

Original Article

Evaluation of Susceptibility Status of *Phlebotomus papatasi*, the Main Vector of Zoonotic Cutaneous Leishmaniasis, to Different WHO Recommended Insecticides in an Endemic Focus, Central Iran

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Abstract

Background: Among neglected zoonotic diseases, leishmaniasis caused by *Leishmania* parasite through infected female sand fly bite, are a group of diseases found in 98 countries and territories representing a critical burden of disease worldwide. Vector management plays a crucial role in reducing the burden of vector-borne diseases by WHO's global plan. The objective of the current study was to assess the susceptibility status of wild phlebotomine sand flies from Esfahan Province, central Iran, to the recommended insecticides by WHO.

Methods: Sand flies were collected by mouth aspirator in Matin Abad desert Eco-resort and were tested using WHO adult mosquito test kit against Dichlorodiphenyltrichloroethane (DDT) 4%, Deltamethrin 0.05%, Malathion 5% and Propoxur 0.1%. The number of knockdown sand flies were recorded during exposure time in ten minutes interval for DDT and Deltamethrin and they were allowed to recover for 24 hours. Knockdown Time₅₀ (KD₅₀) and KD₉₀ were generated for them using Probit software. They were mounted and identified by valid keys.

Results: Among the tested insecticides against female *Phlebotomus papatasi*, DDT, Deltamethrin, and Malathion recorded the highest mortality rate of 100%, followed by Propoxur with 92.2% mortality for a one-hour exposure. For DDT, KD₅₀ and KD₉₀ were calculated 21.87 and 42.93 and for Deltamethrin, they were 23.74 and 56.50 minutes respectively. Total sand flies exposed with DDT and Deltamethrin shed their leg(s).

Conclusion: It is concluded that *Ph. papatasi* from central Iran is susceptible to DDT, Deltamethrin, Malathion, and Propoxur.

Keywords: *Phlebotomus papatasi*; Insecticide; Susceptibility; Iran

Introduction

Leishmaniases caused by parasite (Protozoan) are a group of neglected zoonotic diseases (NZDs) that draw more attention among all the neglected tropical diseases (NTDs). There are over 20 *Leishmania* species that are transmitted by the female phlebotomine sand flies through infected bite; a total of 98 sand fly species are identified as medically important vectors (1– 3). The most common form of the disease is cutaneous leishmaniasis (CL) that causes on the exposed parts of the body skin lesion/s mostly ulcer/s and long-life scars (2). Although CL is a self-healing form of the disease, it creates permanent scars and serious disability (4). Approximately 95 % of CL cases occur in the Middle East Mediterranean basin in the old world, and central Asia and the Americas in the new world, and 70% of worldwide cases are related to the Eastern Mediterranean region (2). In 2018 it was reported that 85 % of cases occurred in 10 countries including Iran (2). According to the 2018 WHO report, 98 countries and territories are endemic for leishmaniasis (5). More than 200,000 new cases reported in 2018 and the disability adjusted life years (DALYs) were about 260,000 in 2017(6). Also CL is one of the skin NTDs affecting subcutaneous tissue and skin resulting in disfigurement, disability, stigmatization, and other socio-economic problems (7).

In Iran, leishmaniasis is endemic in many rural areas of 18 provinces out of 31 (CDC, Ministry of Health and Medical Education, Iran, Unpublished data) in the way that several research groups have worked on different aspects of the disease. In addition, some international courses about the disease and its control were conducted which attracted lots of interest among different countries (8– 21). *Phlebotomus papatasi* is the first line incriminated vector of zoonotic cutaneous leishmaniasis (ZCL) in Iran. Studies have shown there are 48 species of sand flies, among which 30 species belong to the genus *Phlebotomus*, and 18 species of the genus

Sergentomyia. Four species of the family Cricetidae of rodents are considered as the main reservoir host including *Rhombomys opimus*, *Meriones libycus*, *Tatera indica*, and *Meriones hurrianae* in different parts of Iran (22).

Diseases transmitted by vectors cause a critical burden in the world, especially in tropical and neotropical areas. Several important vector-borne diseases as parts of NTDs or Skin NTDs in public health continue to need to intensify vector control interventions aimed at monitoring and reducing transmission. The WHO has several global plans to combat NTDs for decades by the multi-intervention packages including integrated vector management (IVM) (23–28). Vector control has a vital role to play in reducing the burden of vector-borne diseases. However, vector control also has proven well-known weaknesses, including the development of insecticide resistance in vectors that played a critical role in the breakdown of the eradication, elimination, and even controlling. Today, there is a need to learn how to monitor and manage vector resistance in a better way (23). Control methods include insecticide spray, use of insecticide-treated nets, environmental management, and personal protection (2). Residual spraying for endophilic, exophilic, and peridomestic sand flies is recommended by World Health Organization Pesticides Evaluation Scheme (WHOPES). Various insecticide classes can be used for indoor residual spraying (IRS), such as organochlorines (for example DDT), synthetic Pyrethroids (for instance Deltamethrin and Lambda-cyhalothrin), organophosphates (for example Malathion), and carbamates (for example Propoxur) (29).

Although major scientific breakthroughs have been made worldwide during recent decades in the different aspects of leishmaniases diagnosis, prevention, treatment and control, morbidity and mortality of that disease still show a worrying raising trend (29). Vector control with insecticides remains one of the most efficient approach to tackle the disease, and targeting

between 30.3–50.7% (Meteorological Organization - Esfahan Province).

Sand fly collection

Sand flies were collected using a filtered mouth aspirator, most of them on a car trap inside Matinabad Desert Eco-Camp before sunset till early in the next morning around *Haloxylon* bushes and rodent burrows, from July to September 2019. Sand flies were kept in the cage with a wet towel and were transported to the sand fly insectary in Esfahan Health Station. Susceptibility tests were conducted the day after in the laboratory. Sand flies were fed with cotton soaked in 10% sucrose solution, and the insects were kept at 25–28 °C temperature, 70–90% relative humidity, and 14:10 L:D photoperiod.

Insecticides

All WHO test-kit tubes and impregnated papers were procured by CDC, Ministry of Health and Medical Education, Iran by the WHO collaborating center in University Sains Malaysia, Penang, Malaysia. The choice of insecticides was based on highly recommended WHO insecticides at least one from each class such as Organochlorine: Dichlorodiphenyltrichloroethane (DDT) 4% (BATCH No: DD 265), Organophosphate: Malathion 5% (BATCH No: MA 234), Carbamate: Propoxur 0.1% (BATCH No: PR 123) and Pyrethroid: Deltamethrin 0.05% (BATCH No: DE 527).

Bioassay (susceptibility) tests

Since there is no integrated standard protocol for susceptibility testing of sand flies, they were tested using adult susceptibility test procedures of adult mosquitoes based on WHO the latest protocol of 2018. (28)

The WHO susceptibility tube test is a kind of “direct response-to-exposure” test. It measures mosquito mortality to a known standard concentration of a given insecticide, either with a discriminating concentration or with intensity concentrations. (28) Control papers were prepared using ‘acetone and silicone oil’-impregnated paper (0.66 ml oil

+ 1.34 ml acetone) as a control for DDT and Pyrethroid group and ‘acetone and olive oil’-impregnated paper (0.71 ml oil + 1.29 ml acetone) as a control for Organophosphate and Carbamates according to the standard method of World Health Organization Pesticides Evaluation Scheme (WHOPES) Institute of Research for Development (IRD), Montpellier, France.

Standard procedure

Sand flies were offered a 10 % sucrose solution for water and energy sources and kept in insectary condition, then transferred to the tubes about one hour prior to starting the test. Insecticide impregnated papers inside test tubes kept refrigerated in a plastic bag were put at room temperature about 1 hour prior to the test. All sand flies were exposed to insecticides for one-hour paralleling with control tubes for each replication. At the end of exposure time, all tubes were kept in insectary condition (T: 25–28 °C- RH: 70–90%) for 24 hours to recover after exposure, with a cotton pad containing 10% sucrose on the top net. Then the mortality of sand flies in both test and control tubes was read and recorded the day after (28).

All sand flies that had the ability to fly were considered alive, regardless of leg losing. The number of knocked down sand flies was recorded every 10 minutes for sand flies exposed to DDT and Deltamethrin. If observed mortality in control groups after 24 h recovery time ranged between 5 to 20%, mortality in the test tubes of that group should be corrected using Abbott’s formula (35). If observed mortalities in control groups exceeded 20%, the entire tubes of that group were discarded. For mortality percentage calculation and correction of mortality the following formulas, adopted from WHO (2016) were used (28).

$$\text{Observed mortality} = \frac{\text{Total number of dead sand flies}}{\text{Total sample size}} * 100$$

$$\text{Corrected mortality} = \frac{(\% \text{ observed mortality} - \% \text{ control mortality})}{(100 - \% \text{ control mortality})} * 100$$

Based on the 2018 WHO test procedure

if the mortality recorded equal or more than 98%, the tested group will be categorized as susceptible; if the mortality ranged between 90 to 97% it shows the resistance possibility. When it happens, the test must be repeated. If the second test mortality is less than 98% the resistance is confirmed. If the mortality recorded less than 90%, we are facing a confirmed resistance. Then researchers can determine the intensity of resistance or mechanism of resistance by applying following the protocol (28).

Sand flies testing

Total number of 1316 unfed female *Ph. papatasi* sand flies have been tested. Since they were wild, all fed, gravid, semi-gravid females, all males, and other species were excluded at the time of transferring to the test tubes, checking mortality, mounting and also during identification.

Susceptibility tests were carried out on six to fifteen replications in several rounds to obtain enough sand flies tested (at least 100 for each insecticide) with relevant enough control tube/s in each group in parallel.

Sand fly mounting and identification

All sand flies tested after recording the mortality results, transferred to ethanol 70%

for mounting and identification. They were mounted in Pouri’s media and mounted sand flies’ species were identified based on valid identification keys (36, 37).

Knockdown effect and leg loss

The number of knocked down sand flies was counted in the DDT and Deltamethrin test tubes and recorded every ten minutes during the exposure time. Sand flies leg loss was investigated and recorded after 24h recovery in males and females.

Data analysis/ Knockdown curve

The knock down time regression line was created for DDT and Deltamethrin using Probit software and data analysis was made with 95% confidence interval and the KD_{50} and KD_{90} were calculated (Table 1, Fig 3,4) (38) Number of sand flies tested shows in Table 2.

Results

Knock down Time₅₀ (KD_{50}) and KD_{90}

The number and percent of knock down sand flies are shown in Fig. 2 and 3. The Probit parameters and the KD_{50} and KD_{90} with 95% confidence interval were calculated (Table 1).

Table 1. The Parameters of Probit regression line of knockdown times for wild-caught sand flies Matinabad desert Eco-resort, Esfahan Province, 2019

Insecticide Name	A	B ± SE	KD_{50} , (LCL-UCL) 95% C.I.	KD_{90} , (LCL-UCL) 95% C.I.	X^2 (df)	P value
Deltamethrin 0.05%	-4.68	3.4 ± 0.326	19.9	46.75	12.93 (4)	<0.05
			23.74	56.5		
			27.44	75.43		
DDT 4%	-5.86	4.38 ± 0.495	17.74	35.81	23.78 (4)	<0.05
			21.87	42.93		
			25.69	56.84		

A = y-intercept
 B = the slope of the line;
 SE = Standard error;
 KD_{50} , 95 % CI = Time causing 50 % Knockdown and its 95 % confidence interval
 KD_{90} , 95 % CI = Time causing 90 % Knockdown and its 95 % confidence interval
 LCL: Lower Confidence Limit
 UCL: Upper Confidence Limit
 X^2 = Heterogeneity about the regression line
 df = degree of freedom
 P value = Represent heterogeneity in the population of tested

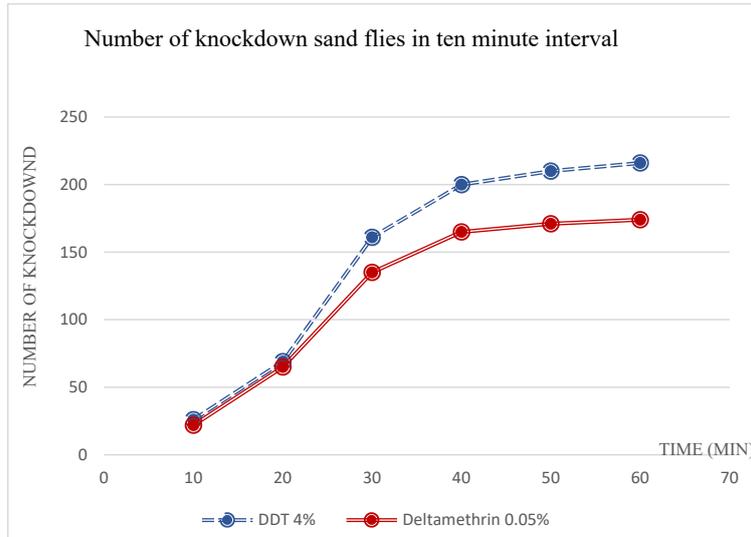


Fig. 2. The number of knockdown sand flies in ten-minute intervals during exposure time with DDT and Deltamethrin. Matinabad desert Eco-resort, Esfahan Province, 2019

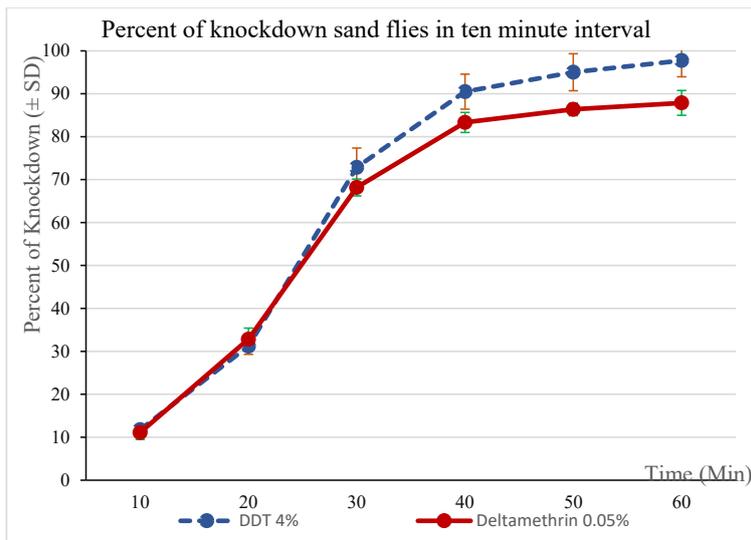


Fig. 3. Knockdown percent of sand flies exposed to DDT and Deltamethrin for one hour in ten-minute intervals. Matinabad desert Eco-resort, Esfahan Province, 2019

Total sand flies exposed with DDT and Deltamethrin shed their leg(s).

Additionally, sand flies exposed to these two insecticides experienced the “knockdown effect” evidently by muscle spasm, involuntary movement/move less (convulsion or erratic movement or paralysis) during the exposure time (39). It was observed that sand flies exposed with DDT had more involuntary movements and

then the ones exposed with Deltamethrin who were more moveless.

Susceptibility status

The susceptibility status of female sand flies is shown in Table 2. The mortality rate of sand flies exposed to Propoxur has shown a possible resistance in the first round of test and according to the most recent test protocol, the test was repeated in 2 more

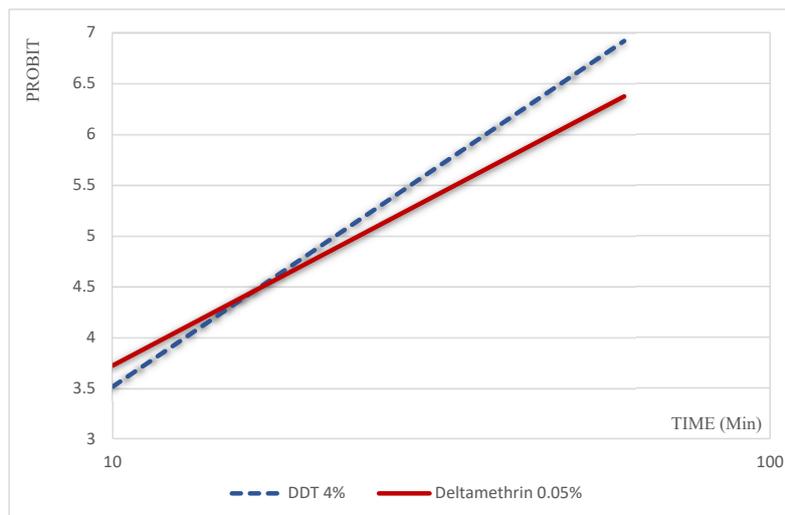


Fig. 4. The regression line for DDT and Deltamethrin for sand flies exposed for one-hour. Matinabad desert Eco-resort, Esfahan Province, 2019

Table 2. Susceptibility status of female *Phlebotomus papatasi* to different insecticides- Matinabad desert Eco-resort, Esfahan Province, 2019

Insecticide/ Concentration	Test			Control			Result
	Total No. of unfed females	No. of dead	Mortality rate (%)	Total No. of unfed females	No. of dead	Mortality rate (%)	
DDT 4%	134	134	100	174	2	1.1	Susceptible
Deltamethrin 0.05%	138	138	100	109	1	0.9	Susceptible
Malathion 5%	223	223	100	75	1	1.3	Susceptible
Propoxur 0.1% 1st round	105	95	90.47	75	1	1.3	
Propoxur 0.1% 2nd round	133	132	99.24	82	1	1.2	Susceptible

rounds and replications obtaining enough number sand flies.

In the current study, 1248 female *Ph. papatasi* were exposed to different standard discriminative concentrations of insecticides. One hundred and thirty-four unfed adult *Ph. papatasi* were exposed to DDT 4% which resulted in 100% mortality, showing that this species is susceptible to DDT insecticide. For Deltamethrin 0.05% and Malathion 5%, 138 and 223 females were tested respectively, and both of them resulted in 100% mortality that was determined as a totally susceptible population. One hundred and five sand flies were tested against Propoxur 0.1%

and resulted in 90.4% mortality which was shown as resistance at the first glance. According to the 2018 WHO guideline, the second round of tests was done using 133 females and resulted in 99.2% mortality that was evaluated as susceptible species. While control groups were tested in parallel for each batch accordingly by recorded mortality of 1.1 and 0.9% for acetone/silicone oil and 1.3% and 1.2% for acetone/olive oil respectively.

Survival curve

Regression analysis was performed for *Ph. papatasi* to estimate KD_{50} and KD_{90}

for DDT and Deltamethrin with a 95% confidence interval. A knockdown time regression line was created for them showed in Fig. 4.

Discussion

The objective of the current research was to investigate the susceptibility/resistance of *Ph. papatasi* to certain insecticides from various chemical classes using the WHO test kit. World Health Organization bioassay susceptibility test kit is a direct response-to-exposure test that is vital in insecticide resistance management worldwide (24). The discovery of DDT in 1939 was one of the most meaningful developments in the history of pest control. Deltamethrin also was the most active insecticide ever known at the time of its discovery. Continuous use of many insecticides is a potential threat in the field of emerging resistance in insects (40).

Wild-caught *Ph. papatasi* in the current study was found to be susceptible to Organochlorine (DDT 4%), Organophosphate (Malathion 5%), Pyrethroid (Deltamethrin 0.05%), and Carbamate (Propoxur 0.1%). There are studies conducted worldwide on baseline susceptibility of various species of sand flies in different countries.

Old world

In India *Phlebotomus argentipes* reported resistant to DDT in 1992 and in different parts of Bihar they found developing resistance to DDT 4% in 2001. (41, 42) In the latter study they do their research on a different species from our study. In North Africa and the Middle East researchers worked on Bendiocarb, Cyfluthrin, DDT, Malathion, Permethrin, and Resmethrin on *Phlebotomus bergeroti*, *Phlebotomus langeroni*, *Ph. papatasi* and *Phlebotomus sergenti* in 2001. They worked on four different species from ours and various insecticide and reported 3 least toxic insecticides in order of toxicity Permethrin, Malathion and DDT, with DDT being the least toxic. It has been stated that the response to three other insecticides:

Bendiocarb, Cyfluthrin and Resmethrin has not been as uniform among species (43). In Italy (2002) *Phlebotomus perniciosus* and *Ph. papatasi* were susceptible to DDT 2%, Lambda-cyhalothrin 0.06% and Permethrin 0.2% (44). It agree with our study while the percentage of DDT is less than current experiment. In some parts of India and Nepal border *Ph. argentipes* in 2010–2012 reported resistant to DDT 4% and susceptible to Deltamethrin 0.05% and Malathion 5%. They conducted the study on different species and their result about DDT was not same as ours. It is explained that the use of DDT in IRS measures for VL control could effect on sand flies susceptibility (45, 46). Also, in 2012 *Ph. papatasi* and *Ph. sergenti* were susceptible to DDT and Lambda-cyhalothrin in Morocco, in parallel with our report (47). In some area of Sudan populations of *Ph. papatasi* was susceptible to DDT, Permethrin, Malathion, and Propoxur that is agree to our research and in some area sensitive to DDT and Permethrin but highly resistant to Malathion and Propoxur in 2012 which is probably due to anti-malaria activities during last 50 years in the area and it is on the contrary to our experiments (48). In 2015 *Ph. argentipes* in West Bengal, India reported developing resistance to DDT (49). In Kerala *Ph. argentipes*, *Ph. sintoni*, *Sergentomyia bagdhadis*, *Se. zeylonica* and *Se. babu* were susceptible to DDT and Deltamethrin (50). *Phlebotomus argentipes* in 2016 reported resistance in Kala-azar endemic region and susceptible to DDT in the non-endemic region in India (51). All of these last-mentioned studies have been done by different sand flies species from ours. In two different Western provinces of Turkey with and without a background of insecticides use, populations of sand flies found resistant and susceptible to Deltamethrin 0.05% and Permethrin 0.75% respectively (2017) as a result of long term application of both insecticides in the region (52). They did not mention the species of sand flies tested. In 13 villages of Bihar *Ph. argentipes* as a different species from our region was highly susceptible to Deltamethrin,

Lambda-cyhalothrin, Alpha-cypermethrin (2016) (53). In Nepal and Bangladesh *Ph. argentipes* was highly susceptible to Alpha-cypermethrin 0.05%, Deltamethrin 0.05%, Lambda-cyhalothrin 0.05%, Permethrin 0.75%, Malathion 5% and Bendiocarb 0.1% in 60 min of exposure (2017) (54). In the last two studies they tested *Ph. argentipes* that this species is a vector on that area but not in Iran.

Also in Iran, there are studies on the susceptibility status of sand flies. During 1985–88 Seyedi Rashti et al experimented on various areas of Iran with the treatment background with DDT which discontinued from 1969. They expressed that sand flies from Esfahan showed more tolerance against DDT in comparison to other areas. (8) But our experiments show different condition in this area now. Yaghoobi Ershadi and Javadian found *Ph. papatasi* tolerant to DDT 4% in Borkhar County in Esfahan Province due to DDT or related compound application in public health or in agricultural pest control which is in contrary to our results, but susceptible to Dieldrin 4% and in Varzane they were susceptible to DDT 4% similar to our research results (9, 10). It is reported that *Ph. papatasi* and *Ph. sergenti* was susceptible to DDT 4% in Kerman province. (11). It agree with our result about *Ph. papatasi*. In 1998 a study showed that *Ph. kandelakii* and *Ph. perfiliewi* as a probable vector of zoonotic visceral leishmaniasis (ZVL) were susceptible to DDT 4% during 1994 in Ardabil province, Northwest of Iran (12). These species are in different area where it is a ZVL foci with different vectors from ZCL. In Arsanjan County of Fars Province, *Ph. papatasi* recorded sensitive to DDT 4% in 1999 same as current report (13). It is showed that *Ph. sergenti* was susceptible to DDT 4% in Esfahan city in 2005 it is a study on a different species in same province (14). In 2004 and 2005 in Bam City, Kerman Province *Ph. papatasi* and *Ph. sergenti* were susceptible to DDT 4% and Deltamethrin 0.05% similar to this reports (15). Wild-caught *Ph. papatasi* in Badrood, Esfahan Province and their progeny were

found susceptible to Permethrin 0.75%, Deltamethrin 0.1%, Cyfluthrin 0.15% and Lambda-cyhalothrin 0.05% and to DDT 4% During summer 2010 (16, 17). Our research also confirm the susceptibility of them in this area to DDT and Deltamethrin. Another study in the same place during summer 2015 showed that there is susceptibility to Cyfluthrin 0.15%, Lambda-cyhalothrin 0.05%, Permethrin 0.75%, and Deltamethrin 0.05% same as our report and tolerant to DDT 4% unlike to our study (18). A study in North Khorasan showed the development of resistance against DDT (4%) in the wild strain of *Ph. sergenti* but susceptible to Bendiocarb 0.1% and Permethrin 0.75% (19). This report is about another species with various insecticide differ from our experiment. During 2016 and 17 Laboratory reared of *Ph. papatasi* were found susceptible to Permethrin 0.75%, Deltamethrin 0.05%, Cyfluthrin 0.15%, and Lambda-cyhalothrin 0.05% but resistant candidate to DDT 4% (20). This study reported likely result about Deltamethrin and unlike result from current research about DDT.

New world

In 1997 a comprehensive study carried out on field population of *Lutzomyia longipalpis* of Venezuela against DDT 2%, Propoxur 0.01 %, Malathion 2%, Fenitrothion 1%, Pirimiphos methyl 1%, Deltamethrin 0.06%, Lambda-cyhalothrin 0.06%, and permethrin 0.2% insecticides and compered with laboratory population of reference strain and reported highly susceptible (55). The species used in this experiment is different from ours because in new world *Lu. longipalpis* has medical importance as a vector but there is no in the old world and the concentration of Deltamethrin, Malathion and DDT used in their study are not same as concentration used in current study. In 2009 researchers reported two wild populations of *Lu. longipalpis* with different exposure backgrounds susceptible to Malathion, Fenitrothion, Lambda-cyhalothrin, Permethrin, and Deltamethrin in Brazil (56). In 2015 another study in Brazil reported *Lu. longipalpis* highly

susceptible to Alpha-cypermethrin (57). Also Brazil located in new world and the vector is *Lu. Longipalpis* and the only common insecticide was Deltamethrin. In the United State, some tests performed on laboratory populations of *Ph. papatasi* and *Lu. longipalpis* using CDC bottle bioassay against different concentrations of Cypermethrin, Deltamethrin, Lambda-cyhalothrin and Permethrin, Chlorpyrifos, Fenitrothion, and Malathion, Bendiocarb, Propoxur and DDT and they documented as susceptible population (39). Same species and same insecticide tested by different methods of CDC bottle bioassay but reported the same result. In Colombia in a study with the same method on *Lu. longipalpis*, Lambda-cyhalothrin showed the highest degree of toxicity followed by Alpha-cypermethrin and Deltamethrin (58). There is another study in Brazil using a modified method of WHO comparing laboratory population of *Lu. longipalpis* with some population in the field with different exposure background and reported that Lab-reared sand flies were more tolerant to field-collected ones against Lambda-cyhalothrin (0.05%), Deltamethrin (0.5%) and control was (Silicone oil) (59). The sand fly species is different and also the concentration of Deltamethrin is not the same.

It can be observed that the only resistant *Phlebotomus* registered in The Arthropod Pesticide Resistance Database is *Ph. argentipes* in 23 locations of Bihar state in India (60– 62). It is reported as resistance to DDT in VL endemic area of Bihar and also developed resistance/ tolerant to Malathion in a larger area but susceptible to Deltamethrin and the wild-caught and their seven offspring's is reported resistant to DDT (60, 61). They also experimented another species in different location and the result also is unlike to current research.

In the current study, it was found that sand flies from Esfahan Province, were highly susceptible to Deltamethrin and DDT and it was also noted that during the exposure time and counting the knockdown numbers of sand flies, those who exposed with DDT had

more involuntary movement in their place but the vast majority of those who exposed to Deltamethrin was moveless. Pyrethroids as a major class of neurotoxic insecticide and DDT, fairly slow-acting on the protein of voltage-gated sodium channels in the cell membrane of the insect nerves. Exposing insects to DDT and Deltamethrin disrupts the normal process leading to paralysis and finally death. Peripheral nervous system influenced by DDT causing tremors in appendages or entire body called “DDT Jitters” then leads to excitatory paralysis and eventually death. Deltamethrin affects both the central and peripheral nervous systems by producing repetitive discharge and cause paralysis the same as DDT but more obvious. After exposure with Deltamethrin, the channels remain open and leads to abnormal hyperexcitability but “Knockdown” is its sub-lethal effect (40).

Sand flies in response to exposure to DDT and Deltamethrin manifested evident leg shedding in the current study. The same observation was made by Denlinger and Alexander (39, 56). Sand flies with shedding legs, as a significant sub-lethal effect, will not be able to transmit the parasite as a consequence of disabling for blood-feeding (56). On the other hand, the authors reported that sand flies after shedding legs could still be capable of blood feed (39). We did not check the ability to have blood meals for leg shedded sand flies because the mortality rate was high, they were wild-caught, and we needed to identify them after keeping in alcohol and mounting. Nevertheless, this will be considered in further studies.

Conclusion

This study revealed that *Ph. papatasi* from central Iran is susceptible to DDT, Deltamethrin, Malathion, and Propoxur. Knowing about the susceptibility/ resistance of sand flies in this endemic area can play a vital role in the field of vector control and pesticide management. Excessive use of insecticide with unsuitable concentration can cause resistance in vector sand flies and complicate

disease control. This result brings additional data to the worldwide need to assess the insecticide susceptibility status of sand flies, in order to strengthen vector surveillance and integrated vector management. We strongly recommend performing susceptibility tests on sand flies in various parts of the world as systematic monitoring and evaluating the status of leishmaniasis vectors against various insecticides, as regular or periodic susceptibility tests can ring a timely alert regarding early resistance. Also doing some further tests on the resistant ones is recommended to determine the resistance intensity and mechanism according to standard protocols of WHO.

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Ethical considerations

This study was conducted as a part of a PhD dissertation, and It has been reviewed and approved by the School of Public Health (SPH), Tehran University of Medical Sciences (TUMS) ethics committee and has been registered with the code IR.TUMS.SPH.REC.1396.3602.

Conflict of interest statement

Authors declare that there is no conflict of interest.

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