Sulfur Application as Pesticide in Pistachio Orchard: Health and Safety

Maryam Afrousheh (PhD)[1*], Hojjat Hasheminasab (PhD)[1]

[1]Pistachio Research Center, Horticultural Sciences Research Institute, Agricultural Research, Education and Extension Organization (AREEO), Rafsanjan, Iran

Information

Article Type:
Review Article

Article History:

Received: 20 May 2018
Accepted: 1 Aug. 2018

DOI: 0.22123/phj.2018.145424.1014

Keywords:
EPA
Pesticides
Pistachio
Sulfur
Toxicity

Corresponding Author:

Maryam Afrousheh

Email: Afrousheh@pri.ir
Tel: +98-343-4225201-7

Abstract

Introduction: The common pistachio psylla, *Agonoscena pistaciae* (Hemiptera: Psylloidea), is one of the most important pests found in pistachio orchards in Iran, that annually causes great economic damages on pistachio yield. The application of sulfur as a pesticide was one of the strategies used in orchards in the recent years but with negative and positive effects as have been reported. The purpose of this review is to investigate sulfur as a pesticide.

Materials and Methods: All pesticides used in the United States must be registered by the Environmental Protection Agency (EPA), based on scientific studies demonstrating their applications without posing risks on people or the environment. Elemental sulfur as a natural component was registered by EPA for application as the insecticide, fungicide, and rodenticide on several hundred of feed crops, ornamental plants, turfs, and residential sites.

Results: The available studies indicate that the application of sulfur within the authorized limits has low toxicity in people and non-target species.

Conclusion: All pesticides containing sulfur as individual active ingredient are acceptable for application in an organically managed orchard. Pesticides containing sulfur can be applied using acceptable techniques without causing unreasonable adverse effects on people or the environment.

►Please cite this article as follows:

Afrousheh M, Hasheminasab H. Sulfur Application as Pesticide in Pistachio Orchard: Health and Safety. Pistachio and Health Journal. 2018; 1 (3): 52-63

1. Introduction

The common pistachio psylla, *Agonoscena pistaciae*, is a key pest affecting pistachio orchards in Iran, especially Kerman province. Psylla is active early spring with the onset of vegetative growth of pistachio trees until late fall. Most first-generation adult of psyllids appear around early May and attack pistachio trees, feed on swollen buds, young leaves and shoots, and reproduce the summer-form generation. So, the pest population increases rapidly from early spring to late autumn through several generations of life cycles. However, the presence of high population densities of psyllid nymphs and adults causes significant economic losses, particularly from the late spring to nearly the end of summer. The control of this pest relies almost exclusively on pesticides [1].

Despite the application of poisons and chemical insecticides in the recent years, especially in Kerman and Semnan provinces, the psylla pest is still considered a serious challenge in pistachio orchards. The application of non-standard and illegally-imported pesticides has led to the inefficient control of pest and diseases- and, as a consequence, multiple applications of pesticides. Therefore, psylla has become quite resistant to the applied insecticides. Having difficulty in controlling psylla with these pesticides, pistachio growers have been forced to try some of the newer chemistries or registrations to make sure that the rotation of active ingredients prevents or at least delay resistance development. The effective application of sulfur as a pesticide has been one of the strategies used in pistachio orchards in Damghan in the recent decades. Therefore various forms of sulfur as a pesticide have been extensively used in pistachio orchards in the recent year in Kerman (2018). The reports by growers contain negative and positive reflections in relation to this pesticide. This study provides a review of the literature on the application of sulfur as a pesticide in agriculture.

2. EPA Pesticide Regulation

EPA is primarily responsible for regulating pesticides used in the United States. Its mission is to protect human health and also the environment. EPA evaluates new pesticides and proposed uses, and periodically reviews the current research on the safety of older pesticides. It also regulates pesticides and provides support to state and regional EPA programs designed to protect, certify, and train pesticide users.

Currently, elemental sulfur (fine powder, 325 mesh) has been registered by EPA as an insecticide, fungicide, and rodenticide to be used for several hundred foods and feed crops, ornamental plants, turfs, and residential sites. It is also widely used for controlling brown rot of peaches, powdery mildew of apples, gooseberries, hops, ornamentals, grapes, strawberries, sugar beets, apple scab, gall mite on blackcurrant, peanut leaf spot, mildew on roses, mites on beans, carrots, lucerne, melons, and tomatoes, etc. [2-7].

The application of sulfur has been recommended for control of pest in some trees as follow [6]:

Pistachios: Sulfur was recommended for control of citrus flat mite (*Brevipalpus lewisi*). Citrus flat mite is a warm season pest whose population increases in June and peaking in late July and August, and then declining gradually. The mite feeds on damaged stems (rachis) of branches as well as nuts. Feeding on the stems causes a browning that gradually develops into a severely roughened and black area resembling a scab. This feeding damage is usually on the inside or back portion of nut branches. Under heavy population pressure, stems and nuts begin to shrivel. The damaged nuts remain on the tree and can provide an overwintering source for navel orange worm. Accurate observation is needed to see citrus flat mite in trees. But they are most easily observed around the shriveled and damaged areas.

The initial sulfur application (50 Ib/acre or 56 kg/ha) must be started when flat mite populations can be easily detected in nut clusters (in June to July), but before nut shriveling the application should be repeated in the ground or air if necessary. When the temperature exceeds 90°F (32°C), lower rates and more frequent applications are suggested in order to avoid crop injury. This pesticide may be applied to non-bearing and bearing pistachio trees. Sulfur sprays are also acceptable for use in organic orchards (Table 1).

Table 1. In pistachio gardens, UC IPM (2014) suggests sulfur sprays as an acceptable technique for use in organically managed orchards [5].

Common name (trade name)	Amount/Acre**	P.H.I.+
Sulfur dust 98%#	30–40 lb (33-44 kg/ha)	0
Comments: Best results are obtained by ground treatments; however, aerial treatments are also effective. It must be used at higher rates in the air. Labels must be checked to confirm products are labeled for pistachio.		
Wettable sulfur#	12–24 lb (13-26 kg/ha)	0
Comments: It may be applied by ground or air. Labels must be checked to confirm product use for pistachio.		

**Unless otherwise noted, it must be applied with enough water to ensure adequate coverage
+Pre-harvest interval. It doesn't apply within many days of harvest
#Acceptable for organically grown products

Almonds: To control of brown rot, scab, and shot hole, sulfur (8-30 Ib/acre or 9-33 kg/ha sulfur spray 97%) must be applied in pre-bloom, bloom, and post-bloom periods and be repeated at 7-10 day intervals when a disease threatens or during rainy days. Sulfur (12-25 Ib/acre or 13-26 kg/ha sulfur spray 97%) must be applied to control brown almond, European red, two-spotted, pacific, and strawberry (Atlantic) mites when the infestation first occurs and the application should be repeated if necessary.

Apples: Sulfur (8-15 Ib/acre or 8.8-16.7 kg/ha, sulfur spray 97%) must be applied to control scab and powdery mildew from green tip or pre-blossom through the second cover spray. The application must be done only on sulfur tolerant varieties. Macintosh, Golden Delicious, Jonathan and certain other varieties may be injured by sulfur under certain climatic conditions. Sulfur (10 to 20 Ib/acre or 11-22 kg/ha sulfur spray 97%) can also be used to control Pear psylla and (blister, red spider, two spotted) mites. It must be applied in during the dormant periods of bud development and post-harvest with suitable spray oil [6].

Peaches and nectarines: Sulfur (10-18 Ib/acre or 11-20 kg/ha sulfur spray 97%) must be applied to control brown rot, coryneum blight, rust, peach silver mites, and powdery mildew from the popcorn stage up to the harvest. For brown rot control, sulfur (up to 30 Ib/acre or 33.5 kg/ha) must be applied about 4-5 weeks in summer before the harvest and be continued at weekly intervals.

Pears: To control scab and powdery mildew, sulfur (8 Ib/acre or 8.8 kg/ha sulfur spray 97% plus 2.5 gallon lime sulfur/ ha) must be applied in the green tip or pre-blossom stages. Sulfur (8-18 Ibs or 8.8-20 kg) must be applied to Bartlett pears at petal fall through the second cover sprays. Sensitive varieties (e.g., Anjou and Comice) may be injured by sulfur under certain climatic conditions. Sulfur (10 to 20 Ib/acre or 11-22 kg/ha sulfur spray 97%) must be applied to control pear psylla and (blister, r spider, and two-spotted) mites with a suitable spray oil in the post-harvest and during the dormant periods of bud development. Sulfur spray must not be applied to sensitive varieties of pears (i.e., D'Anjou) except at the mentioned stages [25]. Plums and prunes: Sulfur (10-18 Ib/acre or 11-20 kg/ha sulfur spray 97%) must be applied to control brown rot and prune rust during summer. The first application begins about 5 weeks before harvesting and consequently on a weekly basis under wet weather conditions.

3. The Importance of Sulfur: Roles and Functions

Sulfur is the tenth most common element by mass in the universe and the fifth most common on the earth. Though sometimes detected in pure and native form, sulfur is usually found as sulfide and sulfate minerals on the earth. Its physical and chemical properties are presented in Table 2 [8].

Sulfur is one of the macro-nutrient elements, which plays an important role in the normal plant growth. Sulfur contained in plants is involved in the composition of amino acids and protein, the formation of secondary components in plants, nitrogen metabolism, and is resistant to pests and diseases. It is also used as a fertilizer and soil amendment for reclaiming alkaline soils [9, 10]. The application of sulfur as a pesticide has been known since very early times and has been registered in the United States since the 1920s. Sulfur as an active ingredient is applied in nearly 300 registered pesticide products. The effect of sulfur is non-systemic contact [8, 11]. Sulfur in the commercial form was produced as a byproduct of coal, natural gas and petroleum refinement and mining process. It is applied as dust (powder), granular (colloidal formulations) or liquid (wettable) form [9]. Generally, sulfur compatibility with other products like insecticides and fungicides is desirable.

Table 2. Physical and chemical properties of sulfur

Chemical name:		**Sulfur, Sulphur (British spelling)**
Appearance, color, odor		Crystal solid material of yellow color with specific odor
Chemical class/Use:		Fungicide, Acaricide
pH		N/A
Solubility in water:		Insoluble
Melting point:		119°C
Boiling point:		444°C
Auto ignition temperature:		190°C.
Sulphur dust explosive concentration in air:		Over 17 g/m^3
Density:	**-liquid**	1790 kg/m^3
	-solid	2100 kg/m^3

4. Sulfur as an inorganic insecticide

4.1. Dusting sulfur

Sulfur in the form of dust is always used drily. It has a good consistency with a wide range of fungicides/miticides. It is actually an acaricide used to control ticks, mites, rusts, leaf spots, powdery mildew, and scab, as it disrupts the mite and insect metabolism. This form of sulfur is recommended to be used as plastic spray equipment (abrasive to metal). It is not used within one month of oil spray. It can cause burns at temperatures above 90°F (32°C) and also in some sensitive plants [2-5].

The application of this type of sulfur has some advantages, eig., it containsa high percentage of active ingredients, is user-friendly (no mixing), requires simple equipment, is effective in hard-to-reach indoor areas, and in places where moisture from the spray may cause damage, and finally it is most effective as a miticide and also useful against aphids and thrips on fruits, vegetables, flowers, ornamentals with very low toxicity for mammalians [7].

However, it has some disadvantages such as easy drifting of the target during application, difficulty in making an even distribution of particles on a surface (it does not stick to surfaces as well as liquids), and the residue is easily moved off the target by air or water movement. Inhalation of sulfur dust may irritate skin, eyes, nose, and throat, and its dampness can cause damages to the lungs [7].

4.2. Granular sulfur

The granular formulation is similar to dust formulation, except granular particles are larger and heavier. They are most often used to apply chemicals to the soil to control nematodes, insects living in the soil, larval mosquitoes, and other aquatic pests [2-5].

The advantages of using granular sulfur include: its easy application (no mixing), low drifting hazard, quick particles settlement, low hazards to the applicator (no spray and little dust), applicability through simple application equipment such as seeders or fertilizer spreaders, and the carriage of the formulation by weight through foliage to the soil or water targets, that make it to break down more slowly [7]. however, its application has some disadvantages including the difficulty of calibrating the equipment, non-stickiness to foliage or other uneven surfaces, to the need for incorporation into the soil or planting medium, and the need for moisture to activate pesticides (not effective in drought conditions) [7].

4.3. Wettable sulfur

Wettable sulfur is the commercial name for dusting sulfur (a dry and finely ground looking like dust) formulated with additional ingredients to make it water miscible for application as a spray. It can be applied as a dust or as a wettable powder, depending on the applicator's preference. The particles don't dissolve in water. They settle out quickly unless they are constantly agitated to keep them suspended. They can be used for most pest problems as a fungicide against mildew and other mold-related problems for plants and the soil. It has an excellent residual activity [2-5].

the advantages of wettable sulfur include easy to storage, transportation and handling, easy measurement and mixture, fewer unwanted harms to the treated plant compared to emulsifiable concentrates and other petroleum-based pesticides, and less skin and eye absorption than ECs (emulsifiable concentrates containing liquid active ingredients and petroleum-based solvents) [7].

The disadvantages of its application include: inhalation hazard to the applicator while measuring and mixing the concentrated powder, the need for good and constant agitation (usually mechanical) in the spray tank and quick settlment if the agitator is turned off, being abrasive to many types of pumps and nozzles and thus wearing out them quickly, difficulty to be mixed in very hard, and alkaline water, and the visibility of clog nozzles, screens, and residues on the treated surface [7].

4.4. Lime sulfur (calcium polysulfide)

Lime sulfur is believed to be the earliest synthetic chemical used as a pesticide the 1840s in France to control grape powdery mildew. In 1886, it was first used in California to control San Jose scale. In the early 1904, commercial suppliers began to produce lime sulfur and prior to that time, growers used to produce their own lime sulfur. By the 1920s, all commercial orchards in western countries were essentially preserved by regular spraying with lime sulfur. However, by the 1940s, lime sulfur began to be replaced by synthetic organic fungicides which risked less damage to the crop's foliage. It is currently applied as a protectant fungicide and insecticide against peach leaf curl, brown rot, leaf spot, powdery mildew, scab, anthracnose, overwintering mites, scales, and aphids. It is usually applied by a contact poison. The lime sulfur spray must be applied in the dormant or delayed dormant periods on fruit trees and many ornamental plants. It should not be used when temperatures are expected to exceed 80°F (27°C) [2-5].

Lime sulfur (a diluted solution made by combining calcium hydroxide with elemental sulfur in water) is used for pest control purposes. It can be prepared by boiling calcium hydroxide and sulfur together with a small amount of surfactant. It is normally solid and reddish-yellow in color and has a distinct offensive odour used as an aqueous solution spray for deciduous trees to control fungi, bacteria, and insects living or dormant on the surface of the bark. Lime sulfur burns leave so it is not useful for evergreen plants. It does not mix with other pesticides, but can mix with oil, and very alkaline solutions (reacting with acids produce toxic gas) [7].

Lime sulfur is not extremely flammable but combustion produces (e.g., sulfur dioxide) are highly irritating. Therefore, safety goggles and gloves should be worn while using lime sulfur. Lime sulfur solutions are strongly alkaline (typical commercial concentrates have a pH of over 11.5), so it is destructive to living parts and can cause blindness if it is splashed in the eyes. It causes severe irritation to skin, eyes, and lungs. And, it general causes low toxicity in mammalians [7].

5. The effects of sulfur as a pesticide on the environment and human

From an environmental aspect, pesticides affect non-target species. Pesticides as chemical components can lead to water and air pollution. Each pesticide comes with a specific set of environmental concerns. Dust pesticide drift occurs when pesticides are suspended in the air as particles are carried by wind to other areas, human settlements, and undeveloped areas, potentially affecting other species. Runoff can also carry pesticides into aquatic environments. Pesticides can enter the body through inhalation of aerosols, dust, and vapor that contain pesticides, and also through oral exposure by consuming food/water and through skin exposure by direct contact. The Integrated Pest Management (IPM) introduces chemical components only when other alternatives are ineffective [7].

Insecticides that are developed from elemental (mineral) sources mined from the earth are classified as natural products and often cost less than other processed insecticides. The toxicity level of mineral-based insecticides depends on the chemical properties of the mined elements. Some mineral insecticides such as sulfur are registered for organic use and have relatively low toxic effects on people and non-target organisms [3, 7]. Sulfur is a ubiquitous, natural component of the environment. Elemental sulfur, when applied as a pesticide, is thought to be incorporated into the natural sulfur cycle [2, 3, 12]. Elemental sulfur is a fine ground powder that can be applied either as dust or a spray. This mineral is one of the oldest known pesticides, and its reported pest resistance is rare. By interfering with chemical reactions, digestion, or transport of substances into or between cells, sulfur acts as a metabolic disruptor for insects such as aphids, thrips, and spider mites [13].

5.1. Sulfur effects on human

Most sulfur formulations have low toxicity [14, 15]. All of EPA's toxicology data requirements for sulfur have been satisfied compared to other pesticides (and it has been grouped in toxicity category IV, the least toxic category for these effects). However, sulfur can cause some eye irritation, dermal toxicity, and inhalation hazards (and thus it has been grouped in toxicity category III for these effects). Furthermore, repeated or prolonged exposure to sulfur dust may cause respiratory disorders, chronic bronchitis, and sinus effects [2, 3, 12, 16- 18]. In California alone, 21,467,908 kg of elemental sulfur was applied in agriculture in 2013 [19]. The results of a study on the effect of elemental sulfur use on pediatric lung function and respiratory symptoms in children living in the Salinas Valley, California, (California, USA) showed that elemental sulfur use, allowed in both organic and conventional farming, in near proximity to residential areas, may adversely effect children's respiratory health. Their results also suggested that elemental sulfur, considered relatively safe in Europe [14] and in the United States [2, 3, 12], and one of the most heavily used agricultural pesticides in Europe and the United States [17, 19- 21], may contribute to the development of non-occupational respiratory diseases in agricultural communities. Given the widespread use of elemental sulfur worldwide, its potential respiratory toxicity deserves more regulatory attention [22, 23].

5.2. Sulfur effects on the environment

All the environmental and ecological effects are satisfied for sulfur. This ubiquitous substance does not cause unreasonable adverse effects in the environment when used according to the approved labeling and causes little or no hazard to non-target organisms. Also, sulfur has been shown to be non-mutagenic in microorganisms. In six studies on ecological effects (involving bobwhite quail, two fish species, daphnia, mysid shrimp, and honey bees), sulfur has been shown to be practically non-toxic to the species tested. Thus, although there is a potential for non-target organisms to be exposed to sulfur, little hazard is expected to occur for them. Sulfur is considered non-toxic to birds. The 8-day dietary LC50 for bobwhite quail is reported to be greater than 5,620 ppm in a study using a 95% sulfur wettable powder formulation. In this study, sulfur has been shown to be practically non-toxic to the species tested. Two beneficial insect studies demonstrated that sulfur (98% dust and 92% wettable powder) is low in toxicity to the honeybee through contact and ingestion [24].

Sulfur is a component of the environment, and the natural cycle of oxidation and reduction reactions transform sulfur into both organic and inorganic products. Elemental sulfur is slowly converted to sulfate in soil by the activity of autotrophic bacteria. Elemental sulfur leaches in soil as sulfate at a slow rate. There is no information currently available about chemical breakdown in surface water.

There is slight oxidation of sulfur to volatile oxide in chemical breakdown on vegetation. Sulfur may cause plant injury when used at summer temperatures. Certain chemicals may cause injury to crops (phyto-toxicity) under certain conditions and some plants (e.g., apricots, raspberries, and cucurbits) have been reported to be sensitive to it. Before applying any pesticide, the stage of plant development, the soil type and condition, the temperature, moisture, and wind should be taken into account. Injury may also result from the use of incompatible materials [25]. With the reference to pistachio, IPM reported sulfur application in pistachio orchards (Table 3).

Table 3. In pistachio, UC IPM (2014) introduced guidelines of the relative toxicity of insecticide and miticide application to natural enemies and honey bees [5]

Common name (trade name)	Chemical class1	Selectivity (affected groups)2	Predatory mites 3	General predators 4	Parasites 4	Honey bees 5	Duration of impact to natural enemies 6
Azinphosmethyl (Guthion)	OP	Broad (insects, mites)	L/m	H	H	I	Long
Bacillus thuringiensis* ssp. *kurstaki	M	Narrow(caterpillars)	L	L	L	Iv	None
carbaryl (Sevin) 4F	C	Broad (insects, mites)	-	-	-	I	Long
carbaryl (Sevin) 80S	C	Broad (insects, mites)	L/h	H	H	I	Long
carbaryl (Sevin) XLR Plus	C	Broad (insects, mites)	L	H	L	Iii	Long
permethrin (Ambush, Pounce)	P	Broad (insects, mites)	L	H	H	I	Long
phosmet (Imidan)	OP	Broad (insects, mites)	H	H	H	I	Moderate to long
spinosad (Entrust, Success)	M	Narrow (caterpillars, thrips, Whiteflies, aphids, scales, Leafminers)	L	L7	L	Iii	Short
sulfur	I	Narrow (mites and citrus thrips)	L/h	L	H	Iv	Short
tebufenozide (Confirm)	IGR	Narrow (caterpillars)	L	L	L	Ii	Short

H= high
M= moderate
L= low
—= no information
1 Chemical class: C= carbamate; I= inorganic; IGR= insect growth regulator; M= microbial; OP= organophosphate; P= pyrethroid.
2 Selectivity: Broad means it affects most groups of insects and mites; narrow means it affects only a few specific groups.
3 Generally, toxicities are to western predatory mite, Galendromus occidentalis. Where differences have been measured, these are listed as pesticide resistant strain/native strain.
4 Toxicities are averages of reported effects and should be used only as a general guide. Actual toxicity of a specific chemical depends on the species of predator or parasite, environmental conditions, and application rate.
5 Ratings are as follows: I= Do not apply to blooming plants; II= Apply only during late evening; III= Apply only during late evening, night, or early morning; and IV= Apply at any time with reasonable safety to bees. For more information, see How to Reduce Bee Poisoning From Pesticides, Pacific
Northwest Extension Publication PNW518.
6 Duration: short means hours to days; moderate means days to 2 weeks; and long means many weeks or months.
7 Kills sixspotted thrips (spinosad)
Acknowledgments: This table was compiled based on research data and experience of University of California scientists working on a variety of crops.

6. Conclusions

Human exposure to sulfur can cause eye irritation, breathing difficulty, and skin irritation, especially in sensitive individuals [14]. But, compared to most other pesticides, the sulfur application has minimal effects on humans and the environment [16, 23]. In fact, it is approved for organic farming and it is a very important and effective tool for managing the major pests and diseases all over the world. Due to public complaints about drift effects of the sulfur application in sensitive areas, where people might be exposed to pesticides, growers should employ a number of practices for effective sulfur management. In pistachio orchards, the pesticide application plays an important role in pest management specially psylla [1]. The employed techniques and equipment must be considered for the success of pest control operations. Best management practices are recommended which include:

- The concerns of neighbors and local communities should be taken into account by talking about the importance of sulfur as a relatively pleasant pesticide, as it will help to increase mutual understanding and develop better relations.
- Sulfur should be applied at the times with the least human activity (e.g., at night and on weekends) [7].
- Diseases should be controlled continuously by using growth and reproduction indexes as a tool for optimal timing and possibly reducing the multiple applications [7].
- Reasonable buffer zones to prevent sulfur drift onto sensitive and residential areas should be established. Creating buffer distances depends on the weather conditions, formulation (dust/ wettable), theapplication method (ground/ air), the presence of buffer (e.g., evergreen trees to serve as windbreaks and absorb the pesticides), and the characteristics of sensitive areas. Such windbreaks are legally required in the Netherlands [7].
- Pesticides applied as dust may travel by the wind to other areas. Therefore, the application of wettable sulfur or other low-risk pesticide sprays should be preferred in extra-sensitive areas [5- 7].
- The application of sulfur or other pesticides should be adjusted to the lowest effective rate according to growth and development of pests or diseases. Higher label rates may not be required early in the season to achieve adequate coverage. The use of lower rates also can decrease he risks of pesticide drift, particularly for dusting sulfur [7, 9].
- Regular maintenance, calibration, and suitable selection of the application tools and equipment must be considered in order to ensure the accurate delivery of the intended rate. For pesticides in the form of dust, extra care should be exercised for drift during row turns, for example, to reduce revolutions per minute(rpm) at row ends or close off dusting equipment if possible [3-7].
- Weather conditions must be controlled before and during the application of the pesticide. The amount of pesticides to be used is often dependent on the season. Weather conditions such as the temperature and relative humidity at the time of application can change the spread of the pesticide in the air. On the other hand, a low relative humidity and high temperature result in more spray evaporating. As the wind speed increases so do the spray drift and exposure. The sulfur application must be avoided when the wind speed exceeds 10 miles per hour (32 km/h), so its application must be postponed to an even lower threshold. Also, sulfur must not be applied in the form of dust when the wind is blowing toward sensitive areas and during temperature inversions [3-7]. Resistance management should be considered at the time of application. Many pests will initially be very susceptible to pesticides, but following mutations in their genetic structure they become resistant and survive to

reproduce. Although mildew resistance to sulfur has never been reported, rotations with other pesticides as a preventive action against resistance and potential sulfur drift should be considered [10, 17].

- The spray of sulfur on fruits must be applied before the harvest if they are to be preserved. Sulfur can produce off-flavours in canned products, and form sulfur dioxide which may cause containers to explode [7, 16, 20].
- Sulfur in the form of dust is phytotoxic to most crops if used two weeks before or after the application of horticultural oils [2- 5].
- Instruction on the pesticide label must be read and followed carefully. It is highly recommended that such products be only used in accordance with its labeling information and based on the worker protection standards [2-5].
- In application, sulfur dust is an eye irritant. So, it is necessary to wear safety glasses. Skin irritation may be aggravated in persons with existing skin lesions. Therefore, the exposed clothing must be washed separately before reuse [3- 5].
- Sulfur dust suspended in the air easily ignites and can cause an explosion in confined areas. The burning sulfur is extremely irritating to the respiratory tract and may cause breathing difficulties and pulmonary edema. For safety, full protective clothing must be worn. Emergency medical care must be provided in advance as required by pertinent regulations [7, 16, 17].
- Eating, smoking, drinking, or chewing must be avoided while using pesticides [2, 5].

Conflict of interest

The authors declare no conflict of interest.

References

1. Mehrnejad MR. Bionomics of the common pistachio psylla, Agonoscena pistaciae, in Iran. Acta Hort. 2002. 591: *535-539*.
2. U.S. EPA. Registration eligibility document (RED). Sulfur list A. Case 0031. Docket number EPA-HQ-OPP-2008-176, 1991b. https://www3.epa.gov/pesticides/chem_search/reg_actions/reregistration/red_PC-077501_16-Apr-91.pdf [accessed 22 July 2017].
3. U.S. EPA. Sulfur. Proposed interim registration review decision. Case 0031. Docket number EPA-HQ-OPP-2008-176, 2015. https://www.regulations.gov/document?D=EPA-HQ-OPP-2008-0176-0058 [accessed 22 July 2017].
4. U.S. EPA. Sulfur 80 WDG. Reg. Number: *19713-674*. 2015.
5. U.S. EPA. UC IPM Pest Management; guidelines pistachio. 2014.[http://ipm.ucanr.edu/PMG/r605400111.html]
6. U.S. EPA. Dusting sulfur for organic production. Reg. No. 2935-48. [http://fs1.agrian.com/pdfs/Dusting_Sulfur_Label5a.pdf]
7. U.S. EPA. Private pesticide applicator training manual. 1994. 19th edition. Chapter 4: Pesticide formulations. Kansas State University Agricultural Experiment. Page *85-104*.
8. Sulfur. wikipedia. (https://en.wikipedia.org/wiki/Sulfur)
9. Interim Registration Review Decision for Sulfur; U.S. Environmental Protection Agency, Office of Pesticide Programs, Pesticide Re-evaluation Division, U.S.

Government Printing Office: Washington, DC. 2015.

10. Norton BR, Mikkelsen R, Jensen T. Better Crops with Plant Food: Sulfur for plant nutrition. Int. Plant Nutr. Inst. 2013. 97(2): *10-12*.

11. National Organic Program: USDA Organic Regulations. Fed. Regist. 2017. 82, 53, *14420-14421*.

12. U.S. EPA (U.S. Environmental Protection Agency). RED facts. Sulfur. Pesticides and Toxic Substances (7508W). 738-F-91-110, 1991a. https://archive.epa.gov/ pesticides/reregistration/web/pdf/0031fact.pdf [accessed 22 July 2017].

13. Turner JA. The Pesticide Manual, A World Compendium, 17th ed.; British Crop Protection Council: Hampshire, UK, 2015. pp *1048-1049*.

14. EFSA (European Food Safety Authority). “Conclusion on Pesticide Peer Review Regarding the Risk Assessment of the Active Substance Sulfur.” EFSA Scientific Report. 221:1–70. 2009.

15. Hazardous Substances Data Bank: Sulfur, Elemental; National Library of Medicine's Toxicology Data Network; National Institutes of Health, Health & Human Services: Bethesda, MD, 2017.

16. International Chemical Safety Cards: Sulphur Dioxide; Centers for Disease Control and Prevention; National Institute for Occupational Safety and Health: Atlanta, GA.2006.

17. Klaassen CD(ed). Casarett and Doull’s Toxicology: The Basic Science of Poisons. NewYork, NY: McGraw-Hill. 2013.

18. Lee K, Smith JL, Last JA. Absence of respiratory in flammatory reaction of elemental sulfur using the California Pesticide Illness Database and a mouse model. J. Agro. Medicine. 2005.10(3):*41–47*.

19. CDPR. Summary of Pesticide Use Report Data 2013 Indexed by Chemical. Sacramento, CA: CDPR. 2015.

20. Federal Office of Consumer Protection and Food Safety Germany (Bundesamt für Verbraucherschutz und Lebensmittelsicherheit).2014. http://www.bvl.bund.de/ SharedDocs/Downloads/04_Pflanzenschutzm ittel/meld_par_19_ 2013 pdf? __blob = publicationFile&v=3 [accessed 22 July 2015].

21. PAN Germany (Pesticide Action Network, Germany). Pesticide Use Reporting: Options and Possibilities for Europe. Hamburg, Germany: PAN Germany. 2003. [Accessed 22 July 2015].

22. Raanan R, Gunier RB, Balmes JR, Beltran AJ, Harley KG, Bradman A, Eskenazi B. Elemental Sulfur Use and Associations with Pediatric Lung Function and Respiratory Symptoms in an Agricultural Community (California, USA). Environ. Health. Perspect. 2017.10: 125(8):087007.

23. Summary of Human Health Risk Assessments to Support Registration Review; U. S. Environmental Protection Agency, Office of Pesticide Programs, Health Effects Division, U.S. Government Printing Office: Washington, DC. 2013.

24. Boone C, Bond C, Hallman A. Jenkins J. Sulfur General Fact Sheet; National Pesticide Information Center, Oregon State University Extension Services. 2017. npic.orst.edu/factsheets/sulfurgen.html.

25. Preliminary Environmental Fate and Ecological Risk Assessment for the Registration Review of Sulfur; U. S. Environmental Protection Agency, Office of Pesticide Programs, Environmental Fate and Effects Division, U.S. Government Printing Office: Washington, DC. 2013.