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GUARDIANS OF THE INSECT REALM: SYMBIOTIC MEDIATION FOR HOST PROTECTION

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ABSTRACT

Symbiosis involves the coexistence of dissimilar organisms, with the symbiont referring to the organism residing in this mutually beneficial relationship. Insects consistently harbor microorganisms, typically non-pathogenic, that prove beneficial or even essential for the insect host's well-being. These microorganisms in the insect gut are commonly referred to as microbiota, acting as symbionts in the symbiotic relationship and constituting a significant portion of the insect's biomass, ranging from 1–10 per cent. Symbionts within insects can be categorized as ectosymbionts or endosymbionts based on their developmental site within the host. Additionally, they may be classified as primary or secondary symbionts depending on the host. In the intricate web of life, insects rely directly and indirectly on their microbiota throughout their life cycle. The symbiont plays a crucial role in safeguarding its host from microorganisms, predators, parasites, and even conferring resistance against insecticides. Through the production of toxic compounds such as antibiotics or bacteriocins, symbionts can eliminate or impede the growth of parasites, while also competing with them for host resources. Furthermore, symbionts induce alterations in the host's immune responses, enhancing resistance to parasites or predators. Symbionts can also be used as a source of paratransgenesis. In honey bee, genetically engineered symbiotic bacteria have been used to combat the varroa mite. These paratransgenic symbionts can interfere with the ability of pathogens to infect bees by enhance the immune response. Importantly, symbionts contribute to the fitness of their host during infection without diminishing the fitness of the parasites. This is achieved by boosting host tolerance, thus highlighting the intricate and often advantageous dynamics of symbiotic relationships in the insect world.

Key words : Endosymbiont, Paratransgenesis, Protection, Symbiont, Xenobiotics.

Introduction

Symbiont refers to an organism living in symbiosis, while symbiosis means 'The living together of unlike organism'. The term symbiosis invented by Albert Frank in 1877 described "all the cases where two different species live on or in one another". Examples of symbiosis can be found in all kingdoms of life. The association between pollinating insects and plants is well well-known example of symbiosis. Commonly, the symbiont is smaller than its host. Insects consistently harbour microorganisms that are generally non-pathogenic, often proving to be beneficial or even essential for the well-being of the insect host. Microorganisms present in the insect gut are usually called microbiota. It acts as a symbiont in a symbiosis relationship and accounts for up to 1–10 per cent of the insect's biomass. The relationship between insects and microbiota is significant for evaluating ecological features and feeding habits in insects. It plays important roles in insect physiology and behaviour, such as food digestion (Warnecke *et al.*, 2007), host nutrition (Engel *et al.*, 2012), immune response (Ryu *et al.*, 2008), pathogen defence (Dillon *et al.*, 2005), plant specialization (Mclean *et al.*, 2011), mating preference (Sharon *et al.*, 2010), degradation of xenobiotics or confer resistance to insecticides (Kikuchi *et al*., 2012; Almeida *et al*., 2017; Blanton and Peterson, 2020). Plant sap-sucking aphids (Baumann *et al*., 1995) or blood-feeding tsetse flies (Rio *et al*., 2003) diet having low protein, amino acid and vitamins (Moran *et al*., 2008). These insects can use these minerals through symbiotic associations with microorganisms. The most common micro-organisms are the bacteria found in Dictyoptera, Isoptera, Hemiptera, Anoplura, Mallophaga, Coleoptera, Hymenoptera and Diptera. Among protozoans, flagellates are widely occurring in wood-eating cockroaches and termites (Honigberg, 1970; Yamin, 1979; Brune, 1998; Brune and Friedrich, 2000; Brune, 2006; Brugerolle and Radek, 2006). The yeast is found in some Homoptera, Coleoptera and actinomycetes in *Rhodnius.* Insects are directly and indirectly depending on symbionts. *Wolbachia* is the most common bacteria present in most of all insects (Hilgenboecker *et al*., 2008; Weinert *et al*., 2015). These are cytoplasmically inherited rickettsiae that are found in reproductive tissues (ovaries and testes) of a wide range of arthropods (Hertig and Wolbach, 1924). *Wolbachia* induced parthenogenesis, feminization, male killing and cytoplasmic incompatibility in various host (Stouthamer *et al*., 1999; Werren *et al*., 2008) and also inhibit apoptosis in parasitic wasp (Pannebakker *et al*., 2007). Symbiosis is a broad term, it may be a Mutualism (+, +), Mutualistic interactions benefit both partners (positive effect on each) and therefore represent cooperative or mutually exploitative relationships. Commensalism (+, 0), is a relationship between different species where one organism gains benefits from the relationship and the other is unaffected. e.g., Sexton beetle (genus *Nicrophorus*) covered with mites. Parasitism (+, -), is a symbiont relationship between two organisms. Where one organism (the parasite) gets benefits from the other organism (Host) e.g., the varroa mite parasite on the honey bee. Competition (-, -), Many species compete for the same resources in an ecosystem. If one species has an abundance of resources and another doesn't both species could suffer and possibly die out. Amensalism (0, -), One organism is inhibited or damaged by the presence of the others, who do not benefit.

Symbionts may be ectosymbionts (e.g., *Pseudonocardia* sp. and *Streptomyces* on the body surface of fungus-growing ants) or endosymbionts (e.g., *Buchnera* present in the gut of aphids) according to the developmental site in the host and according to the host; they may be primary and secondary symbiont (Nation, 2009). Primary symbionts are obligate and obligatory symbionts that often are intracellular and may exist in specialized structures (mycetocytes, pouches, cavities) and vertically transmitted by transovarial transmission and it is necessary for the development and reproduction of insects (Baumann, 2005) e.g., *Wolbachia* present in mosquitoes. Secondary symbionts are facultative, either horizontally or vertically transmitted, confer fitness and also increase survival or reproduction (Morrow *et al*., 2014; Chrostek *et al*., 2017) e.g., *Serratia symbiotica* present in aphids. Some symbionts are transmitted by both the ways, known as a mixed-mode transmission (Ebert, 2013).

The flagellates live in the hindguts of wood-eating cockroaches and termites and the bacteria live in the gastric caecae of the last segment of the midgut in plant-sucking Heteroptera. In *Rhodnius,* Actinomycetes live in crypts between the cells of the anterior midgut. The cell-housing symbionts are known as mycetocytes and these may aggregate together to form organs known as mycetomes and if bacterial symbionts then it is known as bacteriocytes (Tembhare, 1997; Maire *et al*., 2020). According to the presence and colonization of symbionts in the insect gut, variation is observed in the various parts of the insect digestive system (Buchner, 1965; Chapman, 1998; Fukatsu and Hosokawa, 2002; Brune, 2010).

Effect of Symbionts on Insects

Directly and indirectly, insects depend on the microbiota in their life cycle. The overall functions of microbiota in insect life are presented in Table 1. Insects' diets are deficient in one or another of the nutrients and minerals to fulfill their requirements insect depends on the microbes present in their body. Insects that are sap-sucking and feed on xylem and phloem, are generally deficient in vitamins and amino acids and are rich in sugars (Redak *et al*., 2004). Blood-feeding insects like *Glossina, Rhodnius,* bed bugs and ticks have a Vitamin B deficient diet and therefore depends on endosymbionts like *Wiggles worthia*, *Rhodococcus rhodnii* other symbionts to obtain sufficient B vitamins (Baines, 1956; Aksoy, 1995; Pachebat *et al*., 2013; Duron and Gottlieb, 2020; Bonnet *et al*., 2017; Hosokawa *et al*., 2010; Michalkova *et al*., 2014). Symbionts can also protect insects against pathogens, natural enemies, plant metabolites, insecticides and also from the harsh environments (Fig. 1) (Miller *et al*., 2021; Frago *et al*., 2012; Ceja-Navarro *et al*., 2015; Barcoto *et al*., 2020; Brumin *et al*., 2011; Trivedi *et al*., 2024; Phugare *et al*., 2013).

Mechanism of Defensive Symbionts

Symbionts produce toxic compounds, such as antibiotics or bacteriocins, which may either kill the parasite or reduce its growth rate and it also, competes with parasites for host resources (Gerardo and Parker,

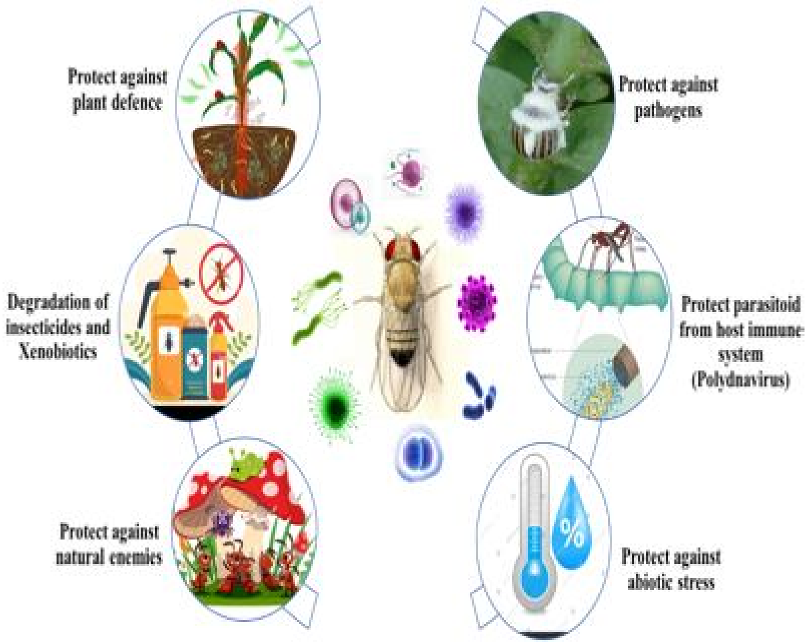

Fig. 1 : Symbionts protect the insect host from different biotic and abiotic stress.

2014; Lombogia *et al*., 2020). It induces changes in their hosts' immune responses that increase resistance to parasites or predators. e.g., in the tsetse fly, *Wiggles worthia* bacteria alter host immune responses such that they suppress trypanosome survival (Gerardo and Parker, 2014). *Wolbachia* activate toll immune pathway in mosquitoes, *Aedes aegypti* to inhibit dengue virus (Bian *et al.*, 2010; Moreira, *et al*., 2009; Pimentel *et al*., 2021). Symbionts increase the fitness of their host during infection without reducing the fitness of the parasites by enhancing host tolerance (Raberg, 2014; Rafaluk-Mohr *et al*., 2022).

Protective Benefit Rendered to insect host by symbionts

Defence Towards Microorganisms

In the year 2009, Yoshiyama and Kimura isolated 35 bacteria from the gut of a Japanese honey bee, *Apis cerana* japonica and they found that out of 35 isolates, seven showed strong inhibitory activity against *Paenibacillus larvae* the causal agent of American foulbrood disease. Most of the symbiont bacteria belonged to *Bacillus* species and also, they reported that symbiont bacteria are absent in first instar larva while present in fourth instar larvae and Forager honey bees. An endosymbiont, *Walbachia* protected fruit flies from Drosophila C virus, Nora and flock house virus (Hedges *et al.*, 2008; Teixeira *et al*., 2008; Brownlie *et al.*, 2009; Schissel *et al*., 2021) and mosquitoes from filarial *Brugia pahangi* infection (Kambris *et al.*, 2009). Koch and Schmid-Hempel (2011) reported that a symbiont bacteria, *Gilliamella apicola* in honey bee and bumble bee gut produces a biofilm on the ileum wall and provides a barrier to attachment or entry of gut parasite, *Crithidia bombi*. Actinobacteria produce secondary metabolites with antifungal activities (Oh *et al*., 2009; Currie *et al.*, 1999; Van Arna *et al*., 2016). Ant-associated *Pseudonocardia* inhibits *Escovopsis* more strongly than it inhibits other fungi (Cafaro *et al.*, 2011). According to Hendry *et al.* (2014), *Rickettsia* infection caused a significant decrease in the death rate related to exposure to the two *Pseudomonas syringe* (B728a and DC3000) strains. A bacterial strain, *Serratia* Y1 infected *Anopheles stephensis* renders the mosquito resistant to *Plasmodium berghei* infection by activation of the toll immune pathway (Bai *et al*., 2019). Symbiont bacteria, *Bombella apis* present in honey bee gut suppress the fungal pathogen, *Beauveria bassiana* and *Aspergillus flavus* by secretion of antifungal metabolites like 1 polyketide, terpene and aryl polyene (Miller *et al*., 2021). A pellet-like structure is present on the legs of mealybugs, which harbours the fungus, *Penicillium citrinum*, protect against other fungal pathogens (Li *et al*., 2024).

Effect on Predation and Parasitisation

A secondary symbiont inoculated aphids (*Acyrthosiphon pisum*) conferred resistance to parasitism by *Aphidius ervi* (Oliver *et al*., 2003; 2005; Oliver and Perlman, 2020; Russell and Moran, 2006). Secondary endosymbiont, *Rickettsiella* increased the amounts of blue-green polycyclic quinines in pea aphids, causing a change in the body color of the host from red to green therefore ladybird beetles tend to consume red aphids on green plants and aphids escape from the predator (Tsuchida, *et al*., 2010, 2014; Polin *et al*., 2015; Nikoh *et al*., 2018). Ladybird beetle, *Hippodamia convergens* larvae fed a diet of aphids (*A. pisum*) with facultative symbionts (*Serratia symbiotica* and *Hamiltonella defensa)* had significantly reduced survival from egg hatching to pupation and therefore had reduced survival to adult emergence (Costopoulos *et al*., 2014; Bennett *et al*., 2016).

Protect against Plant Defense

Insect symbionts degrade secondary metabolites of plants by interfering in the signal transduction pathway (Body *et al*., 2013; Sugio *et al*., 2015). Olive flies (*Bactrocera oleae*) larvae require bacteria (*Candidatus* Erwinia dacicola: Enterobacteriaceae) to develop in

Table 1 : Overall functions of Symbionts in insects.

Insect host species	Transmission route	Symbiont	Proposed roles in hosts	References
Plataspid bug (*Megacopta punctatissima*)	Maternal (egg capsule)	*Ishikawaella capsulatus* (Proteobacterium)	Nutrient provisioning (amino acids)	Fukatsu and Hosokawa (2002), Hosokawa *et al.* (2006)
Grasshopper (*Schistocerca gregaria*)	Acquisition from food	*Enterococcus*, *Serratia*, *Klebsiella*, *Acinetobacter*	Produce components of aggregation pheromone	Dillon *et al.* (2008, 2010)
Fruit fly (*Drosophila melanogaster*)	Acquisition from food	*Lactobacillus* spp., *Acetobacteraceae*, *Orbaceae*	Prime immune system, affect metabolism and mating preferences	Broderick and Lemaitre (2012)
Gypsy moth caterpillar (*Lymantria dispar*)	Acquisition from food	*Pseudomonas*, *Enterobacter*, *Pantoea*, *Serratia*, *Staphylococcus*, *Bacillus*	Unknown, may increase susceptibility to toxin by affecting midgut epithelial permeability	Broderick *et al.* (2004, 2006)
Pea aphid (*Acyrthosiphon pisum*)	Environment	*Staphylococcus*, *Pseudomonas*, *Acinetobacter*, *Pantoea*	Mostly pathogenic, produce signaling compounds that attract aphid predators	Harada *et al.* (1997)
Honey bee (*Apis* spp. and bumble bees (*Bombus* spp.)	Social transmission	*Snodgrassella alvi*, *Gilliamella apicola*, *Lactobacillus* spp.	Digestion, protection against parasites	Koch and Schmid-Hempel (2011), Engel *et al.* (2012), Martinson *et al.* (2011)
Lower termite (*Reticulitermes speratus*)	Social transmission	*Flagellates*, *Bacteroidetes*, *Spirochetes*, *Proteobacteria*, *Firmicutes*	Nutrient provisioning, N recycling, fixation, lignocellulose digestion, fermentation	Nakajima *et al.* (2005), Hongoh *et al.* (2005), Desai and Brune (2012)
Higher termite (*Nasutitermes* sp.)	Social transmission	*Spirochetes*, *Fibrobacteres*, *Bacteroidetes*, *Firmicutes*, *Acidobacteria*, *Proteobacteria*	Nutrient provisioning, N recycling, fixation, cellulose digestion, fermentation	Warnecke *et al.* (2007), Kohler *et al.* (2012)

unripe olives. Bacteria counteract the inhibitory effect of oleuropein which is the principal phenolic glycoside in unripe olives (Ben-Yosef *et al.*, 2010, 2015). Elimination of the gut microbiota, *Pseudomonas fulva* had a significant impact on coffee berry borer (*Hypothenemus hampei*) fitness with approximately a 95 per cent decline in eggs and larvae and no progression to pupa or adults' stage. Bacteria were capable of subsisting on caffeine as a sole carbon and nitrogen source using the digestive tracts of insects (Ceja-Navarro *et al.*, 2015).

Detoxification of Insecticides

In the year 1967, the first case of insecticide resistance by bacterial symbiont was reported by Boush and Matsumur in apple maggot, *Rhagoletis pomonella* (Walsh) against dichlorvos, diazinon, parathion, dieldrin and carbaryl. Bacterial symbionts *Pantoea* and *Pectobacterium* present in different insects like cabbage root flies, flea beetles and aphids degrade isothiocyanates (Welte *et al.*, 2016, 2016a; Shukla and Beran, 2020). Kikuchi *et al.* (2012) from Sapporo (Japan) studied the effect of symbiont bacterial strain on the survival of *Riptortus pedestris* after being exposed to fenitrothion insecticide and concluded that the survival rate of the insects infected with the fenitrothion – degrading *Burkholderia* strains was significantly higher than the survival rate of the insects with non-degrading strains. As per the report of Ramya *et al.* (2015), symbiotic bacteria *Enterobacter asburiae* and *B. cereus* present in the gut of diamondback moth

(*Plutella xylostella*) degraded acephate to methamidophos and *O-O* dimethyl phosphoramidothioate and acephate into O, S-dimethyl phosphoramidothioate, respectively. Almeida *et al*. (2017) isolated several bacteria from the fifth instar larva of the fall armyworm, *Spodoptera frugiperda* which are resistant to lambda-cyhalothrin, deltamethrin, chlorpyrifos ethyl, spinosad and lufenuron. Resistant strain of fruit flies which treated with antibiotics streptomycin significantly increases the mortality of fruit flies as compared to the flies which not treated with antibiotics streptomycin (Cheng *et al*., 2017). Treating certain insects like cockroaches and *Plutella xylostella* L. with antibiotics significantly increases mortality due to the removal of endosymbionts (Xia *et al.,* 2018; Pietri *et al*., 2018). Symbiotic relationships with detoxifying bacteria often develop in hosts after exposure to pesticides, as observed in the case of the brown plant hopper, *Nilaparvata lugens* and its gut symbiont, *Arsenophonus* sp. (Pang *et al.,* 2018). Honey bee gut microbiota promoted the expression of P450 detoxification enzymes in the midgut which increase the survivorship of bees treated with a sublethal dose of thiacloprid or fluvalinate (Wu *et al*., 2020). Symbiotic bacterial strain *Klebsiella pneumoniae* BCH1 isolated from silkworm degrade the imidacloprid insecticides (Phugare *et al.,* 2013). A symbiont, tolerant to pesticides from the genus *Chryseobacterium* within termites demonstrated rapid adaptation to increasing concentrations of imidacloprid insecticides over time (Blanton *et al.* 2023). Bacterial symbionts (*Bacillus* sp., *Klebsiella* sp., *Citrobacter* sp., *Providencia* sp. and *Enterobacter* sp.) present in the hindguts of giant honey bee, *Apis dorsata* degraded the insecticides like Spinosad, fipronil, imidacloprid, cypermethrin and spiromesifen (Trivedi *et al*., 2024).

Protection against Abiotic Stress

Under heat stress, facultative bacterial endosymbionts such as Proteobacteria and Rickettsia confer benefits to pea aphids, *A. pisum* (Montllor *et al*., 2002). The presence of *Rickettsia* in a whitefly, *Bemisia tabaci* induced the expression of genes (Cytoskeleton) under the high temperature which leads to thermotolerance (Brumin *et al*., 2011). *Cardinium* endosymbiont bacteria protect *B. tabaci* against heat stress under 31ºC (Yang *et al*., 2021).

Polydnavirus

Insects possess an immune system to defend themselves against foreign materials. When attacked by parasitoids, they mount a defence against the parasitoid offspring. However, parasitoids especially Ichneumonid and Braconid wasp have evolved a unique strategy to overcome the host's immune response. They carry Polydnaviruses (PDVs) or Virus-Like particles (VLPs), which help protect their offspring from the host's immune defences (Drezen *et al.,* 2017; Herniou *et al.,* 2013). The *Polydnaviridae* family having two genera, *Bracovirus* and *Ichnovirus,* which play a crucial role in suppressing the host's immune system, allowing the parasitoid larvae to develop inside the host without being attacked by its immune defences (Strand and Burke, 2012; Beckage and Drezen, 2012; Stoltz *et al*., 1979; Espagne *et al*., 2004; Webb and Summers, 1982). A Ichneumonid parasitic wasp, *Venturia canescens* produce VLPs from the endogenous PDV nudivirus, which are essential for successful parasitism (Cerqueira de Araujo *et al*., 2022). Polydnavirus (*Toxoneuron nigriceps* BracoVirus; TnBV) present in venom gland and the calyx fluid of endophagous parasitoid wasp, *Toxoneuron nigriceps,* is injected into the *Heliothis virescens* larvae during the injections of eggs and protect parasitoid's eggs from the *H. virescens* immune system by causing loss of haemocyte functionality and inducing cell death (Salvia *et al*., 2023).

Paratransgenesis

Paratransgenesis is the process of symbiont gut bacteria from vectors are isolated sophisticatedly and then genetically modified *in vitro* to produce compounds that prevent the spread of pathogens. The transformed symbionts are then put back into the host vector, where the expression of designed molecules influences the host's vector competence, or capacity to spread the disease (Durvasula *et al*., 1997; Ward *et al*., 2001; Elston *et al.,* 2020). Paratransgenesis can be used to combating the varroa mite, which are a significant threat to bee colonies and also vector for the DWV and *Israeli Acute Paralysis Virus* (IAPV). The Lactic acid Bacterial community, particularly *Lactobacillus* genus having great potential for paratransgenesis in honey bee. Transforming *L. kunkeei* and using it as a vector to promote the health of honey bees and aid in functional genetics research-related activities (Rangberg *et al.*, 2012). In 2020, Leonard *et al*. successfully engineered *Snodgrassella alvi*, a symbiotic bacterium found in honey bees, to induce an RNA interference (RNAi) immune response.

Conclusion

Symbiont-mediated protection is a phenomenon, observed in the natural population of insects. Symbiont enhances the hosts capability to defend against pathogens, predators, parasitoids, insecticides and in some other ways, as an additional immune system. Symbiont mediated protection in insect hosts by employing different protective mechanisms. Protection is mediated as a result of the production of toxins, antibiotics, degradation, or detoxification of harmful compounds which serve as a newer frontier for insect host physiological study.

Future direction and research challenges

Need to understand the nature of toxins and antibiotics utilized in symbiotic mediated protection, isolate and identify beneficial symbiont enzymes for further amplification, develop methods to tuck symbionts in beneficial organisms to impart protection against pesticides and develop methods to suppress facultative symbionts to increase the survival rate of beneficial organisms.

References

Aksoy, S. (1995). *Wigglesworthia* gen. nov. and *Wigglesworthia glossinidia* sp. nov., taxa consisting of the mycetocyte-associated, primary endosymbionts of tsetse flies. *Int. J. Syst. Evolut. Microbiol.*, **45(4)**, 848-851.

Almeida, L.G., Moraes L.A.B., Trigo J.R., Omoto C. and Consoli F.L. (2017). The gut microbiota of insecticide-resistant insects houses insecticide-degrading bacteria: A potential source for biotechnological exploitation. *PLoS One*, **12(3)**, 1-19.

Bai, L., Wang L., Vega-Rodríguez J., Wang G. and Wang S. (2019). A Gut Symbiotic Bacterium *Serratia marcescens* Renders Mosquito Resistance to Plasmodium Infection Through Activation of Mosquito Immune Responses. *Front. Microbiol.*, **10(1580)**, 1-11.

Baines, S. (1956). The role of the symbiotic bacteria in the nutrition of *Rhodnius prolixus* (Hemiptera). *J. Exp. Biol.*, **33(3)**, 533-541.

Barcoto, M.O., Carlos-Shanley C., Fan H., Ferro M., Nilson S.N., Bacci J.M., Currie C.R. and Rodrigues A. (2020). Fungus-growing insects host a distinctive microbiota apparently adapted to the fungiculture environment. *Scientific Reports*, **10**, 12384.

Baumann, P., Baumann L., Lai C.Y., Rouhbakhsh D., Moran N.A. and Clark M.A. (1995). Genetics, physiology, and evolutionary relationships of the genus *Buchnera*: intracellular symbionts of aphids. *Annu. Rev. Bicrobiol.*, **49**, 55–94.

Baumann, P. (2005). Biology of bacteriocyte-associated endosymbionts of plant sap-sucking insects. *Annu. Rev. Bicrobiol.*, **59(1)**, 155-189.

Beckage, N.E. and Drezen J.M. (2012). *Parasitoid Viruses: Symbionts and Pathogens*. Elsevier.

Bennett, A.E., Millar N.S., Gedrovics E. and Karley A.J. (2016). Plant and insect microbial symbionts alter the outcome of plant–herbivore–parasitoid interactions: implications for invaded, agricultural and natural systems. *J. Ecol.*, **104(6)**, 1734-1744.

Ben-Yosef, M., Pasternak Z., Jurkevitch E. and Yuval B. (2015). Symbiotic bacteria enable olive fly larvae to overcome host defences. *Royal Soc. Open Sci.*, **2(150170)**, 1-14.

Ben-Yosef, M., Aharon Y., Jurkevitch E. and Yuval B. (2010). Give us the tools and we will do the job: symbiotic bacteria affect olive fly fitness in a diet-dependent fashion. *Proc. Royal Soc. B: Biolog. Sci.*, **277(1687)**, 1545-1552.

Bian, G., Xu Y., Lu P., Xie Y. and Xi Z. (2010). The endosymbiotic bacterium Wolbachia induces resistance to dengue virus in Aedes aegypti. *PLoS Pathogens*, **6(4)**, e1000833.

Blanton, A.G. and Peterson B.F. (2020). Symbiont-mediated insecticide detoxification as an emerging problem in insect pests. *Front. Microbiol.*, **11**, 547108.

Blanton, A.G., Perkins S. and Peterson B.F. (2023). *In vitro* assays reveal inherently insecticide-tolerant termite symbionts. *Front. Physiol.*, **14**.

Body, M., Kaiser W., Dubreuil G., Casas J. and Giron D. (2013). Leaf-miners co-opt microorganisms to enhance their nutritional environment. *J. Chem. Ecol.*, **39**, 969-977.

Bonnet, S.I., Binetruy F., Hernández-Jarguín A.M. and Duron O. (2017). The tick microbiome: why non-pathogenic microorganisms matter in tick biology and pathogen transmission. *Front. Cell. Infect. Microbiol.*, **7**, 236.

Boush, G.M. and Matsumur F. (1967). Insecticidal Degradation by *Pseudomonas melophthora*, the Bacterial Symbiote of the Apple Maggot. *J. Econ. Entomol.*, **60(4)**, 918-920.

Broderick, N.A. and Lemaitre B. (2012). Gut-associated microbes of *Drosophila melanogaster*. *Gut Microbes*, **3**, 307–321.

Broderick, N.A., Raffa K.F. and Handelsman J. (2006). Midgut bacteria required for Bacillus thuringiensis insecticidal activity. *The Proc. Nat. Acad. Sci.*, **103**, 15196–15199.

Broderick, N.A., Raffa K.F., Goodman R.M. and Handelsman J. (2004). Census of the bacterial community of the gypsy moth larval midgut by using culturing and culture independent methods. *Appl. Environ. Microbiol.*, **70**, 293–300.

Brownlie, J.C. and Johnson K.N. (2009). Symbiont-mediated protection in insect hosts. *Trends Microbiol.*, **17(8)**, 348–354.

Brugerolle, G. and Radek R. (2006). Symbiotic protozoa of termites. Pp. 243-269 in: König, H. and Varma A. (Eds). Intestinal microorganisms of soil invertebrates. Germany, Springer Verlag Berlin Heidelberg. 483 pp.

Brumin, M., Kontsedalov S. and Ghanim M. (2011). *Rickettsia* influences thermotolerance in the whitefly *Bemisia tabaci* B biotype. *Insect Sci.*, **18(1)**, 57-66.

Brune, A. (2010). Methanogenesis in the Digestive Tracts of Insects. *Handbook of Hydrocarbon and Lipid Microbiology,* pp 707-728. Timmis, K.N. (eds). Springer, Berlin, Heidelberg.

Brune, A. (1998). Termite guts: the world's smallest bioreactors. *Trends Biotechnol.*, **16(1)**, 16-21.

Brune, A. (2006). Symbiotic Associations Between Termites and Prokaryotes. In: Dworkin, M., Falkow S., Rosenberg E., Schleifer K.H. and Stackebrandt E. (eds) The Prokaryotes. Springer, New York, NY.

Brune, A. and Friedrich M. (2000). Microecology of the termite gut: structure and function on a microscale. *Curr. Opinion Microbiol.,* **3(3)**, 263-269.

Buchner, P. (1965). *Endosymbiosis of animals with plant microorganisms*. New York, NY: John Wiley & Sons and Inder science Publishers.

Cafaro, M.J., Michael P., Ainslie E.F.L., Shauna L.P., Nicole M.G., Bess W., Alison E.S., Bret L., Patrick A. and Cameron R.C. (2011). Specificity in the symbiotic association between fungus-growing ants and protective *Pseudonocardia* bacteria. *Proc. Royal Soc. B: Biolog. Sci.,* **278**, 1814–1822.

Ceja-Navarro, J.A., Fernando E.V., Ulas K.Z.H., Stefan J., Hsiao C.L., Petr K., Francisco I., Trent R.N. and Eoin L.B. (2015). Gut microbiota mediate caffeine detoxification in the primary insect pest of coffee. *Nat. Commun.,* **6 (7618)**, 1-9.

Cerqueira de Araujo, A., Leobold M., Bézier A., Musset K., Uzbekov R., Volkoff A.N., Drezen J.M., Huguet E. and Josse T. (2022). Conserved Viral Transcription Plays a Key Role in Virus-Like Particle Production of the Parasitoid Wasp *Venturia canescens*. *J. Virol.*, **96(13)**, e0052422.

Chapman, R.F. (1998). The insects: structure and function. Cambridge: Cambridge University Press. 4th ed.

Cheng, D., Guo Z., Riegler M., Xi Z., Liang G. and Xu Y. (2017). Gut symbiont enhances insecticide resistance in a significant pest, the oriental fruit fly *Bactrocera dorsalis* (Hendel). *Microbiome*, **5(13)**, 1-12.

Chrostek, E., Pelz-Stelinski K., Hurst G.D.D. and Hughes G.L. (2017). Horizontal Transmission of Intracellular Insect Symbionts via Plants. *Front. Microbiol.*, **8**, 2237.

Costopoulos, K., Kovacs J.L., Kamins A. and Gerardo N.M. (2014). Aphid facultative symbionts reduce survival of the predatory lady beetle *Hippodamia convergens*. *BioMed Central Ecology*, **14(5)**, 1-7.

Currie, C.R., Scott J.A., Summerbell R.C. and Malloch D. (1999). Fungus-growing ants use antibiotic-producing bacteria to control garden parasites. *Nature*, **398**, 701-704

Desai, M.S. and Brune A. (2012). *Bacteroidales* ectosymbionts of gut flagellates shape the nitrogen-fixing community in dry-wood termites. *ISME J.,* **6**, 1302–1313.

Dillon, R.J., Vennard C.T., Buckling A. and Charnley A.K. (2005). Diversity of locust gut bacteria protects against pathogen invasion. *Ecology Letters*, **8(12)**, 1291-1298.

Dillon, R.J., Webster G., Weightman A.J. and Keith Charnley A. (2010). Diversity of gut microbiota increases with aging and starvation in the desert locust. *Antonie Van Leeuwenhoek*, **97**, 69–77.

Dillon, R.J., Webster G., Weightman A.J., Dillon V.M., Blanford S. and Charnley A.K. (2008). Composition of Acridid gut bacterial communities as revealed by 16S rRNA gene analysis. *J. Inverteb. Pathol.,* **97**, 265–272.

Drezen, J.M., Leobold M., Bézier A., Huguet E., Volkoff A.N. and Herniou E.A. (2017). Endogenous viruses of parasitic wasps: variations on a common theme. *Curr. Opin. Virol.*, **25**, 41–48.

Duron, O. and Gottlieb Y. (2020). Convergence of Nutritional Symbioses in Obligate Blood Feeders. *Trends Parasitol.,* **36(10)**, 816-825.

Durvasula, R.V., Gumbs A., Panackal A., Kruglov O., Aksoy S., Merrifield R.B. and Beard C.B. (1997). Prevention of insect-borne disease: an approach using transgenic symbiotic bacteria. *Proc. Nat. Acad. Sci.,* **94(7)**, 3274-3278.

Ebert, D. (2013). The epidemiology and evolution of symbionts with mixed-mode transmission. *Annu. Rev. Ecol., Evol. Systemat.*, **44(1)**, 623-643.

Elston, K.M., Perreau J., Maeda G.P., Moran N. and Barrick J.E. (2020). Engineering a Culturable *Serratia symbiotica* Strain for Aphid Paratransgenesis. *Appl. Environ. Microbiol.,* **87**.

Engel, P., Martinson V.G. and Moran N.A. (2012). Functional diversity within the simple gut microbiota of the honey bee. *The Proc. Nat. Acad. Sci.,* **109**, 11002–11007.

Espagne, E., Dupuy C., Huguet E., Cattolico, L., Provost B. and Martins N. (2004). Genome sequence of a polydnavirus: insights into symbiotic virus evolution. *Science,* **306(5694)**, 286-289.

Frago, E., Dicke M. and Godfray H.C.J. (2012). Insect symbionts as hidden players in insect–plant interactions. *Trends Ecol. Evol.*, **27(12)**, 705-711.

Fukatsu, T. and Hosokawa T. (2002). Capsule-transmitted gut symbiotic bacterium of the Japanese common plataspid stinkbug, *Megacopta punctatissima*. *Appl. Environ. Microbiol.,* **68**, 389–396.

Gerardo, N.M. and Parker B.J. (2014). Mechanisms of symbiont-conferred protection against natural enemies: an ecological and evolutionary framework. *Curr. Opin. Insect Sci.,* **4**, 8-14.

Harada, H., Oyaizu H., Kosako Y. and Ishikawa H. (1997). *Erwinia aphidicola*, a new species isolated from pea aphid, *Acyrthosiphon pisum*. *The J. Gen. Appl. Microbiol.,* **43**, 349–354.

Hedges, L.M., Brownlie J.C., O'Neill S.L. and Johnson K.N. (2008). *Wolbachia* and virus protection in insects. *Science (New York, N.Y.)*, **322(5902)**, 702.

Hendry, T.A., Hunter M.S. and Baltrus D.A. (2014). The Facultative Symbiont Rickettsia Protects an Invasive Whitefly against Entomopathogenic *Pseudomonas syringae* Strains. *Appl. Environ. Microbiol.,* **80(23)**, 7161–7168.

Herniou, E.A., Huguet E., Thézé J., Bézier A., Periquet G. and Drezen J.M. (2013). When parasitic wasps hijacked viruses: genomic and functional evolution of polydnaviruses. *Philosophical transactions of the Royal Society of London. Series B, Biological sciences*, **368(1626)**, 20130051.

Hertig, M. and Wolbach S.B. (1924). Studies on rickettsia-like micro-organisms in insects. *The J. Med. Res*., **44(3)**, 329.

Hilgenboecker, K., Hammerstein P., Schlattmann P., Telschow A. and Werren J.H. (2008). How many species are infected with *Wolbachia*? – a statistical analysis of current data. *FEMS Microbiol. Lett.*, **281(2)**, 215-220.

Hongoh, Y., Deevong P., Inoue T., Moriya S., Trakulnaleamsai S., Ohkuma M., Vongkaluang C., Noparatnaraporn N. and Kudo T. (2005). Intra- and interspecific comparisons of bacterial diversity and community structure support coevolution of gut microbiota and termite host. *Appl. Environ. Microbiol.,* **71**, 6590–6599.

Honigberg, B.M. (1970). Protozoa associated with termites and their role in digestion. *The biology of Termites*, 1-36.

Hosokawa, T., Kikuchi Y., Nikoh N., Shimada M. and Fukatsu T. (2006). Strict host-symbiont cospeciation and reductive genome evolution in insect gut bacteria. *PLoS Biology,* **4**, e337.

Hosokawa, T., Koga R., Kikuchi Y., Meng X.Y. and Fukatsu T. (2010). *Wolbachia* as a bacteriocyte-associated nutritional mutualist. *Proc. Nat. Acad. Sci.*, **107(2)**, 769-774.

Kambris, Z., Peter E., Hoang K.P. and Steven P.S. (2009). Immune activation by life-shortening *Wolbachia* and reduced filarial competence in mosquitoes. *Science,* **326(5949)**, 134–136.

Kikuchia, Y., Hayatsuc M., Hosokawa T., Nagayamae A., Tagoc K. and Fukatsu T. (2012). Symbiont-mediated insecticide resistance. *The Proc. Nat. Acad. Sci.,* **109(22)**, 8618–8622.

Koch, H. and Schmid-Hempel P. (2011). Socially transmitted gut microbiota protect bumble bees against an intestinal parasite. *Proc. Nat. Acad. Sci. United States of America,* **108(48)**, 19288–19292.

Kohler, T., Dietrich C., Scheffrahn R.H. and Brune A. (2012). High- € resolution analysis of gut environment and bacterial microbiota reveals functional compartmentation of the gut in wood-feeding higher termites (*Nasutitermes* spp.). *Appl. Environ. Microbiol.,* **78**, 4691–4701.

Leonard, S.P., Powell J.E., Perutka J., Geng P., Heckmann L.C., Horak R.D., Davies B.W., Ellington A.D., Barrick J.E. and Moran N.A. (2020). Engineered symbionts activate honey bee immunity and limit pathogens. *Science,* **367(6477)**, 573-576.

Li, Z., Tong H., Ni M., Zheng Y., Yang X., Tan Y., Li Z. and Jiang M. (2024). An at-leg pellet and associated *Penicillium* sp. provide multiple protections to mealybugs. *Communications Biology,* **7**.

Lombogia, C.A., Tulung M., Posangi J. and Tallei T.E. (2020) Antibacterial activities of culture-dependent bacteria isolated from *Apis nigrocincta* gut. *The Open Microbiol. J.*, **14**, 72-76.

Maire, J., Parisot N., Galvao Ferrarini M., Vallier A., Gillet B., Hughes S., Balmand S., Vincent-Monégat C., Zaidman-Rémy A. and Heddi A. (2020). Spatial and morphological reorganization of endosymbiosis during metamorphosis accommodates adult metabolic requirements in a weevil. *Proc. Nat. Acad. Sci.*, **117(32)**, 19347-19358.

Martinson, V.G., Danforth B.N., Minckley R.L., Rueppell O., Tingek S. and Moran N.A. (2011). A simple and distinctive microbiota associated with honey bees and bumble bees. *Molecular Ecology,* **20**, 619–628.

McLean, A.H.C., Van Asch M., Ferrari J. and Godfray H.C.J. (2011). Effects of bacterial secondary symbionts on host plant use in pea aphids. *Proc. Royal Soc. B: Biolog. Sci.,* **278(1706)**, 760-766.

Michalkova, V., Benoit J.B., Weiss B.L., Attardo G.M. and Aksoy S. (2014). Vitamin B6 generated by obligate symbionts is critical for maintaining proline homeostasis and fecundity in tsetse flies. *Appl. Environ. Microbiol.*, **80(18)**, 5844-5853.

Miller, D.L., Smith E.A. and Newton I. (2021). A Bacterial Symbiont Protects Honey Bees from Fungal Disease. *Amer. Soc. Microbiol.,* **12(3)**, 1-9.

Montllor, C., Maxmen A., & Purcell, A. H. (2002). Facultative bacterial endosymbionts benefits pea aphids *Acyrthosiphon pisum* under heat stress. *Ecological Entomol.*, **27**, 189-195.

Moran, Nancy, A., John P., McCutcheon and Atsushi N (2008) Genomics and evolution of heritable bacterial symbionts. *Annu. Rev. Genet.*, **42(1)**, 165-190.

Moreira, L.A., Iturbe-Ormaetxe I., Jeffery J.A., Lu G., Pyke A.T., Hedges L.M., Rocha B.C, Hall-Mendelin S., Day A., Riegler M., Hugo L.H., Johnson K.N., Kay B.H., McGraw E.A., Hurk A.F., Ryan P.A. and O'Neill S.L. (2009). A *Wolbachia* symbiont in *Aedes aegypti* limits infection with dengue, Chikungunya and Plasmodium. *Cell.*, **139(7)**, 1268-1278.

Morrow, J.L., Frommer M., Shearman D.C.A. and Riegler M. (2014). Tropical tephritid fruit fly community with high incidence of shared *Wolbachia* strains as platform for horizontal transmission of endosymbionts. *Environ. Microbiol.*, **16(12)**, 3622-3637.

Nakajima, H., Hongoh Y., Usami R., Kudo T. and Ohkuma M. (2005). Spatial distribution of bacterial phylotypes in the gut of the termite *Reticulitermes speratus* and the bacterial community colonizing the gut epithelium. *FEMS Microbiol. Ecol.,* **54**, 247–255.

Nation, J.L. (2009). *Insect Physiology and Biochemistry*. Florida, USA: CRC Press, pp 592–593.

Nikoh, N., Tsuchida T., Maeda T., Yamaguchi K., Shigenobu S., Koga R. and Fukatsu T. (2018). Genomic Insight into Symbiosis-Induced Insect Color Change by a Facultative Bacterial Endosymbiont, "*Candidatus Rickettsiella viridis*". *Mole. Biol. Microbiol.,* **9(3)**, e00890-18.

Oh, D.C., Scott J.J., Currie C.R. and Clardy J. (2009). Mycangimycin, a polyene peroxide from a mutualist *Streptomyces* sp. *Organic Lett.*, **11**, 633–636.

Oliver, K.M., Moran N.A. and Hunter M.S. (2005). Variation in resistance to parasitism in aphids is due to symbionts not host genotype. *Proc. Nat. Acad. Sci. United States*

America, **102(36)**, 12795–12800.

Oliver, K.M., Russell J.A., Moran N.A. and Hunter M.S. (2003). Facultative bacterial symbionts in aphids confer resistance to parasitic wasps. *Proc. Nat. Acad. Sci. United States America*, **100(4)**, 1803-1807.

Oliver, K.M. and Perlman S.J. (2020). Toxin-mediated protection against natural enemies by insect defensive symbionts. *Adv. Insect Physiol.*, **58**, 277-316.

Pachebat, J.A., Van Keulen G., Whitten M.M., Girdwood S., Del Sol R., Dyson P.J. and Facey P.D. (2013). Draft genome sequence of *Rhodococcus rhodnii* strain LMG5362, a symbiont of *Rhodnius prolixus* (Hemiptera, Reduviidae, Triatominae), the principle vector of *Trypanosoma cruzi*. *Genome Announcements*, **1(3)**, 10-1128.

Pang, R., Chen M., Yue L., Xing K., Li T., Kang K., Liang Z., Yuan L. and Zhang W. (2018). A distinct strain of *Arsenophonus symbiont* decreases insecticide resistance in its insect host. *PLoS Genetics*, **14(10)**, e1007725.

Pannebakker, B.A., Loppin B., Elemans C.P.H., Humblot L. and Vavre F. (2007). Parasitic inhibition of cell death facilitates symbiosis. *Proc. Nat. Acad. Sci. United States America*, **104(1)**, 213-215.

Phugare, S.S., Kalyani D., Gaikwad Y.B. and Jadhav J.P. (2013). Microbial degradation of imidacloprid and toxicological analysis of its biodegradation metabolites in silkworm (*Bombyx mori*). *Chem. Engg J.*, **230**, 27-35.

Pietri, J.E., Tiffany C. and Liang D. (2018). Disruption of the microbiota affects physiological and evolutionary aspects of insecticide resistance in the German cockroach, an important urban pest. *PLoS ONE*, **13(12)**, 1-17.

Pimentel, A.C., Cesar C.S., Martins M. and Cogni R. (2021). The Antiviral Effects of the Symbiont Bacteria *Wolbachia* in Insects. *Front. Immunol.*, **11**, 626329.

Polin, S., Le, Gallic J.F., Simon J.C., Tsuchida T. and Outreman Y. (2015). Conditional Reduction of Predation Risk associated with a Facultative Symbiont in an Insect. *PLOS ONE*, **10(11)**, e0143728.

Raberg, L. (2014). Decomposing health: tolerance and resistance to parasites in animals. *PLoS Biol.*, **12(11)**, 15-21.

Rafaluk-Mohr, C., Gerth M., Sealey J.E., Ekroth A.K.E., Aboobaker A.A., Kloock A. and King K.C. (2022). Microbial protection favors parasite tolerance and alters host-parasite coevolutionary dynamics. *Curr. Biol.*, **32(7)**, 1593–1598.e3.

Ramya, S.L., Venkateson T., Murthy K.S., Jalali S.K. and Varghese A. (2016). Degradation of acephate by *Enterobacter asburiae*, *Bacillus cereus* and *Pantoea agglomerans* isolated from diamondback moth *Plutella xylostella* (L), a pest of cruciferous. *J. Environ. Biol.*, **37**, 611-618.

Rangberg, A., Diep D.B., Rudi K. and Amdam G.V. (2012). Paratransgenesis: an approach to improve colony health and molecular insight in honey bees (*Apis mellifera*)?. *Integrative and Comparative Biology*, **52(1)**, 89–99.

Redak, R.A., Purcell A.H., Lopes J.R., Blua M.J., Mizell Iii R.F. and Andersen P.C. (2004). The biology of xylem fluid–feeding insect vectors of *Xylella fastidiosa* and their relation to disease epidemiology. *Annu. Rev. Entomol.*, **49**, 243–270.

Rio, R.V., Lefevre C., Heddi A. and Aksoy S. (2003). Comparative genomics of insect-symbiotic bacteria: influence of host environment on microbial genome composition. *Appl. Environ. Microbiol.*, **69(11)**, 6825–6832.

Russell, J.A. and Moran N.A. (2006). Costs and benefits of symbiont infection in aphids: variation among symbionts and across temperatures. *Proc. Royal Soc. B: Biolog. Sci.*, **273**, 603–610.

Ryu, J.H., Kim S.H., Lee H.Y., Bai J.Y., Nam Y.D., Bae J.W., Lee D.G., Shin S.C., Ha E. and Lee W.J. (2008). Innate immune homeostasis by the homeobox gene caudal and commensal-gut mutualism in Drosophila. *Science*, ***319*(5864)**, 777-782.

Salvia, R., Scieuzo C., Boschi A., Pezzi M., Mistri M., Munari C., Chicca M., Vogel H., Cozzolino F., Monaco V., Monti M. and Falabella P. (2023). An overview of Ovarian Calyx Fluid Proteins of *Toxoneuron nigriceps* (Viereck) (Hymenoptera: Braconidae): An Integrated Transcriptomic and Proteomic Approach. *Biomolecules*, **13**.

Schissel M., Best R., Liesemeyer S., Tan Y.D., Carlson D.J., Shaffer J.J., Avuthu N., Guda C. and Carlson K.A. (2021). Effect of Nora virus infection on native gut bacterial communities of *Drosophila melanogaster*. *AIMS Microbiol.*, **7(2)**, 216–237.

Shukla, S.P. and Beran F. (2020). Gut microbiota degrades toxic isothiocyanates in a flea beetle pest. *Mole. Ecol.*, **29(23)**, 4692-4705.

Stoltz, D.B., Vinson S.B. and Summers M.D. (1979). Virus particles and viral antigen in the venom apparatus of the endoparasitic wasp *Biosteres (=Opius) longicaudatus* (Hymenoptera: Braconidae). *J. Inverteb. Pathol.*, **34(3)**, 272-278.

Stouthamer, R., Breeuwer J.A. and Hurst G.D. (1999). *Wolbachia* pipientis: microbial manipulator of arthropod reproduction. *Annu. Rev. Microbiol.*, **53(1)**, 71-102.

Strand, M.R. and Burke G.R. (2012). Polydnaviruses: from discovery to current insights. *Virology*, **435(1)**, 7-17.

Sugio, A., Dubreuil G., Giron D. and Simon J.C. (2015). Plant–insect interactions under bacterial influence: Ecological implications and underlying mechanisms. *J. Exp. Bot.*, **66(2)**, 467-478.

Teixeira, L., Ferreira Á. and Ashburner M. (2008). The Bacterial Symbiont *Wolbachia* Induces Resistance to RNA Viral Infections in *Drosophila melanogaster*. *PLOS Biol.*, **6(12)**, e1000002.

Tembhare, D.B. (1997). *Modern Entomology*, p 80 Nagpur, Maharashtra: Himalaya Publishing House Pvt. Ltd.

Trivedi, N., Sisodiya D.B., Raghunandan B.L., Thumar R.K. and Parmar R.G. (2024). Toxicity of Insecticides to

Pollinators in Cucumber Vis-À-Vis Tolerant Gut Microbiota of *Apis dorsata* Fabricius. *Pest. Res. J.,* **36(1)**, 68-73.

Tsuchida, T., Koga R., Horikawa M., Tsunoda T., Maoka T., Matsumoto S., Simon J.C. and Fukatsu T. (2010). Symbiotic bacterium modifies aphid body color. *Science*, **330(6007)**, 1102-1104.

Tsuchida, T., Koga R., Fujiwara A. and Fukatsu T. (2014). Phenotypic effect of "*Candidatus Rickettsiella viridis*," a facultative symbiont of the pea aphid (*Acyrthosiphon pisum*) and its interaction with a coexisting symbiont. *Appl. Environ. Microbiol.*, **80(2)**, 525-533.

Van Arnam, E.B., Ruzzini A.C., Sit C.S., Horn H., Pinto-Tomás A.A., Currie C.R. and Clardy J. (2016). Selvamicin, an atypical antifungal polyene from two alternative genomic contexts. *Proc. Nat. Acad. Sci.*, **113(46)**, 12940-12945.

Wang, Z., Zhao Y., Yong H., Liu Z., Wang W. and Lu Y. (2023). The contribution of gut bacteria to pesticide resistance of *Tribolium castaneum* (Herbst). *J. Stored Prod. Res.*, **103**, 102160.

Ward, T.W., Jenkins M.S., Afanasiev B.N., Edwards M., Duda B.A., Suchman E., Jacobs-Lorena M., Beaty B.J. and Carlson J.O. (2001). *Aedes aegypti* transducing densovirus pathogenesis and expression in *Aedes aegypti* and *Anopheles gambiae* larvae. *Insect Mole. Biol.*, **10(5)**, 397-405.

Warnecke, F., Luginbühl P., Ivanova N., Ghassemian M., Richardson T.H., Stege J.T., Cayouette M., McHardy A.C., Djordjevic G., Aboushadi N., Sorek R., Tringe S.G., Podar M., Martin H.G., Kunin V., Dalevi D., Madejska J., Kirton E., Platt D. and Leadbetter J.R. (2007). Metagenomic and functional analysis of hindgut microbiota of a wood-feeding higher termite. *Nature*, **450**, 560–565.

Webb, B.A. and Summers M.D. (1982). Venom and viral expression products of endoparasitic wasps: Applications in sericulture. *Science*, **218(4577)**, 671-677.

Weinert, L.A., Araujo-Jnr E.V., Ahmed M.Z. and Welch J.J. (2015). The incidence of bacterial endosymbionts in terrestrial arthropods. *Proc. Royal Soc.B: Biolog. Sci.*, **282(1807)**, 20150249.

Welte, C.U., de Graaf R.M., van den Bosch T.J., Op den Camp H.J., van Dam N.M. and Jetten M.S. (2016). Plasmids from the gut microbiome of cabbage root fly larvae encode SaxA that catalyses the conversion of the plant toxin 2 phenylethyl isothiocyanate. *Environ. Microbiol.*, **18(5)**, 1379-1390.

Welte, C.U., Rosengarten J.F., de Graaf R.M. and Jetten M.S. (2016a). SaxA-mediated isothiocyanate metabolism in phytopathogenic pectobacteria. *Appl. Environ. Microbiol.*, **82(8)**, 2372-2379.

Werren, J., Baldo L. and Clark M. (2008). *Wolbachia:* master manipulators of invertebrate biology. *Nature Rev Microbiol.*, **6**, 741–751.

Wu, Y., Zheng Y., Chen Y., Wang S., Chen Y., Hu F. and Zheng H. (2020). Honey bee (*Apis mellifera*) gut microbiota promotes host endogenous detoxification capability via regulation of P450 gene expression in the digestive tract. *Microbial Biotechnol.*, 13(4), 1201-1212.

Xia, X., Sun B., Gurr G.M., Vasseur L., Xue M. and You M. (2018). Gut microbiota mediate insecticide resistance in the diamondback moth, *Plutella xylostella* (L.). *Front. Microbiol.*, **9**, 25.

Yamin, M.A. (1979). Flagellates of the orders Trichomonadida Kirby, Oxymonadida Grassé and Hypermastigida Grassi and Foà reported from lower termites (Isoptera families Mastotermitidae, Kalotermitidae, Hodotermitidae, Termopsidae, Rhinotermitidae, and Serritermitidae) and from the wood-feeding roach Cryptocercus (Dictyoptera: Cryptocercidae). *Sociobiology,* **4**, 3-117.

Yang, K., Yuan M., Liu Y., Guo C., Liu T., Zhang Y. and Chu D. (2021). First evidence for thermal tolerance benefits of the bacterial symbiont Cardinium in an invasive whitefly, *Bemisia tabaci*. *Pest Manage. Sci.,* **77(11)**, 5021-5031.

Yoshiyama, M. and Kimura K. (2009). Bacteria in the gut of Japanese honeybee, *Apis cerana japonica* and their antagonistic effect against *Paenibacillus larvae*, the causal agent of American foulbrood. *J. Invert. Pathol.*, **102**, 91–96.