41.7	1.8
Mealworms	20.2	12.7	N/A	13.3	N/A
Wax moths	15.5	22.1	N/A	28.3	N/A
Super worms	17.4	17.8	N/A	12.4	N/A
Fly larvae	15.5	7.8	N/A	87.4	N/A
Dung beetle	17.2	4.3	2.0	30.9	7.7
Cricket	21.3	6.01	5.1	75.8	9.5
Small grasshopper	20.6	6.1	3.9	35.2	5.0
Large grasshopper	14.3	3.3	2.2	27.5	3.0
June beetle	13.4	1.4	2.9	22.6	6.0
Caterpillars	6.7	N/A	N/A	N/A	13.1
Termites	14.2	N/A	N/A	N/A	35.5
Weevils	6.7	N/A	N/A	N/A	13.1

** N/A= Not Analyzed (Source: Srivastava et al., 2009)

Tête-à-tête with Dr. Kewal Krishan Sharma

INSPIRING LEADER AND RENOWNED LAC ENTOMOLOGIST DR. KEWAL KRISHAN SHARMA SPEAKS TO IE ASSOCIATE EDITOR MR. RAJGOPAL N. N. ABOUT HIS EVENTFUL JOURNEY OF THREE DECADES FROM SCIENTIST TO DIRECTOR OF A NATIONAL INSTITUTE.

Dr. Kewal Krishan Sharma hails from a rural background and did his schooling from a Govt. High School, Kalanwali (Sirsa, Haryana). After completion of graduation from Sirsa, he joined Kurukshetra University, Kurukshetra to pursue his post-graduation in Zoology. His fascination and interest towards insects since childhood encouraged him to choose Entomology over Fisheries in M.Sc. (Zoology) with cyto-genetics as specialization and completed Master's degree in 1983. Inspired by his father, who was a teacher by profession, he dreamt to become a teacher like him and obtained degree in education (B.Ed.) from CR College of Education, Hisar (Haryana) in 1985. During his Master's degree, their struggle to motivate the University to retain Entomology as a major paper in PG programme sustained his interest to become a researcher. That episode destined him to turn into a successful, altruistic and eminent scientist in Entomology and Director of ICAR- Indian Institute of Natural Resins and Gums (ICAR-IINRG). Dr. Sharma has contributed significantly to the field of Lac Entomology and worked for the prosperity and growth of the small farmers. Dr. Sharma started his journey at the then Indian Lac Research Institute (later rechristened as Indian Institute of Natural Resins and Gums in 2007), Ranchi as Scientist, S-1 in March 1986. Later he completed his Ph.D. in 1995 while in-service from CCS Haryana Agricultural University, Hisar and continued to work in the same Institute. Before taking charge as Director of the Institute, he spent nearly three decades in IINRG. During his last 33 years of experience in research and extension, he has published over 150 research publications with three patents filed in his name. By guiding two Ph.D. and three M.Sc. students he also proved that he is a good teacher too. The focus of his research has been on understanding lac insect and host plant interactions, development of improved lac insect breeds, new lac insect-host plant combinations, technologies of lac cultivation; he also contributed to lac insect and host-plant diversity studies, new lac insect and associated faunal studies. During his tenure as Head, Lac Production Division, Director, ICAR-IINRG and Project Coordinator, All India Network Project on Conservation of Lac Insect Genetic Resources, Dr. Sharma has the credit of developing Field Gene Banks of lac insects and host plants, which later on developed into National Lac Insect Germplasm Centre. Dr. Sharma is conferred with Fellow of Entomological Society of India, IARI, New Delhi and is serving as President of Society for Advancement of Natural Resins and Gums, IINRG, Ranchi

Rajgopal N. N. (RNN): What made you to choose Entomology as a subject of interest while pursuing Master's degree in Zoology?

Kewal Krishan Sharma (KKS): I had fascination for insects since my childhood. As I spent my formative years in a village, frequently visiting the agricultural fields was common where insects were part of life. While watching dragon flies hovering like a helicopter, dung beetle making bolls of cow dung and disappearing in sand, bees making honey from flowers, fire flies emitting light, occurrence of larvae in apparently undamaged pods, I wondered how such small creatures could be so dominating in such varied environments. This interest grew stronger with time. Consequently, I opted Entomology over fisheries and cyto-genetics as specialization during my post-graduation in Zoology. I give full credit to these tiny insects for my metamorphosis from Zoologist to Entomologist.

RNN: Who has impacted you the most in your life as an inspiring personality.

KKS: We learn something or other from each person whom we meet, especially teachers. Therefore, it is difficult to name one. The most inspiring personality is my father, who was a school teacher by profession and had significant impact on my life. He commanded huge respect not only from his students but also from their parents. He treated all his students as his own children and parents of the children also considered him as foster father of their children. I inculcated many qualities from him like – serving selflessly without expecting anything in return, putting service before self and morality above materialism, carrying out duty sincerely with dedication and treating all human beings at par. He always advocated that being 'imperfectly perfect' is always better than being 'perfectly imperfect'. Irrespective of what you are going through, you should always keep on doing what you are supposed to do.

RNN: Growing up, did you always dream to be a scientist?

KKS: Since my father was a teacher who greatly influenced and molded lives of many, I also wanted to be a teacher like him. That is why; I obtained degree in education also. Simultaneously, my interest in insects was ticking me to take research as career and explore the unexplored. There is an interesting story that happened while doing PG studies that reinforced my interest in research. During second year of PG, University administration decided to replace entomology as special paper with Limnology. It came as a bolt from blue to me and almost ruined my dream because I wanted to pursue career in entomology. It took lot of efforts to persuade the university to restore entomology as special paper. This episode changed my course of becoming a teacher to a researcher.

RNN: Why have you restricted to Lac Institution, what drives you to stay here for long time?

KKS: I had studied about beneficial insects during my PG studies and when I joined the then Indian Lac Research Institute, I found lac insect interesting to work with. Despite being a plant pest, it is an important source of livelihood for small farmers especially in rain-fed farming system. Lac producing states of our country especially Jharkhand, Chhattisgarh, Odisha *etc.* are water deficit states in terms of availability of water for irrigation, where rain-fed agriculture is the dominating source of food. The situation is exacerbated by adverse biophysical growing conditions and poor socio-economic infrastructure in many areas. Levels of productivity, particularly in rain-fed areas are low but opportunities do exist to diversify land use and raise the productivity.

Lac cultivation offers an excellent opportunity under such situation, which can be easily integrated with agriculture. Lac host plants based agro-forestry models have proven their potential in rain-fed agriculture. Likewise, late maturing varieties of pigeon-pea and bushy lac host plant, *Flemingia semialata* are proven plants for enhancing income through integration with agriculture. While surveying different parts of country for collection of lac insect and host plants during my early career, I realized the importance of lac cultivation in geographically handicapped areas and its potential application in diverse fields. I surveyed more than 100 districts of 19 states for lac insect biodiversity; established Lac Insect and Lac Host Field Gene Banks which later on developed into National Lac Insect Germplasm Centre, identified new lac insect species, developed new varieties of lac insects, introduced new concept of lac insect-host plant combinations and host plant indices for sustainable yield, initiated work on lac insect and host plant interaction towards quality lac production. Lac being an insect commodity, it is an entomologists paradise to shape and advance his / her career.

RNN: What is the most challenging thing about being a lac entomologist and how you dealt with it?

KKS: Lac insect is very fascinating as well as frustrating to work on. Since, lac insect is phyto-succivorous and sedentary in habit, it is not amenable for certain laboratory experiments. We have to work in a semi-field condition where it is difficult to manage / simulate the rearing environment. Intra-specific variations in host plants that affect quality and quantity of lac produced, identification of elite host plants and their mass multiplication, improving industrial quality of lac, nutrient management for better and sustainable yield, climate change affecting host plant as well as associated pests are some of the most challenging areas confronting a lac entomologist.

Biochemical and physiological characterization of lac host plants to explore their nutritional requirement of lac insect, habitat manipulation and biocontrol of insect pests, exploration/establishment of suitable lac insect-host plant combinations, vegetative propagation of good host plants and study of weather parameters affecting lac insect as well as associated fauna have provided meaningful insights in managing these challenges.

RNN: Tell me about your proudest achievement

KKS: Starting a journey from the lowest ladder of scientific cadre and reaching to the top of hierarchy in the same institution where I joined as a scientist gives me a lot of satisfaction. It reinforced my belief that in a fair and equitable system, attainments/ achievements are the by-product of one's sincere and untiring efforts.

"as a Director, one can always contribute to science by mentoring budding scientists, sharing experiences, designing and implementing newer ideas"

RNN: Are there any research gaps in lac, and how to narrow down them in future actions

KKS: Natural Resins and Gums (NRGs) including lac are inherently vulnerable to climatic conditions leading to fluctuations in supply and price, both of which are important for achieving a sustainable demand. All the R&D efforts will have to be made to achieve higher and sustainable productivity with optimal inputs, ensuring high quality of NRGs and development of novel and specialty applications especially in low-volume high value products; emergence of new frontier areas are likely to trigger paradigm shift in application domains. Therefore, biotechnological tools have to be used for harnessing genes for mass production of useful molecules in bio-factories. Such production systems would complement rather than replace the conventional production systems; drastic changes will have to be introduced for raising highly organized plantations with advanced parameter monitoring, automated management systems and precision farming for sustainable production. Taxonomic studies including numerical and molecular approaches, rearing of lac insect on synthetic diet under laboratory setup, identification of resin, dye and wax synthesizing genes, are some of the important areas which merit attention for future studies.

RNN: How would you like to see IINRG in future?

KKS: Being the only institute of its kind in the world, onus lies on us to develop IINRG as institution of world repute. The pace of technological strides has tremendously increased in recent decades and this trend is likely to continue during the forthcoming decades as well. The institute should in future take lead in related new areas such as biopolymers, derived especially from agro-wastes, ushering new domains of research. Newer application areas and products based on natural resins and gums have commercial advantage in terms of being eco-friendly and have immense potential.

The well-being of the rural poor depends on fostering fair and equitable access to productive resources. Therefore, proper sequencing of interventions, building up of technical and organizational capacity of local communities to internalize and sustain interventions will be required.

I would like to see IINRG emerging as global leader in research and development aspects related to NRGs.

RNN: What is the difference between being a Director and a Scientist?

KKS: I see Director as a scientist with additional responsibility of managing the administration for better science. Though lot of time is diverted towards management responsibilities as Director, one can always contribute to science by mentoring budding scientists, sharing experiences, designing and implementing newer ideas, offering new concepts and showing right direction to the colleagues.

RNN: Many a time administration job demands lot of time; how do you manage time?

KKS: It is true that under ever evolving challenges of managing administration, time is the most precious commodity. Delegating research and administrative responsibility not only provides some room but also grooms colleagues as future leaders. Moreover, if one has accepted to assume responsibilities, one should always be prepared to put in extra efforts and time.

RNN: What advice might you have for early career researchers trying to carve their own path?

KKS: My sincere advice to the young scientists would be to take research as passion and not as career. Be systematic and objective in your approach and work sincerely. The ultimate aim of science is to unravel the truth and creation of knowledge. Respect seniors in the system-learn from them at every opportunity; don't sit in cubicles, go to fields. The importance of field work will be realized once you reach mid-ladder of your career.

RNN: Your suggestions / views and opinion on "Indian Entomologist" magazine?

KKS: While going through the first issue of the 'Indian Entomologist', I found it very interesting carrying a lot of information useful for both experts as well as amateurs. As Albert Einstein once said, 'If you can't explain it to a six-year-old, you don't understand it yourself.' the magazine aptly exemplifies it. I am sure, 'Indian Entomologist' will motivate the students to pursue career in science and I hope, the combination of experienced seniors and youth in editorial team bodes well for bright future of the magazine. Bringing out special issues on insects of agricultural importance, eminent entomologists, current aspects of entomology will increase the relevance of the magazine further.

The interview is conducted by Mr. N. N. Rajgopal. He is working as Scientist at Lac Production Division, ICAR- IINRG, Ranchi. He is working in the field of Taxonomy especially Lac insects and Leafhoppers. He is also an Associate Editors of IE.

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The potential role of stingless bees in mango pollination

Gaurav Singh, James Makinson, Robert N. Spooner-Hart and James M. Cook

Stingless bees (Hymenoptera: Apidae) are eusocial bees (Michener, 2000) and closely related to honeybees, bumble bees, carpenter bees and orchid bees (Roubik, 1989). There are over 500 species of stingless bees worldwide, belonging to 36 genera, found in most tropical and subtropical parts of the world; including Africa, Australia, Southeast Asia and tropical America (Michener, 2000). Stingless bees are common flower visitors to at least 90 crop species and have been reported as effective pollinators of nine cultivated food and fruit crops, including mango (Heard, 1999). They can be one of the most common mango flower visitors (Willcox *et al.,* 2019; Anderson *et al.,* 1982) and are the only bees, other than honeybees, that can be effectively managed in hives and deployed into mango crops in tropical regions.

Mango (*Mangifera indica* L.) is one of the most widely grown and important fruit crops worldwide (FAOSTAT, 2018). A typical mango tree has hundreds of pyramidal panicles, which can grow up to 30 cm long and produce thousands of tiny flowers of about 5-10mm in diameter (Figure 1a & b). Mango has two types of flowers: male (staminate) and hermaphrodite (or perfect) flowers (Figure 1c).The flower sex ratio varies between cultivars, environmental conditions and even among trees of the same cultivar (Ramírez & Davenport, 2016). The importance of insects in mango pollination has frequently been demonstrated and a number of insects, including different species of honeybees, stingless bees and flies, frequently visit mango flowers (Ramírez & Davenport, 2016; Huda *et al.,* 2015; Dag & Gazit, 2000).

The European honeybee, *Apis mellifera* Linnaeus, is considered an effective mango pollinator in some parts of the world; however, in many countries, it often plays a negligible role in mango pollination and only visits mango flowers occasionally(Ramirez and Davenport, 2016). Native stingless bees and/or flies are reportedly more effective pollinators than honeybees in Australia (Willcox *et al.,* 2019; Anderson *et al.,* 1982), India (Reddy, 2010) and some other countries (Huda *et al.,* 2015; Sung *et al.,* 2006).

Our research at Western Sydney University focuses on investigating the pollination efficiency of stingless bees and other wild pollinators in mangoes. In 2019, we performed floral visitor surveys on plantations of cv. Kensington Pride mangoes at eight field sites in the Northern Territory (NT), Australia. Our surveys show that a stingless bee, *Tetragonul amellipes* (Friese), is the dominant flower-visiting insect, followed by a hoverfly, *Mesembrius bengalensis* (Wiedemann), and then blowflies, *Chrysomya* sp. (Singh *et al.,* 2019).

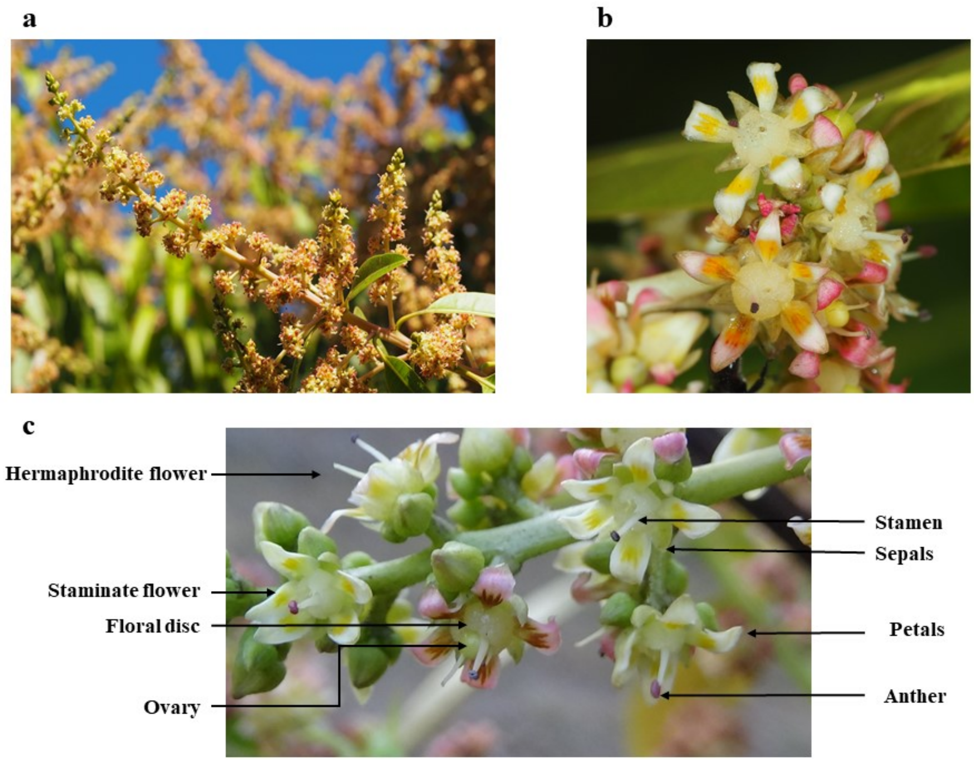

Fig. 1. Typical structure of a panicle (a) and flower (b) and, different types of flowers and floral morphology (c) of Kensington Pride mango variety (Photo: James Makinson and Gaurav Singh)

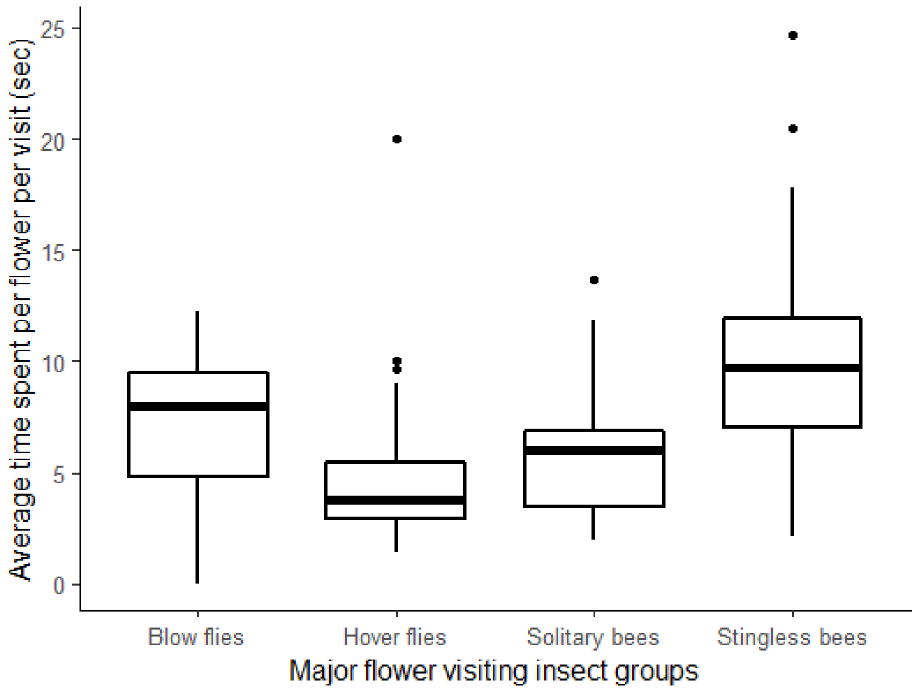

Fig. 2. Average time spent per flower by major floral visitors in mango orchards

Stingless bees actively forage for both nectar and pollen and spend more time on mango flowers than flies and honeybees (Figure 2). Owing to their small size, stingless bees fit completely in the middle of a mango flower (Figure 3) and repeatedly walk around and across the flowers with their abdomen and legs actively contacting the flower's reproductive parts. Stingless bees carry pollen grains distributed widely over their bodies and deposit more pollen grains per single visit compared to other pollinators (Willcox *et al.,* 2019; Anderson *et al.,* 1982). Surprisingly, only a few *A. mellifera* visits were recorded during our surveys at any of the eight farms in the NT, which suggests that mango flowers are not a first-choice food for honeybees.

Fig. 3. A stingless bee, *Tetragonula mellipes* on a mango flower (Photo: James Makinson)

Our observations show that stingless bees frequently visit mango flowers in the NT of Australia, but occur in low numbers towards the centre of orchard blocks of trees. Therefore, moving stingless bee hives into the mango crop is likely to increase their abundance and ability to provide pollination services across the orchards, potentially increasing the productivity of mango farms.

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AICRP on Honey Bees and Pollinators: Four Decades of its Existence

Kumaranag and Balraj Singh

All India Coordinated Research Project on Honey Bees and Pollinators was initiated based on the recommendations of National Commission on Agriculture constituted by Government of India during 1976. In recognizing the importance of the Honey bees in economic empowerment and increasing the crop productivity research project on Honey bees under the ambit of Indian Council of Agricultural Research was recommended by the commission. AICRP on Honey Bee research and Training was commissioned by the council in 1981 with its headquarters based at Central Bee Research and Training Institute, Pune. Five State Agricultural universities involved in bee keeping research at that time inducted under the coordinated research project. The AICRP on Honey Bees and Pollinators network expanded gradually over the years with addition of the new centers to cover the different agro-climatic zones of the country. Project Coordinating Unit was shifted to Chaudhary Charan Singh Haryana Agricultural University, Hisar during 1987 and subsequently to Division of Entomology, IARI during September, 2014 for better administration and coordination with ICAR Headquarters. At present, the project has 18 regular funded and 7 voluntary research centers involved in conducting region specific basic and applied research in on different aspects of bee keeping and also actively engaged in extension by organizing basic and advanced training programmes. The total sanctioned manpower of the project was 64 including 28 Scientist posts and 29 technical and administrative posts. However, the total sanctioned strength was reduced to 48 during 2018-19.

The research activities during the initial years of the project mainly focused on the documentation of the floral resources and development of the floral calendars for the expansion of migratory bee keeping. To revive the bee keeping industry *A. mellifera,* an exotic species was tested for its performance by the coordinating centers and the species was extended to suitable states/areas. Most of the honey produced now comes from this species and has given great impetus to beekeeping development in the country. The preliminary data on the pollinator diversity and quantifying the role of the pollinators in major cross-pollinated crops on priority to know about the pollination and pollinators deficiency. The toxicity of the most widely used insecticides was evaluated for calculating the loss of bee population and crop production. The observations on biological parameters of *Apis mellifera* and the optimum time for division and multiplication of *Apis cerana indica* are relevant still today. Package bee technology was developed and used widely for the introduction of *Apis mellifera* to new areas.

Most challenging phase for the project was sudden outbreak of *Thai sac brood virus* in Indian bee colonies during 1990s. Poor diagnosis and lack of validated disease control measures took a heavy toll of *Apis cerana* bee keeping in northern and southern parts of India. Almost 95 per cent of the *Apis cerana* colonies were lost within a span of two years. Bee keeping with *Apis cerana* was revived with the dedicated efforts of AICRP (HB&P) centers through adoption of dequeening and requeening technique to manage this deadly disease and selecting, multiplying as well as distributing disease resistant stocks. Preventive and curative control measures were worked out for greater wax moth, nosema, *Vorroa* and *Tropelaelaps* mites. Nationwide long-term disease survey and surveillance programmes were started for monitoring the incidence of major pests and diseases to keep a vigil on any such major outbreaks. Multiple cropping systems were evaluated for their honey production potential. Etiological factors for many the newly recorded maladies in managed bees were identified.

The volatility of honey export markets during 2000-2005 prompted for development of the technologies for the extraction and processing of products other than honey from bee hive. Efforts are made to increase the productivity of hive products through standardization of technologies for production of bee venom, propolis and royal jelly. pollen traps, propolis screen and mass queen rearing technologies were developed and tested through multi location trials under the project for their usefulness. The merit of the technologies developed by AICRP (HB&P) centers is that they are cheaper and cost effective. Potential of these technologies in diversification bee keeping enterprise is enormous. Importance of honey bees in pollination and quantification of yield increase in 38 crops has been worked out and documented, so for. Colony stocking rates for managed pollination of crops have been recommended based on scientifically validated trials for different agro-climatic zones. Pollinator diversity studies on different cropping systems provided first hand information diverse pollinator assemblage of different crops and their potential contribution in crop pollination.

Exploration and conservation of alternative pollinators *i.e.* other than true honey bees become a major research theme area of the project during 2005-2010. Project was renamed as AICRP on Honey bees and Pollinators with mandate of sustainable use pollinator resources for sustainable increase in the crop production. Many species of stingless bees, bumble bees, carpenter bees were documented from different parts of the country. Efforts have been made for domiciliation of the Non-apis bees for utilizing their pollination services. Basic studies on the nest architecture provided scientific basis for designing the artificial nesting structures. Novel techniques and methods were evaluated for the management of pests and diseases of bees. Mellisopalynological studies were carried out as supplementary evidence for seasonal major floral preferences of bees. Pollen supplements and pollen substitutes were formulated and evaluated for their acceptance and performance during the dearth periods.

Technical programme of the project during 2010-2015 was majorly emphasized on the impact of habitat on the pollinator diversity in major crops. Established model pollinator gardens for in situ conservation of pollinator species. Nesting preferences of

Apis florea and *Apis dorsata* were studied for making efforts for their conservation. Pollen dispenser, a novel technology was developed and popularized for efficient pollination of apple orchards with low pollenizer proportions. Community based approach for managed pollination in apple orchards at Kinnaur districts was great success. Project provided consultancy for Madhu Sandesh, a CSR programme by Crop Life India and KVK, Baramati for responsible use of pesticides and managed bee pollination in pomegranate and onion seed crop. This programme has received international accolades for innovative communication mode for sustainable agriculture production. Tribal sub plan training programmes of the project have raised the hopes of hundreds of tribal families through promotion of scientific bee keeping as a sustainable livelihood option.

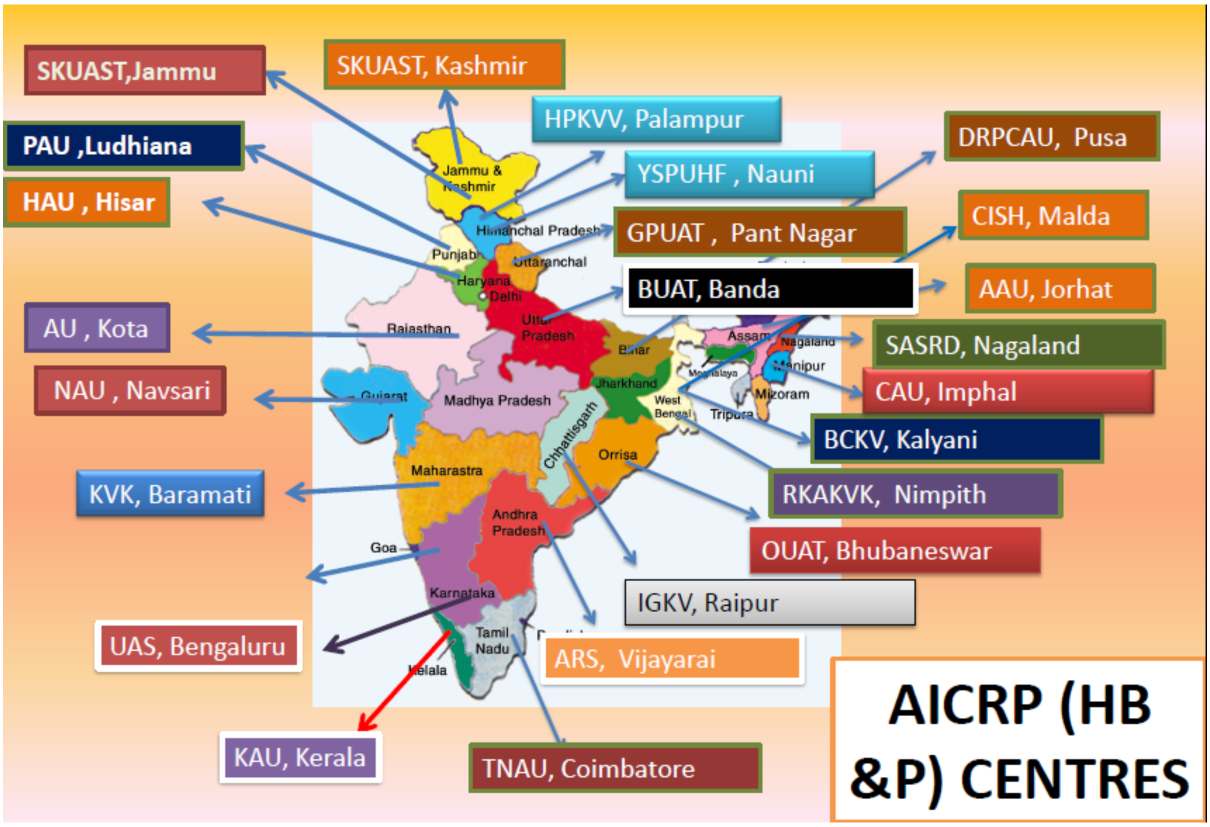

Fig. 1. Location of AICRP centers in India

The main focus of the project during 2015-2020 is on selection and multiplication of high yielding and disease resistant stocks through natural and artificial mating methods. Efforts are being made for mass multiplication of indigenous bumble bees under laboratory and their utilization in pollination of crops under protected cultivation. Similarly, stingless bees and *Xylocopa* will be evaluated for their pollination efficiency under protected cultivation. Pest and disease management employing non–chemical methods will be priority to reduce the contamination of bee products with chemical residues. Designing of new hives and evaluating in different climatic zones for colony productivity and performance. Ecological impact of insecticides and GM crops on foraging behavior of bees is being studied. Climate change simulation studies to foresee the impact of elevated temperature and carbon dioxide on the foraging efficiency and floral rewards and its impact on crop production are on the way.

Table 1. Important achievements in AICRP on Honey Bees and Pollinators

Sl No.	Year	Technology Developed/Standardized
1.	1988	Selective breeding of *Apis mellifera* and *Apis cerana* for Honey production
2.	1989	Pollen substitutes for *Apis mellifera*
3.	1994	Standardization of Royal jelly Production
4.	1995	Modified Woodframe cell locater
5.	1995	Introduction of *Apis mellifera* to Orissa, Assam and Kerala
5.	1996	Developed bee keeping calendars for the state of Himachal Pradesh, Assam, Bihar, Haryana and Orissa
6.	1996	Introduced of *Apis mellifera* to Karnataka, Andra Pradesh
7.	1996	Selective breeding of Apis cerana for Thai sac brood virus resistance
8.	2001	Standardized propolis collection method
9.	2002	Standardized technology for maintaining queen bee reservoirs
10.	2002	Standardized techniques for large scale production of Royal Jelly, Propolis and Bee venom
11	2002	Designed modified hoarding cages for toxicity studies
12.	2003	Developed ELISA Kit for detection of sac brood virus in *Apis mellifera* and Thai sac brood in *Apis cerana*
13	2003	Standardized technology for isolation of EFB pathogen
14.	2003	Characterized local isolate of *Mellisococcus plutonis*
15.	2003	Developed technology for enhanced drone brood rearing for breeding
16.	2004	Standardized technique for mass queen rearing in *Apis mellifera*
17.	2004	Developed bee package technology for establishing colonies at a new site
18.	2005	Developed domiciliation techniques for bumble bees and Xylocopa bees
19.	2005	Designed and tested mating nuclei (baby nucs) for maintaining the queen bee reserves
20.	2006	A simple and efficient pollen trap made up of Kail wood was designed and evaluated
21.	2007	Developed royal jelly extractor
22.	2008	Developed technology for delaying granulation in Brassica honey
23.	2009	Standardized cup kit method for mass queen rearing in Apis mellifera
24.	2011	Developed technology for management of absconding in Apis cerana
25.	2012	Developed light weight pollen dispensers/inserts for pollination of apple crops
26	2012	Documented diversity and biology of stingless bee species
27	2012	Developed Database on mellisopalynology of major bee source plants of Pantnagar
28	2012	Developed and evaluated greater wax moth traps

29	2013	Standardized carpenter bee rearing technique in wooden frames
30	2013	Isolation and characterization of *Nosema ceranae* infecting *Apis mellifera*
31	2014	Selective breeding of *Apis mellifera* colonies for Apple and Litchi pollen preference
32	2016	Selective breeding of *Apis mellifera* colonies through artificial insemination
33	2017	Standardized technology of mass queen rearing in *Apis cerana*
34	2018	Developed low cost domicile structures for nesting of solitary bees
35	2018	Developed value added products of honey

Since the inception of the project, one of the major emphases of the project was to spread the knowledge of scientific bee keeping across the country through basic and advanced training programmes. Landless labourers, rural youth and women were inspired to adopt bee keeping as their livelihood enterprise. Many of the trainees have become successful entrepreneurs by the constant guidance and support of the AICRP (HB&P) centers. Till today AICRP (HB&P) trains thousands of rural youth, women and farmers every year. Awareness programmes on pollinator's health and pollination management are organized to farmers and bee keepers for adaption of managed bee pollination for increasing the crop productivity. National Bee Board and Tribal Sub Plans have provided the necessary financial support for trainings. AICRP (HB&P) with its distinction of being only research network working on honey bees and pollinators after structural weakening of the Central Bee Research and Training Institute, Pune. The project from the beginning has provided yeomen services for the spread of scientific bee keeping and solving problems faced by the bee keepers through need based systematic research. However, research on honey bees and pollinators need to be scaled up further to meet the international standards to cater the anticipated challenges effectively. Hon'ble Prime Minister aspiration of doubling the farmers Income and Sweet Revolution will be reality by promoting bee keeping backed by strong research network with better institutional and infrastructural support.

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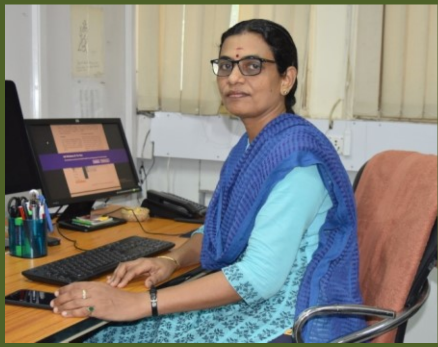
In conversation with Dr. Sengottaiyan Vennila



A torch bearer, holding everlasting credits in the field of Agricultural Entomology who believes in simplicity and creative hard work as ultimate sophistication. She has spoken to IE Associate Editor Dr. Bhagyashree about her journey in the field of Insects.

In second volume of the Indian entomologist, we are featuring amazing woman working in the field of entomology for the past three decades: Dr. Sengottaiyan Vennila, Principal Scientist, ICAR-NCIPM (National Research Center for Integrated Pest Management). She is a pioneer in Integrated Pest Management, who is very grounded, simple, inspiring, and active. However, she is a cryptic worker who performs her duty without expecting any name or fame. With this zest too she won many individual awards *viz.,* ICAR-Panjabrao Deshmukh Woman Agricultural Scientist Award-2007, Late Shri P. P. Singhal Ji Award-2015, Dr. D Bap Reddy Memorial Award-2018 for Biennium 2016-2018 and Late Dr. Sanjay Kushwaha Memorial Award-2018 in addition to part of prestigious organisation awards such as the National e-governance award in 2012 for ICT based solutions as well as the Prime Minister's award for Excellence in Public Administration during 2012–13 for Crop Pest Surveillance and Advisory Project (CROPSAP) of Maharashtra. Dr S. Vennila was born on October 14, 1964 in a small village Thoppapatty, Rasipuram Tehsil of Namakkal (erstwhile Salem) district, Tamil Nadu. Her father was a physical education teacher and mother, a housewife and farm manager. Dr. Vennila completed her primary and high school education at Government schools. She enjoyed studying and playing *kho-kho* during her school days. She fondly remembers her stay under parental care and participation in farm activities till further education took her away from home town for pursuing two years of higher secondary education at Tiruchirappalli and B.Sc (Ag) cum M. Sc (Agricultural Entomology) for six years at Coimbatore. Although she secured admission at Indian Agricultural Research Institute, New Delhi in 1988 for Ph. D, her selection for M. Phil (Applied Biology) at the University of Cambridge, England made her travel abroad. She returned the very next year to pursue her Ph. D from the University of Agricultural Sciences, Bengaluru. Merit scholarship and fellowships at college level aided in lessening the financial burden on her parents. Studies were always an easy part of her life but for the stay away from parents and siblings most of life time.

Selection in Agricultural Research Service-1990 and its acceptance in 1992 following completion of Ph. D marked the beginning of professional career. While the initial posting was at Biological Control Centre, Bengaluru (erstwhile regional station of ICAR- NCIPM, Faridabad), she got her transfer to ICAR- CICR (Central Institute for Cotton Research), Nagpur, Maharashtra in 1994 on account of common posting for couples, with her life partner an Agricultural Economist of ARS who served earlier at Trivandrum, presently working with ICAR headquarters. Dr Vennila was a cotton entomologist for over 15 years working in the areas of insect ecology and Integrated Pest Management. She joined ICAR-NCIPM, New Delhi in 2009 upon direct selection and she gratefully remembers the inspiration and support tendered by Dr O. M. Bambawale, the Director at ICAR-NCIPM who provided foundation for information and communication based pest surveillance not only for field level pest management but also for research database development under National Innovations in Climate Resilient Agriculture. She has been keen to bring out the research outputs into mobile apps for easy dissemination and use by different stakeholders of plant protection. She considers herself as a "cryptic Indian Entomologist" despite handling many national level projects and representing India on transboundary plant pests at the G20 workshop held in Japan. She has near to 150 research publications and associated with many mobile apps (hosted on *Krishi portal* of ICAR & Google Play store - the latest one on FAW_IPM). Her wish is to see more research entomologists take up projects of relevance to field problems of current importance with quality contributions benefitting farmers and the environment. Forging alliance with other disciplines of research of Central and State governmental organizations and with developmental agencies including industries with a well-knit policy for crop protection is need of the hour.

"Dynamism and team work should flourish amongst agricultural entomologists so as to effectively co-evolve with insects and other natural and manmade resources"

Dr. Bhagyashree S N (BSN): Thank you for speaking to the Indian Entomologist magazine during these tough times amidst a pandemic. I am feeling privileged to feature you in Indian Entomologist "Women in Entomology" section. What made you to pursue career in Agriculture and how did you choose Agricultural Entomology?

Dr Sengottaiyan Vennila (SV): Hailing from a farming family, even as child I had natural inclination for crops and animal husbandry. I have grown up amidst banana, cotton, cassava, castor, coconut, groundnut, rice and turmeric, mulberry, cattle, goatery and poultry. I was also too familiar with all kinds of living creatures and non-living resources of a farming ecosystem. Although I liked all the major subjects of Agriculture, I was attracted to reading books like 'The Insects: Structure and Function' by R. F. Chapman and 'Elements of Economic Entomology' by Dr B. Vasanthraj David as an under graduate. Agricultural Entomology was hence the natural choice.

BSN: How did you feel when you got first rank in ARS, which was quite uncommon during 90s for girls?

SV: It was never the goal but I did feel a sense of achievement more for my parents than for myself. I realised that sincerity and hard work are linked to success irrespective of societal patterns.

BSN: Role model/the person you admire/follow in your life as well as in profession life?

SV: My mother for her clarity, patience and dignity and my father for the unhindered freedom of speech and actions he offered. Dr. PC Sundara Babu, my mentor during post-graduation who taught the course on Biological Control, guided my research during Masters and was instrumental in my studies at Cambridge is my role model.

BSN: For women, usually career clock and biological clock go in opposite direction, how can we balance that?

SV: Although easier said than done, making prioritised choices in one's life and making adjustments in accordance with circumstances as they emerge help a lot. As women juggle many responsibilities in a day, their efficiency and ability to balance career are higher. Balancing comes with practice of thoughts and actions in tandem with enthusiasm be it at work or home.

BSN: What working women should possess to have balanced and healthy life?

SV: Realistic aspirations and ambitions are keys for a simple and balanced life. Nurturing positive qualities of being a human boost mental as well physical health. Developing interests beyond academics help calm the mind and centre the self. Allotting time for an activity of interest and passion amidst everyday routines is often refreshing. Practice inner peace- prosperity and dignity follow automatically.

BSN: What are the biggest challenges or hurdles you've come across while working on ICTs?

SV: I work in the areas of ecology and management of plant pests wherein ICT tools are integrated. I find more opportunities than the challenges of using ICT in plant protection for research, education and extension. A single national platform assimilating data and knowledge using ICT with convergence brought in from crop based organisations of ICAR, State Agricultural Universities and *Krishi Vigyan Kendras* having interface with DPPQ&S and NIPHM is essential for better execution of plant protection in the country.

BSN: How would you like to see Information Communication Technology in future?

SV: I am not an expert on the subject per *se,* so I can only speculate on the future of ICT. It is a tool that has tremendous potential and will have an impact on small scale production systems in agriculture. Shrinking family size and labour scarcity will enable a greater role for ICT in agriculture – buttons, knobs, keys, robotics, sensors, internet of things, machine learning, augmented reality, virtual reality etc., may revolutionize agricultural applications and operations. We need to develop rapid expertise with the developing technological advances of ICT to harness the benefits they can offer to agriculture, in general and plant protection, in particular. Suggestions for "ICT in Plant Protection" of the readers are welcome at: *S.Vennila@icar.gov.in*

BSN: Traits or attitude that can help women to be successful as scientist?

SV: Ability for multi-tasking, adopting issue over personal oriented approaches in problem solving and balancing our personal and professional lives are the traits essential for all professionals alike irrespective of gender.

BSN: A change you would like to see in young agricultural entomologists?

SV: The ultimate goal of the young entomologists should be active and effective in contribution to science of the subject and more importantly farmers in the field. The attitude should be to share the resources, care for the fellow workers and to develop entrepreneurial skills for the youth of our country. As students and professionals, one should be aware of the fact that the principles and framework of theory and practice of plant protection remain more or less the same, however, the dynamic system variables over time and space need adaptive policies and management put in place. Dynamism and team work should flourish amongst agricultural entomologists so as to effectively co-evolve with insects and other natural and manmade resources. "*Ecologically Adapt and Evolve to the Needs!*"

BSN: How did you feel when you got prestigious Women scientist award from ICAR very early in your career?

SV: I was exceedingly grateful to the associated scientists, field and skilled workers of the Central Institute of Cotton Research, Nagpur and the cotton farmers of neighbouring villages who were pivotal to all my experimental findings and technological outputs. Since, I could work during the eras of Non Bt and Bt cotton as well as Non IPM and IPM, my contributions to cotton entomology have been considerable and satisfying.

BSN: No doubt you are a brilliant scientist with extreme intellect, why don't you think of administration?

SV: Scientific excellence does not necessarily translate into good administrative skills. It is not an area that evinced interest in me at any point of time.

BSN: Advice to young women of Entomology fraternity?

SV: Nothing I would advice to women differently. My best wishes!

BSN: Your suggestions/views and opinion on "Indian entomologist" magazine?

SV: I am appreciative of the efforts and quality of the "Indian entomologist". "Bug studio- Indian Entomologist Photo Contest" is a personal favorite. I wish to see the magazine reach a larger entomological community as the days goes by. An additional feature announcing "Forthcoming Events" would help the students, researchers and public tune in. I am thankful for the honour of being featured in the magazine. I would like to thank Dr. V.V. Ramamurthy and his editorial team for launching the online periodical that would promote entomological science and entomologists in India. Lastly, thank you Bhagyashree for the interview that made me reminisce my childhood, college, professional days and personalities I came across.

BSN: Thank you so much for sparing your valuable time to inspire us and polishing our minds by your kind words.

Dr. S.N. Bhagyashree is working as Scientist at the Division of Entomology, ICAR- IARI, New Delhi. She is working on IPM of Vegetables and Biological control and also one of the Associate Editors of IE, managing Women In Entomology Section.

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Photo: Dr. Bhagyashree S. N. with Dr. S. Vennila during the interview.

Insect Evolutionary Traps: An Anthropogenic Decoupling of Preference and Performance

Priyankar Mondal

Insects like any other animals use environmental cues to find suitable resources and execute behaviours which can increase their fitness (Robertson *et al.,* 2013). This kind of cue-response system (*e.g.* response to the smell of food by attacking, response to the sight of mate by copulating *etc.*) becomes adaptive over generations but the problem arises when human-induced rapid environmental changes (HIREC) alter these environmental cues in such a way that the previously adaptive behaviour becomes associated with novel habitats that are dangerous or novel resources that can drastically reduce the fitness creating an 'evolutionary trap' (Robertson and Hutto, 2006 and Greggor *et al.,* 2019). These kinds of behavioural maladaptation in the context of habitat selection, foraging, navigation, oviposition and mate selection act as attractive population sinks which not only drive the animals away from positive-fitness resources but rapidly reduce their numbers, even, threatening the species persistence (Fletcher *et al*., 2012 and Robertson *et al*., 2017). In this mini-review, we will first discuss few notable examples of evolutionary traps related to insects, then try to understand the ecological and evolutionary principles underlying this phenomenon and close with a short note on its implication and future areas of research.

Beer is one of the popular beverages among Australians but back in the '80s, they were quite careless in dumping their 'stubbies' – an Australian nickname for beer bottles. People often used to casually throw them out of the car's window and filled the roadsides of Western Australia. These fellows never realized that a group of six-legged males can make use of those stubbies to satisfy their 'forbidden lust'. *Julodimorpha bakewelli* (Buprestidae: Coleoptera) is a jewel beetle inhabiting the arid regions of Australia. The females of this beetle are larger than the males and dimples on their shiny brown elytra serve as a cue for a potential mate to the males. During the mating seasons (August-September) in the '80s, the light reflected from dimpled glass rims at the bottom of the brown stubbies started attracting the male beetles (Gwyne and Rentz, 1983). To the male *J. bakewelli*, a beer bottle lying on the ground looks like a big, sexy and irresistible female. A male immediately mounts the bottle (Fig.1a), tries to insert his penis and during this hardcore sex, he either dies because of scorching sun and mating injuries or gets consumed by the local ants. The males busy with their beer bottles not only ignored the females but experienced reduced survival over the years pushing the species to the verge of extinction. This apparently funny but ecologically depressing incident forced the beer companies to change the shape of their bottles.

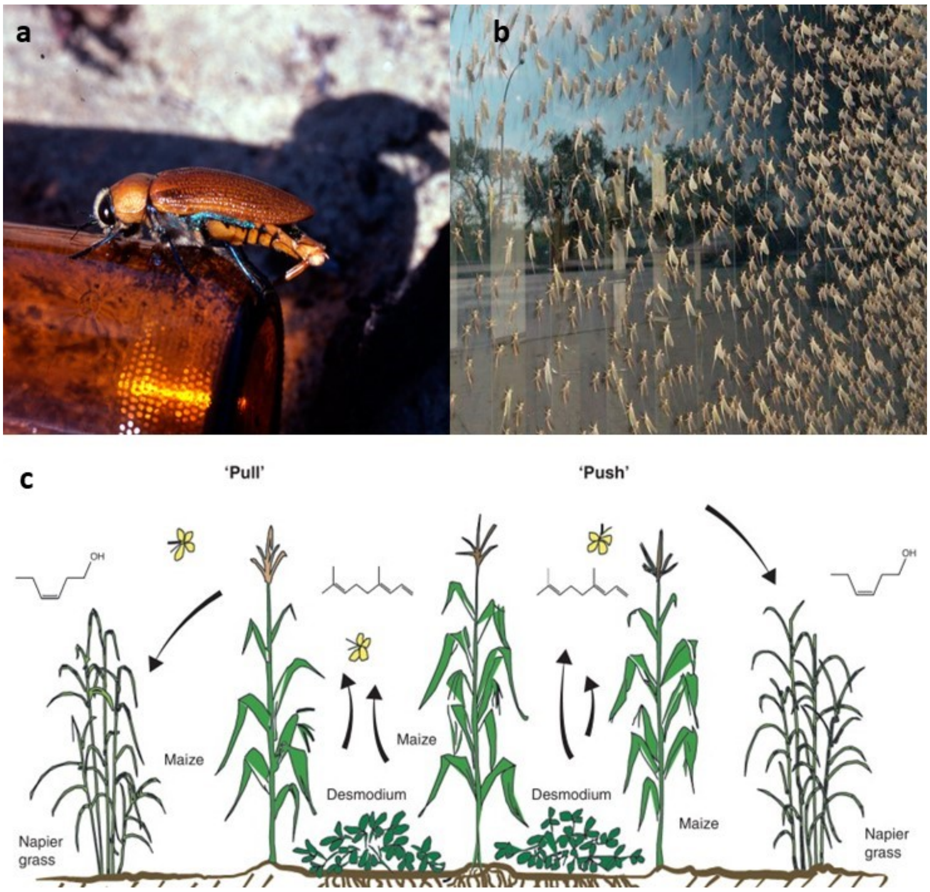

Fig. 1. Example of few evolutionary traps triggering maladaptive behaviour in insects. a) Male *Julodiomorpha bakewelli* mounting a beer bottle(©Darryl Gwynne), b) a group of mayflies attracted to polarized light from a glass window pane(©Will Milne), (Both adapted from Robertson *et al*., 2013) c) push-pull farming involving Napier grass as trap crop to attract the maize borers (modified from Pickett *et al*., 2014).

The search for effective utilization of non-conventional sources of energy has led mankind to invent photovoltaic solar panels with the aim of reducing environmental pollution and boosting ecological sustainability. Surprisingly, the solar panels have been identified as a strong source of polarized light pollution attracting water-seeking (semi)aquatic insects (Horvath *et al*., 2010). Especially the (most widely used) dark coloured solar panels which horizontally polarize the reflected sunlight (90-100% compared to 30-80% from natural water bodies) mimicking the cue a lot of aquatic insects rely upon to identify water bodies suitable for mating or oviposition. In addition to solar panels, other man-made dark coloured objects like glass buildings, and asphalt roads equally influence the decision making of these insects (Fig. 1b) (Kriska *et al*., 1998 and 2008). These supernormally polarized light sources have become preferentially attractive for the aquatic insects and as a result, the adults fail to find a mate and the eggs fail to hatch ultimately bringing their population down (Robertson and Chalfoun, 2016). Aquatic insects have an innate preference for surface areas with increasingly higher percentages of polarized light which eventually make them susceptible to fall prey to such rapid anthropogenic changes (Robertson *et al*., 2019). Recently, a field experiment with adult water-seeking insects across four taxonomic groups *viz*., Chironomidae (10,102), Simuliidae (556), Trichoptera (181) and Ephemeroptera (147) has shown more than 40% adjusted capture for the first three groups and nearly 30% of the same for Ephemeroptera on entirely black solar panels compared to the manipulated panels with different width and density of white gridding where the adjusted capture was reduced to nearly 95% (Black and Robertson, 2020). Of course, the result highlights the severity of such 'solar traps' but it also suggests a way to mitigate the challenge by modest reduction of photoactive area (2-3%) of the panels. Besides aquatic insects, light pollution by artificial city lights has immensely contributed to a rapid decline of nocturnal insects (including pollinators and predators of pests) by impairing their navigation abilities, ocular sensitivity, host-seeking and ovipositional behaviour, pupation and diapause (Owens and Lewis, 2018).

In the earlier examples, the evolutionary traps were created unintentionally, yet drastically affected the species performance creating a higher preference towards negative fitness resources, but such traps can also be set intentionally to manage pestiferous and invasive species. Professor Zeyaur Khan, an IARI graduate and Indo-African scientist, has spent decades for the development of 'push-pull farming' targeting insect's olfactory behaviour of host selection. Thousands of farmers in East Africa have adopted this strategy to protect their maize and sorghum from borer pests (*Chilo partellus*, *Busseola fusca*, *Sesamia calamistis* and *Eladna saccharina*). Molasses grass (*Melinis minutiflora*) and desmodium (*Desmodium uncinatum* and *D. intortum*), when intercropped with maize or sorghum, repel the stem borers and additionally volatiles from molasses increase parasitism by *Cotesia sesamiae*. On the other hand, volatiles from the so-called 'trap crop' of Napier and Sudan grass (*Pennisetum purpureum* and *Sorghum vulgare sudanense*) surrounding the main crop field not only attract the stem borers for oviposition but restricts the larval development with physiological impairments and recruitment of natural enemies (Fig. 1c) (Khan *et al.,* 1997 and 2006). This approach of utilizing an evolutionary trap contributed to increased crop yields, livestock production, enhanced food security and ecological sustainability (Khan and Pickett, 2004 and Robertson *et al.,* 2017). The same principles are now widely used to control *Helicoverpa* in Cotton, Colorado beetle in potatoes, maggots in onion, thrips in chrysanthemum, bark beetles in conifers and different pests of medical and veterinary importance (Cook *et al.,* 2007). In addition to planting crops emitting volatiles attractive to pests, several other traps targeting the insects' visual and olfactory responses such as light trap, yellow sticky plates and pheromone lures have been recommended as an integral part of conservation agricultural practices. The innate phototactic behaviour of many nocturnal insects has provided the basis of designing insecticide based light traps and electric insect killers. Equipped with fluorescent electric tubes the electric insect killers have been widely used for managing household and glasshouse pests such as mosquitoes, moths and beetles. Insecticide based light traps with blue fluorescent light were widely used to control rice borers *Tryporyza incertulus* and *Chilo suppressalis* in Japan during World war-II and afterwards (Ishikura, 1950). Yellow sticky plates and roles have become popular tools to attract and trap a lot of diurnal insects possessing an innate attraction for yellow colours such as planthoppers, leafhoppers, aphids, whiteflies, thrips and leafminers (Shimoda *et al.,* 2013). The pheromone lures, on the other hand, are designed to manipulate the olfactory behaviour of insects. Semiochemicals released from either of the sexes inducing aggregation, foraging or mate searching responses have been synthesized in-vitro and implemented in crop fields, orchards and vineyards for pest monitoring, mating disruption and mass trapping purposes. Pheromone dispensers releasing synthetic sex pheromone plumes at a fixed rate confuse the males and reduce the frequency with which they encounter calling females and thus disrupt the mating and reproduction. The technique has been successfully implemented against bollworms, fruit sucking moths, stem borers, gypsy moths, oriental beetles *etc* (Tewari *et al.,* 2014). Mass trapping involves the use of attractive semiochemicals to lure the pest population towards killing devices such as small amount of insecticides, adhesives, water or other physical killing agents. This strategy gained huge success inmanaging bollworms, tephritid fruitflies, boll weevil, codling moth, bark beetles and palm weevils (El-Sayed *et al.,* 2009 and Tewari *et al.,* 2014).

From the examples cited above, it is quite clear that the 'insect evolutionary trap' occurs when human activity creates or manipulates the environment in such a way that an insect's adaptive strategies no longer correlate with increased fitness and as a result, it prefers to choose dangerous resources or behaviours despite having better options (Robertson and Chalfoun, 2016). In case of any organism, including insects, natural selection should align the relative preference for a resource (*e.g.* mate, food item, territory) with its fitness value such that resources which provide better fitness rewards are preferred over those with a lower fitness value. But human-induced rapid environmental change may decouple this preference-performance correlation such that organisms preferentially exploit negative fitness resources (evolutionary traps) or avoid high-quality resources, which would otherwise increase its fitness (undervalued resources) (Fig. 2) (Robertson *et al.*, 2017).

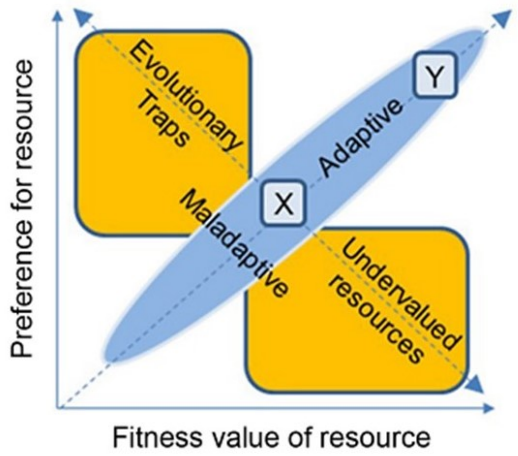

Fig. 2. A conceptual diagram showing the relationship between preference for resources with fitness value associated with the resources. Blue ovoid region indicates the effect of natural selection and yellow rectangles represent trajectories under human induced environmental changes (Adapted from Robertson *et al.,* 2017).

A deep understanding of sensory, cognitive and behavioural mechanisms of a species is necessary to discern its susceptibility towards a trap. Animals often need to generalize cues from experiences as familiar cues also vary in time and space. It is a pitfall where novel environmental changes may also be perceived under the generalized cue. This is the reason why the male *Julodiomorpha* beetles fell for the stubbies. The degree of difference between a familiar and a novel cue determines whether an insect should behave adaptively or it requires further presentation of cues to learn and act accordingly (Ferrari *et al.,* 2007, 2016). Individuals within and between populations differ greatly in their behavioural tendencies (Sih *et al.,* 2004). The bolder individuals are more likely to explore novel cues compared to the shy ones. In that case aggressive, bolder individuals will be easily attracted towards post-HIREC novel dangers and succumb to such evolutionary traps. In this way, even if some traps cannot cause an abrupt decline in species or population, they may exert strong selection pressure depending on personality phenotypes (Madden and Whiteside, 2014). The success of an evolutionary trap also depends on whether it is a single opportunity or a multiple opportunity trap. In case of a single opportunity trap (like toxic food or oviposition site), the outcome of an error is fatal leaving no place for learning but a multiple opportunity trap (such as unpleasant but not fatal gustatory response) can offer scope for learning and avoiding the danger (Greggor *et al*., 2019)

A comprehensive understanding of insect evolutionary traps is necessary both for the conservation of endangered insects and controlling pestiferous and invasive species. The biological principles that cause the decline of nocturnal pollinators by night light pollution are the same to be used for light trapping of nocturnal pests, the quantity and quality of stimulus being the difference. From the conservation point of view, an evolutionary trap can be disarmed by reducing the attractiveness of a trap; increasing its fitness values; or both (Robertson *et al*., 2013). Assessing an anthropogenic novel change as a potential evolutionary trap is of first and foremost importance which require overall consideration of key components of an ecosystem and their interactions. Cautious ecological restoration by increasing habitat connectivity between positive-fitness patches can increase the habitat availability for mobile species making them less vulnerable to succumb to patches with negative fitness value. From the pest management point of view, the efficacy of an evolutionary trap depends on its attractiveness. In simple words, to trap a pest, a negative fitness resource must be (made) attractive over other options available to the pest. Farmers and folks have been using different kinds of evolutionary traps to deter or kill agricultural, livestock and household pests since ages even before the term was scientifically defined. The major risk associated with exploiting an evolutionary trap is its direct and indirect effect on non-target organisms (Robertson *et al*., 2017). However, the framework of an evolutionary trap has a great potential for large scale population control and eradication by making it more taxon-specific, and resistant to escape based on physiological, ecological and evolutionary responses. Multidisciplinary research oriented towards behavioural biology, sensitive and cognitive ecology, the molecular and physiological basis of phenotypic plasticity may yield deeper insights about how well an evolutionary trap can be utilized for pest management or disarmed for the conservation of biodiversity.

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Role of Insects and other Animals in Prediction of Natural Calamities

Kariyanna, B.

Abstract: Insects and other animals have strong receptors to detect the changes in the surrounding environment. They have the special sense organs compared to higher animals to perceive the change in the earth magnetic field and infrasound (<20 Hz) which are faster than the ultrasounds (>20 Hz). The natural calamities *viz*., earthquake, volcanic eruption, tornado, tsunami and avalanches produce the pneuma gasses and infrasound by series of mechanisms and these can be detected by insects and animals with their special receptors to evade. Various reports and eye witnesses data from different parts of the globe says that, unusual behaviour of insects and other animals before the calamities are the first sign of sensing the natural disaster compared to humans. The current article is an endeavour to explain, how insects and animals escape from the natural calamities by adopting different mechanisms with supporting examples. Also, it will promote the researcher to work in line with insects and animal prediction mechanisms against natural calamities in further details.

Key words: Insects, other animals, natural calamities, predictions

The natural phenomenons like earthquake, tsunami, cyclone, forest fire and volcanic eruption are the major calamities which could destroy the ecosystem and economy around the globe. The sign of these disasters would be very difficult to recognise by humans until it hit the earth surface. But there were many studies to tell about the insects and animal activity before the calamity happens. Many attempts were done to use insects as well as wild and domestic animal behaviour to study the earthquake and other disasters across the world (Geller, 1997; Kirschvink, 2000; Kelley and Price, 2017; Kelley et al., 2017). The important observations were recorded on elephants, pet animals and ants, but no consistent data is available to use in forecasting such disasters (Quammen, 1985; Schaal, 1988). Many studies indicated that, the insects can able to sense the earthquake by change in the magnetic field and carbon dioxide concentration in the atmosphere (Oskin, 2013; Martins, 2016; Pereira et al., 2019). For example, the red ants and other insects have chemoreceptors for carbon dioxide gradients and mechanoreceptors for change in the magnetic field (Oskin, 2013). Similarly, animals will use sound signals for predicting disasters especially earthquakes. In general, insects and bats use ultra-sound (20-200 kHz) for navigation and predation (Pollack and Imaizumi, 1999; Fenton and Simmons, 2014; Garstang and Kelley, 2017). Similarly, humans have a tendency to hear sound frequencies more than 20Hz (e.g, piano sound ~27.5 Hz), with the help of the mechanoreceptors present in the skin (Jackson, 2004; Bailey, 2019; Williams, 2020). But animals like elephants, dogs, hippos, rhinos, felines, whales, and many birds depend on infrasonic sounds for communication and navigation because these waves have the frequency of 20 Hz or lower (e.g, Rayleigh waves) (Bailey, 2019; George, 2020; Williams, 2020). For example, giant animals, such as elephants, use infrasound (<20 Hz) for communication to long-distance, which would help in evasion from predator and reproduction (Garstang, 2009; Garstang, 2015). Interestingly, infrasonic sounds and altered magnetic field with modified atmospheric (pneuma) gasses are also caused by extremely energetic events such as earthquakes, tsunami, volcanic eruptions, lightning, meteors, avalanches and iceberg shedding (Jackson, 2004; Martins, 2016; Garstang and Kelley, 2017; Bailey, 2019).

Kelley and Garstang (2013) documented that most of the animals (elephants, dogs and donkeys) could detect thunderstorms hit prior to witness human. A report stated that the elephant detected infrasound 1000 km away from the epicentre where the tsunami breaking at Sumatra seashores (Garstang, 2009). Similarly, insects can detect these disasters by their specialised sensory modification viz., proprioceptors, chemoreceptors and mechanoreceptors by observing the change in the magnetic field and atmospheric gasses (Kirschvink, 2000; Oskin, 2013; Bailey, 2019) and to sense the rainfall and cyclones occurrence based on altered humidity and temperature, insects and spiders have specialised hair-like structure called hygro-sensitive sensilla (Sayeed and Benzer, 1996; Tichy and Loftus, 1996). So, forecasting the disaster by studying the behaviour of these creatures will help to save the lives of animals and human across the globe. Hence, in the present article, I threw light on the importance of insect and animal behaviours and their actions in disaster predictions.

Important theories on disaster prediction mechanism by animals

Prime theories are classified based on the animal and insects prediction to the earthquake by two mechanisms *viz.,* by sensing earth vibration and another by identifying variations in the air or gases (pneuma gas) in the atmosphere produced from the earth (Geller, 1997; Tributsch, 2013; Bailey, 2019; George, 2020). A quantum geophysicist, Motoji Ikeya explained that the variation in electromagnetic filed can also influence most of the animals to detects disasters, especially in more sensitive creature- catfish (Kelley and Garstang, 2013; Garstang and Kelley, 2017). But the exact mechanism involved in sensing earthquake by insect and animals, with the supportive publications is still in an infant stage.

Another important mechanism to detect the calamities is by P wave or compressional wave, these are the wave produced from the seismic body which shakes the ground backward and forward in direction of the wave movement (same and opposite) and easily perceives by most of the animals than human. P waves are not-audible and can travel ten times faster than normal sound waves. Another one is, S waves or shear waves also shakes the earth crust back and forth but perpendicular to the waves moving direction and can easily sensed by humans (Schaal 1988; Kirschvink, 2000; Williams, 2020).

The activity of earth vibration (seismic) produces stress from the surface of the ground into the atmosphere in the form of energy elements (aerosols that generate heat) and those elements will form into ions that trigger the serotonin production in animals, which are detected by rodents and other pet animals (Tributsch, 1982; Geller, 1997; Williams, 2020). Red ants, rodents and other pet animals can also able to sense the changes in the level of carbon dioxide and magnetic field, but the exact mechanism involved in the detection is unclear (Oskin, 2013; Williams, 2020; George, 2020).

Instances of behavioural alteration by various creature based on the eyewitness

Most of the data collected by the researcher were based on unusual behaviour (restlessness and disorientation) made by various creatures before happening of disaster. So, many examples are based on mere observation rather than the experimental results from the calamity areas.

- **Ants,** in usual days, were inside the mounds at night, but before the earthquake of > 2.0 magnitude, they moved outside the nest. Similarly, they construct the mounds around the entry point to protect against heavy rain and they are highly active before the downpour (Oskin, 2013; Kampwirth, 2013; Williams, 2020). As per the United states global survey (USGS) report, some small creatures such as ants, centipedes, squirrels, snakes, rats and soil dwellers leave their nest to find a safe location and many insects were aggregate in massive swarms at the seashores prior to an earthquake (Quammen, 1985; USGS, 2020; Williams, 2020). In China at Qian'an and Ninghe districts huge swarm of dragon flies were reported before the 1976 Tangshan earthquake of 7.8 magnitude (Mei et al., 1982). At the same time, people's commune Miaolingtou and Qianxi districts almost 30 and 100 beehives banished their bees before the Tangshan quake. In the vicinity of harbour town Tingbo, big vehicle and huge oil tanker were completely covered by insects swarms viz., butterflies, grasshoppers, dragon flies, crickets and cicadas (Mei et al., 1982; Tributsch, 2013). In supporting that the cicadas stopped their monotonous noise before the heavy rainfall (Rogers, 2015).

- Bees are seen aggressive and restlessness before thunderstorm approach, similarly tropical leafcutter ants and bees were rushing back into the hive before an imminent rainstorm (Rogers, 2015). The butterflies need solar radiation for their flight; if they found overcast sky then they tend to settle in shelters (Rogers, 2015), that avoid them wet from the raindrops and escape from the predator because cool weather prior to rain will reduce their flight efficiency (Raupp, 2016). The aggregation of ladybird beetle is the primary indication of forthcoming hot weather and that help to safeguard the moisture (Viegas, 2014). The beetles, *Melanophila* detect the forest fire before it approach, maybe due to the initial heat produce in the forest (Zivkovic, 2011), by using their specialised organs called as infrared (IR) receptors, which are developed from hair mechanoreceptors on the cuticle (Klocke et al., 2011; Bousack et al., 2015).

- In South-Andaman, India, fishermen stated that, if the earthworms plenty outside, termites making holes in wet soils, snails climbing trees, increased activities of insects and moving ants to the safer location are the indication of cyclone approach (Sethi *et al.,* 2011). Before the Boxing day tsunami during 2004, the flamingos were flee away from the Indian wildlife sanctuary (Martins, 2016)

- In Italy at L'Aquila toads deserted their mating site before the strike of an earthquake and it was due to atmospheric electric field alteration (Bailey, 2019).

- In Sri Lanka elephants made trumpets strangely, breach the chain holding to a pole and ran away (upper ground) from the source of sounds which was low in frequency rumbled from tsunami in the Indian Ocean (Nature news-letter, 2008).

- At Mount Etna in Sicily, many researchers noted that goat became nervous and ran away from the pens before the hour of volcanic eruption during 2012 and they hypothesised that the gasses produced from the tremors are the first sign of warning (Rachel, 2015; Bailey, 2019).

- At Yanachaga National Park, Peru in 2011, scientists observed that the unusual behaviour of the birds and mammal before the earthquake, animals activities decreased sharply with an altered ionosphere in a week before the earthquake (Rachel., 2015; Bailey, 2019). The pigeons in China flew away from the place of the earthquake at the magnitude of 4.0 and the researcher concluded that the presence of tiny sensors between the tibia and fibula are the main source of prediction. Similarly, sparrows were flying unusually, wolves running randomly in the container and dogs were barking strangely, before the earthquake of 8.5 magnitude in Ninghsia province, Haiyuan in 1920. Based on the unusual behaviour observed by deer, tigers, giant pandas, loaches, yaks and seagulls, sharks, some fish species inland and Pohai Sea respectively, made to issue a warning at Tientsin before the earthquake of 7.4 magnitude in 18th July 1969 (George, 2020).

- As per the eyewitness of the local public in Liaoning province, snakes came out from hibernation and many animals (cows, horses, dogs and pigs) showed unusual behaviour preceded to 4th February 1975 earthquake (7.3 magnitude) (George, 2020; Little Peckers, 2020). Similarly, horses and mules were jumping and kicking instead of eating till knot breach and ran away before earthquake of 7.8 magnitude hit with dazzling illuminated white flash in sky at Tangshan area in 1976, which is 40 km away from these animals shed (Tributsch, 2013; George, 2020).

- Some of the unusual behaviour recorded based earlier reports are; dogs and cats carry their offspring outdoor by picking, goats refuse to go into huts, pigs screaming weirdly, chickens jumping out of the cages at midnight and fish moving aimlessly (Bailey, 2019; George, 2020). Similarly, snakes, lizards and other small mammals evacuated their nest prior to 7.3 magnitude earthquake at Haicheng, China (Achenbach, 2016; George, 2020).

- Due to Gujarat, Bhuj earthquake 2001, peacocks were unusually screaming, dogs were restless and barking, donkey were braying in Teras located 80 km away from Bhuj epicentre (The Times of India, 2001). At the same time, unusual roaring and screaming of various animals, for example Asiatic, lions were more aggressive and restlessness (by erection of their tail) was observed in the Gir forest, India before the Bhuj quake (Vyas, 2001; Tributsch, 2013).

Conclusions

The natural calamities are most common across the world and many of the insects, wild creatures and domestic animals can able detect the future threat of the natural disaster by the active or passive process. These natural calamities occur based on the series of events that happen after the tectonic movement (speed of light guide the earth magnetic field to form ionosphere) which helps to predict and forewarn the danger by insects and animals. So, technologies should develop in such a way that, they can detect the calamities prior to their occurrence, by artificial intelligence or simulation models comparing with insects and animals. Hence, the extensive funding is required in this arena to promote the studies on mechanism involved in the disaster prediction by insects as well as other animals that may be either behavioural changes or genetic evolutionary.

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Can insects spread COVID-19?

Mogili Ramaiah, Naresh M. Meshram and P.R. Shashank

Insects are beautiful creatures in nature and found in every environment on Earth. Many insects are considered to be pests by humans. However, some insects are crucial components of several ecosystems, performing many important functions such as pollination, decomposition *etc*. besides beneficial insects producing useful substances, such as honey, wax, lac, silk. Some insects act as food and medicine but some insects like mosquitoes, especially female ones act as vector for many bacterial and viral diseases as female mosquitoes need blood to nourish the development of young ones from eggs. Viruses take advantage of this biological requirement of mosquitoes to move from one host to host. In the process, the mosquitoes spread pathogens and results in half a million deaths each year and hundreds of million cases of severe illness.

Coronaviruses are important human and animal pathogens. At end of 2019, a novel coronavirus was identified as the cause of a cluster of pneumonia cases in Wuhan, China. This disease rapidly spread, resulting in an epidemic throughout the world. In February 2020, the World Health Organization designated the disease COVID-19, which stands for coronavirus disease 2019. The virus that causes COVID-19 is designated severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2).

Full-genome sequencing and phylogenic analysis indicated that the coronavirus that cause COVID-19 is a beta-coronavirus in the same subgenus at the severe acute respiratory syndrome (SARS) virus, but in a different clade.

The mechanism of viral entry and replication and RNA packing in the human cell, the lungs are the organs most affected by COVID-19 because the virus accesses host cells via the enzyme angiotensin converting enzyme 2 (ACE2), which is most abundant in type II alveolar cells of the lungs. The virus uses a special surface glycoprotein called a "spike" (S) protein attaches to angiotensin converting enzyme 2 (ACE2) receptors that is found on the surface of many human cells, including those in the lungs allowing virus entry. The coronavirus S protein is subjected to proteolytic cleavages by host proteases (i.e. trypsin and furin), in two sites located at the boundary between the S1 and S2 subunits. In a later stage happens the cleavage of the S2 domain in order to release the fusion peptide. This event will trigger the activation of the membrane fusion mechanism. As the alveolar disease progresses, respiratory failure might develop and death may follow (Belouzard *et al*., 2012)

Understanding of the transmission risk is incomplete. Epidemiologic investigation in Wuhan, China at the beginning of the outbreak identified an initial association with a seafood market that sold live animal, where most patients had worked or visited and which was subsequently closed for disinfection. However, as the outbreak progressed, person-to-person spread became the main mode of transmission.

Virus present on contaminated surfaces may be another source of infection if susceptible individuals touch these surfaces and then transfer infectious virus to mucous membranes in the mouth, eyes or nose. The frequency and relative importance of this type of transmission remain unclear. There may be a possibility of transmission of COVID-19 by insects such as Mosquitoes (through blood), House flies and cockroaches (through mucous). But there is no scientific evidence to suggest mosquitoes are transmitting SARS-CoV-2, the virus that causes COVID-19. There is much more to learn about the coronavirus but based on current understandings, it's highly unlikely a mosquito will pick up the virus by biting an infected person, let alone be able to pass it on.

Mosquitoes can transmit a number of viruses, including dengue, yellow fever, chikungunya, Zika and Ross River virus. The mosquitoes can also transmit malaria, which is caused by a parasite. But they can't transmit many other viruses, including HIV and Ebola. For HIV, mosquitoes themselves don't become infected. It's actually unlikely a mosquito will pick up the virus when it bites an infected person due to the low concentrations of the HIV circulating in their blood. For Ebola, even when scientists inject the virus into mosquitoes, they don't become infected. One study collected tens of thousands of insects during an Ebola outbreak but found no virus. Here actual question will arise that,

Can mosquitoes transmit corona virus?

The new coronavirus is mostly spread via droplets produced when we sneeze or cough, and by touching contaminated surfaces. Although coronavirus has been found in blood samples from infected people, there's no evidence it can spread via mosquitoes. Even if a mosquito did pick up a high enough dose of the virus in a blood meal, there is no evidence the virus would be able to infect the mosquito itself. And if the mosquito isn't infected, it won't be able to transmit it to the next person she bites(Cameron, 2020).

Why only some viruses and why not others like Corona?

It's easy to think of mosquitoes as tiny flying dirty syringes transferring droplets of infected blood from person to person. The reality is far more complex. When a mosquito bite a COVID-19 patient and sucks up some blood that contains a virus, the virus quickly ends up in the gut of the insect. From there, the virus needs to infect the cells lining the gut and "escape" to infect the rest of the body of the mosquito, spreading to the legs, wings, and head. The virus then has to infect the salivary glands before being passed on by the mosquito when it next bites. This process can take a few days to over a week. But time isn't the only barrier. The virus also has to negotiate getting out of the gut, getting through the body, and then into the saliva. Each step in the process can be an impenetrable barrier for the virus. This may be straightforward for viruses that have adapted to this process but for others, the virus will perish in the gut or be excreted. The U.S. Department of

Agriculture is studying whether the novel coronavirus can be spread by mosquitoes, although the theory was ruled out by the World Health Organization and independent experts say such transmission is virtually impossible.

Joseph Conlon, a former U.S. Navy entomologist and technical adviser for the American Mosquito Control Association, said that possibility of mosquito transmission of the coronavirus is "nil." The WHO has definitively stated that the coronavirus cannot be transmitted via mosquitoes, while the U.S. Centers for Disease Control and Prevention said it "has no data to suggest" that the coronavirus is spread by mosquitoes or ticks. Independent experts said there has been no demonstrated case of any of the family of viruses to which the novel coronavirus belongs being transmitted by a mosquito.

Tarik Jasarevic, a WHO spokesman said that Mosquitoes cannot transmit the Covid-19 disease because the virus does not widely circulate in blood and is more prevalent in lungs and the respiratory tract. Even if the mosquito did digest the virus, it would have to survive the digestive process and transfer to the insect's salivary glands to then infect a human. Conlon also said that "It's an extremely complicated process and there are a number of different barriers there in insect body.

Can House flies and Cockroaches transmit corona virus?

Yes, these insects can transmit COVID-19 mechanically. Feces can be considered a one of important possible source of COVID-19 transmission. Therefore, insects or any organism in contact with or feeding on human feces may play a role in COVID-19 transmission. Therefore, the role of insects such as houseflies and cockroaches in the transmission of COVID-19 becomes important. These insects have the potential to mechanically transmit pathogens such as viruses, bacteria, and parasites. They are capable of transmitting more than 100 pathogens through their legs, body hair, mouthparts, feces, and vomit. Houseflies and cockroaches feed a variety of substances including human and animal food waste, milk, sugar, rotten fruits, sputum, nasal secretions, various wastes, fresh and dried blood, decaying corpses, stool, *etc*. Given that these insects feed contaminated materials, return them, and defecate on food materials, they are among the most important insects that can mechanically carry bacteria, viruses, worm eggs, and protozoan cysts. Flies and cockroaches play a role in the transmission of agents that cause diseases such as tuberculosis, leprosy, diarrhea, dysentery, cholera, typhoid, trachoma, conjunctivitis, polio, and hepatitis A. They are also vectors of rotaviruses, coronaviruses, some fungi (such as those in the genera Trichophyton and Candida) and eggs of parasitic worms and protozoan cysts. Flies and cockroaches are restless, active insects with strong visual and olfactory powers, and are constantly moving between food, feces, objects, and humans (Dehghani and Kassiri, 2020).

Dealing with the COVID-19 virus and preventing its rapid spread is a global challenge. Therefore, the fight against this disease requires universal management. In this regard, it is important eliminate possible mechanical vectors such as cockroaches and flies in public places and residential homes by improved environmental sanitization and also people still need to avoid even mosquito bites because mosquitoes cannot spread corona virus but transmit several other diseases and these diseases can weaken our immune system, that would make people particularly susceptible to a coronavirus infection. So, please stay at home - stay safe - stay happy.

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Genetically Modified Baculoviruses- An Important Tool in Insect Pest Management

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Insect viruses are important pathogens of many arthropod species. They have been recorded from a wide range of insects (Miller and Ball, 1998), and their association with these hosts is long, perhaps for more than 200 million years. Insect viruses are submicroscopic, obligate, intracellular, pathogenic entities. These viruses are simplest living forms, composed of a protein shell (capsid) that surrounds the nucleic acid. The nucleic acid is infectious in nature while capsid provides the morphological properties. Each virus has one type of nucleic acid, either deoxyribonucleic acid (DNA) or ribonucleic acid (RNA). The nucleic acid may be double or single stranded. The nucleic acid together with capsid forms the nucleocapsid or virion. Insect virus particles may be either *enveloped or nonenveloped.* A bilayer lipid membrane referred as the viral membrane or the viral envelope surrounds the nucleocapsid of many complex viruses. Virion is embedded either singly or in multiple in protective crystalline protein matrix known as occlusion body (OB). As on date, 6590 species of viruses have been defined by the International Committee on Taxonomy of Viruses (ICTV), of which more than 1100 viruses are known to infect insects belonging to over 20 different families of insects. Out of 1100 insect viruses, more than 50% viruses belong to a single family Baculoviridae (Eberle *et al*., 2012).

Baculoviruses makes up the large family of insect viruses and most thoroughly studied insect pathogens, they are widely used both as insect control agent and as protein expression vector. In baculovirus it is a bi-phasic infection process in which genotypically identical, but phenotypically different virus forms are produced *viz*., intracellular occlusion derived virus (ODV), or extracellular viral progeny (budded virus or BV). The ODV´s transmit infections from insect to insect, whereas the BV's spread the infection from cell to cell within an infected insect (Granados, 1980).

Based on the genome sequence analysis, morphological, biological and phylogenetic features and host it infects, Jehle *et al*. (2006) classified the members of Baculoviridae and placed under four genera. The Alpha baculoviruses are all Lepidoptera specific nucleopolyhedroviruses (NPVs), and their OBs are the classic many-sided (polyhedral) shape as seen in the type species *Autographa californica* multiple NPV (AcMNPV). The ODV produced by members of this genus can contain one or many nucleocapsids per enveloped virion, a feature not found among members of the other genera. The Betabaculoviruses include Lepidoptera-specific granuloviruses (GVs) and the type species is *Cydia pomonella* GV (CpGV). The Gamma baculoviruses are Hymenoptera-specific NPVs such as the *Neodiprion lecontei* SNPV (singly enveloped NPV) with polyhedral OBs.

Lastly, the Deltabaculoviruses are Diptera-specific NPVs with crystalline OBs of 0.5–15 μm containing many virions. The viral occlusion matrix protein of this virus is significantly larger than those of the viruses from the other three genera. The type species for Deltabaculovirus is *Culex nigripalpus* nucleopolyhedrovirus (CuniNPV). Most species of baculovirus are found within the alpha and beta baculoviruses.

Infection process of Baculoviruses

Infections occur following ingestion of OBs by a susceptible larva by feeding on OB-contaminated food such as foliage. Once ingested, the OB is carried to the alkaline (pH 8–10) larval midgut region where the OB dissolves as the polyhedrin and solubilizes to release the ODV within minutes. The released ODV then needs to pass through the peritrophic membrane (PM), found in the midgut, to access the midgut epithelial cells in order to establish infection. Once they pass PM, virions then attach to and enter the midgut epithelial cells and fuse with the epithelial membrane, allowing the nucleocapsids to enter the cells. Virions entering host cells, reach the nucleus through nuclear pores and start replicating in host cell nucleus. Viral replication in the nucleus of midgut epithelial cells results in the appearance of many progeny nucleocapsids and emerges as budded virus (BV). As BV are known to infect from one cell to another cell, after epithelial cells they reach tracheal cells and tracheoblasts. By moving through the network of trachea and by translocation within the motile tracheoblasts, the virus is able to rapidly spread through the host tissues colonizing haemolymph cells and most larval tissues including gonad, hypodermis, muscles, nerve ganglia, and pericardial cells. The infection and destruction of these tissues eventually results in larval death.

Baculoviruses have numerous unique features that have generated interest in their use as microbial insecticides *viz*., (i) host specificity, (ii) virulence in host insect (iii) no residual toxicity, (iv)environmental and mammalian safety (v) long shelf life, (vi) easily applied using conventional spray equipments, (vii) causing epizootic and (viii) compatibility with other control agents.

On the other hand, limitations include like restricted host range, costly *in vivo* production, limited market size, and relatively low cost-effective, slow speed of action particularly in the crops with low damage threshold, vulnerable to solar UV light and low virulence against the older instars. These limitations necessitate the need for development of recombinant viruses through genetic engineering techniques either by gene insertion or gene deletion. Through genetic engineering, recombinant baculoviruses have been developed aiming at increased speed of action by inserting insect specific toxin genes, affecting physiological process by over expression or inactivation of hormones and enzymes.

Expression of insect hormone genes:

Insect growth and development is majorly regulated by hormones. Disruption, over expression or inactivation of one or more insect hormones results in abnormal growth, feeding cessation and/or death. So, the insertion of genes that encode insect hormones were the first strategies used to generate genetically modified baculovirus. A recombinant virus of *Bombyx mori* MNPV (BmNPV) that encodes an active diuretic hormone (DH) found to be 20% faster in killing larvae than wild type virus (Maeda *et al*., 1989). Some of other hormones that have been expressed in the recombinant NPVs include eclosion hormone, prothoracicotropic hormone, juvenile hormone, but over expression of these hormones did not brought any significant improvement in the speed of kill as compared to wild type.

Expression of insect-selective toxin:

Expression of insect selective toxin *AaIT* gene from *Androctonus australis* scorpion in recombinant baculovirus resulted in increased speed of kill. A recombinant virus containing this gene showed 40% faster in killing larvae than the wild type and a reduction of host feeding by 60% (Inceoglu *et al*., 2001), this is due to inability of infected larvae to control muscle coordination. The site of action of this neurotoxic polypeptide is on insect sodium channel. Lepidopterous larvae infected with an AaIT-expressing baculovirus reveal symptoms of paralysis identical to those induced by injection of the native toxin (Elasar *et al*., 2001) and many of the physiological effects are very similar to those of pyrethroid insecticides which also act at the same target (Gordon *et al*., 1992).

Other useful insect-selective neurotoxins are SFI1 (obtained from a European spider, *Segestria florentina*) and ButaIT (derived from the South Indian red scorpion *Mesobuthus tamulus* (Wudayagiri *et al*., 2001). Some toxins could exert a cooperative effect when they are co-expressed, such as LqhIT1 and LqhIt2, obtained from *Leiurus quinquestriatus* scorpion (Regev *et al*., 2003).

Deletion of an endogenous baculovirus gene:

Baculovirus-encoded ecdysteroid UDP-glucosyltransferases (egt) inactivate ecdysteroid hormones in infected insect larvae by conjugating these compounds with glucose or galactose. As a result of this inactivation, normal development of the insect, such as moulting, is arrested, thereby prolonging the larval stage. Larvae continue to grow and feed and ultimately produce large numbers of polyhedra. Thus, egt functions to prolong the length of time the insect feeds after infection, with a resultant increase in the weight gain of the insect. This gene is found in many viruses belonging to the two baculovirus genera that infect Lepidoptera, *Alpha baculovirus* and *Beta baculovirus.* Deletion of the egt gene from viral genome shows 10-20% reduction in lethal time relative to virus having egt gene and 40% reduction in feeding damage. The egt negative AcNPV is likely to be the first recombinant baculovirus approved for commercial use as a pesticide (O'Reily, 1995).

Genetic engineering for increased virulence:

Enhancin is a metalloprotease commonly expressed by baculoviruses that degrades insect intestinal mucin in the peritrophic membrane. Insertion of the *Enhancin* gene derived from *Trichoplusia ni* GV enhanced AcMNPV virulence by 2 to 14-fold in various insect species. Conversely, deletion of two *Enhancin* genes from *Lymantria dispar* MNPV reduced viral potency 12-fold. (Kroemer *et al*., 2015). AcMNPV has been genetically engineered to express an algal virus pyrimidine dimer-specific glycosylase, cv-PDG, so that it is less susceptible to UV inactivation. Additional benefit of such a recombinant was that its virulence also increased 16-fold while killing *Spodoptera frugiperda.*

Recent development in the baculovirus genetic engineering is the development of baculovirus genomes capable of replicating in a bacterial host as bacterial artificial chromosomes, these recombinant baculoviruses are called bacmids. The principal advantage bacmids have over other high insert capacity vectors like yeast artificial chromosomes (YAC) and mammalian artificial chromosomes is stability of insert propagation over multiple generations. Once transferred into the bacterial host, the baculovirus genome can be manipulated easily through site-specific recombination, Rec-A mediated homologous recombination or transposition (Hasse *et al*., 2013). The first bacmid developed contained the AcMNPV genome, later bacmid systems are also being developed for *Bombyx mor*i NPV, *Helicoverpa armigera* single-nucleocapsid nucleopolyhedrovirus (HearSNPV) and *Cydia pomonella* granulovirus (CpGV) (Hilton *et al*., 2008; Wang *et al*., 2003)

Conclusion

One of the common factors associated with genetic optimization for increased speed of kill, is that the faster the virus kills the host insect, the fewer OBs are produced. Hence, large scale production of these recombinant baculoviruses *in vivo* becomes a challenge. Hence biosafety, commercialisation and resistance from pests are concerns. Another scope is regarding co-expression of two different neurotoxins encoded by a single recombinant baculovirus which could sometimes exhibit a synergistic increase in the degree of reduction in host survival time as well as broadening the host range.

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Potential Role of Insects in Rescue Mission - A Boon for Artificial Intelligence

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Abstract: This article presents an extensive global review of literature on the role of insects in "rescue mission". From times immemorial, insects were used as a biological weapon on a foe country and it's an age-old concept wherein they were targeted against healthy crops as well as used as vectors for transmission and dissemination of diseases in animals and human beings. In both the former cases their after effects are devastating. Apart from the bane, exploitation of potential role of insects in the rescue mission is now a boon for mankind with ample scope due to the present day advancement of artificial intelligence which is in vogue in military operations such as search, rescue and explosive detection.

Key words: Insects, search and rescue operation and explosive detection

As we all know that insects are mankind's greatest foes, ironically, they have become sources of innovation for advanced military technology (Lockwood, 2012). The significance of this article is to reveal the potential role of insects in a rescue mission and also the multitudinous ways in which their services can be exploited in various military operations such as search and rescue operations and sniff out the explosives.

1. Walking/running insect species in: search and rescue operations

For search and rescue missions that require navigating narrow, unreachable spaces with rubble and debris, crawling insects are the best choice (Table 1 and 2). For example, crawling cyborg insects could explore disaster zones and aid in search-and-rescue operations. By effectively surveying areas inaccessible to rescue teams, these remote-controlled insects equipped with artificial intelligence could help find people buried under collapsed buildings (Maharbiz and Sato, 2010).

1.1. HI-MEMS (Hybrid Insect Micro-Electro-Mechanical Systems)

The hybrid insect micro-electro-mechanical systems (HI-MEMS) program, also known as the cyborg program powered by energy harvested from the insect itself, to drive various electronic devices is a proposal from the defence advanced research projects agency (DARPA) in 2006 to encourage the development of cyborg insects that can be controlled by humans.

1.1.1 Cyborg cetonid beetle

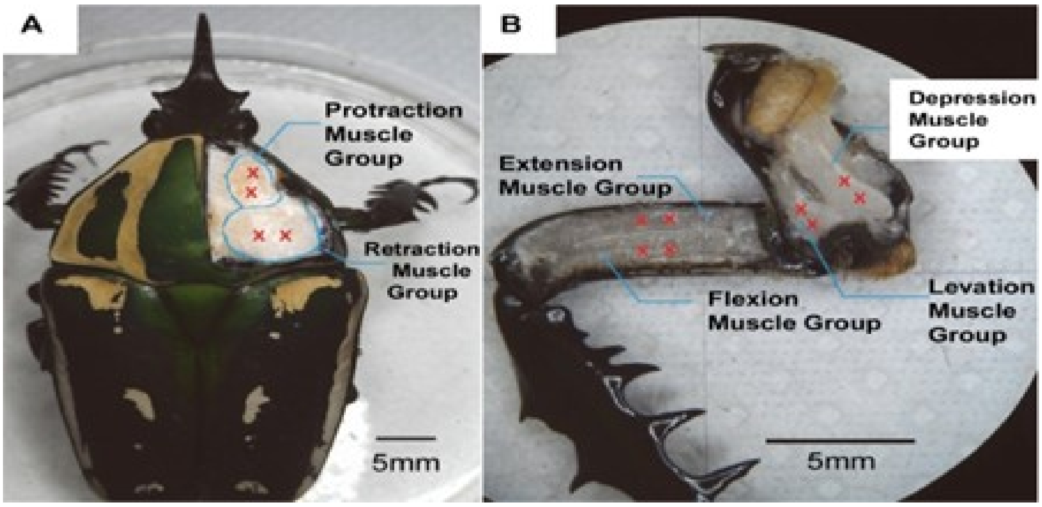

Fig. 1. Anatomical view of a beetle's front leg. Anatomical view of the three pairs of antagonistic muscle groups that control a beetle's front leg. Red crosses indicate the implantation sites for stimulation electrodes (A) The protraction/retraction muscle groups inside the prothorax, connect the coxa to the pronotum, and control the protraction/retraction motion of the coxa. (B) The levation/depression muscle groups inside the coxa control the levation/depression motion of the femur. The extension/flexion muscle groups inside the femur and control the extension/flexion motion of the tibia. [*Source*: Photographs were adapted from Sato *et al*. (2014) with permission].

In this study, a biological microactuator was demonstrated by closed-loop motion control of the front leg of an insect (*Mecynorrhina torquata*, beetle) *via*. electrical stimulation of the leg muscles (Fig.1). The three antagonistic pairs of muscle groups in the front leg enabled the actuator to have three degrees of freedom: protraction/retraction, levation/depression, and extension/flexion.

Protraction, retraction, flexion, and extension motions of a beetle's front leg elicited by electrical stimulation with a positive pulse train at 1 V, 100 Hz and a 1 ms pulse width. Each locomotion type was first stimulated individually, as shown in the upper four images; two muscles were then stimulated simultaneously to produce combined leg motion, as shown in the lower four images (Fig. 2). Each light-emitting diode (LED) near the beetle's head indicated the time when a particular stimulation site had been switched on. These findings related to and demonstrations of the leg motion control offer promise for the future development of a reliable, low-power, biological legged machine (i.e., an insect–machine hybrid legged robot) (Sato *et al*., 2014).

1.1.2 Locomotion control of hybrid cockroach robots

Locomotion control was achieved through electrical stimulation of the prothoracic ganglia, via. a remotely operated backpack system and implanted electrodes (Fig. 3). The hybrid discoid cockroach (*Blaberus discoidalis*) was able to move in forwarding motion, and turn-in response to an electrical stimulus to its nervous system but lack backward movement control. Initiation: Applying a controlled stimulus (2 V, 20 Hz) to the pro-ganglion elicits movement in the 1st set of legs. Left turn: Stimulating the right side of the ganglion with 2.5 V, 20 Hz. Right turn: Stimulating the left side of the ganglion with 2.5 V, 20 Hz. Cessation of walking or running: Any monostable signal above 2V applied for a long period. Application of another asymmetric signal will reinitiate movement (Liang *et al*., 2015). Eventually, Liang *et al*. (2015) were successful in finding the remote-controlled initiation, turnings and

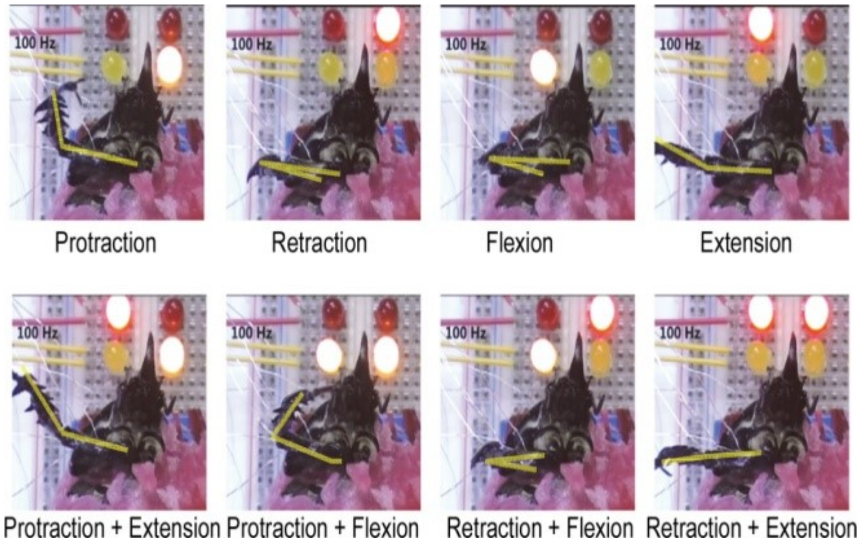

Fig. 2. Demonstration of controlling a beetle's front leg motions by electrical stimulation of muscles. Protraction, retraction, flexion, and extension motions of a beetle's front leg elicited by electrical stimulation with a positive pulse train at 100 Hz and a 1 ms pulse width. Each locomotion type was first stimulated individually, as shown in the upper four images; two muscles were then stimulated simultaneously to produce combined leg motion, as shown in the lower four images. Each light-emitting diode (LED) near the beetle's head indicated the time when a particular stimulation site had been switched on. [*Source*: Photographs were adapted from Sato *et al*. (2014) with permission].

cessation of cyborg cockroach. However, the fro movement of cockroach has to be fine-tuned.

1.1.3. Cyborg Darkling beetle

Zophobas morio, also known as darkling beetle, was used as the platform for this insect machine hybrid robot. The insect is an ideal model for this study because of its relatively small size (2-2.5 cm), lightweight (0.4-0.6 g), and long-life span (3 months). First scientists anaesthetized using CO_2 and implanted two electrodes in both antennae (Fig. 4) to stimulate the beetle. Two outputs are used to generate pulse trains at frequencies of 1–50 Hz for each of the antennae, and one input is used to receive command signals. The infrared (IR) receiver module is connected to this input to receive the IR signal emitted by the computer. One light-emitting diode (LED) is connected to each of the outputs to indicate the side, which is being stimulated (Sato *et al*., 2017). A pulse applied to the left antenna muscle produces a rightward motion; Right antenna muscle produces a leftward motion. The success rate ranges from 65% to 80% for stimulation frequencies between 1 and 10 Hz respectively, whereas, for the range from 20 to 50 Hz, the success rate is more than 85%. Stimulating both antennae with 2.5 V, 2 ms pulse width at the same time drove the beetle backwards. Eventually, Sato *et al*. (2017) found wireless control for initiation, turnings and cessation and even backward movement too.

2. Futuristic Bio Unmanned Aerial Vehicle in India

Proceedings of 4th national conference on "Emerging technologies and applications of UAVs" held on 22nd and 23rd march 2017 at International Institute for Aerospace Engineering and Management (IIAEM), Jain university, Bangalore reported the following proposal for search and rescue operation (Anonymous, 2017) (Table 3).

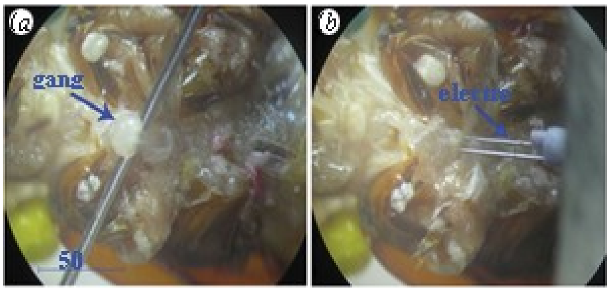

Fig. 3. Dissected images of (a) the location of the first thoracic ganglion (b) placement of two electrodes for localized stimulation in discoid roaches. [Source: Photographs were adapted from Liang et al. (2015) with permission]

3. Flying insect species in: - search and rescue operations.

3.1 Remote-controlled cyborg beetle:

Sato *et al*. (2009) presented the first report of radio control of a cyborg beetle in free-flight. The microsystem consisted of a radio-frequency receiver assembly, a micro battery and a live giant flower beetle platform (*Mecynorhina torquata*).

The assembly had five electrode stimulators implanted in between the left and right optic lobes, brain, posterior pronotum (counter electrode), right and left basalar flight muscles. Flight commands were wirelessly transferred to the beetle-mounted system via a radio frequency transmitter operated by a laptop running custom software (Beetle Commander V1.0) through a USB/Serial interface.

3.1.1 Flight Control

Flight initiation and cessation:

Above figure shows that flight initiation was triggered by applying a 2 V, 100 Hz, 20 % duty cycle that means 10 % positive pulse and 10 % negative pulse this way, alternating positive and negative potential pulses initiate flight in the beetle. One longer pulse to the

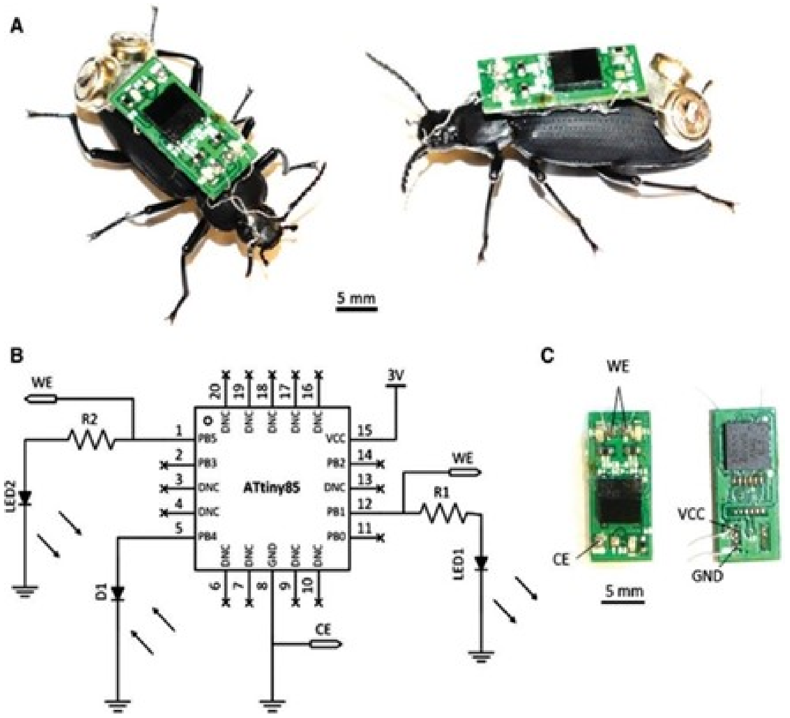

Fig. 4. (A) An overview of the insect–machine hybrid robot. A wireless stimulator backpack was mounted on to the living insect platform (*Zophobas morio*), with two WE, one implanted in each antenna and one CE implanted in the pronotum of the beetle. (B) Schematic view of the backpack. (C) Top view (left) and bottom view (right) of the backpack. CE, counter electrode; GND, ground terminal; VCC, positive power terminal; WE, working electrodes. [*Source*: Photographs were adapted from Sato *et al*. (2017) with permission].

same area stopped the wing oscillation completely.

Left and right turn

The turn could be elicited in free flight by applying 2 V, 100 Hz, 2.5 milliseconds positive potential pulses to either left or right basalar flight muscle. Right basalar muscle stimulation was elicited turn into the left side and left basalar muscle stimulation was elicit turn into the right side.

The flight path of a flying beetle wirelessly stimulated for turn control. T0 (0.00 sec) is the start time of the filming. At T1 (0.6 sec), the operator signalled a left turn from the base station (right basalar muscle stimulation). At T2 (1.6 sec), the operator switched the stimulated side from the right to the left basalar flight muscle, and the beetle turned right. At T3 (3.1 sec), the right basalar flight muscle was stimulated (left turn). At T4 (4.2 sec), the left basalar flight muscle and turning right again. At T5 (4.8 sec), the beetle touched on the curtain and stopped the flight.

They present the first-ever wireless flight control microsystem using a small RF receiver mounted on a live beetle and an RF transmitter operated from a base station. Flight initiation and cessation were accomplished by neural stimulation of both optic lobes while turning in free flight which were elicited by muscular stimulation of basalar flight muscle on either side. Finally, the first-ever wireless flight control microsystem using a small RF receiver mounted on a live beetle and an RF transmitter operated from a base station were presented.

3.2 Cyborg moth

Tsang *et al*. (2010) reported the first remote flight control of an insect using microfabricated flexible neuroprosthetic probes (FNPs) that directly interface with the animal's central nervous system. The FNPs have a novel split-ring design that incorporates the anatomical bi-cylinder structure of the nerve cord and allows for an efficient surgical process for implantation. Additionally, they have integrated carbon nanotube (CNT)-Au nanocomposites into the FNPs to enhance the charge injection capability of the probe. They created the insect-based Micro-Air-Vehicles (i-MAVs). The two basic components of the i-MAV are the telemetry system and the neuroprosthetic probe. The telemetry system provides a communication link between the insect and the base station, while the probe interfaces with the nervous system of the insect to bias the insect's flight path.

3.2.1 Implantation

They can implant the CNT- Au FNPs into adult moths as well as pupal stages (7-2 days before eclosion). The implantation is performed at the position of the ventral 4th abdominal segment for pupae and the ventral 1st abdominal segment for the adult moths.

3.2.2 Neural Stimulation & Flight Control

The observations were made on that stimulation of CNT- Au FNPs could elicit multi-directional abdominal movements in both pupae and adult moths. The directions of abdominal movement depend on the specific stimulation sites selected for stimulation, and the magnitude of the movements increased with increases in either voltage magnitude or pulse frequency of the stimulation signal. Additionally, the results of the CNT- Au FNPs stimulation of an adult moth using the wireless system are shown vertical and horizontal planes have been achieved with stimulations using various site pairs. Importantly, in the flight control experiment, we can force a freely flying moth to perform turning motions using the abdominal ruddering with these elicited abdomen motions. (Voldman *et al*., 2010).

3.3 Dragonfly Model with Optogenetic insect control backpack

Activate and steering neurons with light pulses
Channel rhodopsin - a photosensitive protein derived from *Chlamydomonas reinhardtii*, used for control neuronal activity - **(ChR).**
Holorhodopsin derived from the species *Natronomonas pharaonic* - **(HR).**
Gene transformation method- plasmid vector (pUAST) used to develop genetically modified dragonfly sensitive to light pulses.

3.3.1 Mode of action of Channel Rhodopsin and Holo Rhodopsin

Both are bacterial photosensitive proteins responding to a light pulse. These two protein genes inserted into dragonfly via a vector (pUAST). In case of blue LED light switch on by backpack system of a dragonfly. It allows $\mathbf{Na^{+}}$ and $\mathbf{Ca^{2+}}$ Influx and depolarization will generate the action potential and leads to flight initiation (Channel Rhodopsin). Whereas Halo Rhodopsin responds to the yellow LED light when switch on by backpack system of a dragonfly. It allows $\mathbf{Cl^{-}}$ influx and hyperpolarization will lead to neural silencing and flight cessation (Ackerman *et al*., 2017).

4. Insect species in: Explosive detection

4.1 Sniffer Bees

The team at Los Alamos national laboratory have begun to explore the potential for bees to be weapons detection devices. Stealthy Insect Sensor Project Team produces very accurate gradient maps showing the distribution of radioactive materials and other toxic contaminants. DARPA-funded research to train free-flying bees to detect certain scents- of landmines, for example-by

placing traces of the explosive chemicals near food sources (Timothy *et al*., 2005).
Pavlovian conditioning of bees just in 6 seconds. First time expose clean air, after exposing clean air with TNT (Tri nitro toluene) vapour and supply nectar water on antennae. Next time expose both TNT vapour and clean air, finally expose clean air with TNT vapour and supply nectar water to bouton. Now, these trained honey bees can detect TNT vapour with a food source. After visiting field (Place) honey bees come back then they are inserted into the cartridge to be placed in the monitoring apparatus to detect chemical traces.

The above photograph shows that automatic machine for training bees and detecting explosive chemical traces. It was first started by Ivan Hoo chief executive of Inscentinel (Entrepreneur Company) in Harpenden, UK. Now they have used trained bees in the airport to check passengers and sniff out explosive chemicals.

4.2 Sniffer moth:

Insects, such as moths, can be trained to respond to explosives odours. A prototype system that can be used to train insects such as moths to detect explosives were designed, assembled and tested (Tony *et al*., 2004). It compares the electromyographic signals of insects trained to respond or not respond to a target explosive vapour to determine whether or not explosive devices, such as bombs or landmines, are present. Sniffing moth detecting the bomb vapour within 5.5 to 10.5 seconds.

5. Conclusion

HE-MEMS creates a platform to invade personal privacy, national security and cybersecurity, on the other hand, the integration of global positioning and autonomous navigation systems create a danger as nefarious users could command this technology, Whereas Bio Unmanned Aerial Vehicles (Bio-UAV) is emphasizing its focus vividly in recent times on academics and also in myriad applications of the research to unfold several other astonishing aspects but the present works being carried out are restricted only to prototypes being used in the laboratory. However, after Biological and Toxin Weapon Convention (BTWC, 1972) the insects has a potential role to play military as real-time situation awareness, location of trapped persons and detection of buried hazardous material.

Acknowledgements

I am specially thanks to Dr. Prabhuraj A., Professor and Head, Department of Agricultural Entomology, UAS, Raichur; who inspired me writing this article and also thanks to Sato H and Liang H; who given permission to reproduce images and figures in this article. Meanwhile I also extended my gratitude to Publishers like PLOS ONE, Mary Ann Liebert, Inc., The Royal Society who permitted copyright clearance immediately.

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Table 1. Walking/running insect species in search and rescue operations

S.No.	Insect species	Family	Order	Specific role	References
1.	*Mecynorrhina torquata*	Cetonidae	Coleoptera	Protraction/retraction motion of the coxa; levation/depression motion of the femur; extension/flexion motion of the tibia	Sato *et al.*, 2014
1.	*Blaberus discoidalis*	Blaberidae	Dictyoptera	Initiation, turnings, cessation and lack of backward movement	Liang *et al.*, 2015
2.	*Zophobas morio*	Tenebrionidae	Coleoptera	Initiation, turnings and cessation and have even backward movement	Sato *et al.*, 2017

Table 2. Indian insect cyborgs proposed at Defense Research and Development Organization, India

S.No.	Common name	Scientific name	Family, Order	Proposed institutes
1.	Ground beetle	*Anthia sexguttata*	Carabidae Coleoptera	UAS, Raichur; Inst. of wood science, NDRF
2.	Jumping cyborg Cricket	*Gryllus* Spp.	Gryllidae Orthoptera	NDRF, IISc, University of Hyderabad

Table 3. Indian insect cyborgs proposed at Defence Research & Development Organization, India (IIAEM), Jain University, Bangalore) for search and rescue operation (Anonymous, 2017).

S.No	Common name	Scientific name	Family, order	Proposed institutes
1.	Hawkmoth	*Agrius convolvuli*	Sphingidae, Lepidoptera	National centre for Biological Sciences

Contributions of Dr. K.N.Mehrotra to the field of Entomology

Isaiyamudhini, T., Sagar, D. and Sachin S. Suroshe

Kailash Narain Mehrotra, an esteemed scientist is acknowledged by his inevitable contributions in the field of entomology. He has inspired many through his excellent work in Insect Physiology and Insect Biochemistry. Due to his brave, unpredictable and confident nature he was regarded as "The Tiger" of the Entomology Division, IARI. His life journey has a truthful dedication to the field of Entomology.

Early life of Dr. Mehrotra

On December 1, 1930 he was born to Mr. Srinarain Mehrotra and Mrs. Shyam Sundari Mehrotra at Kanpur, UP. He completed his early schooling at Etawah. Later, he pursued his B.Sc and M.Sc in Zoology at Banaras Hindu University, Varanasi . There he was influenced by Prof. A. B. Mishra, from whom he took first lesson in Entomology to continue his studies in the field of biology throughout his life. After a short stint as research assistant at IVRI, Izatnagar from 1954-1955, he proceeded to the University of Western Ontario, Canada in 1955 to do his Ph.D under the supervision of Prof. A.W.A. Brown. He initiated his work on "Development of cholinergic system in insect eggs" as studies on insect nervous system was on trend at that time. Due to the congenial atmosphere in the university along with guidance of experts like Drs. B.N. Smallman, William Chefurka, E.H. Colhoun, Norman E. Good, E.Y. Spencer, R.D. O'Brien and Hubert Martin, a deep impression has been created on his mind to continue these studies as a postdoctoral fellow at the Cornell university, Ithaca, New York during 1959-1962 (Gujar, 1994 & Subrahmanyam, 2006)

His professional career

In response to the strong call from the mother land, he returned India in 1962 and joined as a pool officer for a brief spell in the Department of Physiology, G.S.V.M Medical College, Kanpur. Finally, on the invitation of the then leading entomologists, Dr. E.S. Narayanan and Dr. S. Pradhan, he came to the Division of Entomology, IARI, New Delhi on November 4, 1963 as Insect Physiologist to work in the domain of Insect

Physiology at IARI in view of his vast expertise abroad. Later, he rose to the position of Senior Insect Physiologist (1969-1990). He was the third professor of the Division of Entomology and worked during 1973-1976. Twice he served as the head of the Entomology Division, IARI in the time period of 1977-1978 and 1980 and also the youngest person to reach that position. Later he succeeded Dr. D.N. Srivastava as Assistant Director General (Plant Protection) at ICAR in 1982. He was selected as Professor of Eminence in 1983 and continued to serve that position till 1986 and became the Principal Scientist of the division till his retirement in 1990. During his career, he has been honoured with fellowships of various academies like Indian National Science Academy, New Delhi; National Academy of Sciences, Allahabad; Indian Association for Advancement of Insect Science, Ludhiana, Punjab and as a Pitambar Pant fellow at BHU, Varanasi after his superannuation. (Gujar, 1994 & Subrahmanyam, 2006)

Dr. Mehrotra as a mentor

Dr. Mehrotra has been as outstanding teacher. In fact it was Dr. Mehrotra and Dr. N. C. Pant, his contemporary together has established Insect Physiology teaching and research at IARI that had helped in the development of vast human resource in this field in our country. Due to his efforts Insect Biochemistry has grown parallel to vertebrate biochemistry. He laid the foundation for the introduction of basic entomological courses *viz*., Insect Physiology II, Insect Biochemistry and Biochemistry of Insecticides for M.Sc and Ph.D students. He established the research laboratory on Insecticide Resistance Management at BHU, Varanasi, UP and also a section of Insect Physiology at IARI. His lectures were highly educative, thought provoking and up-to-date due to his in-depth knowledge of the subject. As a research guide, he has supervised 2 M. D. students at G.S.V.M medical college, Kanpur and 25 Ph.D. and 1 M.Sc students at IARI. He performed his part as a mentor very well by bringing best out of his students by providing them challenging topics. Many students have occupied higher positions in the field of agricultural education and research in India as well as abroad. Out of the students under his supervision, three of them continued their service at IARI *viz.,* Dr. P. J. Rao, Dr. Amrit Phokela and Dr. G. T. Gujar and promoted Insect Physiology as a "basic science with applied value". In this respect Dr. M. S.Chadha called him as "True Guru" who created an active, professional and respectable school of Insect Physiologist in the country (Gujar, 1994 & Subrahmanyam, 2006).

Major Research accomplishments

Dr. Mehrotra was primarily concerned with studies on insect cholinergic system and effect of anticholinesterases from his early years till 1980. With his profound knowledge of the subject, he has published more than 170 research publications in well reputed journals like Nature, Pesticide Biochemistry & Physiology, Journal of Insect Physiology etc., and has been associated with the editorial boards of a number of research journals in India and abroad from time to time. His research work in collaboration with Prof. W.C. Dauterman on the characterization of acetyl cholinesterases and choline acetylase during his studies at Cornell University remains a highly quoted one in insect neurobiology. Because of his dedication and devotion towards this work he referred that as "My baby". Other prominent areas of research were characterization of carboxylesterase, physiological effects of insecticides, metabolism of insecticides, host plant–insect pest interaction, pheromones and kairomones and insect resistance to insecticides. Regarding acetylcholine metabolism in insect, he has identified the presence and time of occurrence of cholinergic elements such as acetylcholine (ACh), acetyl cholinesterase (AChE) and choline acetylase (ChA) in the developing eggs of housefly and milkweed bug and also characterized the enzymes, AChE and ChA using various pharmacological and biochemical techniques (Mehrotra, 1960). He also analyzed the substrate specificity of AChE using different analogues of Ach and revealed the difference in the shape and distance between the static and anionic sites in AChE which is the primary target of organophosphorous and carbamate insecticides (Mehrotra and Dauterman, 1963). At molecular level, he has shown the occurrence of various aggregates forms of different molecular weight of AChE which leads to the qualitative selectivity of the enzyme. Because of the importance of carboxylesterase (CE) in the metabolism of xenobiotics and insecticides, he demonstrated their presence, substrate specificity, kinetic properties in *Chilo partellus* Swinhoe, *Dacus dorsalis* Hendel, *Schistocerca gregaria* Forsk, *Lipaphis erysimi* Kalt. and the presence of extra anionic site in CE of *L. erysimi* (Mehrotra and Phokela, 1982). Extensive work was done by him on the metabolism of various insecticides viz., DDT, malathion, parathion and methyl parathion in the fat body of desert locust and also explained the role of the enzyme DDT- dehydrochlorinase in the deactivation of DDT in desert locust. Despite the fact that the insecticides are extensively used in plant protection work, only little is known about their effects on the physiology of non-target species. He mainly worked to reveal those effects by finding the difference in the mechanism of action of anti AChE in house sparrow and desert locust and existence of an endogenous reactivator of AChE in birds (Mehrotra *et al*., 1967). The host-plant relationship is mainly based on the interaction between biochemical systems of insects and those of plants, interlinked ecologically. In that case, he has found the phagostimulant activity of various edible oils and the phagodeterrent activity of *Calotropis gigantean* L. and neem (Mehrotra and Rao, 1972) towards desert locust, *Schistocerca gregaria.* Occurrence and efficacy demonstration of sex pheromone of female almond moth, *Ephestia cautella* Walker (Mehrotra *et al*., 1967) and the demonstration on the presence of a kairomone in the hexane extract of *Corcyra cephalonica* Stainton for the parasitoid, *Bracon brevicornis* Wesmael has been considered as the significant ones. He also initiated studies on protein, amino acid and carbohydrate metabolism and also on insect behaviour. These basic studies were widened to include more and more of the applied developmental studies.

Other notable contributions

Dr. Mehrotra during his tenure as ADG, was largely responsible for the formulation of the National Pesticide Policy through which several insecticides were phased out, new insecticides were synthesized and indiscriminate use of insecticides were discouraged. His efforts led to attainment of fair recognition of the science of plant protection in the agricultural sector through the foundation of the Society of Pesticide Science in India in 1988. The main objective of this society is to put the use of pesticides in proper perspectives. The organisation of a symposium "Plant protection in 2000 A.D." on the sponsorship of Indian National Science Academy in 1982 stands as a testimony to his efforts in this direction. He attended the meetings of Codex Alimentarius Commission which prescribes the permissible limits of pesticides in food held in France representing our country. Dr. Mehrotra along with Dr. V. K. Sharma, the former director of National Institute of Malaria Research, New Delhi has done a careful scientific analysis and ascribed the reason for malaria resurgence from intensive agriculture to several other socio-economic causes. When insecticide resistance has been already alarming in developed countries, he is one who brought to the fore, the development of pyrethroid resistance in *Helicoverpa armigera* Hubner nationwide and was responsible for initiating resistance monitoring studies (Gujar, 1994 & Subrahmanyam, 2006). He demised on 18th April of 1999. His student Dr. G. T. Gujar dedicated a book named "Recent advances in Insect Physiology & Toxicology" in his honour to portray his accomplishments. Till his last breath, he solely treasured his knowledge for the betterment of the field of Entomology which will remain as a milestone in the history of Entomology with potential agricultural application.

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SECOND INDIAN ENTOMOLOGIST PHOTO CONTEST

The Indian Entomologist photo contest aims to encourage insect photography among photographers, professionals, amateur entomologist and the layman. The theme of the second episode of the photo contest was 'Insects and aspects related to insect life'.

With these objective entries were invited during June 2020. Each participant was to submit one good photograph which 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 a total from 102 entries which were screened first for the prescribed standards and overall quality of the image. Final evaluation was done by a committee of three independent members in the presence 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 was hidden and the evaluators were only presented with the photograph, caption, description and technical specifications.

The first place was won by Revathe Thillaikumar, (Jawaharlal Nehru Center for Advanced Scientific Research, Bengaluru, E-mail id: revathethillaikumar @gmail.com); who captured a twilight congregation of Blue tiger butterflies at her campus.

The second place was won by Alfred Daniel J, (Timber Depot Road, Ranithottam, Nagercoil, Kanyakumari District, Tamil Nadu, E-mail id: danieljalfred@gmail.com); who captured an *Erebus* moth infected by *Cordyceps* fungus during his collection trip at the Aralam Wildlife Sanctuary, Kerala.

The third place was won by Harigaran S., (Agaram Village, Pochampalli, Krishnagiri, Tamil Nadu E-mail id: harigaran6@gmail.com); for his photograph of paper wasps sharing food.

BUG STUDIO ASSOCIATE EDITORS

Mr. S. S. Anooj

Mrs. S. Rajna

1st Place: *Twilight congregation of Blue tiger butterflies*. Bengaluru, 22.07.2019 (Canon 80D with Canon 100-300 mm F/4-5.6 IS USM lens, ISO400, F/5, 1/250, exposure bias 7 steps). By Revathe Thillaikumar, JNCASR, Bengaluru, Karnataka.

2nd Place: *Hey Erebus! Wanna be a zombie? Host a Cordyceps.* Aralam Wild life Sanctuary, Kerala, 11.01.2020 (Panasonic FZ 2500 with Raynox DCR 250 lens, ISO 80, 1/125, F/10, focal length 23.4, Inbuilt flash+1EV). By Alfred Daniel J, Nagercoil, Kanyakumari, Tamil Nadu.

3rd Place: *Caring by sharing.* Krishnagiri, 19.05.2020 (OnePlus 7t, ISO 160, F/1.6, 1/100, focal length 4.8). By Harigaran S., Pochampalli, Krishnagiri, Tamil Nadu.

Gaurav Singh, PhD Researcher

Hawkesbury Institute for the Environment, Western Sydney University, Australia

Email: g.singh4@westernsydney.edu.au

Gaurav Singh, PhD researcher from Hawkesbury Institute for the Environment, Western Sydney University, Australia. His PhD research is part of a broader project concerning the pollination potential of Australian stingless bees in key crops such as avocado, cucumber, litchi, macadamia, mango and strawberry. His work focuses on identifying key flower visitors on mango in Australia and their potential as mango pollinators. Aim of the work is to generate a comprehensive understanding of native pollinators of mango, their foraging behaviour, spatial distribution, pollination efficiency and pollination effectiveness. Addressing these key issues is expected to promote stingless beekeeping in Australia and increase the likelihood of using managed as well as wild stingless bees for mango pollination.

N. Ramya Sri, PhD Scholar

Department of Entomology, College of Agriculture, Rajendranagar, PJTSAU, Hyderabad, India

N. Ramya Sri is a PhD scholar at Department of Entomology, College of Agriculture, Rajendranagar, PJTSAU, Hyderabad. Her research work is on “Studies on Bioecology of Pink bollworm, *Pectinophora gossypiella* (Saunders) (Gelechiidae: Lepidoptera) on Cotton” under the supervision of Prof. T. Uma Maheswari. Aim of her work is to study the carryover of pink bollworm during offseason, for which biology and morphometrics of pink bollworm was carried on cotton and it’s alternate hosts. Diapause studies were carried out by her by maintaining different temperature and photoperiod in BOD's and year-round monitoring of pink bollworm at ginning mills and surrounding fields at 5, 10 and 15 km radius. Further, genetic variation in pink bollworm collected from 16 locations all over India was studied using universal primer (mtCO1). In future, she would like to continue her research in chemical ecology by conducting olfactometer experiments using different host plant volatiles to study the preference of pink bollworm to different host plants.

Vrunda Shrihari Thakare, Ph.D. Researcher,

Department of Agricultural Entomology,
Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola,
Maharashtra, India.

Vrunda Thakare is a Ph.D. researcher, working on "Exploration of resistant sources in brinjal to *Leucinodes orbonalis* Guenee" under the guidance of Dr. D. B. Undirwade (Head, Department of Agril. Entomology, Dr. PDKV, Akola). She is working on the aspect of host plant resistance which is one of the cornerstones of environmentally benign pest management systems. In this context, she conducted field screening of twenty-two genotypes of brinjal (13 university genotypes, 8 hybrids and 1 local cultivar) for their reaction against *L. orbonalis.* Then the crossing programme of selected genotypes of brinjal with wild relative has been executed with an objective to transfer resistant trait. Then the obtained F1 and selected promising genotypes will be screened in next season. She is understanding biophysical characteristics as well as biochemical constituents of selected genotypes of brinjal against *L. orbonalis*. In addition, she is working on the digestive enzyme activity (amylase, protease and lipase) of *L. orbonalis* collected from particular genotype in order to correlate them with infestation level. It will help in selecting inhibitors against these digestive enzymes as they are potential target for pest management. She is also carrying out molecular characterization using SSR and ISSR primers for assessing the genetic diversity in selected genotypes of brinjal along with wild relatives, which is essential for utilization of germplasm in resistance breeding programme.

Ms. Arya P. S., Mr. Mogili Ramaiah, Ms. Aparna S, Student Associate Editors of IE compiled the information for this section.

Ant mimicry: An adventure for life

Madhusudan, M

Every living organism interacts with other organisms and gets benefited for its existence and survival in this world, one or the other way. Some are parasitic, some are predators and some are even mutualistic, but what I want to recount here is way different from these. In this case, an organism gets benefited from other organism usually without any direct interaction. Yes! that is “mimicry”. By mere copying the shape and color of the well protected species, let’s call it ‘model species’, the beneficiary species, let’s call it ‘mimic species’, gets protection from its enemy (predator) or by mimicking the other species help them to gain access to food resources of the model species or the later can be achieved just by mimicking the chemical, such as, cuticular hydrocarbons of the model species.

In this article, I am going to discuss about such extraordinary mimic-model systems associated with the ants that I had encountered during COVID-19 lockdown days around my university campus. In this story, ants are models. Let me advocate ants for qualifying them to be “models”. Ants are generally avoided by many predators, because of its bite, sting, defensive chemicals it produces and also, they taste bitter/sour. By mimicking these nasty, tasteless ants, mimics may get the protection from its predators (it is called ‘Batesian mimicry’). Secondly, does mimic get any direct or interactive benefits by mimicking the model? Yes! we all know how fierce ants are, so by mimicking the body or the behavior or even smell, they perfectly deceive them. Being able to go near the prey without giving a clue is a great deal to the predator, here mimic, and this type of mimicry is called ‘Aggressive mimicry’.

One day, on my way to the laboratory, I was parking my bicycle under a cashew tree. I happened to see an ant with unusual behaviour! Ant that was on tree bark suddenly dropped down with a silken thread! I haven’t seen or heard of ants that are capable of producing silken threads. Alas, I found a new species! Then, I carefully observed it closely. No, no, no! It is not an ant! It is a spider. It was mimicking a weaver or red ant. It had a pair of pedipalps, front legs which looked exactly as antennae and used as antennae, and totally four pairs of legs. That spider is *Myrmarachne plataleoides*, belonging to the family Salticidae. They are jumping spiders and they live in trees and bushes near the weaver ants’ nests, and they hunt down the ants when they find them singly. Poor ants become the prey because they get deceived by their own skin tones wore by spiders.

Another day, when I was doing my research in a glass house, there was another spider which was exactly mimicking an ant, but this was a different one. It was *Myrmarachne melanotarsa* which mimics *Crematogaster* sp. ant. As I had seen an ant mimicking spider few days back, I could easily identify it as a spider with little observation. As I approached the spider, it showed typical spider behaviors by turning to its back, moving sideways, trying to hide *etc*. What bewildered me most aren't these ones, but of its precision of mimicking! even the color shades, shape & size of the body were similar to *Crematogaster* sp. When I googled about it, I got something very intriguing story about it. It was called as 'Collective mimicry' or I would say 'Social batesian mimicry', a mimicry at the next level. Unlike the previous case, where the spider lives in the same habitat of the ant, here this spider lives in a very close proximity often inside the ant colony/nest, much more intricate part is even sharing the living space with other salticid spiders, mostly *Pseudicius* spp. *Memerus* spp. and also with a non-salticid spider, *Hersilius caudata.*

Fig. 1. Top image- *Myrmarachne plataleoides* (mimic), bottom image- *Oecophylla smaragdina* (model) (Image Courtesy: Project Noah)

Aren't these spiders risking their lives by living in close proximity with fiercest ants? And when they are ready to risk, are there any benefits? Well, ants can steal the eggs and juveniles of the spiders, let's consider this as a main loss, but here comes an advantage to the mimic, *Myrmarachne melanotarsa* which mimic social insect (ant), this spider deceives other spiders in the nest complex and steal those spiders' eggs and juveniles. Second benefit is, for enemies of mimic or even for us, it is difficult to distinguish mimic from model- when a group of *Myrmarachne melanotarsa* and swarm of *Crematogaster* ants present together. Even when predators try to prey on them, ants may come for rescue thinking of them as conspecifics. And other spiders associated with ants and the mimic also get protection from their enemies as many predators avoid ants, which are actually around these spiders. Comparing all these, a little loss of eggs and juveniles might be compensated with these protections.

Fig. 2. *Crematogaster* sp. (Image Courtesy: bugguide.net).

Recently, I got to see another insect which was mimicking an ant. To my surprise, it was a hemipteran insect (bug) bug which was mimicking. I never thought a bug can mimic an ant to this extent. Unless you go near and closely observe it, for sure, you will not identify it as an ant. Well, any mimic would leave some clue to unravel its mystery. In this case, my first clue was its antennae. It had typical heteropteran filamentous antennae and when I looked at the bug from the lateral side, I could easily see its beak/proboscis, not just that, I also observed it piercing into the plant tissue. By the way, this 'crazy' bug belongs to the family Alydidae, genus *Dulichius*.

When I searched on the internet, I found loads of insects which mimic ants, some examples are- crickets, freshly hatched phasmids, thrips, flies, mantids and even beetles. What amazed me most is that even plants mimic ant's presence by having dark dots and stripes on their flowers to deter ant avoiding predators/herbivores! Isn't this astounding?

Ants are always extraordinary and like 'Superheros' of animal kingdom. One way of defeating or get benefited from them, at least in this background, is by being like them.

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My notorious mites: A tale of every neophyte Acarologist

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Mites, the siblings of insects are the tiny arthropods belonging to the class Acari. As most of us think, working with mites is a cinch, a blink of an eye, because of their non flying habit and pretty shorter life cycle, but the opposite is true. Here I am sharing my hurdles as a novice Acarologist and also few tips for fledglings like me.

I started my research with mites as an M Sc scholar, and these tiny creatures made me weep like anything during those days. Despite lifting them (of course using a hairbrush) like a rose petal, they use to die after a day. As a young acarologist, I was unaware of the fact that, even though mites seem resting on the leaf, they might be enjoying their meal over there. If we try to transfer them, it may cause breakage of their delicate chelicera and cannot feed anymore. In addition to desiccation, starvation also fastens their death. It will be hard for you to believe that I spent a whole semester to learn its rearing and life stages. But yes, I did.

Our common understanding about mites is that they require higher temperatures, and complete their life cycle quickly when the temperature is high. Like every other organism, there exist a threshold temperature for mites too, or stop laying eggs or even no hatching of eggs. Besides some subtropical mites are stenothermic (organisms with very narrow temperature range), which was one more problem until I trotted out which are all those culprits in my study as they cannot be cultured and maintained at all prevailing temperatures. One more so-called assumption is that the life cycle of mites is going to end by 3-4 days. But it's not just 3-4 days; it was an alarm clock for every 3-4 hours!!! Yes, if we are doing biology of mites then you should do mere vigilance until the cycle is over. Because they change their stages overnight, so fixing an alarm every 3 hours is must to trace their developmental period. Isn't it too easy?

After toiling so hard in front of microscope day and night for a long period, with a slight increase in the eyesight, I thought this liaison with mites came to an end when I submitted my thesis. But it was just a trailer; the whole film was waiting for me in Ph.D. Again it was acarology, but this time came up with a twist called taxonomy. As usual, I assumed that it's going to be easy due to the overconfidence of holding a thesis in acarology, but again it was a standout.

My experience taught me that collecting too many samples of mites at a time can only cause a huge mess and resource and time wastage. One more concern is that, as we collect mites along with leaves, chance of predation inside the polythene bags is much higher by predatory mites and other insect predators like *Stethorus, Oligota,* Staphylinid beetles, Cecidomyiids, predatory thrips which coexists with prey mites. Moreover, chances of leaf rot also exist. Eureka… we have got a refrigerator for that! Miserably, it won't work beyond 4-5 days, mites will die out of freezing and we get nothing in our hands. Even some mono and oligophagous endemic mites, won't multiply in the laboratory however hard we may try.

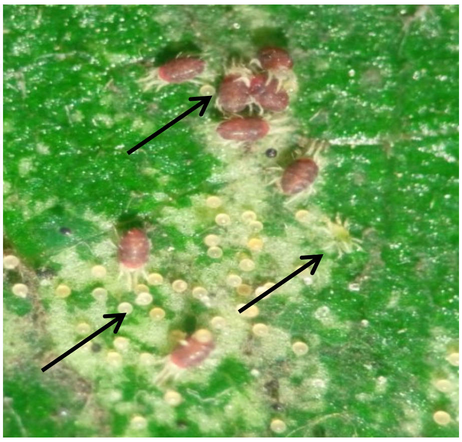

Fig. 1. Colony of *Tetranychus hirsutus* Zeity & Srinivasa: Red large mites – females, small whitish green circles – eggs, small greenish mites – males (arrows indicating the mites).

After losing my samples multiple times, I started exploring some tricks and techniques; increasing the sample size. So that, paramount of mites will be retained even after a few consumed by the predators present on the same leaves. Additionally, these predators retained on those leftover mites can be used to build the repository of predatory mites and also the multiple mite pests on the same host, which might have differentiated their niches wisely. Additionally, never forget to keep your slides, culturing trays and vials with absolute alcohol (or the buffer for DNA extraction) while processing, so that you can simultaneously transfer few mites to the culturing trays in addition to making slides and taking them into alcohol/buffer. This will reduce the time of searching them again for different purpose.

Fig. 2. Predatory Cecidomyiid grub: *Feltiella* sp. feeding on *Tetranychus macfarlanei* Baker and Pritchard

While working with mites which are sparse in number and difficult to culture in the laboratory, it's always better to preserve specimen in alcohol to analyze using molecular tools. Always try to make sketches and photographs as soon as slides are ready, otherwise we may miss some novel key features later in a hurry. Never miss to note down even a silly point about the behaviour (webbing pattern, post egg laying rituals/operations, host preferences, crowding and ballooning behaviour, *etc*.) during the processing, although it is not a part of the present research, for sure it's that portentous part, where we will learn science beyond our research for which we all here. For example the webbing, which varies from regular spider mite webbings to multistoried webs in *Tetranychus hirsutus* Zeity & Srinivasa and to nests like webs in *Schizotetranychus* spp, by which sometimes mites can be identified in those samples (at least up to genus level) where only webbings are leftover and can go back to the same location and collect if found interesting.

With all my vigil as a novice in acarology, I can proudly say that mites are one among the masterpieces that Mother Nature has bestowed us with. If we follow a few basic rules with little patience, we can enjoy ourselves with mites too. No alarms are needed; we'll be sitting with eyes full of curiosity, fascination and surprises in front of the microscope. Happy quaren-time.

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Indian Entomologist is a biannual magazine 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.

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