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An Overview of German Cockroach, *Blattella germanica*, Studies Conducted in Iran

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Abstract: The control and elimination of German cockroach, the most important worldwide pest species, has been an economic and public health success. Too many studies have been conducted in Iran, whereas these researches was scattered in form of national and international articles that has needed to add up of them in an overview article. With doing of this work the way is smooth to future studies and the strategies of these studies will be distinguished. This article is outlook in direction of above aims. The susceptibility level and insecticide resistance mechanisms of German cockroach to organochlorated, organophosphate, carbamate and pyrethroid insecticide groups have been studied. The new insecticidal compounds include fipronil and avermectins acting at GABA and glutamate receptors in proximity to chloride channels, diacylhydrazines mimicking the action of ecdysone, indoxacarb acting at a novel site in sodium channels and imidacloprid, thiamethoxam and spinosad acting at novel sites on the nicotinic acetylcholine receptor, several promising products acting at new target sites, which are currently not affected by resistance that will be used for pest control specially *Blattella germanica*. Attentive to resistance of *B. germanica* to current consuming insecticides and ever-increasing add to intensity of it, the researchers have been considering the susceptibility level of *B. germanica* and efficiency estimation of them to above-mentioned insecticides for control of this pest. The strategies of future researches are study of the susceptibility level of *B. germanica* and efficiency estimation of them to above-mentioned insecticides for control of this pest in Iran.

Key words: German cockroach, *Blattella germanica*, overview, Iran

INTRODUCTION

German cockroach (*Blattella germanica* L.), belonging to the Order Blattaria, Blattellidae family (Foltz, 2001), is the most important worldwide pest species due to small size, nutritional habits and specific behavior (Vatandoost and Mousavi, 2001), in addition to compliance with the human environment can cause transmission of pathogen factors (Berenji *et al*., 2007; Salehzadeh *et al*., 2007) and also cause aggravate allergic diseases, asthma (Golshan *et al*., 2002; Ghazi *et al*., 2003; Farhoudi *et al*., 2005; Safari *et al*., 2009) and even invasion to human (Nagaty and Emami-Nouri, 1977). Today, German cockroach is the important pest of residential, commercial, office and industrial places and is shared with humans in food, water, shelter and warmth. German cockroach eats any human, animal and plant foods or drinks, human and animal materials, leather, glue, hair, wall paper, fiber and stiffness in binding to books and regurgitates parts of eaten foods which can cause distribution of infection and food spoiling, wasting. Also, secretes nauseating discharges from oral or body glands that cause cockroach specific smell remains for a long time on the food or in its environment. Fear due to existence of cockroaches and its horrified appearance are the most important factors which are considered as an introduced pest. Cost of fighting to this pest insect is allocated significantly own income of families. German cockroaches can be shelter of bacteria (Vahabi *et al*., 2007; Zarchi and Vatani, 2009) and intermediate host of pathogenic intestinal worms (Berenji *et al*., 2007); also can transfer viruses, fungi and protozoa that they pass to adverse effects on human and other vertebrate animals.

Combat to German cockroach, the worldwide important human environment pest and its elimination from surrounding humans is considered a great success in terms of economic, health and medicine and in recent decades, is an important species to a review of new insecticide resistance level, because of its ability to gain significant resistance to pesticides similar to House fly. In Iran many studies have been conducted to select a method for evaluating the level of German cockroach susceptibility and resistance to insecticides, evaluate the German cockroach susceptibility and resistance level to insecticide, determine German cockroach mechanism insecticide resistance, application of baits for German cockroach control, German cockroach as a transmitter of disease agents and infections, German cockroach as producer of allergens, German cockroach semiochemical-based food-foraging, record of *Anastatus*

(*Anastatus*) *tenuipes* (Hymenoptera: Eupelmidae), a parasitoid of *Blattella germanica*, but these studies are been in the form of, national and international articles which it will be needed their compiling as a review article. With doing of this work, the way will be paved for future studies and future study strategies will be cleared. This study is a perspective in the line of above objective.

STUDIES CONDUCTED TO SELECT A METHOD FOR EVALUATING THE LEVEL OF GERMAN COCKROACH SUSCEPTIBILITY AND RESISTANCE TO INSECTICIDES

Topical application, tarsal contact and knockdown testing methods are the most sensitive methods for measuring susceptibility and resistance levels of adult and nymphal German cockroach to insecticides (Ladonni, 2000; Ladonni *et al*., 2001; Nasirian *et al*., 2006a, d, 2009). Studied have been showed that various methods such as topical application, tarsal contact and knockdown testing methods have a similar results for measuring susceptibility and resistance of adult and nymphal German cockroach to insecticides. For example studied such as glass petri-dish at permethrin 15 mg m^{-2} and insecticide impregnated paper 2%, using first-instar nymphs of German cockroach, *Blattella germanica* L. (Dictyoptera: Blattellidae); permethrin resistance ratios compared by two methods of testing nymphs of the German cockroach, *Blattella germanica*; evaluation of three methods for detecting permethrin resistance in adult and nymphal *Blattella germanica* (Dictyoptera: Blattellidae); comparison of biochemical and bioasay methods in assessing organophosphate resistance in *Blattella germanica*; duration of fipronil topical application toxicity in *Blattella germanica* field population strains; duration of fipronil WHO glass jar method toxicity against susceptible and feral German cockroach strains; Iranian non-responding contact method German cockroach permethrin resistance strains resulting from field pressure pyrethroid spraying have been showed similar results or a negligible differences between them (Ladonni, 2000, 2001; Nasirian *et al*., 2006a, e, 2009).

STUDIES CONDUCTED TO EVALUATE THE LEVEL OF GERMAN COCKROACH SUSCEPTIBILITY AND RESISTANCE TO INSECTICIDES

Generally, in Iran so far insecticide resistance to permethrin, cypermethrin, cyflutherin, deltamethrin, coopex, Actelic, Ficam, diazinon and lambdacyhalothrin have been reported (Table 1) but in some studies the susceptibility to pirimphos methyl, lambdacyhalothrin, diazinon, fenitrothion and propoxor have been reported (Table 2).

Mixture of insecticides application: Mousavi (2000) studied the sensitivity level of German cockroach to deltamethrin, pirimphos methyl and propoxur insecticides and mixtures of insecticides and also examined the effect of temperature on the sensitivity level of German cockroaches to insecticides. German cockroach was resistant to deltamethrin, tolerant to propoxur and susceptible to pirimphos methyl. In order to assess the

Table 1: German cockroach resistance to insecticide groups have been reported from Iran

Groups	Insecticide	Reference(s)
Organochlorine	DDT	Limoee *et al*. (2006)
Pyrethroid	Permethrin	Ladonni (1993; 1997, 2000, 2001), Naieni *et al*. (2004), Ghavami *et al*. (2005), Limoee *et al*. (2006), Nasirian *et al*. (2006b, d, 2009 Enayati and Haghi (2007), Haghi *et al*. (2007)
	Deltamethrin	Mousavi (2000), Naieni *et al*. (2004), Haghi *et al*. (2007), Enayati and Haghi (2007), Shahi *et al*. (2008)
	Cypermethrin	Limoee *et al*. (2006), Haghi *et al*. (2007), Shahi *et al*. (2008)
	Cyfluthrin	Limoee *et al*. (2006)
	Lambda-cyhalothrin	Kamyabi *et al*. (2006), Shahi *et al*. (2008)
	Gokilhat	Ladonni (1993)
	Sulfac	Doroudgar and Asadi (2001)
	Trebon	Ladonni (1993)
	Icon	Naieni *et al*. (2004)
	Kupex	Salehzadeh and Mahjub (2007)
Organophosphate	Diazinon	Ladonni *et al*. (1988), Ladonni (1993), Shahi *et al*. (2008)
	Pirimphos methyl	Mousavi (2000)
	Actillic	Salehzadeh and Mahjub (2007)
	Alfacron	Ladonni (1993)
	Chlorpyriphos	Limoee *et al*. (2010)
	Malathion	Limoee *et al*. (2010)
Carbamate	Propoxur	Ladonni *et al*. (1988)
	Ficam	Doroudgar and Asadi (2001), Salehzadeh and Mahjub (2007)
	Carbaryl	Limoee *et al*. (2010)
	Bendiocarb	Limoee *et al*. (2010)
Phenylpyrazole	Fipronil	Nasirian *et al*. (2006a, b, d, e)

Table 2: German cockroach susceptibility to insecticide groups have been reported from Iran

Group	Insecticide	Reference(s)
Pyrethroid	Beta-cyfluthrin	Ladonni (1998)
	Solfac	Ladonni (1993), Naieni *et al.* (2004)
	Kupex	Doroudgar and Asadi (2001)
Organophosphate	Actillic	Ladonni (1993), Doroudgar and Asadi (2001), Naieni *et al.* (2004)
	Empire-20	Ladonni (1993)
	Diazinon	Naieni *et al.* (2004), Salehzadeh and Mahjub (2007)
	Pirimphos methyl	Kamyabi *et al.* (2006)
	Feninitrothion	Salehzadeh and Mahjub (2007)
Carbamate	Propoxur	Mousavi (2000), Naieni *et al.* (2004), Kamyabi *et al.* (2006)
Pyrethroid+carbamate	Negon® (permethrin+propoxur)	Shahi *et al.* (2008)
IGR	Fenoxycarb	Fathpour *et al.* (2009a)
	Pyriproxyfen	Fathpour *et al.* (2009b)
Phenylpyrazole	Fipronil gel bait	Nasirian *et al.*, (2006c), Nasirian (2007), Nasirian (2008)
Neonicotinoid	Imidacloprid gel bait	Nasirian *et al.* (2006c), Nasirian (2007), Nasirian (2008)

sensitivity strains to mix insecticides, the insecticides mixed in a 1:1 ratio. The results showed a significant LD_{50} reduction in mixture of deltamethrin + propoxur compared to propoxur alone and pirimphos methyl + deltamethrin to pirimphos methyl alone on German cockroach strains, respectively. Using mixed pirimphos methyl + propoxur on wild strains of German cockroach was caused that the regression line of dose-mortality shifted even slightly lower than the line related to the use of each insecticide alone constituent and caused resistance was broken. Generally, using mixed propoxur with pirimphos methyl or deltamethrin in comparison to using propoxur and pirimphos methyl alone had showed better performance in German cockroach (Mousavi, 2000).

The results of the effect of temperature after using LD_{50} insecticide dose showed that the mortality of German cockroach was reduced by using deltamethrin with increasing the temperature or in other words, with increasing the temperature the toxicity of deltamethrin was decreased. In propoxur insecticide the mortality rate was decreased by increasing temperature up to 25°C but the mortality was increased by the higher temperature than 25°C. The insecticide pirimphos methyl had negative effects on the mortality rate by rising the temperature to 20°C but had positive effect up to 20°C (Mousavi, 2000). These results are showed that when insecticides are applied the environment temperature should be considered.

Antagonistic effect of azadirachtin on cyfluthrin and permethrin: Efficacy of some traditional pesticides either individually or in combination, against *Blattella germanica* was studied by Salehzadeha and Mahjub (2011). The results showed that maximum knockdown was achieved with 0.5 cyfluthrin with KT_{50} of 8.9 min. The KT_{50} values for 0.1% permethrin, 2.5% Primifos methyl, 2.5 and 5% malathion, 0.0 and 5% Diazinone and also 0.25 and 0.5% Bendiocarb were 13.8, 88.03, 131.4, 75.16, 86.94, 41.08, 103.5 and 42.9 min, respectively. Surprisingly the combination of azadirachtin with permethrin or cyfluthrin showed the least effect which could be due to competition of azadirachtin and pyrethoids for same site or some conformational changes in target sites or receptors (Salehzadeha and Mahjub, 2011).

STUDIES CONDUCTED TO DETERMINE GERMAN COCKROACH MECHANISM INSECTICIDE RESISTANCE

Different classes of insecticides have extensively been used for German cockroach control leading to insecticide resistance development. Hence, for an optimal control of this pest, the status and underlying mechanisms of insecticide resistance should be studied (Enayati and Haghi, 2007).

MFOs are a large diverse superfamily of enzymes found in all insect tissues. They are involved in the metabolism of xenobiotics (e.g., drugs, pesticides and plant toxins) and endogenous compounds (e.g., ecdysteroids and juvenile hormones). They are also involved in bioactivation of phosphorothioate compounds such as organophosphorus insecticides. They have very diverse activities like hydroxylation, epoxidation, N-, O-or S-dealkylation, deamination, sulfoxidation, desulfuration and oxidative dehalogenation. Their diverse functions are achieved through diversity in structure. MFO-mediated insecticide metabolism is a common mechanism by which insects become resistant to insecticides (Enayati and Ladonni, 2006). In a study German cockroach permethrin resistance was abolished by cotreatment with the synergist piperonyl butoxide plus permethrin, indicating that mixed-function oxidases were inhibited as a major metabolic pathway in German cockroach resistant strains (Ladonni and Sadegheyani, 1998; Ladonni, 2000). Biochemical assays of esterases, monooxigenases and Glutathione S-Transferase (GST) level studies have been showed that a vigour tolerance has been existed to insecticides and pyrethroids particularly (Enayati and Haghi, 2007).

Insecticide resistance in the German cockroach can be mediated by a number of mechanisms, the most common being enhanced enzymatic metabolism. The investigation of possible mechanisms responsible for permethrin resistance of field-collected German cockroach strains with various levels of resistance to pyrethroids, some which were also cross-resistant to DDT using the synergists PBO, DEF and DMC and biochemical assays, including general esterases, glutathione *S*-transeferases and monooxygenases assays, have been showed that PBO and DEF, the inhibitors of cytochrome p_{450} monooxygenases and general esterases, respectively, affected permethrin resistance to varying degrees depending on the strain. DDT resistance was not completely eliminated by the synergist DMC, an inhibitor of glutathione *S*-transferase enzymes, suggesting that a further non-metabolic resistance mechanism such as kdr-type may be present. The synergist inhibitor mechanism resistance supported by biochemical assays implicated that cytochrome p_{450} monooxygenases or hydrolases are involved in permethrin resistance in some strains. However, these results implicated both enhanced oxidative and hydrolytic metabolism of permethrin as resistance mechanism in the other strains. The results of synergist and biochemical studies implicated that all the field-collected permethrin resistant strains have developed diverse mechanisms of resistance. It is of interest to note that because resistance to permethrin was not completely eliminated by DEF and PBO, it is likely that one or more additional mechanisms are involved in permethrin resistance in every strain studied (Limoee *et al*., 2007). Hence, insecticide resistance monitoring techniques should be put in place and also resistance management strategies and measures should be considered implementing in the area (Enayati and Haghi, 2007).

APPLICATION OF BAITS FOR GERMAN COCKROACH CONTROL

Application of insecticidal baits is one of the most common and effective strategies for controlling German cockroach. Baits have become popular and effective formulations against urban insect pests. Compared with residual sprays, toxic gel baits are used more and more frequently to control urban cockroach populations (Corrigan *et al*., 1997; Reierson, 1995).

Application of fipronil and imidacloprid gel baits: Investigations the susceptibility level of German cockroach to fipronil and imidacloprid gel baits have been showed that mortality rate after 2 h ingestion of fipronil and imidacloprid gel baits for 144 h (6 days) was 100%. Observations have been indicated that the imidacloprid gel bait operates faster than the fipronil gel bait (Nasirian *et al*., 2006c). German cockroach has been showed a similar susceptibility to fipronil and imidacloprid gel baits, compared with the susceptible laboratory strain. The steep slopes of ingested bait mortality curves indicated that the feral German cockroach strains were homogenous to fipronil and imidacloprid ingested gel baits. These results suggest that fipronil and imidacloprid gel baits appear to have considerable potential as bait for insecticide resistant of German cockroach (Nasirian, 2007).

Elimination of field German cockroach infestation: Investigation the usage of two commercially available fipronil and imidacloprid gel bait formulations against Blattella germanica field infested in Iran have been showed that density reduction was increased with the 0.05% fipronil and 2.15% imidacloprid gel baits in treated areas from 1st to 9th week in comparison to control areas. After 60 days, German cockroaches eliminated completely from these areas. These results have been showed that fipronil and imidacloprid gel baits are highly effective in field German cockroach infested after insecticide spraying control failure. Therefore, fipronil and imidacloprid gel baits are appropriate candidates for controlling German cockroach infested dwellings in Iran where control with other insectices failed because of resistance (Nasirian, 2008).

GERMAN COCKROACH AS A TRANSMITTER OF DISEASE AGENTS AND INFECTIONS

Cockroaches play an important role in transmission of different diseases either mechanically and occasionally biologically. The German cockroach can be an effective transmitter of nosocomial infections by virtue of its ubiquitous presence and its behavioral characteristics, as its move freely from areas within and around hospitals that may harbor pathogenic organisms. Cultures of the external body surface and digestive tract produced filamentous, actinomycetes, yeasts and yeast-like fungal colonies. Notable among these isolates were *Candida*, *Mucor*, *Rhizopus*, *Penicillium*, *Aspergillus niger* and the highly virulent *Aspergillus fumigatus* and *Aspergillus flavus* species.

Bacterial studies showed that 100% of the German cockroach carried rich bacterial floras, most commonly including *Klebsiella*, *Klebsiella pneumoniae*, *Pseudomonas*, *Proteus*, *Proteus vulgaris*, *Citrobacter*, *Enterobacter*, *Enterococcus*, *Bacillus* sp., *Streptococcus*, *Staphylococcus*, *Shigella*, *Haemophilus*, *Esherichia coli*,

Edward siella, *Morganella morgani*, *Salmonella* sp., *Serratia* species and *Streptococcus* beta-hemolytic type A. Many of these bacteria demonstrated antibiotic resistance. These results establish cockroaches as effective mechanical transmitters of multi-drug resistant bacteria (Fathpour *et al*., 2003; Naieni *et al*., 2004; Doroodgar *et al*., 2005; Vahabi *et al*., 2007; Salehzadeh *et al*., 2007; Zarchi and Vatani, 2009; Mahjoob *et al*., 2010).

GERMAN COCKROACH AS PRODUCER OF ALLERGENS

Asthma is the most common chronic disease of childhood. Exposure to allergens plays an important role in asthma. Exposure to cockroaches was reported to be a cause of asthma in many parts of the world. Evaluation of cockroach allergens in Iranian asthma children among asthmatic children have been showed that 27-29% of patients were detected positive by skin prick test (SPT). Children cockroach sensitive group had a more severe asthma ($p<0.02$). Asthmatic patients with cockroach allergy had perennial symptoms ($p<0.05$). A remarkable number of sensitive patients were born in winter ($p<0.05$), indicated that cockroach allergy was more prevalent in winter born children. Eosinophilia was more common in sensitive group ($p<0.02$) and they had a higher level of serum total IgE ($p<0.04$). The prevalence of cockroach allergy was near to other common aeroallergens. Cockroach sensitive group had perennial symptoms, which are compatible with other indoor allergens. May be these children are kept at home during their first months of life and are more exposed to cockroaches. The higher prevalence of eosinophilia and higher IgE level in sensitive group may be the reasons of more severe asthma in this group (Farhoudi *et al*., 2002). There were no significant correlations between the prevalence of cockroach skin test positivity in male and female children, rural and urban areas or infants under 2 years and older. The age of the youngest subject with a positive skin test for cockroach was 2 months. There was also no significant correlation between the total serum IgE and eosinophilia and the prevalence of cockroach skin test positivity (Safari *et al*., 2009).

GERMANCOCKROACHSEMIOCHEMICAL-BASED FOOD-FORAGING

In two-choice, still-air arena olfactometer experiments, Porapak-Q headspace volatile extract of peanut butter and solvent extract of beer were shown to attract males of the German cockroach, *Blattella germanica* (L.) (Dictyoptera: Blattellidae). Coupled gas chromatographic-electroantennographic detection (GC-EAD) and GC-Mass Spectrometric (MS) analyses of these attractive extracts, or fractions thereof and of synthetic standards, revealed many candidate semiochemicals. Elaborate olfactometer experiments determined that 1-hexanol from peanut butter and ethanol and 2,3-dihydro-3,5-dihydroxy-6-methyl-4(H)-pyran-4-one (DDMP) from beer, are the key semiochemicals of these food sources. 1-Hexanol is a well known headspace volatile of decomposing lipids, ethanol conveys food fermentation and DDMP with a caramel-type flavor has been found in many types of (heated) food. By responding to these rather general food-derived compounds, the omnivorous German cockroaches appear to exploit semiochemicals that indicate the presence of various food types, such as lipids and carbohydrates (Karimifar, 2009).

RECORD OF *ANASTATUS* (*ANASTATUS*) *TENUIPES* (HYM.: EUPELMIDAE), A PARASITOID OF *BLATTELLA GERMANICA* IN IRAN

In a study conducted by Fallahzadeh *et al*. (2008), the natural enemies of German cockroach (*Anastatus* (*Anastatus*) *tenuipes* Bolivary Pieltain (Hymenoptera: Eupelmidae), after collecting egg cases (ootheca) and emerging adult parasitoids from placing under room temperature in Petri dishes was distinguished and recorded from Fars, Iran (Fallahzadeh *et al*., 2008).

CONCLUSIONS

Currently, the fights against German cockroaches are considered as a serious problem. Despite all the losses would be caused by use of chemical insecticides and although much research to be going in the field of alternative methods for pest control. Insecticides are still considered the most appropriate tool in the management of pests and disease vectors. Even in advanced combat integration systems, application of the insecticides is the most important keys in the cockroach combat programs, especially German cockroach (Alali *et al*., 1998). Repeated application and widespread use of insecticides have been caused, German cockroach resistant to insecticides that have the second rank in resistance to insecticides after the House fly (Vatandoost and Mousavi, 2001). Therefore the use of poisoned bait insecticides are to be sounded one of the most common and effective strategy to combat German cockroaches (Nasirian *et al*., 2006c; Nasirian, 2007, 2008).

The new insecticidal compounds include fipronil and avermectins acting at GABA and glutamate receptors in

proximity to chloride channels, diacylhydrazines mimicking the action of ecdysone, indoxacarb acting at a novel site in sodium channels and imidacloprid, thiamethoxam and spinosad acting at novel sites on the nicotinic acetylcholine receptor, several promising products acting at new target sites, which are currently not affected by resistance that will be used for pest control specially *Blattella germanica*. Attentive to resistance of *B. germanica* to current consuming insecticides and ever-increasing add to intensity of it, the researchers have been considering the susceptibility level of *B. germanica* and efficiency estimation of them to above-mentioned insecticides for control of this pest. The strategies of future researches are study of the susceptibility level of *B. germanica* and efficiency estimation of them to above-mentioned insecticides for control of this pest in Iran.

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