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Original Research

Impact of Foliar Treatments on *Aulacaspis tubercularis* Control and Mango Yield

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Abstract

Aulacaspis tubercularis (Newstead) (Hemiptera: Diaspididae) is one of the most important pests of mango trees. Therefore, the first objective of the work is to field-evaluate some chemical and non-chemical control agents against the white-scale insect on Golek mango trees. The second goal is to determine the effectiveness of eight foliar treatments applied with and without the addition of potassium silicate and zinc sulfate in improving the productivity and quality of mango fruits. According to the findings, *A. tubercularis* adult females were less susceptible to the evaluated treatments than the nymphs. Additionally, Actellic treatment proved to be the most successful in controlling *A. tubercularis* nymphs and adult females on mango leaves. Even though orange oil treatment was the least dangerous treatment for this pest, a number of evaluations are necessary to determine how effective these treatments are for beneficial insects. Also, the highest increase in the fruits' physical characteristics, yield, and fruit quality compared to untreated trees was recorded in trees treated with pirimiphos-methyl in addition to a mixture of potassium silicate at 5 ml/liter of water and zinc sulfate at 5 g/liter of water. The lowest of them was seen in trees treated with orange oil only.

Keywords: chemical control, *Aulacaspis tubercularis*, insecticide, reduction, mango yield

Introduction

Aulacaspis tubercularis (Newstead) (Hemiptera: Diaspididae), known as the white mango scale insect, is a harmful mango pest with a high risk of expansion currently in countries such as Brazil, Egypt, Ethiopia, Mexico, Spain, South Africa, Italy, etc. [1-3]. In past times, this pest count was noted on mango plantations

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in several different global locations. This insect causes wilting, drying of young branches, mortality, poor flowering, and reduced fruit yield when it feeds on mango plant sap, primarily through the leaves, twigs, and fruits [4]. When infestation occurs during the fruiting stage, the fruit becomes deformed and may fall, and the infested fruit may ripen without a sufficient amount of juice [5, 6]. Mango fruit infestations result in noticeable pink spots surrounding the pest's feeding spots, which negatively impact the fruits' ability to be exported and their market value [7, 8]. The waxy secretions on their body surface also add to the difficulty of managing this pest. The use of chemicals is unsuccessful because of the waxy substance that covers their bodies and their overlapping generations. Additionally, overusing chemical pesticides leads to resistance issues [9]. Atnafu [10] stated that this pest has the capacity to increase its population within shoots, branches, and apexes, which makes it hard to control using pesticide sprays on the leaves. Mango productivity in plantations may be lowered by the insect if preventative measures are not taken, endangering mango productivity in the long run [11, 12]. It's crucial to remember that factors like geography, weather, and management techniques can influence the severity and spread of the pest [13].

Pesticide application that is careless or disregards resistance management strategies may lead to the formation of insect populations that are resistant. Certain insects may survive and procreate if they are repeatedly exposed to the same pesticide or other comparable substances because of naturally occurring genetic variants or mutations that lessen their vulnerability to the pesticide's effects. The insecticide loses some of its effectiveness as resistant individuals proliferate in the population [14].

In addition to promoting cell division and expansion, water and nutrient transport, growth regulation, improved glucose biosynthesis, and amino acid creation, nutrients play a critical role in plant metabolism [15].

An important micronutrient needed for healthy plant growth and development is zinc. In plant metabolism, zinc is essential for the synthesis of hormones, the activation of enzymes, the manufacturing of chlorophyll, pollen germination, and water absorption [16]. Reduced fruit set, poor fruit growth, and decreased production can result from zinc deficiency [17]. It is well recognized that mangoes are susceptible to zinc deficiencies, which can result in smaller fruit, lower yields, and inferior-quality fruit. Zinc foliar fertilization is crucial for robust mango trees and extremely fruitful trees [18].

Zinc is a cofactor for more than 300 enzymes and proteins and regulates cell division, DNA metabolism, and protein synthesis [19]. Foliar application of zinc sulfate accelerates the rate of zinc absorption in mango trees, promotes healthy tree growth and vitality, increases fruit size, weight, and sugar content, improves fruit quality, and enhances auxin production [20].

Potassium silicate is a compound that can provide plants with silicon (Si), which is an important nutrient for many crops, including mangoes. Contemporary and non-traditional horticulture methods have been developed to utilize silicon, a crucial antioxidant for plants grown under adverse environmental conditions [21].

Studies have demonstrated that silicon greatly increases and speeds up plant development, strengthens cell walls, increases disease resistance, increases tolerance to drought in plants, and lessens insect attacks, even if its function in plant biology is still unclear [22]. It maintains water balance, improves drought resistance, and lessens the possibility of physiological anomalies, making it especially helpful for plants subjected to biotic and abiotic stressors [23]. In times of drought, silicon is also essential for root development and water transportation [24]. Additionally, it can prevent powdery mildew from growing on grapes [25].

The positive impacts of silicon on crops may stem from the reinforcement of cell walls, which increases the mechanical strength of plant tissues, provides greater resistance against various pests, and reduces the occurrence of physiological disorders [26]. For mangoes, applying potassium silicate has been shown to improve the growth characteristics and anatomical and physiological characteristics of the leaves, in addition to enhancing the hardness and shelf life of the fruit and increasing fruit size, weight, and quality [27]. As well as improving resistance to fungal diseases like powdery mildew [28].

Combining potassium silicate and zinc sulfate can have additive or complementary effects on mango productivity, such as 1) potassium silicate can improve overall tree health and vigor, while zinc sulfate can improve overall plant metabolism and fruit quality; 2) strengthening the plant's resistance to diseases and environmental stresses; and 3) increasing fruit size, weight, and quality [29, 30]. Zinc sulfate and potassium silicate work together to influence insect populations; potassium silicate directly lowers pest insect populations [31], while zinc sulfate indirectly controls nutrient levels, enhancing plant health and yield [32].

On the leaves and stems, potassium silicate creates a protective covering that can prevent or interfere with some insects from feeding or depositing their eggs. Additionally, some insect pests may find plant tissues tougher and less appetizing due to the compound's silica content. One environmentally friendly and reasonably safe insecticide alternative is potassium silicate [33].

In contrast, zinc sulfate is not commonly employed as an insecticide in and of itself. However, a lot of living things, including insects, require zinc as a vitamin. By guaranteeing appropriate growth and development, the environment's ideal zinc concentrations can maintain robust insect populations. However, certain insects may become poisonous to high zinc levels, whether from applications of zinc sulfate or other sources, which could cause population disruption [34].

Farmers can develop a more integrated and practical approach to pest management that reduces the use of dangerous pesticides, encourages overall plant and ecosystem health, and yields better pest control results by combining the use of potassium silicate and zinc sulfate with a variety of other integrated pest management techniques [35].

The main objective was to determine the most effective chemical treatment that would reduce *A. tubercularis* while adding nutrients that would improve fruit weight and quality, which was conducted in Egypt.

Material and Methods

Experiment Site

This research was done in a private mango orchard during the 2021-2022 and 2022-2023 seasons on 10-year-old Golek mango trees grown in clay loam soil of about 4.20 hectares (ha) planted 6 x 6 meters apart at Esna village, Luxor governorate, Egypt (25º25'49"N, 32º32'17"E), to evaluate some chemical and non-chemical control agents against the nymphs and adult females of the white-scale insect, *A. tubercularis*, on Golek mango trees.

Experiment Treatments

Control Efficacy of the Tested Chemical and Non-Chemical Agents against A. tubercularis

Four chemical insecticides, including Sulfur (Sulfur® 30% L): at a rate of one liter per 100 liters of water; Pirimiphos-methyl (Actellic® 50% EC): (0,2-diethylamino-6-methylpirimidin-4-yl O, O-dimethyl phosphorothioate), at a rate of 150 milliliters (ml)/100 liters of water; Pyriproxyfen [(Admiral® 10% EC): 4-Phenoxyphenyl (*R/S*)-2-(2-pyridyloxy) propyl ether 2-[1-(4-Phenoxyphenoxy) propan-2-yloxy]pyridine] at a rate of 50 ml per 100 liters of water; Malathion [(Malatox® 57% EC): Diethyl 2-[(dimethoxyphosphorothioyl)sulfanyl]butanedioate], at a rate of 250 ml per 100 liters of water. The bio-insecticide [(Biover® 10% WP), containing 10% *Beauvaria bassiana* and 90% inert ingredient, used at the rate of 200 g per 100 liter water], the mineral oil (KZ-oil 95% EC) is recommended for controlling this pest at concentration 1.5% (V./V.), produced by Kufr El-Zayaat Co. for Pesticides and Chemicals, Kufr El-Zayaat, Egypt, at a rate of 1.5 liter per 100 liters of water, and plant oil (Orange oil), produced by Captain CO. (Cap. Farm), at a rate of 400 ml/100 liters of water, were used to evaluate the toxicity of them against this pest on mango leaves. The experiment also involved a control treatment (water spray).

Therefore, this experiment consisted of eight treatments. Each treatment was replicated ten times, each with one mango tree. The experiment, which included eighty trees (80 trees), was arranged in a completely randomized block design. The selected mango trees were of a similar age, approximately the same size, shape, height, and vegetative growth, and received usual and common horticultural practices (fertilization and irrigation). Twenty infested mango leaves were collected from each tree and selected randomly, representing the four directions and different heights of the trees. Samples were taken before spraying (BS) and after one, two, three, and four weeks after spraying (WAS), respectively. The method was adopted by Mohamed and Bakry [36].

The samples were stored in paper bags and then transported to the laboratory for examination. The total samples amounted to 16.000 leaves, i.e., 20 leaves × 10 fruitful trees × 8 treatments × 5 inspection dates × 2 seasons. Each season had 8,000 leaves.

The tested treatments were sprayed by utilizing a six-horse-powered motor sprayer (beam), with a 600-liter tank capacity and two pounds per inch^2 of pressure, at a rate of 20-25 liters per tree to ensure complete coverage of all parts of the tree during the first week of December for each season (2021 and 2022). Next, all leaves from all tested treatments were placed in polyethylene bags and transported to the laboratory for examination. The numbers of live nymphs and adult females of *A. tubercularis* on the upper and lower surfaces of mango leaves were counted and recorded; data from pre-spraying and post-spraying samples and control samples were recorded; and the reduction percentage was calculated according to Henderson and Tilton [37] as follows:

$$\% \text{ Reduction Percentage} = 100\ [1 - (Cb/Ca \times Ta/Tb)]$$

where: Cb: the control counts before spraying; Ca: the control counts after spraying; Ta: the treatment counts after spraying; and Tb: the treatment counts before spraying.

The overall effectiveness rate (also known as the overall mortality ratio) is calculated by taking the average of the mortality ratios from four different time points after the treatment was given [38, 39].

$$AOM = [A/(B+C)]$$

AOM = average overall mortality (%). A = total adjusted mortality rates for each time period (%). B = the number of weeks after spraying the treatments. C= Initial date of kill

Statistical Analysis

The percentages of nymph and adult females' mortality between different treatments at different examination periods (in weeks) were separated by a two-way analysis of variance (ANOVA). A Bonferroni corrected test was applied at P ≤ 0.05 to determine the significant studied parameters. All data obtained in the two study seasons were statistically analyzed using SPSS software version 19 [40].

The Combined Effect of A. tubercularis Control Treatments, along with or without the Addition of Potassium Silicate and Zinc Sulfate, on the Yield and Quality of Mango

This study was conducted in the same orchard in which the above-mentioned study was conducted. The same trees considered in the first experiment were divided into trees treated either with or without the addition of potassium silicate and zinc sulfate". That is, ten trees for each treatment were divided into five trees treated with the addition of "potassium silicates and zinc sulfate" and five other trees without treatment.

The experiment included the following fifteen treatments:

T_1: Trees were treated with sulfur in the first week of December only.

T_2: Trees were treated with sulfur in the first week of December in addition to a mixture of potassium silicate at 5 ml/liter of water and zinc sulfate at 5 g/liter of water.

T_3: Trees were treated with KZ oil in the first week of December only.

T4: Trees were treated with KZ oil in the first week of December in addition to a mixture of potassium silicate at ml/liter of water and zinc sulfate at 5 g/liter of water.

T_5: Trees were treated with bio-insecticide (Biover) in the first week of December only.

T_6: Trees were treated with bio-insecticide (Biover) in the first week of December in addition to a mixture of potassium silicate at 5 ml/liter of water and zinc sulfate at 5 g/liter of water.

T_7: Trees were treated with Actellic pesticide in the first week of December only.

T_8: Trees were treated with Actellic pesticide in the first week of December in addition to a mixture of potassium silicate at 5 ml/liter of water and zinc sulfate at 5 g/liter of water.

T_9: Trees were treated with Admiral pesticide in the first week of December only.

T_{10}: Trees were treated with Admiral pesticide in the first week of December in addition to a mixture of potassium silicate at 5 ml/liter of water and zinc sulfate at 5 g/liter of water.

T_{11}: Trees were treated with Malatox pesticide in the first week of December only.

T_{12}: Trees were treated with Malatox pesticide in the first week of December in addition to a mixture of potassium silicate at 5 ml/liter of water and zinc sulfate at 5 g/liter of water.

T_{13}: Trees were treated with orange oil in the first week of December only.

T_{14}: Trees were treated with orange oil in the first week of December in addition to a mixture of potassium silicate at 5 ml/liter of water and zinc sulfate at 5 g/liter of water.

T_{15}: Untreated trees (spraying water only).

Foliar spraying was done with potassium silicate at a rate of 5 ml/liter of water and zinc sulfate at a rate of 5 g/liter of water twice before flowering in the first week of January and at the beginning of flowering in the first week of February in each season (2022 and 2023).

Yield and fruit quality of Golek mango trees in response to control agents against the white scale insect, either with or without the addition of potassium silicate with zinc sulfate, were measured. Firstly, the estimated yield weight (kg) was recorded for each tree separately at harvest.

Next, twenty fruits were randomly selected from each tree for the following fruit quality measurements: A. Physical properties of the fruit: In this respect, average fruit weight (g), fruit dimensions (length and width in cm), fruit shape (length/width ratio), fruit thickness (cm), and fruit size (cm^3) were determined using a vernier caliper, and the average mean of each parameter was estimated for all tested treatments. B. Fruit chemical properties: The following chemical properties of mango fruit have been determined in the laboratory: Total soluble solids% (TSS%) of fruit flesh: using a refractometer as described by Payane [41]. Total acidity (%) was determined according to the Association of Official Agricultural Chemists [42]. The TSS/acidity ratio was determined by dividing the total soluble solids percentage by the total acidity percentage. The total sugar % was volumetrically determined according to Lane and Eynon [43]. A one-way analysis of variance (ANOVA) and a Bonferroni post hoc test were performed on the data to evaluate differences between the studied parameters at $P \leq 0.05$.

From the yield and quality data of Golek mango fruits, the percentage increase in yield of treated trees compared to untreated (control) trees and the avoidable loss of each treatment were estimated using the following formula: Paul [44].

$$\text{Increase in yield over control (\%)} = (A–B) / B$$

where A= means a given parameter of the treated trees, while B = means a given parameter of the untreated trees (control).

$$\text{Avoidable loss (\%)} = (T-t) / T$$

where T= the highest yield for a given measurement in treated fruits, while t = the same parameter as in the other treated fruits.

To discuss the percentages of increase in yield or avoidable loss in all measurements studied in all tested treatments on the basis of variance, standard deviation, and standard error.

Fig. 1. The visual symptoms of *A. tubercularis* infestation on the leaves, stems, and fruits of mango trees (Source: Samples collected from the infested mango farm by Dr. Moustafa M.S. Bakry, July 2022).

Results

The visual symptoms of *A. tubercularis* infestation on the leaves, stems, and fruits of mango trees are shown in Fig. 1.

Effect of the Tested Chemical and Non-Chemical Control Agents against the Different Stages of the White Mango Scale Insect, *A. tubercularis* Infesting Mango Trees under the Field Conditions

Results showed the before-spraying (BS) counts of *A. tubercularis*, as well as the evaluated control agent treatments with their accumulative reduction percentages on nymphs and adult females counts after 1st, 2nd, 3rd, and 4th weeks after spraying (WAS) in 2021/2022 and 2022/2023 seasons, respectively (Tables 1-4 and Figs. 2 and 3).

On A. tubercularis Nymphal Population

The data exhibited that the percentage reduction in *A. tubercularis* nymph counts varied significantly between the seven compounds tested four weeks after spraying. The average reduction percentages were evaluated at 59.45 ± 1.23% and 58.22 ± 1.32% after the first week of spraying in the two seasons, respectively (Tables 1 and 2).

In the second week after spraying, the reduction percentages increased for all tested treatments. The average reduction percentages were listed at 75.69 ± 1.14 and 74.48 ± 1.09% after the second week of application (Tables 1 and 2).

Likewise, on the third week after the spraying, the reduction percentage increased in all tested compounds, with averages of 84.21 ± 1.02% and 82.41 ± 0.80%, during both seasons, respectively.

In the same way, on the fourth week after spraying, the reduction percentage increased compared to the

Table 1. Nymphs reduction percentage of *A. tubercularis* under certain chemical and non-chemical control agents on mango leaves under field conditions in the 2021/2022 season.

Treatments	Reduction % ± S.E.				Residual impact (Accumulative reduction %)	Overall activities (General reduction %)
	1 WAS	2 WAS	3 WAS	4 WAS		
Sulfur	53.40 ± 3.27 n	69.17 ± 0.78 j	78.98 ± 1.64 gh	88.40 ± 0.84 cd	72.49 ± 0.46 CD	57.99 ± 0.37 CD
KZ oil	61.62 ± 0.04 l	77.90 ± 1.56 ghi	84.08 ± 0.86 ef	90.47 ± 0.79 abc	78.52 ± 0.70 AB	62.82 ± 0.56 AB
Biover	56.37 ± 2.66 m	75.89 ± 1.25 i	83.34 ± 0.76 f	89.93 ± 0.09 bc	76.38 ± 1.08 BC	61.11 ± 0.87 BC
Actellic	64.49 ± 2.18 k	80.23 ± 2.10 g	89.87 ± 0.47 bc	92.71 ± 0.29 a	81.82 ± 0.75 A	65.46 ± 0.60 A
Admiral	64.04 ± 0.27 kl	79.91 ± 1.00 gh	88.45 ± 0.30 cd	91.92 ± 0.81 ab	81.08 ± 0.31 A	64.86 ± 0.25 A
Malatox	63.34 ± 2.16 kl	78.97 ± 0.95 gh	87.32 ± 0.66 d	91.15 ± 0.69 ab	80.19 ± 0.81 AB	64.16 ± 0.65 AB
Orange oil	52.88 ± 0.28 n	67.74 ± 0.84 j	77.41 ± 0.77 hi	86.37 ± 1.87 de	71.10 ± 0.72 D	56.88 ± 0.99 D
Average reduction % / week	59.45 ± 1.23 D	75.69 ± 1.14 C	84.21 ± 1.02 B	90.14 ± 0.54 A	77.37 ± 0.90	61.90 ± 0.72

Note: S.E. = standard error; WAS = week after spraying; Values indicated by different letters (capital letters for tested treatments or inspection dates & small letters for the interaction between tested treatments and different inspection dates) for nymphs and adult females individuals are statistically significant differences at P ≤ 0.05 (Bonferroni corrected test)

Table 2. Nymphs reduction percentage of *A. tubercularis* under certain chemical and non-chemical control agents on mango leaves under field conditions in the 2022/2023 season.

Treatments	Reduction % ± S.E.				Residual impact (Accumulative reduction %)	Overall activities (General reduction %)
	1 WAS	2 WAS	3 WAS	4 WAS		
Sulfur	50.56 ± 7.93 mn	65.99 ± 4.96 k	77.88 ± 2.62 hij	86.75 ± 2.12 bcde	70.30 ± 3.68 BC	56.24 ± 2.94 BC
KZ oil	60.43 ± 2.93 l	77.25 ± 1.35 hij	83.89 ± 1.51 ef	89.61 ± 1.05 abc	77.79 ± 1.68 A	62.24 ± 1.35 A
Biover	54.44 ± 1.82 m	74.97 ± 0.80 ij	82.97 ± 0.45 efg	88.82 ± 0.91 abcd	75.30 ± 0.61 AB	60.24 ± 0.48 AB
Actellic	65.55 ± 1.63 k	80.15 ± 2.83 fgh	86.86 ± 1.80 bcde	91.80 ± 0.88 a	81.09 ± 1.75 A	64.87 ± 1.40 A
Admiral	64.60 ± 3.20 kl	79.42 ± 2.29 gh	85.99 ± 0.77 cde	91.32 ± 1.70 a	80.33 ± 1.84 A	64.27 ± 1.47 A
Malatox	62.93 ± 2.69 kl	78.41 ± 1.88 hi	85.55 ± 0.18 cde	90.58 ± 0.58 ab	79.37 ± 1.17 A	63.50 ± 0.94 A
Orange oil	49.04 ± 3.07 n	65.17 ± 2.00 k	73.74 ± 2.37 j	84.62 ± 1.94 de	68.14 ± 1.92 C	54.51 ± 1.53 C
Average reduction % / week	58.22 ± 1.32 C	74.48 ± 1.09 B	82.41 ± 0.80 A	89.07 ± 0.50 A	76.05 ± 0.87	60.84 ± 0.69

Note: S.E. = standard error; WAS = week after spraying; Values indicated by different letters (capital letters for tested treatments or inspection dates & small letters for the interaction between tested treatments and different inspection dates) for nymphs and adult females individuals are statistically significant differences at P ≤ 0.05 (Bonferroni corrected test).

previous weeks in all studied treatments, with averages reaching 90.14 ± 0.54% and 89.07 ± 0.50% during the 2021/2022 and 2022/2023 seasons, respectively (Tables 1 and 2).

Statistically, there were highly significant differences between periods after spraying (in weeks) on the nymphs reduction percentage (F value = 673.34; df = 54; Bonferroni corrected p-value was 0.0000) in the first season and (F value = 241.57; df = 54; Bonferroni corrected p-value was 0.0000) in the second season, as shown in Tables 1 and 2 and Fig. 2.

In general, it was clear that the efficiency of seven compounds tested on *A. tubercularis* nymphs was evident from the first week after application and continued gradually until the fourth week, meaning that the longer the period after spraying, the greater

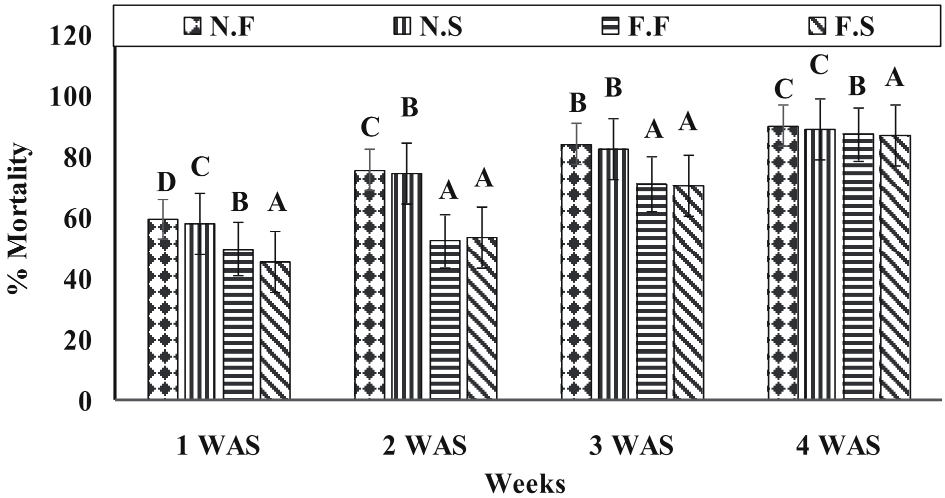

Fig. 2. Mortality percentages of *A. tubercularis* nymphs and adult females under certain chemical and non-chemical control agents on mango leaves in the different inspection dates (in weeks) in the two seasons. (N.F = Nymphs first season; N.S= Nymphs second season; F.F= Females first season; F.S = Females second season). Values indicated by different letters for the various inspection dates (in weeks) tested treatments are statistically significant differences at P ≤ 0.05 (Bonferroni corrected test).

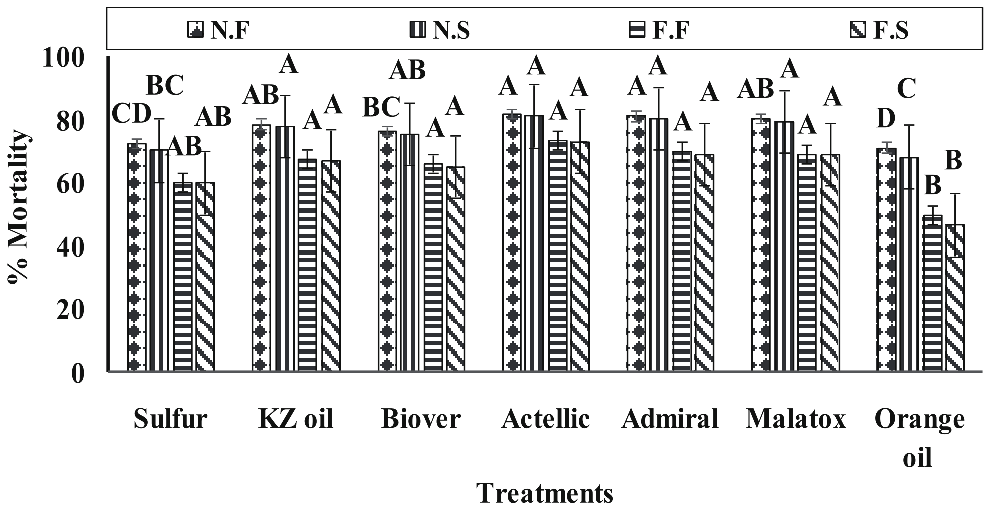

Fig. 3. Mortality percentage of *A. tubercularis* nymphs and adult females under certain chemical and non-chemical control agents on mango leaves under field conditions in the two seasons. (N.F = Nymphs first season; N.S= Nymphs second season; F.F= Females first season; F.S = Females second season). Values indicated by different letters for tested treatments against nymphs and adult females are statistically significant differences at P ≤ 0.05 (Bonferroni corrected test).

the reduction in the nymph counts (Tables 1 and 2), as illustrated in Fig. 2.

It is clear that there are variances in the percentages of reduction in the numbers of *A. tubercularis* nymphs in the tested compounds, which may be due to variances in the chemical composition of these compounds and different weeks after spraying, as shown in Tables (1 and 2) and illustrated in Fig. 2.

The treatment with the Actellic compound showed a higher effectiveness in the percentage of cumulative reduction of the nymph population by 81.82 ± 0.75% and 81.09 ± 1.75% for the two seasons, respectively, than the other tested compounds. The treatment with orange oil showed less effectiveness in the percentage of cumulative reduction in the number of nymphs by 71.10 ± 0.72 and 68.14 ± 1.92% during both seasons, respectively, as illustrated in Fig. 3.

In this context, the overall reduction percentage in Actellic pesticide also increased by (65.46 ± 0.60% and 64.87 ± 1.40%) for the two seasons, respectively, compared to the other tested compounds. On the contrary, the lowest activity was found in orange oil treatment (56.88 ± 0.99 and 54.51 ± 1.53%) for the two seasons, respectively (Tables 1 and 2 and illustrated in Fig. 3).

Statistical analysis showed that there were highly significant differences for the tested compounds on the numbers of nymphs in the two seasons (F value = 38.57; df = 54; Bonferroni corrected p-value was 0.0000) in the first season and (F value = 20.05; df = 54; Bonferroni

Table 3. Adult female reduction percentage of *A. tubercularis* under certain chemical and non-chemical control agents on mango leaves under field conditions in 2021/2022 season.

Treatments	Reduction % ± S.E.				Residual impact (Accumulative reduction %)	Overall activities (General reduction %)
	1 WAS	2 WAS	3 WAS	4 WAS		
Sulfur	45.31 ± 6.97 kl	42.21 ± 12.81 l	67.38 ± 5.63 efg	85.29 ± 0.93 abc	60.05 ± 4.65 AB	48.04 ± 3.72 AB
KZ oil	52.30 ± 2.32 ijk	55.58 ± 10.99 hij	73.08 ± 2.79 def	88.39 ± 1.00 ab	67.34 ± 2.71 A	53.87 ± 2.17 A
Biover	49.15 ± 3.77 jkl	56.03 ± 8.86 hij	72.59 ± 1.90 def	86.42 ± 1.11 abc	66.05 ± 3.02 A	52.84 ± 2.42 A
Actellic	60.05 ± 0.72 ghi	64.18 ± 5.12 fgh	77.25 ± 2.92 cde	91.99 ± 1.11 a	73.37 ± 0.91 A	58.70 ± 0.73 A
Admiral	55.06 ± 4.11 hijk	58.84 ± 9.24 ghij	74.96 ± 1.47 de	91.49 ± 0.79 a	70.09 ± 2.73 A	56.07 ± 2.18 A
Malatox	55.16 ± 3.37 hijk	58.90 ± 10.56 ghij	72.82 ± 0.75 def	89.01 ± 1.44 ab	68.98 ± 2.85 A	55.18 ± 2.28 A
Orange oil	30.06 ± 5.07 m	30.52 ± 14.41 m	58.75 ± 8.90 ghij	79.21 ± 3.65 bcd	49.64 ± 7.28 B	39.71 ± 5.82 B
Average reduction % / week	49.58 ± 1.71 B	52.32 ± 2.94 B	70.98 ± 1.33 A	87.40 ± 0.74 A	65.07 ± 1.46	52.06 ± 1.16

Note: S.E. = standard error; WAS = week after spraying; Values indicated by different letters (capital letters for tested treatments or inspection dates & small letters for the interaction between tested treatments and different inspection dates) for nymphs and adult females individuals are statistically significant differences at P ≤ 0.05 (Bonferroni corrected test).

corrected p-value was 0.0000) in the second season, as illustrated in Fig. 3.

On A. tubercularis Female Adult Population

According to the findings, the reduction rates of *A. tubercularis* female adults showed significant differences among the seven tested compounds after four weeks of spraying. After one week of spraying, the mean reduction rates were calculated to be 49.58 ± 1.71% and 45.73 ± 2.07% in the two seasons, respectively (Tables 3 and 4).

It is noted that after the second week of spraying, the average reduction rates increased and reached 52.32 ± 2.94% and 53.53 ± 2.50% during the two seasons, respectively (Tables 3 and 4).

On the third week after application, a noticeable increase in the reduction percentages for all tested compounds was observed, reaching an average of 70.98 ± 1.33% and 70.65 ± 1.69% during both seasons (Tables 3 and 4).

Similarly, during the fourth week after the spray treatment, there was a notable increase in the percentage of reduction compared to the previous weeks. The average reduction reached a high level of 87.40 ± 0.74% and. 86.92 ± 0.73% in the two seasons, respectively (Tables 3 and 4).

Overall, it was evident that the seven tested compounds were highly efficient in reducing the *A. tubercularis* adult female population. This effectiveness was noticeable as early as the first week after application, with gradual improvement observed until the fourth week. It can be seen that the longer the period after spraying, the greater the decrease in the number of adult females, as shown in Tables 3 and 4 and illustrated in Fig. 2.

In addition, there were differences in the percentage reduction in adult females of *A. tubercularis* between the compounds tested. These differences may be due to differences in the chemical composition of the compounds and the time elapsed after spraying, as shown in Tables 3 and 4.

Statistically, there were significant differences between periods after spraying (in weeks) in the percentage reduction in the adult females (F value = 75.33; df = 54; Bonferroni corrected p-value was 0.0000) in the first season and (F value = 95.76; df = 54; Bonferroni corrected p-value was 0.0000) in the second season, as shown in Tables 3 and 4 and illustrated in Fig. 2.

Compared to the other compounds examined, Actellic treatment demonstrated a large percentage of cumulative reduction of adult females' counts, reducing it by 73.37 ± 0.91% and 73.06 ± 1.84% for each of the two seasons, respectively, as illustrated in Fig. 3.

In both seasons, the percentage of cumulative reduction in the number of adult females was 49.64 ± 7.28% and 46.67 ± 7.29%, respectively, indicating lower effectiveness of orange oil treatment (Tables 3 and 4) and illustrated in Fig. 2.

In comparison to the other chemicals tested, the overall reduction percentage for Actellic pesticide increased by 58.70 ± 0.73 and 58.45 ± 1.47% for the two seasons, respectively. Conversely, the orange oil

Table 4. Adult female reduction percentage of *A. tubercularis* under the certain chemical and non-chemical control agents on mango leaves under field conditions in 2022/2023 season.

Treatments	Reduction % ± S.E.				Residual impact (Accumulative reduction %)	Total Activities (General Mortality %)
	1 WAS	2 WAS	3 WAS	4 WAS		
Sulfur	40.60 ± 7.35 m	46.23 ± 9.39 lm	67.89 ± 5.97 defg	84.86 ± 1.56 ab	59.90 ± 4.64 AB	47.92 ± 3.71 AB
KZ oil	49.87 ± 2.02 jkl	56.92 ± 8.79 hijk	72.81 ± 2.90 cde	88.41 ± 0.44 a	67.00 ± 2.01 A	53.60 ± 1.61 A
Biover	47.83 ± 3.59 klm	54.92 ± 7.08 ijkl	71.41 ± 1.95 cdef	85.77 ± 2.50 ab	64.98 ± 2.17 A	51.99 ± 1.74 A
Actellic	58.78 ± 5.98 ghij	64.29 ± 3.43 efgh	77.22 ± 1.34 bc	91.96 ± 0.94 a	73.06 ± 1.84 A	58.45 ± 1.47 A
Admiral	48.38 ± 2.04 klm	62.31 ± 5.98 fghi	75.10 ± 4.47 cd	89.82 ± 1.14 a	68.90 ± 2.26 A	55.12 ± 1.81 A
Malatox	53.31 ± 3.63 ijkl	59.19 ± 6.99 ghi	74.08 ± 5.33 cd	89.18 ± 2.05 a	68.94 ± 1.86 A	55.15 ± 1.49 A
Orange oil	21.33 ± 6.28 o	30.87 ± 12.77 n	56.04 ± 12.28 hijk	78.44 ± 0.35 bc	46.67 ± 7.29 B	37.34 ± 5.83 B
Average reduction % / week	45.73 ± 2.07 C	53.53 ± 2.50 C	70.65 ± 1.69 B	86.92 ± 0.73 A	64.21 ± 1.52	51.37 ± 1.22

Note: S.E. = standard error; WAS = week after spraying; Values indicated by different letters (capital letters for tested treatments or inspection dates & small letters for the interaction between tested treatments and different inspection dates) for nymphs and adult females individuals are statistically significant differences at $P \leq 0.05$ (Bonferroni corrected test).

treatment had the lowest activity for both seasons (39.71 ± 5.82% and 37.34 ± 5.83%, respectively), as presented in Tables 3 and 4 and illustrated in Fig. 3.

Based on statistical analysis, it was found that the tested chemicals significantly affected the number of adult females in both seasons (F value = 8.71; df = 54; Bonferroni corrected p-value = 0.0000) in the first season and (F value = 12.36; df = 54; Bonferroni corrected p-value = 0.0000) in the second season, as shown in Tables 3 and 4 and illustrated in Fig. 3.

The results showed that *A. tubercularis* nymphs were more sensitive to the treatments assessed than adult females, as shown in Tables 1-4 and illustrated in Figs. 2 and 3.

Yield and Fruit Quality of Golek Mango Trees in Response to Control Agents against *A. tubercularis*, either with or without the Addition of Potassium Silicate with Zinc Sulfate

On the Physical Properties of the Fruit

Table 5 showed that the physical measurements of the fruits of mango trees were affected by the combined effect of control agent compounds, whether with or without the addition of potassium silicate and zinc sulfate, in the two seasons studied.

The results indicated that the mango trees treated with Actellic pesticide in addition to a mixture of potassium silicate at a rate of 5 ml/liter of water with zinc sulfate at a rate of 5 g/liter of water (T_8 treatment) increased in all physical characteristics of the fruit, i.e., the average weight of the fruit and the dimensions of the fruit (length and width), fruit shape (length to width ratio), fruit thickness, and fruit size compared to all other different treatments in addition to that for untreated trees (control) during the two seasons, respectively (Table 5).

On the contrary, the untreated trees (T_{15}) gave the lowest significant values in all physical characteristics of the fruits compared to the other treatments tested during the two seasons.

Statistically, it was observed that there were statistically significant differences between the different treatments studied in all physical characteristics of mango fruits during the two seasons (Table 5).

On the Fruit Chemical Properties

It was demonstrated that spraying some chemical and non-chemical control agents against the white scale insect, with or without the addition of potassium silicate with zinc sulfate, had an impact on the yield productivity and the fruit chemical properties of Golek mango trees over the two seasons (Table 6).

The treatment (T_8), which used Actellic pesticide in addition to a mixture of potassium silicate at a rate of 5 ml/liter of water and zinc sulfate at a rate of 5 g/liter of water, produced the highest values in the resulting yield and the fruit chemical properties over the two seasons as compared to the other tested treatments. However, the untreated trees (T_{15}) gave the lowest values in the

Table 5. Effect of spraying some chemical and non-chemical control agents against the white scale insect, either with or without the addition of potassium silicate with zinc sulphate, improve the fruit physical characteristics of Golek mango trees during 2021/2022 and 2022/2023 seasons.

Treatments	Fruit length (cm)		Fruit width (cm)		Fruit shape index		Fruit thickness (cm)		Fruit size (cm^3)		Fruit weight (g)	
	2022	2023	2022	2023	2022	2023	2022	2023	2022	2023	2022	2023
T_1	11.05 ± 0.05 K	11.36 ± 0.05 K	6.69 ± 0.12 J	6.70 ± 0.07 J	1.65 ± 0.03 EF	1.70 ± 0.02 CDE	7.22 ± 0.12 J	7.33 ± 0.13 J	232.31 ± 4.65 J	238.88 ± 2.67 J	223.09 ± 3.84 J	226.21 ± 3.89 I
T_2	11.37 ± 0.11 J	11.68 ± 0.12 J	6.81 ± 0.10 I	6.83 ± 0.08 I	1.67 ± 0.01 CDEF	1.71 ± 0.02 CDE	7.35 ± 0.11 IJ	7.45 ± 0.11 I	243.00 ± 5.99 I	250.51 ± 3.92 I	226.89 ± 3.38 I	230.06 ± 3.43 HI
T_3	12.29 ± 0.12 G	12.64 ± 0.13 G	7.41 ± 0.07 G	7.42 ± 0.02 G	1.66 ± 0.01 DEF	1.70 ± 0.02 CDE	8.00 ± 0.08 G	8.11 ± 0.08 G	286.24 ± 5.53 G	294.34 ± 2.90 G	242.13 ± 1.00 G	245.52 ± 1.02 F
T_4	12.32 ± 0.11 G	12.66 ± 0.12 G	7.46 ± 0.05 G	7.48 ± 0.04 G	1.65 ± 0.01 EFG	1.69 ±0.02 DEF	8.05 ± 0.06 I	8.17 ± 0.06 G	288.63 ± 4.63 G	297.61 ± 2.73 G	243.68 ± 0.73 G	247.09 ± 0.74 F
T_5	11.58 ± 0.16 I	11.90 ± 0.16 I	6.86 ± 0.09 I	6.86 ± 0.03 I	1.69 ± 0.01 A	1.73 ± 0.02 BCD	7.40 ± 0.10 I	7.51 ± 0.10 I	249.38 ± 6.90 I	256.39 ± 4.42 I	227.26 ± 1.56 I	230.44 ± 1.58 H
T_6	11.87 ± 0.12 H	12.20 ± 0.13 H	7.12 ± 0.07 H	7.14 ± 0.02 H	1.67 ± 0.01 DEF	1.71 ± 0.02 CDE	7.68 ± 0.08 H	7.79 ± 0.08 H	265.29 ± 5.27 H	273.50 ± 2.30 H	234.54 ± 0.73 H	237.83 ± 0.74 G
T_7	14.23 ± 0.16 B	14.63 ± 0.16 B	8.29 ± 0.02 B	8.29 ± 0.06 B	1.72 ± 0.01 C	1.76 ± 0.03 AB	8.95 ± 0.03 B	9.07 ± 0.03 B	370.40 ± 5.08 B	380.92 ± 1.83 B	268.64 ± 0.75 B	272.40 ± 0.77 A
T_8	15.27 ± 0.15 A	15.45 ± 0.25 A	8.56 ± 0.11 A	8.59 ± 0.14 A	1.78 ± 0.01 B	1.80 ± 0.05 A	9.24 ± 0.12 A	9.22 ± 0.05 A	410.62 ± 9.13 A	416.48 ± 4.64 A	275.61 ± 2.51 A	276.14 ± 3.19 A
T_9	13.46 ± 0.12 D	13.83 ± 0.13 D	7.92 ± 0.11 D	7.94 ± 0.10 D	1.70 ± 0.01 CD	1.74 ± 0.01 BC	8.55 ± 0.12 D	8.67 ± 0.12 D	334.64 ± 7.65 D	345.08 ± 7.14 D	256.64 ± 3.71 D	260.23 ± 3.76 C
T_{10}	13.68 ± 0.08 C	14.06 ± 0.08 C	8.09 ± 0.05 C	8.11 ± 0.05 C	1.69 ± 0.01 CDE	1.73 ± 0.02 BCD	8.73 ± 0.06 C	8.85 ± 0.06 C	347.36 ± 3.52 C	358.19 ± 5.96 C	262.20 ± 1.72 C	265.87 ± 1.74 B
T_{11}	12.69 ± 0.12 F	13.05 ± 0.13 F	7.66 ± 0.10 F	7.69 ± 0.08 F	1.66 ± 0.01 DEF	1.70 ± 0.02 DE	8.27 ± 0.11 F	8.39 ± 0.11 F	305.51 ± 7.03 F	314.98 ± 4.75 F	248.17 ± 2.07 F	251.65 ± 2.10 E
T_{12}	13.11 ± 0.16 E	13.47 ± 0.16 E	7.79 ± 0.13 E	7.81 ± 0.12 E	1.68 ± 0.01 CDE	1.73 ± 0.02 BCD	8.40 ± 0.14 E	8.52 ± 0.14 E	320.56 ± 8.98 E	330.52 ± 8.01 E	252.27 ± 4.20 E	255.81 ± 4.26 D
T_{13}	10.41 ± 0.25 M	10.70 ± 0.26 M	6.48 ± 0.07 KL	6.50 ± 0.02 K	1.61 ± 0.02 GH	1.65 ± 0.04 F	6.99 ± 0.07 KL	7.09 ± 0.07 KL	211.80 ± 7.41 L	218.27 ± 5.04 L	215.88 ± 2.27 KL	218.90 ± 2.30 JK
T_{14}	10.68 ± 0.11 L	10.98 ± 0.12 L	6.56 ± 0.08 K	6.59 ± 0.05 JK	1.63 ± 0.01 FG	1.67 ± 0.02 EF	7.08 ± 0.09 K	7.18 ± 0.09 K	219.92 ± 5.06 K	227.24 ± 2.69 K	218.55 ± 2.82 K	221.61 ± 2.86 J
T15	10.10 ± 0.05 N	10.24 ± 0.07 N	6.40 ± 0.03 L	6.48 ± 0.03 K	1.58 ± 0.01 H	1.58 ± 0.01 G	6.89 ± 0.03 L	6.98 ± 0.02 L	203.08 ± 1.86 M	208.30 ± 2.43 M	213.37 ± 1.00 L	216.93 ± 2.27 K

Note: T_1: Trees were treated with Sulfur only; T_2: Trees were treated with Sulfur in addition to a mixture of potassium silicate at 5 ml /liter of water + Zinc sulphate at 5 g/liter of water; T_3: Trees were treated with KZ oil only, T4: Trees were treated with KZ oil in addition to a mixture of potassium silicate at 5 ml /liter of water + Zinc sulphate at 5 g/liter of water; T_5: Trees were treated with bio-insecticide (Biover) only; T_6: Trees were treated with bio-insecticide (Biover) in addition to a mixture of potassium silicate at 5 ml /liter of water + Zinc sulphate at 5 g/liter of water; T_7: Trees were treated with Actellic pesticide only; T_8: Trees were treated with Actellic pesticide in addition to a mixture of potassium silicate at 5 ml /liter of water + Zinc sulphate at 5 g/liter of water; T_9: Trees were treated with Admiral pesticide only; T_{10}: Trees were treated with Admiral pesticide in addition to a mixture of potassium silicate at 5 ml /liter of water + Zinc sulphate at 5 g/liter of water; T_{11}: Trees were treated with Malatox pesticide only; T_{12}: Trees were treated with Malatox pesticide in addition to a mixture of potassium silicate at 5 ml /liter of water + Zinc sulphate at 5 g/liter of water; T_{13}: Trees were treated with Orange oil only; T_{14}: Trees were treated with Orange oil in addition to a mixture of potassium silicate at 5 ml /liter of water + Zinc sulphate at 5 g/liter of water; T_{15}: Untreated trees (spraying water only). Values indicated with different letters for different physical properties of fruit are statistically significant differences at $P \leq 0.05$ (Bonferroni corrected test). However, the means followed by the same letter(s) in each column did not differ significantly at the 5% level.

Table 6. Effect of spraying some chemical and non-chemical control agents against the white scale insect, either with or without the addition of potassium silicate with zinc sulphate, on enhancing the yield productivity and the fruit chemical properties of Golek mango trees during 2021/2022 and 2022/2023 seasons.

Treatments	Yield / tree (kg)		TSS %		Acidity %		TSS / Acidity ratio		Total sugars %	
	2022	2023	2022	2023	2022	2023	2022	2023	2022	2023
T_1	79.33 ± 1.37 K	81.55 ± 1.40 K	18.19 ± 0.36 J	18.48 ± 0.37 J	0.29 ± 0.01 D	0.28 ± 0.01 D	62.92 ± 1.99 K	65.23 ± 2.06 K	10.49 ± 0.17 JK	10.96 ± 0.24 IJ
T_2	80.67 ± 1.20 JK	82.93 ± 1.24 J	18.82 ± 0.33 I	19.12 ± 0.34 I	0.25 ± 0.01 DE	0.25 ± 0.01 DE	74.90 ± 2.19 J	77.65 ± 2.27 J	10.77 ± 0.24 IJ	11.20 ± 0.21 J
T_3	86.17 ± 0.82 H	88.58 ± 0.85 H	21.50 ± 0.30 G	21.85 ± 0.30 G	0.20 ± 0.01 FGHI	0.20 ± 0.01 FGHI	106.05 ± 2.69 G	109.94 ± 2.78 G	11.96 ± 0.14 F	12.17 ± 0.14 GH
T_4	88.43 ± 0.65 G	90.90 ± 0.67 G	21.67 ± 0.23 G	22.02 ± 0.24 G	0.21 ± 0.01 FGH	0.20 ± 0.01 FGH	105.30 ± 2.36 G	109.17 ± 2.45 G	11.65 ± 0.15 G	12.56 ± 0.11 FG
T_5	81.28 ± 1.12 J	83.56 ± 1.15 J	19.00 ± 0.26 I	19.30 ± 0.27 I	0.23 ± 0.01 EF	0.22 ± 0.01 EF	83.74 ± 2.09 I	86.81 ± 2.17 I	11.00 ± 0.21 HI	11.31 ± 0.20 I
T_6	84.38 ± 0.84 I	86.74 ± 0.86 I	20.10 ± 0.26 H	20.42 ± 0.26 H	0.22 ± 0.01 EFG	0.22 ± 0.01 EFG	91.02 ± 2.17 H	94.36 ± 2.25 H	11.11 ± 0.19 H	11.85 ± 0.15 H
T_7	98.23 ± 0.28 B	100.98 ± 0.28 B	26.61 ± 0.37 B	27.04 ± 0.38 B	0.14 ± 0.01 K	0.13 ± 0.01 K	193.89 ± 4.94 B	201.02 ± 5.12 B	13.64 ± 0.11 B	14.29 ± 0.05 B
T_8	101.48 ± 1.28 A	103.99 ± 1.13 A	29.13 ± 0.47 A	29.27 ± 0.38 A	0.13 ± 0.01 K	0.13 ± 0.01 K	220.99 ± 6.04 A	226.47 ± 4.65 A	14.05 ± 0.05 A	14.86 ± 0.23 A
T_9	93.84 ± 1.33 D	96.47 ± 1.37 D	24.04 ± 0.35 D	24.42 ± 0.36 D	0.16 ± 0.01 IJK	0.16 ± 0.01 IJK	151.68 ± 3.97 D	157.26 ± 4.11 D	13.02 ± 0.26 CD	13.52 ± 0.23 CD
T_{10}	95.87 ± 0.63 C	98.56 ± 0.65 C	24.95 ± 0.25 C	25.35 ± 0.26 C	0.15 ±0.01 JK	0.14 ± 0.01 JK	168.94 ± 3.53 C	175.14 ± 3.66 C	13.29 ± 0.23 C	13.87 ± 0.11 BC
T_{11}	90.82 ± 1.22 F	93.36 ± 1.25 F	22.74 ± 0.41 F	23.11 ± 0.42 F	0.18 ± 0.01 GHIJ	0.18 ± 0.01 GHIJ	125.16 ± 3.71 F	129.75 ± 3.85 F	12.35 ± 0.11 E	12.98 ± 0.21 EF
T_{12}	92.28 ± 1.51 E	94.87 ± 1.55 E	23.43 ± 0.47 E	23.81 ± 0.48 E	0.17 ± 0.01 HIJK	0.16 ± 0.01 HIJK	142.05 ± 4.47 E	147.27 ± 4.64 E	12.76 ± 0.21 D	13.24 ± 0.27 DE
T_{13}	76.76 ± 0.81 LM	78.91 ± 0.83 L	17.01 ± 0.24 L	17.28 ± 0.25 K	0.41 ± 0.01 B	0.39 ± 0.01 B	41.59 ± 1.06 M	44.18 ± 0.80 M	10.17 ± 0.06 L	10.51 ± 0.14 K
T_{14}	77.71 ± 1.00 L	79.89 ± 1.03 L	17.44 ± 0.29 K	17.72 ± 0.30 K	0.35 ± 0.01 C	0.34 ± 0.01 C	50.42 ± 1.43 L	52.27 ± 1.48 L	10.32 ± 0.14 KL	10.68 ± 0.18 JK
T_{15}	75.87 ± 0.36 M	77.39 ± 0.31 M	16.03 ± 0.02 M	16.20 ± 0.49 L	0.49 ± 0.01 A	0.47 ± 0.01 A	32.75 ± 0.40 N	34.46 ± 1.09 N	10.09 ± 0.24 L	10.35 ± 0.06 K

Note: Values indicated with different letters for different fruit chemical properties and the yield productivity are statistically significant differences at $P \leq 0.05$ (Bonferroni corrected test). However, the means followed by the same letter(s) in each column did not differ significantly at the 5% level.

Table 7. The increase in the fruit physical characteristics of Golek mango trees over the control treatment as a result of spraying some chemical and non-chemical control agents against the white scale insect, whether with or without the addition of potassium silicate and zinc sulphate.

Treatments	Fruit length (cm)		Fruit width (cm)		Fruit shape index		Fruit thickness (cm)		Fruit size (cm^3)		Fruit weight (g)	
	2022	2023	2022	2023	2022	2023	2022	2023	2022	2023	2022	2023
T_1	9.40	10.98	4.56	3.34	4.68	7.42	4.79	4.92	14.39	10.40	4.56	4.28
T_2	12.50	14.13	6.34	5.38	5.81	8.32	6.58	6.71	19.66	14.35	6.34	6.05
T_3	21.67	23.43	15.83	14.49	5.04	7.81	16.09	16.23	40.95	29.26	13.48	13.18
T_4	21.93	23.69	16.55	15.52	4.61	7.09	16.82	16.96	42.13	30.37	14.21	13.90
T_5	14.58	16.23	7.14	5.89	6.94	9.76	7.38	7.51	22.80	16.35	6.51	6.23
T_6	17.44	19.13	11.22	10.22	5.59	8.09	11.47	11.61	30.63	22.17	9.93	9.63
T_7	40.86	42.90	29.48	28.00	8.79	11.67	29.77	29.93	82.39	58.70	25.91	25.57
T_8	51.13	50.87	33.76	32.59	13.00	13.90	34.06	32.05	102.19	70.79	29.17	27.29
T_9	33.19	35.12	23.69	22.59	7.70	10.24	23.97	24.12	64.78	46.51	20.28	19.96
T_{10}	35.35	37.31	26.37	25.25	7.11	9.64	26.66	26.81	71.04	50.97	22.89	22.56
T_{11}	25.64	27.46	19.71	18.64	4.97	7.45	19.98	20.13	50.44	36.27	16.31	16.00
T_{12}	29.72	31.60	21.64	20.56	6.66	9.19	21.91	22.06	57.85	41.56	18.24	17.92
T_{13}	3.03	4.52	1.18	0.27	1.80	4.25	1.41	1.53	4.29	3.39	1.18	0.91
T_{14}	5.70	7.23	2.43	1.75	3.20	5.40	2.66	2.79	8.29	6.44	2.43	2.16
Variance	193.64	188.96	110.61	108.49	7.17	6.00	111.11	105.67	862.89	422.39	79.34	75.43
Standard deviation	13.92	13.75	10.52	10.42	2.68	2.45	10.54	10.28	29.38	20.55	8.91	8.69
Standard error	3.72	3.67	2.81	2.78	0.72	0.65	2.82	2.75	7.85	5.49	2.38	2.32

resulting yield and chemical properties of the fruits during the two seasons compared to the other tested treatments (Table 6).

In addition, there were clear and noticeable differences between the different treatments in the resulting yield and the chemical properties of the fruits during the two seasons (Table 6).

It is obvious that spraying trees with some chemical and non-chemical control agents with the addition of potassium silicate and zinc sulfate caused a supplemental increase in all tested parameters as compared with using the chemical and non-chemical control agents alone.

The improvement in physical characteristics of the fruits, fruit quality, and resulting yield due to the present treatments could be attributed to the effect of such chemicals (sulfur and silicon) on maintaining the vitality of trees and raising their nutritional status in favor of forming more carbohydrate and advancing fruit ripening.

The Increase in the Fruit's Physical Characteristics, Resulting Yield, and Quality of Golek Mango Trees over the Control Treatment

As for the increase in the fruit's physical characteristics, the resulting yield and quality of Golek mango trees compared to the control treatment (untreated, i.e., spraying water) were calculated for all the different tested treatments. It indicated that the highest increase in the fruit's physical characteristics, yield, and quality compared to untreated trees was recorded in trees treated with Actellic pesticide in addition to a mixture of potassium silicate at 5 ml/liter of water and zinc sulfate at 5 g/liter of water (T_8). The lowest of them was seen in the trees treated with orange oil only (T_{13}), as shown in Tables 7 and 8.

With regard to calculating the avoidable losses in the physical characteristics of the fruits, resulting yield, and quality of the Golek mango trees compared to the tested treatments, they were determined for all the different treatments tested (Tables 9 and 10). It showed that the highest avoidable loss in all the studied traits (the physical characteristics of the fruits, the resulting yield, and their quality) was calculated in trees treated

Table 8. The increase in yield and quality of Golek mango fruits over the control treatment as a result of spraying some chemical and non-chemical control agents against the white scale insect, whether with or without the addition of potassium silicate and zinc sulphate.

Treatments	Yield / tree (kg)		TSS (%)		Acidity (%)		TSS / Acidity ratio		Total sugars (%)	
	2022	2023	2022	2023	2022	2023	2022	2023	2022	2023
T_1	4.56	5.37	13.47	14.07	-40.91	-39.73	92.10	89.28	3.92	5.88
T_2	6.34	7.16	17.41	18.02	-48.64	-47.62	128.66	125.31	6.70	8.17
T_3	13.58	14.47	34.13	34.84	-58.56	-57.74	223.77	219.02	18.47	17.52
T_4	16.55	17.46	35.16	35.87	-57.95	-57.11	221.49	216.77	15.39	21.35
T_5	7.14	7.97	18.50	19.13	-53.64	-52.72	155.66	151.91	9.02	9.21
T_6	11.22	12.09	25.38	26.05	-54.87	-53.97	177.88	173.80	10.06	14.47
T_7	29.48	30.48	66.00	66.88	-71.95	-71.39	491.97	483.28	35.16	38.02
T_8	33.76	34.37	81.72	80.62	-73.06	-72.52	574.69	557.15	39.21	43.54
T_9	23.69	24.65	49.93	50.72	-67.61	-66.97	363.10	356.30	28.98	30.56
T_{10}	26.37	27.35	55.60	56.42	-69.83	-69.23	415.77	408.20	31.66	34.01
T_{11}	19.71	20.64	41.85	42.59	-62.86	-62.13	282.11	276.50	22.35	25.42
T_{12}	21.64	22.58	46.16	46.93	-66.28	-65.61	333.70	327.33	26.47	27.91
T_{13}	1.18	1.96	6.10	6.66	-16.42	-16.83	26.99	28.21	0.75	1.52
T_{14}	2.43	3.23	8.80	9.37	-29.30	-27.89	53.93	51.68	2.29	3.13
Variance	110.93	111.46	508.88	499.93	276.36	275.18	27353.23	26083.16	166.40	184.54
Standard deviation	10.53	10.56	22.56	22.36	16.62	16.59	165.39	161.50	12.90	13.58
Standard error	2.81	2.82	6.03	5.98	4.44	4.43	44.20	43.16	3.45	3.63

with orange oil only (T_{13}), except for the acidity trait (%). The least avoidable loss in all tested parameters was seen in trees treated with Actellic treatment only (T_7), as presented in Tables 9 and 10.

Discussion

The infestation symptoms of *A. tubercularis* on mango trees consist of abundant shedding of leaves and abnormal growth in young trees; the withering of young branches leads to a loss of vitality; insufficient flowering; infected mango fruits display noticeable pink or pale marks around the feeding areas of the scales; premature fruit falls; fully grown fruits are smaller in size and less succulent; and intensive infestation in the early stages delays the growth of young nursery plants [45].

The detrimental consequences of *A. tubercularis*, methods to lower its population, and techniques to increase mango tree productivity and improve fruit quality are all poorly covered in the literature. Chemical pesticides are the main tool used in the treatment of *A. tubercularis*. The management of *A. tubercularis* relies primarily on the use of chemical insecticides. Therefore, this work was conducted to evaluate the efficiency of certain chemical and non-chemical compounds against *A. tubercularis* on Golek mango trees under field circumstances. A study was also conducted to evaluate the combined effect of these compounds, either with or without the addition of potassium silicate and zinc sulfate on improving the productivity and quality of Golek mango fruits.

Obviously, according to the results, adult females of *A. tubercularis* were less susceptible to the evaluated treatments compared to the nymphs. According to Bakry et al. [46], they mentioned that nymphs of *A. tubercularis* were more sensitive to pesticides than adults.

According to the findings, Actellic pesticide was the most efficient in terms of the residual impact percentage of *A. tubercularis* nymphs (81.82 ± 0.75 and 81.09 ± 1.75) and adult females (73.37 ± 0.91 and 73.06 ± 1.84).

The effective constituent of the Actellic pesticide is pirimiphos-methyl, which is an insect growth regulator against different insect pests. Abd-Rabou and Badary [47] reported that Actellic pesticide also showed the highest efficiency against the red-scale insect, *Aonidiella aurantii*, on citrus trees, which was consistent with our results.

Although orange oil (71.10 ± 0.72 and 68.14 ± 1.92 for nymphs and 49.64 ± 7.28 and 46.67 ± 7.29

Table 9. The avoidable loss in the fruit physical characteristics of mango trees in the tested treatments compared to the control treatment as a result of spraying some chemical and non-chemical control agents against the white scale insect, whether with or without the addition of potassium silicate and zinc sulphate.

Treatments	Fruit length (cm)		Fruit width (cm)		Fruit shape index		Fruit thickness (cm)		Fruit size (cm^3)		Fruit weight (g)	
	2022	2023	2022	2023	2022	2023	2022	2023	2022	2023	2022	2023
T_1	27.61	26.44	21.83	22.06	7.36	5.69	21.83	20.55	43.42	42.64	19.06	18.08
T_2	25.56	24.35	20.50	20.52	6.36	4.90	20.50	19.19	40.82	39.85	17.68	16.69
T_3	19.49	18.19	13.41	13.65	7.04	5.34	13.41	11.98	30.29	29.33	12.15	11.09
T_4	19.32	18.01	12.86	12.87	7.42	5.98	12.86	11.43	29.71	28.54	11.59	10.52
T_5	24.19	22.96	19.90	20.14	5.36	3.63	19.90	18.59	39.27	38.44	17.54	16.55
T_6	22.30	21.03	16.85	16.87	6.55	5.10	16.85	15.48	35.39	34.33	14.90	13.87
T_7	6.79	5.28	3.20	3.46	3.72	1.95	3.20	1.61	9.80	8.54	2.53	1.35
T_8	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
T_9	11.87	10.44	7.53	7.54	4.69	3.21	7.53	6.01	18.50	17.14	6.89	5.76
T_{10}	10.44	8.99	5.52	5.53	5.21	3.73	5.52	3.97	15.41	14.00	4.87	3.72
T_{11}	16.87	15.52	10.50	10.52	7.11	5.66	10.50	9.03	25.60	24.37	9.96	8.87
T_{12}	14.17	12.77	9.06	9.08	5.61	4.13	9.06	7.57	21.93	20.64	8.47	7.36
T_{13}	31.83	30.72	24.36	24.37	9.91	8.47	24.36	23.11	48.42	47.59	21.67	20.73
T_{14}	30.06	28.93	23.42	23.26	8.67	7.46	23.42	22.16	46.44	45.44	20.70	19.75
Variance	84.78	83.02	61.83	61.71	5.62	4.63	61.83	60.60	211.07	210.60	47.55	46.55
Standard deviation	9.21	9.11	7.86	7.86	2.37	2.15	7.86	7.78	14.53	14.51	6.90	6.82
Standard error	2.46	2.44	2.10	2.10	0.63	0.58	2.10	2.08	3.88	3.88	1.84	1.82

for adult females) was the least effective in both seasons, respectively. It may be considered or applied to the integrated management of *A. tubercularis* if its reduction effect reaches a certain level. A mixture of aloe, ginger, garlic, and hot pepper botanical extracts showed an 83.60 and 72.52% reduction of scale insects in the reported experimental seasons, respectively [48]. Some more effective plant extracts may also be applied to integrated pest management against *A. tubercularis,* according to the actual field situation.

The results indicated that the highest productivity was observed in all tested traits as a result of using Actellic pesticide in December with the addition of potassium silicate at 5 ml/liter of water and zinc sulfate at 5 g/liter of water, which was sprayed twice on mango trees during each season. Concisely, this may be attributed to the effect of spraying with Actellic pesticide in reducing *A. tubercularis* and adding nutrients, which was reflected in improving the fruit productivity of mango trees and the nutritional status of the trees in favor of producing more fruits. The lowest of them was seen in the trees treated with orange oil only. Given their critical role in numerous metabolic processes, essential nutrients are necessary for plants to function properly. According to Singh and Legese [49], these nutrients are also essential for the production of amino acids and the movement of water and nutrients.

Mango fruit productivity may be enhanced by the combination of two nutrients: potassium silicate and zinc sulfate. Studies that emphasize the separate advantages of these two nutrients on plant development and fruit quality are available, but there is little data, particularly on the combined impact of potassium silicate and zinc sulfate on mango trees. In fact, the foliar application of zinc is crucial for maintaining the health and high productivity of mango trees [50]. The application of zinc sulfate through foliar fertilization has been shown to not only improve the rate of zinc absorption in mango trees but also improve fruit quality, as seen in the increased total sugar content [51].

In addition to improving mineral contents and general plant growth and development, silicon is employed to boost photosynthetic activity and tolerance to drought in plants [52]. Zinc sulfate might increase fruit quality and overall plant metabolism, whereas potassium silicate may strengthen the plant's defenses against pests and diseases [53]. Some sources indicate that silicon may also act as an antioxidant for trees

Table 10. The avoidable loss in the yield and quality of mango Golek fruits in the tested treatments compared to the control treatment as a result of spraying some chemical and non-chemical control agents against the white scale insect, whether with or without the addition of potassium silicate and zinc sulphate.

Treatments	Yield / tree (kg)		TSS (%)		Acidity (%)		TSS / Acidity ratio		Total sugars (%)	
	2022	2023	2022	2023	2022	2023	2022	2023	2022	2023
T_1	21.83	21.58	37.56	36.85	29.30	27.54	71.53	71.20	25.35	26.24
T_2	20.50	20.25	35.39	34.66	38.54	37.02	66.11	65.71	23.36	24.64
T_3	15.08	14.81	26.19	25.35	50.42	49.19	52.01	51.45	14.90	18.13
T_4	12.86	12.58	25.62	24.78	49.69	48.44	52.35	51.80	17.11	15.46
T_5	19.90	19.65	34.79	34.05	44.53	43.15	62.11	61.67	21.69	23.92
T_6	16.85	16.58	31.00	30.22	46.00	44.66	58.81	58.33	20.94	20.25
T_7	3.20	2.89	8.65	7.61	66.44	65.60	12.26	11.24	2.91	3.85
T_8	0.00	0.00	0.00	0.00	67.76	66.96	0.00	0.00	0.00	0.00
T_9	7.53	7.23	17.49	16.55	61.25	60.29	31.36	30.56	7.35	9.05
T_{10}	5.52	5.22	14.37	13.40	63.90	63.00	23.55	22.67	5.42	6.64
T_{11}	10.50	10.22	21.94	21.05	55.57	54.46	43.36	42.71	12.11	12.62
T_{12}	9.06	8.77	19.57	18.65	59.66	58.66	35.72	34.97	9.15	10.89
T_{13}	24.36	24.12	41.61	40.95	0.00	0.00	81.18	80.49	27.63	29.28
T_{14}	23.42	23.18	40.13	39.45	15.40	13.30	77.18	76.92	26.52	28.15
Variance	62.00	61.73	154.10	153.24	395.62	397.82	600.90	603.99	85.86	89.57
Standard deviation	7.87	7.86	12.41	12.38	19.89	19.95	24.51	24.58	9.27	9.46
Standard error	2.10	2.10	3.32	3.31	5.32	5.33	6.55	6.57	2.48	2.53

and has a positive effect on water transport and root growth in drought conditions, providing resistance against pests and diseases [54], i.e., the Asian citrus psyllid, *Diaphorina citri* [55], and against *Helicoverpa punctigera* (Lepidoptera: Noctuidae) in soybean [56]. Silicon can also act on the progress of mango fruit ripening, which could give a reasonable explanation for its effect on improving fruit quality. Khalil *et al.* [57] reported that the properties of mango fruits were gradually enhanced when potassium silicate was applied in higher concentrations and more frequently. It was noted that the impact of silicon was significant among interactions between plants and insects in this study.

Pests that have been effectively managed by incorporating potassium silicate and zinc sulfate into broader IPM strategies: a) Citrus thrips (*Scirtothrips citri*); potassium silicate creates a physical barrier that disrupts the feeding and movement of citrus thrips, preventing them from establishing large populations on the citrus trees [58], b) the citrus mealybug, *Planococcus citri*; potassium silicate can deter mealybug infestations by creating a physical barrier that impedes their ability to establish on the citrus plants [59], c) the sweet potato whitefly, *Bemisia tabaci*: the silica-rich layer formed by potassium silicate applications can make the vegetable plants less attractive and less suitable for whitefly settlement and feeding [60], and d) against spider mites on tomato plants [61].

Our study exhibits that spraying trees with some chemical and non-chemical control agents with the addition of potassium silicate and zinc sulfate led to a complementary increase (increase in yield over control) in all tested parameters compared to using chemical and non-chemical control agents alone. Among the insecticides tested, the least increase in fruit physical characteristics, yield, and fruit quality compared to untreated trees was seen in trees treated with orange oil only. As for the highest avoidable loss in all studied attributes, it was calculated in trees treated with orange oil only, except for the acidity (%) characteristic. While the least avoidable loss was seen in trees treated with Actellic treatment only, cultivars of mangos have different sensitivity to *A. tubercularis* [62].

Conclusions

By minimizing tree damage, managing white-scale insects can greatly increase mango fruit yield. Insecticides and other chemical control agents can be useful, but incorporating cultural practices can improve outcomes. Mango trees can greatly reduce bug populations and increase the quantity and quality of mango fruits by using potassium silicate and zinc sulfate. These treatments lead to more strong and resilient mango orchards by fostering robust development, boosting plant health, and eliciting natural defenses. The precise effect on Golek mango fruits, however, would rely on a number of variables, including the weather, the way treatments are applied, and when they are applied. It may be recommended to spray Golek mango trees with Pirimiphos-methyl in December to reduce and control *A. tubercularis* and the addition of potassium silicate and zinc sulfate, which are sprayed twice on mango trees during each season, to obtain the highest productivity of the trees and enhance fruit quality. The following steps are critical when using potassium silicate and zinc sulfate in an integrated pest management (IPM) program: A) regularly monitor insect populations and plant health; B) modify application rates and timing based on crop needs and pest pressures; C) combine these compounds with other IPM strategies, such as cultural practices, biological controls, and selective use of insecticides; and D) provide with entomologists or agricultural experts to ensure the most sustainable and effective pest management program.

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Author Contributions

MMSB designed the experiment, data collection, wrote the paper and performing data analysis. XW revising the first draft of the manuscript and revising the final manuscript and interpretation of the results and fund. XH final manuscript review and funding. All authors agreed the final manuscript.

Conflicts of Interest

The authors declare that they have no conflict of interest.

Data Availability Statement

Data sets are available upon request from the corresponding author.

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