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HOW APHIDS AND HYGIENE INSECT PESTS RESPOND TO STRESSFUL ENVIRONMENTAL CONDITIONS

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ABSTRACT

Environmental stressors such as heat, cold, or natural enemies may alter insect genetics, behavior, morphology, or physiology, increasing their offspring's survival. Special traits and variations in population characteristics of insects enhance their resistant genotypes and can lead to adaptation to stressors under local conditions. Insects' reactions to stressors, such as toxins, plant defense toxicants, or insecticides, trigger internal hormonal secretions. Changes in host plants or feeding on blood produce metabolic stress and neural signal responses in insects. Mild stress is often tolerated by insect pests. Continued stress may activate the neuroendocrine system and produce hormones that defend against stress, increasing the pest's tolerance. Mimesis and camouflage in insects are evolutionary responses to escape the stresses of natural enemies. Fluctuating asymmetry and morphological changes in pest populations are also caused by stress. The reaction of cells to stress involves cytogenetic changes and the formation of various proteins through genetic signals that affect cell energy acquisition. In this article, we discuss the effects of stress on a few species of medically important insects and how pests cope with stress factors that affect their biology.

Keywords:

Aphids, Pests, Hygiene, Stress.

INTRODUCTION

Insects are very sensitive to environmental stress and are known to be stress indicators. They are frequently showing some deviation from symmetry called fluctuating asymmetry (FA) after living for a few generations in stressful conditions (3, 46). The fluctuating asymmetry (FA) is very common method for measuring stress effects on insect morphology (3). Exposition to nutrition deficiency, toxicants, pesticides, or excessive heat or cold conditions may produce asymmetry. Insect brain reacts quickly to stress by secretion of neuro-hormones, octopamine, serotonin, diamine and other biogenic amines (14, 50, 51). Insects feel stress by their sensory organs that cause brain reaction by octopamine, ecdysteroids, and glucocorticoids secretion. Stress hormones change insect physiology and behavior and with its continuous stimuli their metabolic hormones may cause morphological changes. Stress reactions on honeybee is intensively studied and reviewed by Even et al. 2012 (13). Most insect activities such as, flight, photoperiodic effects or circadian rhythms and migration are regulated by endocrine biogenic amines and neurosecretory hormones such as octopamine (51).

Environmental stress influence life process of insects and their host plants. *Myzus persicae* with variable life cycle is adapted to live on more than hundred herbaceous plants. In localities with freezing winter temperatures *M. persicae* produce sexual morphs and after copulation female lays eggs on *Prunus persica*. In spring crowding and high temperature stress changes many aphid species to winged morph for migration and living on summer hosts. In areas with warm winters they reproduce pathenogenetically throughout their life (62). Desertification of lands and climatic changes forced insects to adapt and feed on available plants or crops or they become extinct (23). Rarity or extinction of their natural hosts is also another reason for insects to feed on local crops. The main research activities on insect pests are concentrated on understanding their population genetic variation. These pests quickly acquire genetic traits in parts of their populations to increase their fitness and adaptation to survive unsuitable field practices. Rotation can produce stress of starvation for special crop pests. When temperatures exceed 25 C. and drought increases aphids fitness on natural vegetation decrease while it can increase their damage on crops and greenhouse plants (35).

Stress with various effects on hygiene insects such as mosquito cockroach or bed bugs is also studied (1, 2). Insects like mosquitoes which feed on human blood face severe oxidative stress due to the release of iron from hemoglobin which in turn can potentially induce oxidative damage and eventually death. To face such odd situation, blood-feeding insects evolved with strong defense mechanisms against the stress. Survived houseflies are evolved by antioxidant capacity to produce H_2O_2 and detoxification enzymes. Superoxide dismutase is well known enzyme that catalases superoxide anion to (O^{2-}) as defense line against oxidative stress. Glutathione peroxidase and peroxiredoxins are group of enzymes mediating cell signal transduction. They are stress-related proteins with some evidence of acting as aging process in flies. The evolutionary reaction of houseflies to stressors needs further genome sequencing research that may affect their evolution (18).

The basic effects of stress on insects beside brain and FA are physiological, development, ecological, cellular, and genetic traits (9, 20, 27, 36, 37). Stressors signal received by extra receptor transmitters via sensory nerves is carried to brain along insect cardiac nerves signaling for release of corpora cardiac (CC) hormones. It mobilizes the fat body adipokinetic hormone (ADPKH) and activates biogenic amines. In case of continuous or severe stress ecdysteroids stimulates can regulate secretion of ecdisidropic neurohormones. Environmental stressors can increase developmental instability (DI) in insect offspring. It causes the appearance of populations with various traits that resist stress. FA can produce the directionally-random small perturbations from perfect symmetry and is often used as an indicator of DI (11).

Body cells and molecular signals secrete hormone in reaction to stress. Octopamine to increase the flight and leg muscle activation, neuropeptides and biogenic amines in honey bee are examples stress secretions in insects through signaling process (13,44).Biotic and abiotic stress change insect metabolism and behavior. Crowding stress in aphids, locust and army worm causes changes in morphology and produce migratory forms by increasing their activity as a result of stress (22,23). Biogenic amines play a crucial role in the regulation of basic life processes (14). They act not only as neurotransmitters and neuromodulators in nervous tissues but also, depending on the situation, they can release hormones into body fluids in reaction to stress (41)

Stress induces changes in release of ecdysio-regulatory and allato-regulatory neurohormones, modifying ecdysones and juvenile hormones synthesis in prothoracic gland and *corpora allata.* The involvement of hormones of an ecdysteroid or JH type in response to stress creates the danger of an untimely induction of morphogenetic process in target cells. Limiting the quantity of secreted hormones and shortening the period when target cells are sensitive to morphogenetic stimuli removes this danger (51). Octopamine modulates the control of numerous metabolic and life history traits against environmental stressors and increase the survival chance of aphids. They influence secretion of various hormones which mediate in producing appropriate reaction to important stressors such as starvation and heat (38). It is believed that insects have evolved a variety of genetic responses to stress. Their evolutionary reaction to toxic materials in their body is genetic, epigenetic or physiological. Biological reaction to metal toxic concentrations may be directly damaging DNA or producing oxidative stress. Oxidative stress (OS) and anti-oxidant enzymes have major roles in insect migration and metal response (47, 60). The main relation of pest stress in variable environment is rooted in gene expression, cellular stress, specialization and adaptive process caused by selection and evolution. Before pointing out specific research of stress effects in aphids and medically important pests current basic research related to stress are briefly discussed (25, 38, 50). Figure 1 shows that speciation according to modern synthesis may have been started by variation and plasticity in introducing new traits such as mimicry and camouflage. Environmental stress and population genetic can produce polymorphism in insect species. Species group or biotypes appeared in various insects which is the source of difficulties in incipient species identification. One of the problems in pest control is their outbreak and resistance to pesticides. Stress is known to be the main reason for pest outbreaks. Cytogenetic studies have revealed that stress affecting insect brain by neuroendocrine secretions and signaling biogenic amines that can change insect biology. Environmental pollutions and anthropogenic activities force insect biological changes by various factors such as free radicals ATP and NADPH oxide to produce reactive oxygen species (ROS) to defend insect with neutrophil effects.

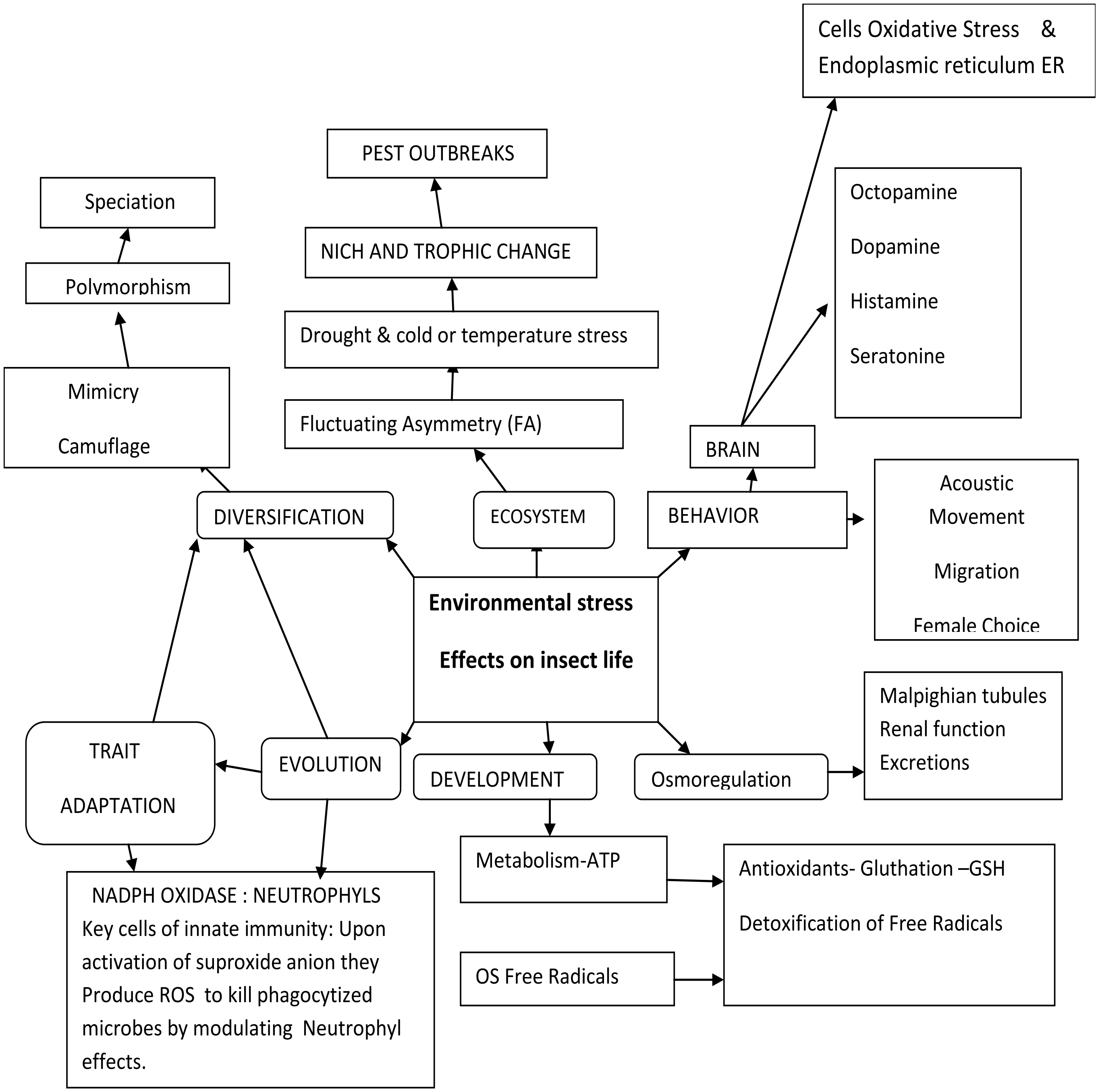

Figure1. Effects of environmental stress on insect life

Various factors such as environmental inconsistency, FA, symbionts, gene expression, host shifts are responsible for changes in in insect biology. They are discussed in the following three parts:

A-General stress factors affecting insects

B-Stress effects on aphid species

C-Stress effects on hygiene pests

A-FACTORS RELATED TO INSECTS STRESS

1-Environmental stress: Abiotic environmental stress such as heat, cold, strong winds and unsuitable living conditions may affect insets in the same way as biotic stress such as food shortage, plant defense or natural enemies. Insect defense against predators is by alarm pheromone secretion. Alarm pheromones can also be perceived by predators, who take advantage of alarm cues to locate preys. Reaction of insect population is different to sensing the alarm pheromones. According to the structure of their surroundings they react by movement away from their locality fainting death or hiding among the soil debris. The involved organs for body defense against stress are mainly Malpighian tubules or endoplasmic reticulum in body cells. Various other factors help insect to prevent the effects of stress. Adipokinetic hormones (AKH) is actively causing the signaling for various genetic markers to recognize and reduce appropriate reaction to stress (3).

2-Fluctuating asymmetry (FA): To define stress and FA effects on living organisms is similar to explaining the struggle that living organism have to take for continuation of his survival. (Dancewicz and Markunas, 2018). Stressors can change fitness, traits and FA in plants and insects after one to few generations. Many leaves of *Betula pubescens* increased deviation from symmetry by stress but slight damage by insects to shoots and leaves showed reduction of leaf FA on the next year. It is concluded that slight pest damage of leaves can decrease the next generation FA stress effects (32). Therefore FA is considered to be a good biomarker for future studies of environmental stress effects on living organisms (3, 43).

Stress can changes gene markers through epigenetic factors and affect FA in the insect offspring that may create an adaptive population to live or leave stressful situations. FA in housefly can be the result of genetic signals imposed by stressful environmental and changing their morphology (7). Stress in the leaf roller (*Deporaus betulae*), leaf miner and other defoliators can also affect insect pest symmetry (3, 32).

3-Symbionts: Important changes in insects that enabled them to feed on plants caused by evolutionary coexistence with symbionts. Selection of adapted insects are genetic divergence and forces for insects to escape the dangerous or unsuitable environments. Continuous interactions between insect and hosts during the evolutionary periods have created variation and diversification of insect species. Symbionts help insect to acquire nutrients and resist stressors. In aphids symbionts are in special cells called bacteriocytes and assisting them to survive from stress (59).

Buchnera aphidicola and nine other symbionts are commonly found in aphid cells. Their reaction to aphid stress is regulating aphid physiology by providing cells with needed proteins through endoplasmic reticulum (ER). The cellular proteins can change the aphid morphology in pea aphid (15). The bacteriocyte cell death caused by stress is through accumulation of non-apoptosis vacuoles and a sequence of biochemical alteration in various biochemical steps that increase the vacuoles. Therefore cell death in bacteriocytes starts by hyper-vacuolation. Stress can activate the cell defense system by reactive oxygen species (ROS). Lysosome cell organelles are involved in various cell processes such as breaking down excess or worn-out cell parts or the particles presence during the cellular stress. Lysosomes are serving to digest obsolete components of the cell. The organelles are morphologically diverse in cells but are defined by their common function of degrading intracellular materials. Their function through the ER for the cell digestive system is described by Davies et al, 2014(9).

4-Gene expression: The genetic basis of adaptation is known only from a few organisms. A wide variety of cardenolides compounds in plants are for defense against insects. Cardenolides are steroid that have produced resistance in some insects or they use them as a defense against predation. Insensitivity to cardenolides is studied by molecular research in various insects. They have specialized reaction for pumping (Na,K-ATPase) for their internal metal metabolism. So far 18 species of insects feeding on cardenolide-containing plants have lowered their sensitivity to it by amino acid substitutions. Oxidative stress (OS) and anti-oxidant enzymes have major roles in their adaptation. Metals such as Zn, Cd, Cu affected only four genes in *Pterostichus, Phyllobius* or *Anopholese gambiae* with different responses (47).

Phenotypes of aphid species are changed and wingless aphids in reaction to crowding or heat stress change to winged forms. Changing aphids to winged form is accompanied by reduction in reproduction (22,23). New aphid clones with distinct genotypes are produced early in the spring after the emergence of fondatrix and fundatrigenia. The genetic structure of *A. gossypii* collected from north of Iran was variable and survey carried out for, seven polymorphic microsatellite loci with different multilocus genotypes, indicated that from 240 individuals 142 of them were different genotypes (17). *A. gossypii, A.glycines* and *A. rhamnicola* are morphologically indistinguishable. *A. gossypii* is changing its minor characters in various environments or on different hosts. *A. frangulae, A. rhamnicola* and other aphids in this group respond differently to their stressors. Gene expression of *Aphis* species are separated in a neighbor-joining tree in East Asia (34).

Aphid clones survive and increase their population until autumn and with the start of cold seasons they die out. Sometimes variability by mutation in asexual aphids is produced otherwise few aphid clones survive the winter. Polymorphic microsatellite marker with different set of multi-locus genotypes or MLGs of *Metopolophium* and *Macrosiphoniella* had single or low number of repeats rather than large multiple copies. Therefore it indicates that the production of sexual morphs in aphids increase their genotypes variation and survival chance (40).

5-Aphid hosts interactions: Insect-plant interactions are affected directly or indirectly by stress factors. The effect of environmental resource availability on insect-plant interactions is focused on aphid-host plant interactions. Aphids are poikilothermic and temperature is the main factor influencing their survival and distribution. Ambient temperature influence their life cycle and reproduction. An increase of temperature to 28 C. had a negative effect on development of *Macrosiphum rosae* and reduced their reproductive longevity (8). Low light stress and complete darkness decreased chlorophyll, carotenoids, saccharides and phenols and the aphid activity (Dancewicz, 2018).

How aphids will respond to drought and high temperature stress depends to regional climate conditions. In favorable conditions the basal level of aphid fitness will differ between the susceptible clones to resistant. Plant-mediated responses to drought stress are likely to cause a reduction in plant vigor and a decrease in plant palatability and aphid population, but differential levels of basal fitness between the two plant types leads to differences in the extent to which aphid fitness is affected (35). Meta-analysis of published articles on climatic drought stress has shown that stress reduces the fitness of aphids and plant vigor. In other words drought stress reduces both agricultural crop yields and aphid rate of reproduction (35).

6-Stress affecting crop and pests: For agricultural forecasting of pest population weather data especially temperature and rain are key factors. Other important factors are natural enemies, phenology, pathogens and insect-crop-weed relationship (6,10,49).Before humans learn to cultivate crops for food 10000 years ago ants, termites and beetles had fungus culture in their nests about 20-60 Mya (46). Pest control research is now carried out in various research institutes for breeding resistant crops to pests. Selection of pest resistant crops or genetic modification (GM) technologies is new. The production of GM plants is a common practice in many countries and in pest management is considering the Specro-radiometer changes of crop color damaged by pests and diseases in various ecosystems (52, 61).

Stress on crops by global climate change can integrate into plant for natural resistance to local conditions and a new approach to produce genetic resistance into plants to prevent pest damage are also new research trends in pest management (29). Stem borers and internal feeder of insect pests such as leaf miners or root nematodes and diseases will change the type of proteins in them. By comparing proteomics in healthy and damaged plant it is possible to identify the damage caused by pests. For date palm weevil the proteomic analysis of leaves indicate the tree infestation (53).

7-Toxins and toxicants: The earliest insects were not plant feeders, but insect diversity expanded greatly as angiosperms became diverse and abundant in the Cretaceous period (about 100 million years ago) (66). Relationship between weeds, insects and plant cultivars started before crops were bred from natural plants (6, 48).

Plant defenses to stress are in two ways, by resistance and by tolerance, both of which are affected by abiotic factors. The information gathered from studies on plant-aphid interactions show that water availability in plant increase their resistance to drought stress and high temperature. (16). elicits lower resistance, while 34.5%, 20.1% and 3.4%, showed higher, no change and conditional effects on plant resistance, respectively.

8-Neuroendocrines and stress metabolic pathways: Changes in the main metabolic pathways is made in response to stress through neurotransmitter by biogenic hormones or peptide markers giving direct and indirect signals. G-protein-coupled receptor kinas are a family of proteins such as serine, threonine, protein kinase are biogenic amines signaling mediators in mammals acting in response of stress in cells or kidneys. Octopamine (OCT) acts like norepinephrine in regulating aggression and starvation resistance in insects (38). It can accumulate in nervous system and is found in neuronal tissues of most invertebrate species. It can also modulate the activity of flight muscles, peripheral organs, and most sense organs. In the central nervous system regulate motivation, desensitization of sensory inputs, arousal, initiation, and maintenance of various rhythmic behaviors, hygiene behavior, and complex social behaviors, including establishment of labor, as well as learning and memory in social insects. As a neurohormone, OCT is released into hemolymph, transported to target tissu**e**s, and induces mobilization of lipids and carbohydrates, preparing insects

for a period of extended activity or assisting recovery from a period of increased energy demand. OCT modulates hemocytic nodulation in nonimmune larvae and enhances phagocytosis as a neurohormone (38, 51). Activation of octo-paminergic receptor types is coupled with different second messenger pathways depending on the species, tissue source, receptor type, and cell line used for expression of the cloned receptor. OCT is associated with changes in cellular response, affecting insect cells.

9-Aphid-Ants Relationship: Ecology and evolution of ant-aphid relationship is reviewed in a book (57). Their social relationship is benefitting aphids to free the colony from sticky honey dew and to give ants rich food. Aphids are stressed when natural enemies are in their colonies. Ants use specific mixtures of cuticular hydrocarbons (CHCs) in the presence of natural enemies as recognition factor to protect aphids. CHCs effects are frequently neutralized by chemical mimicry produced by aphid natural enemies. Ants tending *Prociphilus tessellatus* (Homoptera: Aphididae) from *Chrysopa slossonae* (Neuroptera: Chrysopidae), and *Syrphus ribesii* (Diptera: Syrphidae) attack secrete three distinct CHC for each predator. CHCs in aphid natural enemies are recognition cue for ants (39).

Solenopsis invicta (Myrmecinae) are very vulnerable and feign death because of their relatively soft cuticle. After danger has passed, they look around before fully reviving. This seems a sensible strategy. It was shown that death feigning increases their chances of survival fourfold compared to older workers. This is important, because these young workers have the longest life expectancy and are hence most valuable to the colony (24).

10-Cellular stress: Stress at cell level are affecting insects or influencing insect behavior by neurohormones and endoplasmic reticulum (44, 51). Unfolded protein in cells at the endoplasmic reticulum (ER) contribute to biogenesis of the protein folding machinery for activating cell mechanisms to adapt insects against variable environmental conditions (20). Biogenic amines bind to G-Protein coupled receptors (GPCRs) and, depending on the receptor type and target tissue, stimulate different types of secondary messengers, mainly cAMPor Ca2C (14).

The pathways of cell specific signals in *Drosophila melanogaster* from Malpighian tubule's epithelial cells or digestive tract principal cells are V-type proton-motive ATPase (V-ATPase) at apical membrane. Cell signaling in the principal cell are for oxidative stress, immune stress, salt stress or desiccation stress (9, 13, 37). Biotic factors influencing honey bee health and colony productivity is commonly measured by malondialdehyde (MDA) biomarker. Reactive oxygen species are the main cause of oxidative stress and bees suffer from diminished redox homeostasis. Cells that lose their ability to remove excess ROS undergo oxidative stress causing damage of proteins, and membrane instability. Oxidative stress can lead to apoptosis and cellular damage and is linked to aging. The MDA biomarker is a common measure of oxidative stress in honey bees. It is the main organic compound produced from lipid peroxidation of polyunsaturated fatty acids in cellular membranes. Gene expression in relation to pathogen loads, metabolic stress, and organ function is studied in honeybee (56). For gathering information and knowledge about the biological reaction to stress within ER it is necessary to know how the machinery in enzyme production is working. A forum review and explanation of other researchers help reader to understand how cell stress affect defense system of insect and *Galeria melonella* (20, 30, 44).

11-Specialization and traits to escape stress: Escape from heat, cold, and natural enemies will reduce the harmful environmental stress effects. Adaptation or selection is gradually introduced into the genome and caused new genetic, physiological or morphological traits in successive population of insects. As a result of variation or plasticity and survival of fittest pest populations that fit the local habitat is increased in various localities. Crypsis, mimicry, camouflage are some factors that are combined with life cycle variation increase insects' ability to avoided stress (26, 55).

B- STRESS AFFECTING APHIDS SPECIES

***Aphis* Linnaeus, 1758:** Five genera of the subtribe Aphidina have been recorded from Iran. *Absinthaphis* Rem.*Brachyunguis* Das, Protaphis Borner, *Toxoptera* Kesch, and *Aphis* L. Fifty Aphis species are recorded in Iran but four species are very polyphagous i.e. *A. frangula* Kalt subsp *gossypii* Glover, *A. fabae* Scopand its subspecies, *A. craccivora* Koch, and *A.citricola* van Der Goot. Most of other aphid species are either on trees or are scattered on various herbaceous plants. This is why aphids are also called plant lice (21).

Aphids with many species are difficult to identify because of high plasticity and quick response to environmental stress. The main cause of their variations in their characters is their response to host plant metabolites and rapid speciation by host shift. Host shift and their close genetic distance on various host species is the main taxonomist problem to identify them. This is why similarly looking aphids in various genotypes are grouped together. Environmental stress affects plants and aphids by molecular genetic markers and various groups have shown differences in stem cells and genomes. Stress and hox genes differential transcriptions in cells affect physiology and morphology in their populations affecting life cycle and can produce new genotype. Heat shock environmental stress can regulate a set of genetic characters in histone assembly on chromosomes and change genes by reacting to various stressors (12). Efforts is made to study the effect of stress on most common aphid hosts are described for the following species.

1-*Aphis gossypii* group: *Aphis gossypii* group is classified as *A. frangulae* spp or *gossypii* commonly found on cotton, tomato, melon and many other plants. Many other aphids with similar morphology to *A. gossypii* are also regarded as members of this group (58). At warm districts with mild winters it produces parthenogenetically on more than fifty hosts in Iran (21). The survival of clones on new hosts might also have been reinforced by mutation (40).

There is an indication that environmental stress by physiological change in body function can cause variation among populations for the host plant choice (31, 34, 54). The host plant virus aphid transmission (Vat) gene can react to stress of aphid by feeding on *Cucumis melo*. Callose and lignin in the cell increases after peroxidase is deposited on walls adjacent to the stylet path (4). Vat gene produce an active defense mechanism in *A. gossypii* hosts that by cell apoptosis produce plant resistance to aphids and viruses (63).

Abiotic and biotic effects of stress in *Aphis glycines* produced variable molecular response in Wisconsin. Heat and starvation induced variable transcriptional response. There was minimal overlapping effect on aphids affected by different stressors. Glutathion is antioxidant defense mechanism that increase oxidization in cells. Continuous stress reaction is caused by mitogen activated protein kinase and NF.kB (nuclear factor light chain of activated B-cells) proteins and cell apoptosis follows (12). The stress effects of plant allelochemicals from two of its hosts produced new trait on parts of their population (42).

2-Pea aphids, *Acyrthosiphon pisum*: *A. pisum* (Harris, 1775) is a large green to rosy aphid with thin long siphunculi measuring 2.2 – 4.4 mm. Many populations or subspecies are living on alfalfa, clover, beans and peas. Pea aphids are a model system for understanding how facultative symbionts protect their hosts from thermal stress. Obligate symbionts in this species increase their tolerant to heat. *Acyrthosiphon pisum* under heat shock stress were assisted by symbionts that provide them with necessary nourishments and increasing their fitness (19).

3-*Myzus persicae*: *Myzus persicae* only in cooler regions where winter temperatures reach subzero at least more than a weak produce sexual and females that lay egg on peach or almond trees. In warmer regions they live and reproduce parthenogenetically on many different herbaceous plants. Host specialization by *Myzus persicae* needs selection of suitable hosts. Aphid needs to use their vision, olfaction, mechano-sensation and gestation to settle on their hosts. Vision interacts with olfaction because similar colors exist in a wide range of plants. The olfaction is primarily mediated by volatiles emitted by plants. Aphids are attracted and repelled by plant volatiles after active flight during host selection. Mechano-sensation and phloem tasting are also used for host recognition by aphids, and these can take place even without probing at the surface of the plant. A lack or excess of nutrients (*e.g.*, nitrogen, water, CO_2) and stress factors (*e.g.*, heat, radiation) alter natural interactions that are emphasized on the signals of abiotic stresses on *Myzus persicae* and its hosts (62).

4-Wheat aphids: Wheat is infested by ten species of aphids but its common aphid pests are: *Sitobion avenae, Rhopalosiphum padi, Rhopalosiphum maidis, Diuraphis noxia* and *schizaphis graminum* (21). The main stress affecting what aphid populations are heat and drought. Plant reaction to aphid infestation is production of reaction oxygen species (ROS) such as superoxide anion radical and hydrogen peroxide. Aphid defense is by secretion of ascorbate peroxide that catalyze hydrogen peroxide (28). Heat and drought together decreased aphid reproduction and increased plant defense against aphids (64).

C- HYGIENE PESTS

1-Bed bugs: Bed bugs (*Cimex* spp.) are important blood sucking insect with high tolerance to survive and recover from environmental stress. Bed bugs have an extraordinary power of resisting starvation and dehydration between blood meals. They are adapted to tolerate various stressors such as heat, cold or lack of sufficient humidity. They live in rural old houses with old furniture and in walls cracks or in old beds or under the carpets. They feed at night by sucking human blood. *Cimex lectularius* and *C. hemipterus* can survive long-term exposure to temperatures above 35 °C. Heat and a long period of starvation cause the heat shock proteins expression (Hsps). Disturbing or distressing copulation can produce microbial infection in females and reduce their population. Bed bugs are controlled by washing beds, cloths and applying seam to infested furniture (2).

2-Mosquitoes: Increasing the population of mosquito larvae in breeding waters and exposure of larvae up to third instars to temperatures of 40-50 and 45 C. and chromosomal assay show their cell proliferation at 50 C is inhibited with increased death and decrease in their miotic index. Heat stress can induce chromosome aberration and reduced micronuclei affecting their development. Stress also increased the hemolymph antioxidants such as superoxide dismutase (SOD) and glutathione (GSH). Predator pressure on larvae of *Aedes, Culex* and *Anopheles* increased as a result of higher temperatures in central district of Botswana. Predators play a critical role in regulating larval mosquito prey populations in aquatic habitats and their presence around mosquito larvae is stressful (5,47).

Mosquitoes by feeding on blood are facing osmotic misbalance stress. Stress of ingesting warm blood disturbs mosquito cellular homeostasis. Mosquitoes produce a drop of blood on their anus while feeding. The repletion is reaction to hot blood entering their digestive system. This action decreases their body and surrounding temperature by evaporation. The cooling is more effective in *Anopheles* by distancing the terminal part of the body away from its host. Prediuration also reduce body weight and easier take off from the host. Scape of mosquitoes from heat stress is believed to be adaptive (33).

3-House Fly: Stress decreases the wing length in housefly but increase their mating frequencies (7). Stress of crowding and starvation show a high rate of mortality. By increasing the number of fly larvae in similar sized containers from 2 to 6-12-24-74 their mortality and the size of their adults decreased (66). Stress also affects the efficiency of their defensive system. Proteomes associated with oxidative stress in cytochrome P450 and acetylcholinesterase genes become upgraded in response of sublethal dose of nicotinoid pesticides and CYPGDs increase fly resistance to treatments (18). Stress increases the antioxidant activity. The increases in total antioxidant capacity, measured by sequencing the primers, enhance the cytotoxic effects. The reaction of defense system to stressful conditions is also identifiable by the prevalence of cytotoxicity in housefly body. (11).

4-Cockroaches: *Periplaneta americana* (American cockroach) were treated with conidia of entomopathogenic fugal isolates of *Metarhizium anisopliae*. Body defense of cockroaches revealed a decrease in the thiol content and an increment in the levels of oxidized glutathione (GSH). Thiol content in treated cockroach suggested oxidative stress. Enzymatically glutathione acts as electron donor to detoxify hydrogen peroxide. Dynamics in the levels of GSH, H_2O_2 and thiols in the insects treated with different fungal isolates of *Metarhizium anisopliae* in a time and dose dependent manner reveals oxidative stress induced by the fungal infection (1). This method of stressing insect by fungal toxin can be used as biological control method for the control of this pest.

CONCLUSION

Stress, trait, adaptation and selection in insects are interconnected to many other subjects such as polymorphism, plasticity and systematic. Subjects from cell biology to applied pest control have been dealt by numerous authors that make the task of describing stress effects on pest insects difficult. The authors had to summarize literatures at introductory section of this review and give examples of research carried out on a few pest insects. One of the problems introduced from pest species is that they change to different similar groups of species with different pathogenic or crop pest characters. The problem for species group forming various biotypes or sibling species is described for Iranian species of aphids and grasshoppers. The authors hope that the article stimulates readers to follow research about problem of insect pathways to various similar groups of species with different damaging potential.

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There is no found.

CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest.

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