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Feasibility of using mineral sulfur to reduce damage by the palm stem borer, *Oryctes elegans* Prell. in date palm plantations

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Abstract

The date palm horn beetle, *Oryctes elegans* (Coleoptera: Scarabaeidae), is a significant wood-boring pest of date palms, causing substantial damage to the tree and fruit through the feeding activity of adults and larvae. This study evaluated the potential of Zarkooh mineral sulfur, a formulation, in mitigating beetle damage and enhancing physiological traits and nutrient absorption in *Phoenix dactylifera* cv. 'Piarom'. The research was conducted over 2.5 years (2020–2022) in a randomized complete block design (RCBD) with four treatments and five replications. Treatments included control and three levels of Zarkooh sulfur (below, at, and above the recommended concentration). Results showed no significant effect of sulfur application on pest mortality *O. elegans*, population reduction (Henderson-Tilton formula), or tree damage across evaluation intervals (9, 20, 51, and 82 days post-treatment). In addition, sulfur did not significantly affect physiological traits (chlorophyll index, electrolyte leakage, relative water content, dry matter percentage, fresh/dry leaf weight) or macro- and micronutrient uptake (N, P, K, Ca, Mg, S, Fe, Mn, Zn, Cu, B). These findings suggest that using this fertilizer for pest control in date palm plantations is ineffective, especially when applied without expert guidance, and caution is recommended to avoid excessive or unnecessary applications.

Key words: Zarkooh mineral sulfur, physiological traits, nutrients, date palm, horn beetle

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امکان سنجی استفاده از گوگرد معدنی در کاهش خسارت سوسک چوبخوار *Oryctes elegas* Prell. در نخلستان

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چکیده

سوسک شاخدار خرما *Oryctes elegans* (Coleoptera: Scarabaeidae) یکی از مهمترین آفات چوبخوار خرما در جهان می‌باشد که در اثر تغذیه بالغین و لاروها خسارت جبران ناپذیری به درختان خرما و محصول آن وارد می‌سازد. این مطالعه به بررسی تأثیر گوگرد معدن زرکوه در کاهش خسارت این آفت و بهبود صفات فیزیولوژیک و جذب عناصر غذایی در نخل خرما ، *Phoenix dactylifera* رقم پیارم بررسی شد. این پژوهش طی ۲/۵ سال در قالب طرح بلوک‌های کامل تصادفی با ٤ تیمار و ٥ تکرار اجرا شد. تیمارها شامل شاهد و سه سطح متفاوت از گوگرد معدن زرکوه (کمتر، برابر، و بیشتر از توصیه شرکت سازنده) بودند. نتایج نشان داد که استفاده از گوگرد زرکوه تأثیر معناداری روی تلفات آفت، کاهش جمعیت سوسک شاخدار خرما (هندسون-تیلتون) و خسارت ناشی از آن روی درخت در فواصل زمانی (۹، ۲۰، ۵۱ و ۸۲ روز بعد از تیماردهی) نداشت. علاوه بر این، گوگرد تأثیر معنی‌داری بر صفات فیزیولوژیکی (شاخص کلروفیل، نشت الکترولیت، محتوای نسبی آب، درصد ماده خشک، وزن تر/خشک برگ) یا جذب عناصر ماکرو و میکرو (N، P، K، Ca، Mg، S، Fe، Mn، Zn، Cu و B) نداشت. این یافته‌ها نشان می‌دهد که استفاده از این کود برای کنترل آفات در نخلستان‌های خرما مؤثر نیست، به‌ویژه زمانی که بدون راهنمایی کارشناسانه اعمال شود و توصیه می‌شود برای جلوگیری از کاربردهای بیش‌ازحد یا غیرضروری احتیاط شود.

کلیدواژه‌ها: گوگرد معدن زرکوه، صفات فیزیولوژیکی، عناصر غذایی، نخل خرما، سوسک کرگدنی

دبیر تخصصی: دکتر معصومه ضیائی

Introduction

The date palm (*Phoenix dactylifera* L.; Arecaceae) is a significant and economically valuable plant species cultivated in arid and semi-arid regions of the world. Its fruit is one of humans' most important food resources (Ehteshami et al., 2017). Iran ranks third globally, following Iraq and Algeria, in date palm cultivation area and is among the world's top producers (Shahbande, 2024). It is also the third-largest producer worldwide after Egypt and Saudi Arabia. According to the 2022 agricultural statistics report, the major date-producing provinces in Iran include Sistan and Baluchestan, Khuzestan, Kerman, Fars, Bushehr, South Kerman, and Hormozgan, with Khuzestan being one of the primary centers of date production in the country (Agricultural Statistics Yearbook, 2023). Unfortunately, in recent years, due to persistent droughts, insufficient nutrient management, and weakened date palms, these trees have become susceptible to attacks by significant pests, particularly wood-boring insects. These include horn beetles such as *Oryctes agamemnon matthiesseni* Reitter and *Oryctes elegans* Prell. (Coleoptera: Scarabaeidae), as well as the longhorn beetle *Jebusaea hammerschmidti* Reiche (Coleoptera: Cerambycidae). In date-producing regions, their damage levels range from 20% to 90% (El-Shafie et al., 2017; Zarghami et al., 2024). Among these, the date palm horn beetle or rhinoceros beetle, *O. elegans*, is a major wood-boring pest of palms, causing damage ranging from 5% to 20% in date-producing areas (Gharib, 1967). This insect has been reported from the Middle East, including Iraq, Jordan, Qatar, the United Arab Emirates, Libya, Saudi Arabia, and Mauritania (Walker and Pittaway, 1987). In Iran, this wood-boring pest of date palms has been documented in the provinces of Fars, Sistan and Baluchestan, Isfahan, Yazd, Bushehr, Khuzestan, Ilam, Kerman, and Kermanshah (Gharib,1967, Mohammadpour and Avand Faghih, 2007, Fasihi, 2014). Both adult beetles and larvae cause damage. Adults feed on the peduncle, fruit clusters and primary veins in the crown, creating tunnels that lead to fruit deformation, shriveling, and reduced economic value. Larvae spend their entire lifecycle within the crown and trunk of the tree. Their activity creates numerous tunnels and cavities, sometimes extending into the main trunk. The sap exuding from these cavities provides an ideal fungal and bacterial growth environment. Ultimately, larval activity weakens the structural integrity of the crown or trunk, making the affected areas prone to breakage during strong winds (Buxton, 1920; Hussain, 1963, Gharib, 1967; El Bouhssini and Faleiro, 2018; Zarghami and Mostaan, 2022). Recent studies in Iraq and Iran (Khuzestan Province) have revealed that adult beetles of this species can act as vectors of the fungus *Fusarium proliferatum* Matsushima, a major causal agent of leaf wilt disease in date palms (Khudhair et al., 2014, Al-Jassany and Al-Saedy, 2019, Ghaedi et al., 2020).

Sulfur is an essential nutrient for plants, absorbed as sulfate anions. Its content in plants ranges between 0.1% and 0.4%, with uptake constituting 10–15% of the nitrogen absorbed by plants. In calcareous soils, sulfur application fulfills the plant’s nutritional needs for this macronutrient, improves soil properties, and locally enhances the rhizosphere. This localized improvement facilitates better absorption of critical nutrients, such as phosphorus and micronutrients, leading to increased vegetative and reproductive growth in the plant (Motesha’re Zadeh and Mousavi, 2018). The fungicidal properties of sulfur have been recognized for centuries, and since the 19th century, it has been widely used in managing plant diseases, arthropods, and plant mites (Strand, 1998). By enhancing the plant’s ecological resistance, sulfur increases its defense against pests, making it a key component of integrated pest management (IPM) (Williams and Copper, 2004). Sulfur's mechanism of action involves direct contact or vapor effects. It dissolves well in lipids, penetrating the semi-permeable cytoplasmic membrane and entering the cell. Finer sulfur particles are more effective, so colloidal sulfur is more toxic. In cellular respiration, sulfur competes with oxygen for electrons, particularly between cytochrome b and cytochrome c. The molecular form S6 interferes with the conversion of acetate to citrate, effectively halting metabolic processes in the cell (Tweedy, 1981; Zhou et al., 2022).

Various studies highlight sulfur's role in pest management: Zappala et al. (2012) evaluated the efficacy of two sulfur formulations, dustable powder (DP) at 3.75 g/plant and as wettable powder (WP) at 300 g/hl, against *Tuta absoluta* (Meyrick) (Lep., : Gelechiidae) and reported that weekly applications significantly reduced pest populations in greenhouses and fields. Venzon et al. (2013) tested lime sulfur, Bordeaux mixture, and Supermagro against *Leucoptera coffeella* (Guérin-Mèneville & Perrottet) (Lep.: Lyonetiidae). Biweekly or monthly lime sulfur applications (0.5, 1.0, 1.5, 2.0, and 2.5%, v/v) only at the beginning of pest occurrence were effectively reduced miner populations in coffee plantations. Abedini et al. (2017) found Kaolin at a concentration of 5%, or in combination with wettable sulfur (300 ppm) to be among the most effective methods for reducing populations of *Arboridia Kermanshah* Delabola (Hem.: Cicadellidae). Shahbani et al. (2019) investigated the use of liquid Sitam fertilizer with silica (2ml/l) and Parumi-S fertilizer with sulfur (2ml/l) as foliar sprays on *Morus papyrifera* L. to reduce infestations by *Aleuroclava jasmine* (Takahashi) (Hem.: Aleyrodidae). They reported significant reductions in whitefly populations using these combinations. However, sulfur application poses challenges, notably phytotoxicity. Sulfur does not vaporize below 14°C but can cause plant burns above 35°C. To minimize this risk, sulfur application rates should be reduced and spraying or dusting should be conducted early in the morning or near sunset to avoid sublimation during high temperatures.

In date palm orchards, applying sulfur alongside chemical fertilizers or well-decomposed manure is common practice. Research indicates that incorporating sulfur during the vegetative phase at planting enhances seedling growth. In mature date palms, sulfur application increases the concentration of nutrients such as potassium, sulfur, and zinc in the leaves, reduces iron concentration, and improves fruit yield and length (Dialami and Garshasbi, 2018; Abo-Rady et al., 1988). There is limited information on sulfur use for controlling pests and diseases in date palm cultivation (Shabani Boroujeni, 2016). El-Shafie (2020) referenced sulfur as a tool for managing certain diseases and pests in organic farming systems. Further research is necessary to evaluate sulfur's role in managing date palm pests and diseases.

This study aimed to assess the potential of Zarkooh mineral sulfur (Garmsar, Iran) in mitigating damage caused by *O. elegans* and its impact on the physiological traits and nutrient uptake of *P. dactylifera* L. cv. 'Piarom.'. Additionally, the study aimed to provide insights into sulfur's efficacy as a component of integrated pest management strategies for date palm plantations.

Materials and Methods

The study was conducted in a date palm orchard located in Ahvaz at the Date Palm and Tropical Fruit Research Institute (31°15'05.0"N, 48°32'35.9"E). The experiment followed a randomized complete block design (RCBD) using 20 mature Piarom date palms over 2.5 years (2020–2022). Piarom, a commercially important cultivar from Hajiabad, was chosen for its economic significance and observed susceptibility to *O. elegans* infestation in the study area.

Experimental Setup

Four treatments were selected, with five replicates per treatment, each replicate consisting of one Piarom date palm infested with *O. elegans*. In the first year, during autumn and winter, Piarom date palms were monitored to identify infested trees. Infestations were confirmed through direct evaluation, such as observing chewed stems or active larval activity evidenced by visible holes. Infested trees were selected, and treatments were applied at the end of winter on March 6, 2021, when the mean temperature was 18.9°C. Observations were carried out at intervals of 9, 20, 51, and 82 days after treatment application.

Treatments

Control: No application of sulfur.

T1-Stage 1: Trunk spraying with 25% less than the recommended concentration of "Super Golden" mineral sulfur (45 kg in 1000 L water).

T1-Stage2: Soil application of "Golden" mineral sulfur at 25% less than the recommended concentration (15 kg per tree).

T2-Stage 1: Trunk spraying with the recommended concentration of "Super Golden" mineral sulfur (60 kg in 1000 L water).

T2-Stage 2: Soil application of "Golden" mineral sulfur at the recommended concentration (20 kg per tree).

T3-Stage 1: Trunk spraying with 25% more than the recommended concentration of "Super Golden" mineral sulfur (75 kg in 1000 L water).

T3-Stage 2: Soil application of Zarkooh "Golden" mineral sulfur at 25% more than the recommended concentration (25 kg per tree).

Both stages were performed simultaneously. For soil application, the trench method was used: four trenches, each 40 cm deep and wide, were dug 1 m away from the trunk within the irrigation basin. After applying the sulfur treatments, the trenches were covered with soil and immediately irrigated. According to Zarkooh company guidelines, the sulfur was sieved before adding it to the sprayer, and dishwashing liquid was used to ensure suspension during spraying. trunk applications were performed in the early morning.

Evaluation of pest activity

Due to the concealed nature of larval stages within the trunk, pest activity was assessed using an index based on the number of active holes observed. Active holes were identified by the presence of chewed wood or exudates from the tree. Sampling began in winter 2020 by inspecting trees for active larval stages. Treatments, including soil, trunk applications as above, were applied in the first week of March, and subsequent evaluations were carried out at 9, 20, 51, and 82 days post-treatment. Observations included active holes, presence of immature stages (larvae or pupae), or adult beetles on the tree, between offshoots, and around basal suckers, which are the primary activity zones for these pests (Latifian and Zandi-Sohani, 2019).

Measurement of physiological and biochemical properties of the leaves

Fresh and dry leaf weight

To determine the fresh and dry weights of leaves in the treatments, the following procedure was used: After washing and surface drying the selected samples (three green leaves per plant treatment, collected from different orientations, with 15 replicates per treatment) in the laboratory, the fresh weight of the leaves was measured using an analytical balance. The leaves were then dried in an oven at 70°C for 72 hours, and their dry weight was recorded using the same balance. The dry matter percentage was calculated based on the fresh and dry weights of the leaves.

Chlorophyll and relative water content

Chlorophyll content (greenness index) was measured using a chlorophyll meter (MINOLTA SPAD-502). Relative water content (RWC) of the leaves was assessed following the method of Yamasaki and Dillenburg (1999). For this, the surface of the leaf samples was cleaned, and five 1-cm² segments were prepared from the leaves of each treatment. The fresh weight of these segments was measured. The segments were then submerged in distilled water in sealed Petri dishes and kept in a cool (20±2 °C), dark room for 24 hours to allow rehydration. Afterward, the segments were gently removed, their surfaces blotted dry with filter paper, and their turgid weight was measured. The samples were then dried in an oven at 80°C for 48 hours, and their dry weight was recorded. Finally, the relative water content of the leaves was calculated using the following formula (Barr and Weatherley, 1962):

$$RWC\ (\%) = [(FW-DW)/(TW-DW)] \times 100$$

In the above equation, FW refers to the fresh weight of the sample, TW refers to the turgor weight of the sample, and DW refers to the dry weight of the sample.

The method of Linden et al. (2000) was used to measure ion leakage percentage. According to this method, several 1-cm leaf segments were prepared from each leaf sample. After cleaning their surfaces and rinsing with distilled water, the segments were placed in test tubes. Eight milliliters of high-purity distilled water were added to each tube. The tubes were covered with aluminum foil and incubated at room temperature (22–25 °C) on a shaker at 150 rpm for 21 hours.

Electrical conductivity

The electrical conductivity of the samples (L_1) was measured using a conductivity meter. Subsequently, the samples were autoclaved at 121°C for 15 minutes, allowed to cool to room temperature, and the secondary electrical conductivity (L_2) was recorded. Finally, the ion leakage percentage was calculated using the following equation (Sairam et al., 1997). Prior to each conductivity reading, the samples were thoroughly shaken by hand for 30 seconds.

$$EL\ (\%) = \frac{EL_1}{EL_2} \times 10$$

Macro- and micronutrient contents

To measure the macro- and micronutrient contents in the leaves of Piarom date palms, leaf samples were collected in September by taking 20–25 leaflets from the middle of the second row of leaves from the top and transferring them to the laboratory. The samples were initially washed with distilled water, followed by a 0.1% hydrochloric acid solution, and then rinsed again with distilled water before being air-dried. Subsequently, the samples were placed in an oven at 75°C for 72 hours. The dried samples were sent to the Soil and Water Laboratory in Babol for nutrient analysis. The elements measured included macro-elements such as nitrogen, potassium, phosphorus, calcium, magnesium, and sulfur (as a percentage of dry weight), and micro-elements such as iron, manganese, zinc, copper, and boron (measured in ppm).

Data analysis

Raw data were converted to percentage mortality using the Henderson-Tilton formula (Henderson and Tilton, 1955) to account for pest population variations across treatments. The efficacy percentages for each treatment were calculated, and data normality was verified using the Kolmogorov-Smirnov test prior to statistical analysis. Analysis of variance (ANOVA) was performed using SAS 9.4 software, following a randomized complete block design (RCBD). Treatment means were compared using Tukey's test for mortality data.

Physiological traits were measured over two consecutive years, and a combined ANOVA was conducted based on the RCBD. Mean comparisons for these traits were carried out using Duncan's multiple range test at a 5% significance level (SAS ver. 9.4).

Results and Discussion

Tables 1 and 2 display the analysis of variance and mean comparison of the percentage mortality of *O. elegans* following the application of Zarkooh mineral sulfur on Piarom date palms at intervals of 9, 20, 51, and 82 days. No significant pest population or activity reductions were observed at any sulfur concentration. Observations during sampling revealed the emergence of adults and the gradual inactivity of feeding holes. However, upon inspection of emptied holes, no dead insects were found. Active holes decreased over time due to natural adult emergence rather than sulfur application. Hence, using Zarkooh sulfur as a control measure for the red palm weevil is not recommended. The ineffectiveness of sulfur is likely due to the hidden nature of the beetle's larval stage, which remains buried deep within the woody tissue, preventing contact with sulfur or any contact-based pesticide.

Furthermore, larval activity persisted the following year, demonstrating that sulfur did not deter oviposition or reinfestation. Sulfur has proven effective in managing various fungal diseases, such as brown rot in peaches (Holb and Schnabel, 2008), powdery mildew in apples (Holb and Kunz, 2016), and leaf spot in almonds (Culbreath et al., 2019). Additionally, sulfur has been applied for contact control of the pistachio psyllid (Nazoori et al., 2022). However, prolonged sulfur use has been reported to degrade product quality and potentially lead to resistance development (Gispert et al., 2001). The mechanism of sulfur action involves direct contact or vapor phase effects. Sulfur readily dissolves in lipids, penetrating the semi-permeable cytoplasmic membrane and entering cells. Smaller sulfur particles, such as colloidal sulfur, exhibit higher toxicity. Sulfur disrupts cellular respiration by competing with oxygen for electron acceptance, blocking reactions in the electron transport chain and halting cellular functions. This mode of action highlights its effectiveness against certain pests and diseases (Zhou et al., 2022).

Table 1. Results of combined analysis of variance for the effect of Zarkooh sulfur on the physiological traits of date palm cv. Piarom

		Mean of squares			
Source	*df*	9 days after treat.	20 days after treat.	51 days after treat.	82 days after treat.
Treatment	2	16.02 ns	95.05 ns	615.74 ns	348.80 ns
Block	4	23.02	1357.69	1685.18	1166.67
Error	8	33.51	1541.70	3046.29	796.82
Total	14	--------	--------	-------	-------
C.V.		29.37	16.56	16.02	21.06

n.s.: No significant difference

Table 2. Variance in mortality rate (mean ± SE) of *O. elegans* following the application of Zarkooh sulfur on date palm cv. Piarom at intervals of 9, 20, 51 and 82 days after treatment, 2020–2021

Treatment	Efficacy (%)			
	9 days after treat.	20 days after treat.	51 days after treat.	82 days after treat.
25% below rec.	12.5±8.8 a*	19.4±13.1 a	41.22±6.8 a	14.3±9.2 a
recommendation	2.4±2.4 a	25.1±18.9 a	40.24±0.5 a	25.5±11.4 a
25% more rec.	0 a	27.9±18.9 a	21.6±19.1 a	30.6±18.3 a

*Means followed by same letters within each column are not significantly different (according to Tukey´s tests) at a significance level

Although a review of some sources indicates that sulfur has a significant impact on managing certain pests, Zappala et al. (2012) evaluated the efficacy of two types of sulfur formulations, dustable and wettable, against *T. absoluta* on tomato. According to their results, sulfur dust exhibited repellent properties and demonstrated high ovicidal activity against the eggs of the tomato leaf miner. They reported that weekly applications of this type of sulfur reduced the population and infestation of the pest in both greenhouses and fields. Venzon et al. (2013) assessed three formulations—lime sulfur, Bordeaux mixture, and Supermagro against *L. coffeella*. Only lime sulfur exhibited strong ovicidal activity on coffee leaf miners among the three. They recommended biweekly or monthly applications of lime sulfur as an effective strategy for reducing the pest population in coffee plantations. Abedini et al. (2017) reported that using kaolin combined with wettable sulfur was one of the most effective methods for reducing the population of *A. kermanshah*. Shahbani et al. (2019) investigated the effects of silicon and sulfur fertilizers applied as foliar sprays on mulberry trees to reduce infestations of *A. jasmine*. According to their findings, the combination of silicon and sulfur significantly reduced the whitefly population. They suggested that, besides its nutritional effects on plants, this combination could serve as an alternative to chemical insecticides for controlling whiteflies on mulberry trees (Shabani Boroujeni, 2016). There is limited information regarding sulfur use in controlling pests and diseases of date palms. El-Shafie (2020), in his book on pest management in organic farming systems, highlighted the use of sulfur for controlling specific diseases and pests, such as: 1) Applying Bordeaux mixture (0.3–0.5%) or 50 g powdered sulfur per tree after harvest and before inflorescence formation to manage inflorescence rot caused by *Mauginiella scaettae* Cavara. 2). Applying Bordeaux mixture or 80% powdered sulfur (2.5 g per 1000 liters of water) post-harvest to control *Thielaviopsis thielavioides* (Peyr.). 3). Using powdered sulfur (5 g per palm tree) during the flowering period (February–March) to control inflorescence weevils (*Drelomus* sp.) and *Macrocoma* sp. Alhewairini and Al-Azzazy (2024) reported that Piowetsulf (Micronized Sulfur 80%) and Sulfur (99.5%) achieved mortality rates of 45.24% and 46.94%, respectively, against the date palm mite *Oligonychus afrasiaticus* (Acari: Tetranychidae) under laboratory conditions, and 64.14% and 65.35% under field conditions. Furthermore, field applications of these treatments resulted in mortality rates of 21.25% and 19.87% for the predatory mite *Amblyseius swirskii* (Acari: Phytoseiidae). Additionally, Jafari Nadooshan et al. (2024) demonstrated that the application of sulfur formulation (WP80%) negatively affects the efficiency of *Chrysoperla carnea* (Stephens), a key predator of *Agonoscena pistaciae* Burckhardt & Lauterer (Hemiptera: Psyllidae), in pistachio orchards, significantly reducing its population. Carpenter and Elmer (1978) also mentioned the use of contact sulfur formulations for controlling the date palm mite, *Oligonychus afrasiaticus* McGregor, and the grass mite, *O. pratensis* (Banks) (Prostigmata: Tetranychidae).

Based on the combined analysis of variance results from two years of experiments, the application of Zarkooh mineral sulfur fertilizer had no significant effect on the physiological traits of the date palm cultivar ‘Piarom’ at either the 1% or 5% statistical probability levels (Table 3). No significant differences were observed between the treatment means (Table 4). This indicates that under conditions where the trees are affected by the pest in question, applying Zarkooh mineral sulfur fertilizer did not improve the physiological traits related to optimal growth and tree resistance against the pest. Consequently, no differences were found between the control treatment (no application of Zarkooh mineral sulfur fertilizer) and various levels of fertilizer application. Dialami and Dialami and Pourghayoumi (2022) also reported in their study on the effect of Zarkooh mineral sulfur fertilizer on the nutrition of date palms that its application did not enhance soil fertility or optimize the nutritional conditions of date palms. Moreover, its use had no significant impact on the yield or quality of date fruits. The results of this research align with their findings.

According to the analysis of variance, the levels of nitrogen, potassium, phosphorus, calcium, magnesium, and sulfur were not significantly affected by the treatments studied (Tables 5 and 6). As shown in Tables 7 and 8, the levels of the measured micronutrients were not significantly affected by the application of mineral sulfur.

Table 3. Combined analysis of variance results for the Effect of Zarkooh mineral sulfur on physiological traits of date palm (*Phoenix dactylifera* L.) cv. Piarom.

Source	**Mean of squares**						
	Df	**EL***	**RLWC**	**CI**	**FLW**	**DLW**	**DMP**
Time (year)	1	1.660 ^{ns}	19.656*	18.652 ^{ns}	1510 ^{ns}	5522.50**	170.280**
Error	8	8.139	30.19	17.320	10311.25	1405	16.022
Treatment	3	10.376 ^{ns}	2.355 ^{ns}	17.841 ^{ns}	13150 ^{ns}	1215.83 ^{ns}	22.547 ^{ns}
Time×Treatment	3	11.492 ^{ns}	14.878**	4.067 ^{ns}	9590 ^{ns}	909.16 ^{ns}	15.364 ^{ns}
Error	24	4.286	3.909	8.430	4542.91	658.33	8.777
Total	38	-----		----	-----	----	----
C.V.		8.32	2.06	4.80	24.28	24.14	7.67

*EL –Electrolyte leakage, RLWC – Relative leaf water content, CI – Chlorophyll index, FLW – Fresh leaf weight, DLW – Dry leaf weight, DMP – Dry matter percentage. n.s.: No significant difference. *: Significant at the 5% level. **: Significant at the 1% level

Table 4. Effects of different levels of Zarkooh mineral sulfur (mean ± SE) on physiological traits of date palm cultivar 'Piarom'.

Treatment	**Efficacy (%)**					
	EL*	**RLWC**	**CI**	**FLW**	**DLW**	**DMP**
Control	23.87±1.13 ^{a**}	95.84±0.87 ^{a}	60.01±1.58 ^{a}	376±34.43 ^{a}	138±10.67 ^{a}	36.95±1.30 ^{a}
25% below rec.	26.85±1.23 ^{a}	97.31±1.23 ^{a}	59.53±0.95 ^{a}	224± 31.72 ^{a}	96±11.66 ^{a}	43.39±1.48 ^{a}
Recom.	25.66±0.94 ^{a}	96.31±0.87 ^{a}	62.04±1.54 ^{a}	267±55.82 ^{a}	106±18.60 ^{a}	41.41±2.68 ^{a}
25% more rec.	22.74±1.45 ^{a}	96.64±1.12 ^{a}	57.59±2.15 ^{a}	322±48.52 ^{a}	132±20.35 ^{a}	40.95±1.09 ^{a}

*EL-Electrolyte leakage, RLWC – Relative leaf water content, CI – Chlorophyll index, FLW – Fresh leaf weight, DLW – Dry leaf weight, DMP – Dry matter percentage. **Means followed by same letters within column are not significantly different (according to Duncan´s tests).

Table 5. Analysis of variance for the effect of different concentrations of Zarkooh mineral sulfur application on macroelement content in leaves of offshoots of date palm cultivar 'Piarom.

Source	**Mean of squares**						
	df	**N***	**K**	**P**	**Ca**	**Mg**	**S**
Block	4	0.005 ^{ns}	0.003 ^{ns}	0.002 ^{ns}	0.012 ^{ns}	0.00002 ^{ns}	0.006 ^{ns}
Treatment	3	0.013 ^{ns}	0.002 ^{ns}	0.002 ^{ns}	0.003 ^{ns}	0.0001 ^{ns}	0.004 ^{ns}
Error	12	0.016	0.003	0.002	0.029	0.00008	0.004
Total	19	----	----	----	----	----	----
C.V.		14.72	3.81	22.1	22.48	15.60	22.75

n.s.: No significant difference. *Nitrogen (N), Potassium (K), Phosphorus (P), Calcium (Ca), Magnesium (Mg), Sulfur (S).

Table 6. Analysis of variance for the effect of different concentrations of Zarkooh mineral sulfur application on microelement content in the leaves of offshoots of date palm cultivar 'Piarom'.

Source	Mean of squares					
	df	Fe*	Mn	Zn	Cu	B
Block	**4**	394.98	163.07	124.36	10.57	683.3
Treatment	3	179.10	102.7	79.90	10.78	982.8
Error	12	174.21	83.48	61.41	4.69	252.7
Total	19	----	----	----	----	----
C.V.		19.24	18.07	20.1	18.22	19.75

n.s.: No significant difference. *Iron (Fe), Manganese (Mn), Zinc (Zn), Copper (Cu), Boron (B)

Table 7. Effect of different concentrations of Zarkooh mineral sulfur application (mean ± SE) on macro- content in the leaves of offshoots of date palm cultivar 'Piarom'.

Treatment	Efficacy (%)					
	N	K	P	Ca	Mg	S
Control	0.88±0.07[a*]	1.51±0.02[a]	0.11±0.02[a]	0.76±0.01[a]	0.06±0.01[a]	66.4±0.02[a]
25% below rec.	0.95±0.05 [a]	1.48±0.02 [a]	0.13±0.02 [a]	0.79±0.08 [a]	0.06±0.01 [a]	70.75±0.04 [a]
Reco.	0.83±0.04 [a]	1.47 ±0.02 [a]	0.08 ±0.02 [a]	0.74 ±0.07 [a]	0.05±0.01 [a]	75.6±0.04 [a]
25% more rec.	0.85 ±0.01[a]	1.48 ±0.02 [a]	0.09 ±0.01[a]	0.74 ±0.04 [a]	0.06±0.01 [a]	61.6±0.07 [a]

*Means followed by same letters within column are not significantly different (according to Duncan´s test).

Table 8. Effect of different concentrations of Zarkooh mineral sulfur application (mean ± SE) on micro- content in the leaves of offshoots of date palm cultivar 'Piarom'.

Treatment	Efficacy (%)				
	Fe	Mn	Zn	Cu	B
Control	66.40 ±7.25 [a]	44.84 ±4.68 [a]	18.34 ±2.7 [a]	13.1±1.07 [a]	58.36 ±10.75 [a]
25% below rec.	70.75 ±7.65 [a]	38.4 ±3.67 [a]	17.95 ±2.09 [a]	12.5 ±1.32 [a]	47.47 ±3.11 [a]
Reco.	75.6 ±5.81 [a]	34.08 ±5.81 [a]	24.84 ±6.65 [a]	9.76 ±0.48 [a]	46.58 ±5.95 [a]
25% more rec.	61.6±6.2 [a]	41.1±6.14 [a]	15.48 ±2.40 [a]	12.2 ±1.33 [a]	76.72 ±11.28 [a]

*Means followed by same letters within column are not significantly different (according to Duncan´s test).

Conclusion

The lack of significant effects of Zarkooh mine sulfur on both physiological traits and nutrient content (macronutrients and micronutrients) could be attributed to several factors, including the timing of application, the formulation of sulfur used, and potential soil or environmental conditions that may have limited sulfur's bioavailability. These findings align with previous studies that suggested sulfur application alone might not be sufficient to significantly improve the physiological status of date palms, particularly in environments already under stress from pests. Further studies focusing on the combined effects of sulfur with other nutrient management practices or pest control strategies may offer more insight into the role of sulfur in improving date palm growth and resistance to pests. Based on the results of this study, Zarkooh mineral sulfur did not affect reducing the population of *O. elegans*, altering physiological traits, improving nutrient uptake, or ultimately increasing the resistance of the Piarom date palm cultivar to the mentioned woodboring pest. Given the ineffectiveness of Zarkooh sulfur against *O. elegans*, future studies should focus on alternative integrated pest management strategies, such as biological control or systemic insecticides that target concealed larval stages.

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