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Article

Efficiency of some commercial stimulants in inducing tomato resistance to *Tetranychus urticae* (Acari: Tetranychidae)

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ABSTRACT

The effect of some commercial stimulants on inducing resistance in tomato cultivars K186 F_1 and 023 F_1 to two-spotted spider mites (*Tetranychus urticae* Koch) was evaluated. The experiment was conducted under open-field conditions during the 2017 and 2018 summer seasons. Stimulants were applied to field-grown tomato plants after observing *T. urticae* individuals. The population of the movable stages of *T. urticae* at the start of the application and weekly intervals was counted as a measure of plant resistance. The initial population at three weeks after transplanting on both cultivars was within the economically safe range (< 1 mite/leaflet) for both seasons. The population of *T. urticae* increased gradually with plant age. The applied stimulants delayed the arrival of the economically significant damage until the 11 weeks after transplanting, especially with the spraying of Silical® (45% silicon oxide, 9% calcium, and 0.9% boron) and Stansh® (35% silicon oxide, 11.5% potassium oxide, and 13.4% silicon). The density of glandular and non-glandular trichomes on tomato leaves for various treatments was assessed at 13 weeks after transplanting. The stimulants had a significant positive effect on trichome density. The highest densities were found with Silical®, Stansh®, and Ultrafit® (38% salicylic acid, 2.8% nitrogen, 6.2% phosphor, and 23% potassium) for both cultivars. The foliar essential oil in Silical®, Ultrafit®, and control treatments was analyzed using the GC-MS technique. Silical® and Ultrafit® spraying stimulated tomato leaves to synthesize compounds that have acaricide activity. Chlorfenapyr was synthesized in both cultivars, and 2-dehydro-1,8-cineole, -gurjunene, -humulene, and heptacosane were synthesized in cultivar 023 F_1. Silical® and Ultrafit® spraying also increased the synthesis of some monoterpenoids that helped tomatoes resist *T. urticae*. Induced tomato resistance does not eliminate pest problems, but helps reduce pest populations and damage below the economic threshold. Silicon compounds can be accepted as part of integrated pest management, which must be carefully chosen for long-term agricultural sustainability.

KEYWORDS: GC-MS, Silicon, *Solanum lycopersicum*, trichomes, two-spotted spider mites.

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INTRODUCTION

Tomato (*Solanum lycopersicum* L.) is an economically and nutritionally important solanaceous vegetable grown worldwide in open fields and protected cultivations. Global annual tomato

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production in 2020 exceeded 186.8 million tons, from 5.05 million ha. Egypt is the largest tomato producer in Africa and ranks fifth in production (FAO 2022). Tomato is significantly injured by several destructive pests, causing 34.4% of global yield losses (CABI 2001). If inadequately managed, yield losses can reach 77.7% (Oerke *et al.* 1994). The two-spotted spider mite, *Tetranychus urticae* Koch (Acari: Tetranychidae), is a severe tomato pest because it is a highly polyphagous species with a short life cycle, high offspring production, a remarkable ability to develop pesticide resistance, and it is widespread worldwide (Macke *et al.* 2011; Ximenez-Embun *et al.* 2017). *Tetranychus urticae* has a stylet-like chelicera used for piercing host plants. The cellular substance of the epidermal cells is released, and the mite sucks on it with its rostrum. Mite feeding causes the mesophyll cells to collapse, creating tiny white chlorotic spots on the leaves where the chlorophyll has been destroyed (Sabelis 1985). The foliage has a stippled appearance as the feeding damage progresses. Necrotic spots appear on leaf tissue after many days of heavy mite feeding, with leaves becoming yellow or gray and collapsing. Severe early infestation with *T. urticae* may lead to wilting and the death of the plant (Foster and Barker 1978). *Tetranychus urticae* feeding damage to tomato flowers produces browning and withering of the petals, which is uncommon. At the same time, *T. urticae* feeds on tomato fruits, usually at the stem end of the cap area (Meck *et al.* 2009). This feeding damage is rough to the touch, with small, depressed areas where the mites have taken chlorophyll and collapsed the cells. Gold flecking, which appears as yellow or gold flecks spreading throughout the surface of the fruit as it ripens, is another *T. urticae*-related fruit issue. When flecking is severe, it might lower the market value of the fruit (Bensoussan *et al.* 2016). Generally, yield losses from *T. urticae* range from 10% to 50%, relative to environmental conditions and management programs (Wilkerson *et al.* 2005).

Integrated pest management (IPM) in a sustainable agriculture system depends on four critical practices: host plant resistance, agricultural practices, biological control, and chemical control. Chemical acaricides are reasonably effective at reducing the harm caused by pests. However, they also harm the environment and humans (Ahmed *et al.* 2021). *Tetranychus urticae* develops rapid resistance to acaricides after a few applications (De Ponti 1985; Van Pottelberge *et al.* 2008). Therefore, it is urgent to prevent/reduce their use. Host plant resistance to pests is an effective, economic, and environmentally friendly strategy to control pest damage and spread. Plants defend themselves from stressors through a variety of chemical and physical defenses. Plant defenses can be either constitutive (always present in the plant) or induced (produced in reaction to stressors). Induced resistance is a state of enhanced defensive capacity developed by a plant when it is appropriately stimulated. This enhanced state alert the plant to resist further biotic and abiotic stresses (Thakur and Sohal 2013).

Induced resistance is regulated by a complex network of signal molecules and transcriptional regulators. The phytohormones salicylic acid [SA, generally associated with (hemi) biotrophic pathogens], jasmonic acid (JA, related to necrotrophic pathogens and insect herbivores), ethylene (ET, regarded as 'fine-tuning' the JA defense response), and abscisic acid are the primary actors in signaling pathway control (Morkunas *et al.* 2011; Verma *et al.* 2016). Plant resistance is also influenced by nutrients, through their functions in plant metabolism and their influence on growth and production. Changes in growth pattern, plant shape, anatomy, or chemical composition may increase or decrease plant resistance (Huber *et al.* 2012). Calcium, silicon, and boron in the epidermal cell walls act as a mechanical barrier to the penetration of sucking insects, such as mites (Huber *et al.* 2012). Silicon (Si) enhances plant resistance or tolerance to attacks from herbivore insects (Reynolds *et al.* 2009; Frew *et al.* 2018; Laane 2018). The element Si is deposited in plant tissues in the form of phytoliths [primarily composed of silicon oxide (SiO_2)] (Katz 2015). The deposition of phytoliths increases plant rigidity and physical toughness (tensile strength) and acts as a physical barrier to insect penetration (Massey *et al.* 2007). Silicon deposition can also wear down the feeding mouth parts, or mandibles, of insects (Massey and Hartley 2009), reduce plant digestibility to both insect and mammalian herbivores (Massey and Hartley 2006; Massey *et al.* 2006), adversely affect herbivores

(reducing growth and consumption rates), and also minimize predatory behavior toward prey fed on high-Si diets (Ryalls *et al.* 2017). Si can also increase the activities of defense enzymes (e.g., catalase, peroxidases, polyphenol oxidase, phenylalanine ammonia lyase) (Afifi *et al.* 2015).

Several researchers have used exogenous applications of synthetic phytohormones, their derivatives, and mineral nutrients to induce plant resistance to biotic and abiotic stresses. Tomato resistance to *T. urticae* was induced by foliar spraying of elicitors, such as JA, SA, and ET (Shivaji *et al.* 2010; War *et al.* 2012; Afifi *et al.* 2015; Pulga *et al.* 2020). Foliar spraying with SA, methyl jasmonate, potassium humates, and potassium silicate reduced the *T. urticae* population on tomato foliage (Afifi *et al.* 2015; Ahmed 2018). Most attempts to stimulate pest resistance in plants involve elicitors in laboratory or greenhouse conditions (Stout *et al.* 2002). Only more rarely has the stimulation of crop resistance to pests been attempted under field conditions (Thaler 1999; Iverson *et al.* 2001). In these cases, elicitor-induced increases in resistance have been moderate or transient, but potentially useful as a management program component. Despite much exciting work on induced resistance to arthropods in tomatoes, minimal progress has been made in developing commercial approaches to using induced resistance. Alyousuf *et al.* (2021) found that foliar spraying of a commercial product AB Yellow® [2.5% plant-available SA (0.8% Si), 0.3% boron, 1.5% zinc, 0.15% copper, and 0.1% molybdenum] on tomato plants in the greenhouse significantly reduced the population of immature forms of both *Bemisia tabaci* Gennadius (Hemiptera: Aleyrodidae) and *Tuta absoluta* Meyrick (Lepidoptera: Gelechiidae). Therefore, the current study was conducted to evaluate the efficiency of some commercial products as tomato resistance inducers against *T. urticae* and their structural and chemical mechanisms.

MATERIALS AND METHODS

This study was conducted from 2017 to 2018 on a private farm in Barnsht Village, Al-Ayat, Giza Governorate, Egypt (29° 40′ 58.3″ N 31° 13′ 50.4″ E) to study the effect of five commercial stimulants (Table 1) on the induction of resistance in tomato cultivars K186 F_1 and 023 F_1 to *T. urticae*. Tomato seeds were purchased from Green Seeds and Sakata Seed Companies. Stimulants were purchased from Prosper Way Group, Giza, Egypt.

Table 1. Composition, rate and method of application for the used commercial stimulants.

Stimulant[z]	Composition	Application rate	Application method
Postar®	41% Potassium oxide and 2.17% boron.	2 g/l	Foliar spraying
Silical®	45% Silicon Oxide, 9% calcium, and 0.9% boron.	2 g/l	
Stansh®	35% Silicon oxide, 11.5% potassium oxide, and 13.4% silicon.	2 g/l	
Xtracal®	20% Calcium, and 1.8% boron.	2 g/l	
Ultrafit®	38% Salicylic acid, 2.8% nitrogen, 6.2% phosphor, and 23% potassium.	1 g/l	
		0.25 g/l	Soil-drenching (50 ml/plant).

[z] All products are from Prosper Way Group, Giza, Egypt.

Procedures for planting and treatment

Tomato seeds were sown on May 20 of both seasons in seedling trays (209 cells) filled with a mixture of peat moss and vermiculite (1:1 v/v) enriched with macro and microelements under net-house conditions. The healthy 4–5-week-old seedlings were field-transplanted under a drip irrigation system on rows 1.2 m width × 40 m height with one drip line/row (30 cm between drips) and with 60 cm among transplants. Transplants were subjected to standard agricultural practices without applying

fertilizers and insecticides. On the western side of the tomato field, there were cucumber greenhouses at the end of the season. The plastic cover of the cucumber greenhouses was removed one week after transplanting of tomato plants to allow the natural spreading of mites on tomato plants.

Tomato plants were severely infested with mites two weeks after transplantation. Therefore, the tomato field was divided into 42 experimental units using a randomized complete block design (RCBD) in a factorial scheme (two cultivars × seven stimulant treatments) with three replicates. Foliar spraying of the stimulants was applied. Additionally, Ultrafit® was applied to the soil to compare the effects of foliar and soil treatments. Each experimental unit consisted of 10 plants. Stimulant treatments were applied three weeks after transplanting and repeated weekly for 12 weeks. A 16-liters air pressure sprayer was employed. The sprayer was run at a flow rate of 1 $l.min^{-1}$ at an air pressure of 4 bar. Each time, the spray solution filled up one-fourth of the capacity of the sprayer. Table 1 shows the rate and method of stimulant application.

Estimation of the population of movable stages of T. urticae

The population of movable stages of *T. urticae* was estimated before spraying and then weekly for 11 weeks during both seasons. The level of plant resistance to different treatments was determined. A total of 30 leaves/treatments were randomly collected from the upper half of the plant early in the morning. The collected leaves were kept in a polyethylene bag with wet tissue paper among the leaves to keep them fresh. The bags were closed with a rubber band and placed in an icebox to transfer to the Acarology Laboratory, Faculty of Agriculture, Cairo University, Giza. A stereomicroscope was used to count the movable stages of *T. urticae*/leaf.

Estimation of leaf trichomes using a scanning electron microscope

A total of 10 leaves per treatment were collected from the upper third of tomato plants 13 weeks after transplanting in 2018. The leaves were kept in a polyethylene bag with a rubber band and stored in an icebox to transport to the Central Laboratory of Water Station Fustat, Greater Cairo Water Company, Cairo, Egypt. Leaf samples were prepared according to Fischer *et al.* (2012) and Karnovsky (1965) for imaging the upper and lower surfaces using a scanning electron microscopic technique (SEM, Joel JSM-6390LA). The density of glandular (GT) and non-glandular trichomes (NGT, numbers/mm^2) were determined from eight spots of both surfaces/leaves using the Compu Eye, Leaf & Symptom Area program (Bakr 2005).

Estimation of plant essential oils by gas chromatography-mass spectrometry (GC/MS)

According to the trichomes density results, essential oils of the leaves were extracted from high-density treatments, especially for GT (Silical® and Ultrafit®), compared to the control to determine their components. A total of 1,000 g of fresh leaves per treatment were collected from the upper half of the tomato plants 13 weeks after transplanting in the 2018 season. The leaves were kept in a polyethylene bag with a rubber band and stored in an icebox to transport to the Chromatography Laboratory, Central Laboratories Network, National Research Centre, Giza, Egypt. According to the Council of Europe (1997), the collected leaves were hydro-distilled in a Clevenger-type apparatus. The extracted essential oil was kept at 4 ℃ away from light and analyzed using GC-MS, according to Adam *et al.* (1998). A Thermoquest-Finnigan Trace GC-MS equipped with a DB-5 (5% phenyl) methylpolysiloxane column (60 m–0.25 mm i.d., film thickness 0.25 μm) was used for the GC/MS analysis. The injection temperature was 220 °C, and the oven temperature was increased at a rate of 5 °C min G1, at a flow rate of 1.0 ml min G1. A total of 1 μl of the sample was injected using helium as the carrier gas. The mass spectrometer was scanned with a 70 eV ionizing voltage across the 40–500 m/z range. The identification was based on a standard mass library developed by the National Institute of Standards and Technology (NIST Version 2.0) to detect the possibilities of essential oil components.

Statistical Analysis

All collected data were checked for normality using the Shapiro–Wilk test (Shapiro and Wilk 1965). Data collected on the population of movable stages of *T. urticae* were subjected to an analysis of variance (ANOVA) based on an RCBD for factorial scheme two cultivars (C) × six plant ages (PA) × seven stimulant treatments (S). While data on foliar trichome density were analyzed using an ANOVA based on an RCBD for factorial scheme two cvs × seven stimulant treatments. Significant means were compared using Tukey's multiple range test at the 5% probability level (Wickens and Keppel 2004). The data were statistically analyzed using MSTAT-C v.2.1 (Michigan State University, Michigan, USA).

RESULTS

The population of movable stages of T. urticae

The population of movable stages of *T. urticae* was significantly ($p < 0.001$) affected by cultivars (C), PA, and stimulants (S), along with interactions (C × PA, C × S, PA × S, and C × PA × S) during both seasons, except "C" in the 2017 season (Table 2). Wickens and Keppel (2004) stated that whenever the interaction among factors was statistically significant, focusing on the interaction effects is more important than the main effects. However, during both seasons, PA had the highest incidence on total variance (88.8 and 85.4%, respectively), followed by S (5.2 and 6.2%, respectively), interaction PA × S (4.3 and 6.0%, respectively), interaction C × PA × S (0.6 and 0.3%, respectively), and interaction C × S (0.5 and 0.3%, respectively) (Table 2). "C" had a minimal influence on the population in both seasons (0.0001 and 1.4%, respectively), notably in the first season, when it had an insignificant effect on the population. Therefore, we will focus only on the individual impact of PA and S and the triple interaction of these variables.

Table 2. Summary of the main results of the analysis of variance of the main factors and their interaction for the populations of movable stages of *Tetranychus urticae* (number/leaflet) during the 2017 and 2018 summer seasons, with the corresponding significance of the variance.

Source of variance	df	Population - 2017			Population - 2018		
		SS[y] (%)	MS[x]	F	SS[y] (%)	MS[x]	F
Replication	2	0.005	0.232^{ns}	3.031	0.014	0.829^{***}	11.541
Cultivar (C)	1	0.0001	0.008^{ns}	0.184	1.386	170.858^{***}	2680.323
Plant age (PA)	5	88.765	1483.598^{***}	32655.284	85.370	2104.729^{***}	33017.774
C × PA	5	0.613	10.243^{***}	225.454	0.356	8.773^{***}	137.625
Stimulants (S)	6	5.155	71.793^{***}	1580.226	6.162	126.6^{***}	1986.113
C × S	6	0.472	6.567^{***}	144.539	0.339	6.955^{***}	109.108
PA × S	30	4.311	12.009^{***}	264.338	5.969	24.527^{***}	384.772
C × PA × S	30	0.589	1.640^{***}	36.101	0.319	1.310^{***}	20.546
Error	166	0.090	0.045		0.085	0.064	

[z] A randomized complete block design with factorial scheme for two tomato cultivars, six plant ages, and seven stimulant treatments.
[y] SS: Sum of squares.
[x] MS: Mean square. Highly significant ($p < 0.001$) and [ns] non-significant.

The population of movable stages of *T. urticae* (leaflet^{-1}) was significantly ($p < 0.001$) affected by PA and interaction between age and cultivar during both seasons (Table 2). The population of movable stages of *T. urticae* gradually increased with PA in both cultivars (Fig. 1). There were no significant differences in population between the cultivars during the first two weeks following treatment. However, in the weeks that followed, significant differences were found. The oldest age

(13 weeks after transplanting) recorded the highest significant ($p < 0.05$) population, while the youngest age recorded the lowest significant population of both seasons (Fig. 1).

The stimulants had significant ($p < 0.001$) effects on the population (leaflet^{-1}) of movable stages of *T. urticae* (Table 2, Fig. 2). Stimulants Stansh® (4.8 and 6.4) and Silical® (4.4 and 5.8) had the lowest significant ($p < 0.05$) populations on tomato leaves of both cultivars, with significant ($p < 0.05$) differences in both seasons. They were followed by Xtracal® (5.7 and 7.1), Postar® (5.7 and 7.5), and Ultrafit®, which had no significant ($p < 0.05$) differences in the first season (Fig. 2). Water spraying (control) recorded the highest significant ($p < 0.05$) population of both seasons (8.4 and 11.1, respectively). The Ultrafit® treatment method (spray vs. soil drench) affected the *T. urticae* population. Foliar spraying had the significantly smallest population compared to soil-drenching.

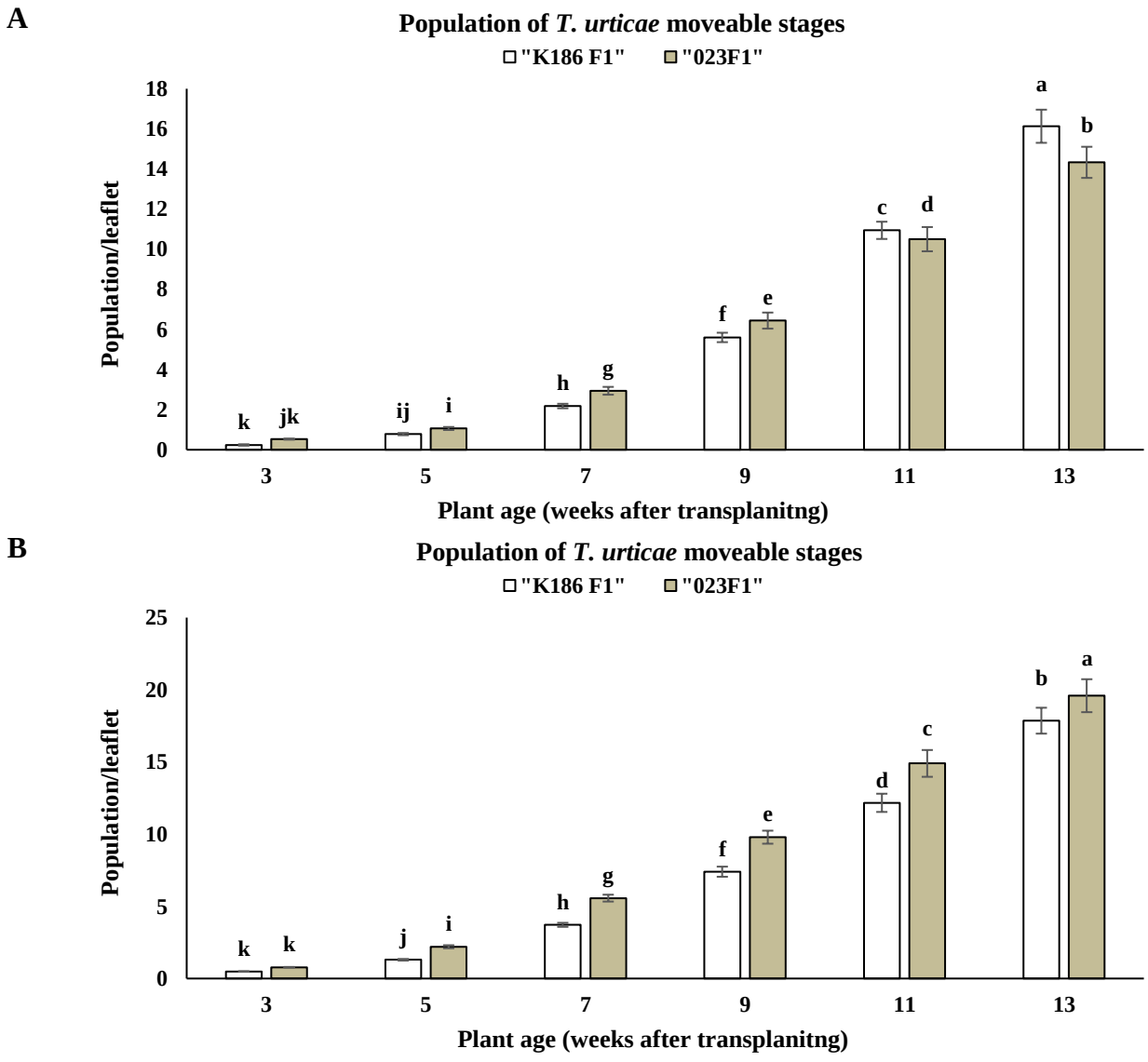

Figure 1. Population of movable stages of *Tetranychus urticae* on tomato leaves of several plant ages for cultivars K186 F_1 and 023 F_1 treated with some commercial stimulants during the 2017 (A) and 2018 (B) summer seasons. Population at three weeks after transplanting was immediately before treatment. Columns with the same letter represent means that are not significantly different according to Tukey's multiple range test ($p < 0.05$). Vertical bars represent ± standard error of the mean ($n = 21$).

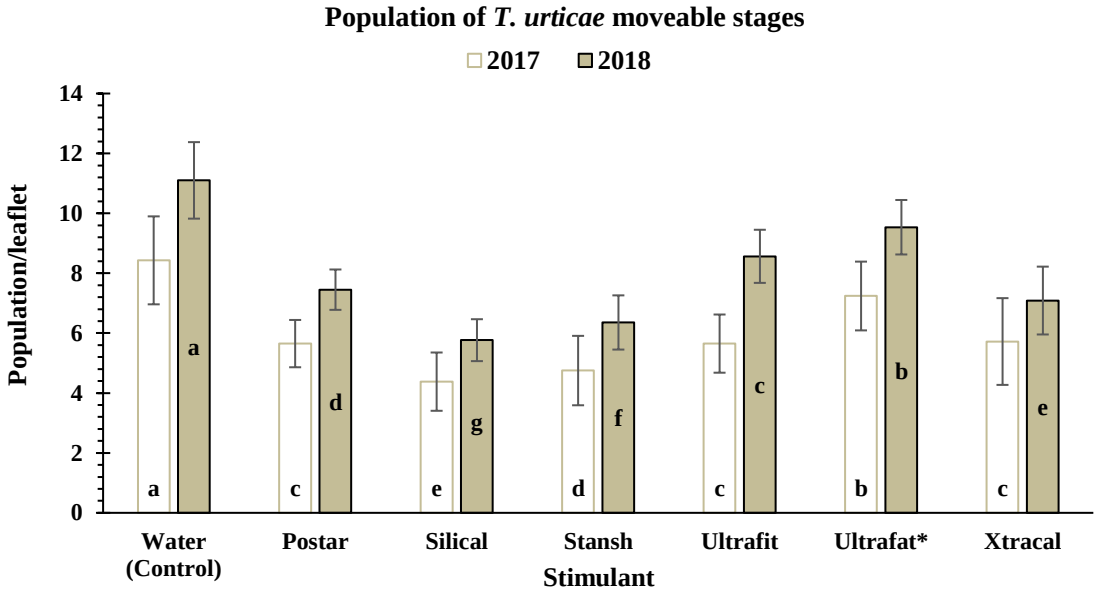

Figure 2. Population of movable stages of *Tetranychus urticae* on tomato leaves over old 3–13 weeks after transplanting for two cultivars treated with commercial stimulants during the 2017 and 2018 summer seasons. Ultrafat* applied by adding to soil below the plants. Columns with the same letter represent means that are not significantly different according to Tukey's multiple range test ($p < 0.05$). Vertical bars represent ± standard error of the mean (n = 36).

Effect of stimulants on the density of foliar trichomes

The effect of cultivars, stimulants, and their interactions on the density of GT, NGT trichomes, and total trichomes (TT) are shown in Table 4 and Figs. 3 and 4. The density (per mm^2) of NGT and TT on both leaf surfaces of both cultivars differed significantly. In contrast, the density of GT on both leaf surfaces of both cultivars did not differ significantly (Table 4).

The tomato cultivar K186 F_1 had the highest significant density of NGT (1.89 and 2.75 NGT/mm^2, respectively) and TT (3.03 and 3.68 TT/mm^2, respectively) on both leaf surfaces. The density of GT, NGT, and TT, particularly on the upper surface of leaves, was likewise influenced by stimulants. Stimulants had no significant effect on the density of GT and NGT on the lower surface of the leaves. Generally, Silical® spraying increased the density of GT and NGT on the upper surface of the leaves of both cultivars (1.63 GT/mm^2 and 2.25 NGT/mm^2 respectively; Figs. 3C, D, 4C, D), and the TT on both leaf surfaces (3.88 and 4.25 TT/mm^2, respectively). A similar tendency was observed with Ultrafit® (Figs. 3G, H, 4G, H) and Stansh®, but without significant differences from the control.

The interaction between cultivars and stimulants significantly affected the density of GT, NGT, and TT on both leaf surfaces, except GT on the lower surface. The best treatments (cultivar and stimulant) were cultivar K186 F_1 with stimulants Silical® (Figs. 3C, 4C), Stansh®, and Ultrafit® (Figs. 3G, 4G). In such treatments, there was the highest significant density (per mm^2) on both leaf surfaces of GT (3.00 and 3.50, 2.25 and 3.00, and 2.25 and 3.25 GT/mm^2, respectively), NGT (2.00 and 1.75, 1.25 and 1.25, and 1.50 and 0.75 NGT/mm^2, respectively), and TT (5.00 and 5.25, 3.50 and 4.25, and 3.75 and 4.00 TT/mm^2, respectively) compared to other treatments. However, these treatments did not differ significantly from the control treatments for both cultivars.

Foliar essential oil composition

The effects of spraying stimulants Silical® and Ultrafit® compared to water (control) on the foliar essential oil composition of tomato cultivars K186 F_1 and 023 F1 are shown in Table 5. A total of 50 compounds were identified. Among these, 39 compounds were considered significant because their RT was higher than 10%.

Table 3. Population of movable stages of *Tetranychus urticae* (number/leaflet) on tomato leaves of cultivars 186 and 023 treated with some stimulants at the 3–13 weeks after transplanting during the 2017 and 2018 summer seasons.

Cultivar (C)	Plant age (PA; weeks after transplanting)	Stimulants[z] (S)							Mean	
		Control	Silical®	Stansh®	Xtracal®	Postar®	Ultrafit®	Ultrafat®[y]	(C × PA)	(C)
						2017 season				
K186 F_1	**3[x]**	0.50 ± 0.15	0.20 ± 0.06	0.23 ± 0.03	0.20 ± 0.01	0.13 ± 0.03	0.30 ± 0.06	0.13 ± 0.03	0.24 ± 0.03 K	5.98 ± 0.88[ns]
	5	1.17 ± 0.18	0.43 ± 0.03	0.53 ± 0.10	0.85 ± 0.03	0.82 ± 0.06	0.85 ± 0.08	0.82 ± 0.04	0.78 ± 0.06 IJ	
	7	3.00 ± 0.06	1.52 ± 0.06	1.72 ± 0.04	1.85 ± 0.03	2.12 ± 0.07	2.45 ± 0.09	2.62 ± 0.04	2.181 ± 0.11 H	
	9	7.27 ± 0.09	4.00 ± 0.06	4.62 ± 0.07	5.27 ± 0.14	5.38 ± 0.07	6.17 ± 0.19	6.48 ± 0.16	5.60 ± 0.24 F	
	11	14.00 ± 0.15	8.33 ± 0.04	8.60 ± 0.10	10.23 ± 0.15	11.37 ± 0.12	11.27 ± 0.17	12.77 ± 0.09	10.94 ± 0.43 C	
	13	22.38 ± 0.12	11.63 ± 0.12	12.28 ± 0.09	13.60 ± 0.08	15.63 ± 0.15	17.85 ± 0.06	19.55 ± 0.06	16.13 ± 0.83 A	
023 F_1	**3[x]**	0.70 ± 0.06	0.50 ± 0.58	0.63 ± 0.03	0.57 ± 0.03	0.37 ± 0.03	0.43 ± 0.03	0.53 ± 0.03	0.53 ± 0.03 JK	5.97 ± 0.79
	5	1.73 ± 0.04	0.75 ± 0.03	1.13 ± 0.03	1.12 ± 0.06	0.65 ± 0.03	0.90 ± 0.06	1.17 ± 0.09	1.06 ± 0.08 I	
	7	4.72 ± 0.04	2.35 ± 0.10	2.87 ± 0.09	2.33 ± 0.04	2.30 ± 0.19	2.33 ± 0.09	3.67 ± 0.07	2.94 ± 0.20 G	
	9	9.78 ± 0.07	4.80 ± 0.26	5.07 ± 0.12	6.43 ± 0.09	5.28 ± 0.20	5.33 ± 0.07	8.37 ± 0.31	6.44 ± 0.40 E	
	11	15.70 ± 0.13	7.42 ± 0.20	8.13 ± 0.06	10.85 ± 0.14	10.05 ± 0.26	8.63 ± 0.07	12.70 ± 0.18	10.50 ± 0.60 D	
	13	20.25 ± 0.06	10.62 ± 0.14	11.18 ± 0.10	15.32 ± 0.20	13.67 ± 0.52	11.25 ± 0.16	18.05 ± 0.23	14.33 ± 0.78 B	
Mean C × S	**K186 F_1 × S**	8.05 ± 1.91 b	4.35 ± 1.04 i	4.66 ± 1.08 h	6.48 ± 1.53 e	5.33 ± 1.22 g	5.91 ± 1.39 f	7.06 ± 1.70 d		
	023 F_1 × S	8.81 ± 1.75 a	4.41 ± 0.89 i	4.84 ± 0.92 h	4.81 ± 0.98 h	6.10 ± 1.32 f	5.39 ± 1.21 g	7.41 ± 1.54 c		
						2018 season				
K186 F_1	**3[x]**	0.37 ± 0.03	0.50 ± 0.058	0.57 ± 0.03	0.50 ± 0.058	0.50 ± 0.058	0.53 ± 0.03	0.47 ± 0.03	0.49 ± 0.02 K	7.16 ± 0.95
	5	1.37 ± 0.09	1.03 ± 0.06	1.55 ± 0.13	1.47 ± 0.04	1.08 ± 0.07	1.03 ± 0.06	1.55 ± 0.09	1.30 ± 0.6 J	
	7	4.57 ± 0.12	2.88 ± 0.12	3.88 ± 0.10	3.4 ± 0.13	3.03 ± 0.09	3.90 ± 0.058	4.37 ± 0.19	3.72 ± 0.14 H	
	9	11.00 ± 0.28	6.00 ± 0.029	6.93 ± 0.12	6.71 ± 0.14	6.37 ± 0.16	7.47 ± 0.04	7.32 ± 0.36	7.40 ± 0.35 F	
	11	18.05 ± 0.35	10.10 ± 0.06	9.57 ± 0.06	10.08 ± 0.26	10.78 ± 0.34	12.88 ± 0.17	13.72 ± 0.31	12.17 ± 0.63 D	
	13	25.12 ± 0.16	13.00 ± 0.20	13.50 ± 0.18	16.10 ± 0.15	16.80 ± 0.06	19.42 ± 0.09	21.10 ± 0.08	17.86 ± 0.90 B	
023 F_1	**3[x]**	0.83 ± 0.09	0.67 ± 0.03	0.83 ± 0.03	0.66 ± 0.07	0.77 ± 0.03	0.83 ± 0.03	0.83 ± 0.03	0.78 ± 0.02 K	8.80 ± 1.06[**] [*]
	5	2.63 ± 0.05	1.40 ± 0.03	1.75 ± 0.03	2.10 ± 0.09	2.63 ± 0.15	2.20 ± 0.10	2.67 ± 0.15	2.20 ± 0.11 I	
	7	6.60 ± 0.21	3.72 ± 0.14	4.87 ± 0.09	5.47 ± 0.18	6.45 ± 0.20	5.10 ± 0.06	6.82 ± 0.23	5.57 ± 0.24 G	
	9	12.77 ± 0.29	6.77 ± 0.06	7.68 ± 0.14	8.98 ± 0.18	9.98 ± 0.12	10.50 ± 0.10	11.85 ± 0.39	9.79 ± 0.45 E	
	11	21.50 ± 0.28	9.50 ± 0.10	10.42 ± 0.15	12.90 ± 0.14	13.82 ± 0.09	17.07 ± 0.32	19.07 ± 0.16	14.90 ± 0.93 C	
	13	28.37 ± 0.06	13.62 ± 0.04	14.72 ± 0.04	16.67 ± 0.29	17.20 ± 0.21	21.85 ± 0.18	24.68 ± 0.06	19.59 ± 1.14 A	
Mean C × S	**K186 F_1 × S**	10.08 ± 2.20 c	5.59 ± 1.13	6.00 ± 1.10 j	7.54 ± 1.64 g	6.38 ± 1.31 i	6.43 ± 1.41 hi	8.09 ± 1.76 f		
	023 F_1 × S	12.12 ± 2.43 a	5.94 ± 1.11 j	6.71 ± 1.18 h	9.59 ± 1.88 d	7.80 ± 1.38 fg	8.48 ± 1.42 e	10.99 ± 2.09 b		

		2017 season	2018 season
F values	**C (df = 1)**	0.184[ns]	2680.323[***]
	PA (df = 5)	32655.284[***]	33017.774[***]
	C × PA (df = 5)	225.454[***]	137.625[***]
	Stimulants (df = 6)	1580.226[***]	1986.113[***]
	C × S (df = 6)	144.539[***]	109.108[***]
	PA × S (df = 30)	264.338[***]	384.772[***]
	C × PA × S (df = 30)	36.101[***]	20.546[***]

Means followed by the same letters in each season are not significantly different according to Tukey's multiple range test ($p < 0.05$).

[y] Applied by adding to soil below the plants; [x] Immediately before treatment; [w] Capital and small letters were used to indicate the significant differences between the interaction means C × PA and C × S, respectively, in each season.

Table 4. Density[z] of glandular and non-glandular trichomes on the upper and lower surfaces of tomato leaves of cultivars 186 and 023 treated with different stimulants during the 2018 summer season.

Cultivar (C)	Stimulant (S)	Glandular trichomes (mm^{-2})		Non-glandular trichomes (mm^{-2})		Total number of trichomes (mm^{-2})	
		Upper surface	Lower surfaces	Upper surfaces	Lower surfaces	Upper surfaces	Lower surfaces
K186 F_1	**Control**	0.50 ± 0.29 bc	0.75 ± 0.25^{ns}	1.50 ± 0.29 bc	2.50 ± 0.29 abc	2.0 ± 0.0 defg	3.25 ± 0.48 bcd
	Poster®	1.00 ± 0.25 bc	0.75 ± 0.48	1.25 ± 0.25 bc	2.00 ± 0.41 bc	2.25 ± 0.63 cdef	2.75 ± 0.75 bcd
	Silical®	2.00 ± 0.41 a	1.75 ± 0.25	3.00 ± 0.41 a	3.50 ± 0.65 a	5.00 ± 0.71 a	5.25 ± 0.85 a
	Stansh®	1.25 ± 0.25 abc	1.25 ± 0.25	2.25 ± 0.25 ab	3.00 ± 0.41 ab	3.50 ± 0.50 bc	4.25 ± 0.25 ab
	Ultrafit®	1.50 ± 0.25 ab	0.75 ± 0.25	2.25 ± 0.25 ab	3.25 ± 0.25 a	3.75 ± 0.48 ab	4.00 ± 0.41 abc
	Ultrafit®[y]	1.00 ± 0.41 bc	0.75 ± 0.25	1.50 ± 0.29 bc	2.50 ± 0.29 abc	2.50 ± 0.50 bcde	3.25 ± 0.25 bcd
	Xtracal®	0.75 ± 0.25 bc	0.50 ± 0.29	1.50 ± 0.29 bc	2.50 ± 0.29 abc	2.25 ± 0.25 cdef	3.00 ± 0.41 bcd
023 F_1	**Control**	0.25 ± 0.25 c	0.50 ± 0.29	0.50 ± 0.29 cd	1.75 ± 0.25 c	0.75 ± 0.48 g	2.25 ± 0.25 d
	Poster®	0.50 ± 0.29 bc	0.50 ± 0.29	0.75 ± 0.25 cd	1.75 ± 0.25 c	1.25 ± 0.48 efg	2.25 ± 0.25 d
	Silical®	1.25 ± 0.25 abc	1.50 ± 0.50	1.50 ± 0.29 bc	1.75 ± 0.25 c	2.75 ± 0.48 bcd	3.25 ± 0.63 bcd
	Stansh®	0.75 ± 0.25 bc	1.00 ± 0.41	0.75 ± 0.25 cd	2.00 ± 0.00 bc	1.50 ± 0.29 defg	3.00 ± 0.41 bcd
	Ultrafit®	0.75 ± 0.48 bc	1.00 ± 0.41	1.50 ± 0.29 bc	1.75 ± 0.25 c	2.25 ± 0.48 cdef	2.75 ± 0.63 bcd
	Ultrafit®[y]	0.75 ± 0.25 bc	0.50 ± 0.29	0.75 ± 0.25 cd	1.50 ± 0.29 c	1.50 ± 0.29 defg	2.00 ± 0.41 d
	Xtracal®	0.50 ± 0.29 bc	0.75 ± 0.25	0.50 ± 0.29 cd	1.75 ± 0.48 c	1.00 ± 0.41 fg	2.50 ± 0.50 d
Mean (C)	**K186 F_1**	1.14 ± 0.14^{ns}	0.93 ± 0.13^{ns}	1.89 ± 0.15*	2.75 ± 0.16*	3.03 ± 0.25**	3.68 ± 0.24*
	023 F_1	0.68 ± 0.12	0.82 ± 0.14	0.89 ± 0.12	1.75 ± 0.10	1.57 ± 0.19	2.57 ± 0.17
Mean (S)	**Control**	0.38 ± 0.13 B	0.63 ± 0.22^{ns}	1.00 ± 0.35 C	2.13 ± 0.75^{ns}	1.38 ± 0.49 C	2.75 ± 0.97 AB
	Postar®	0.75 ± 0.27 AB	0.63 ± 0.22	1.00 ± 0.35 C	1.88 ± 0.66	1.75 ± 0.62 BC	2.50 ± 0.88 B
	Silical®	1.63 ± 0.57 A	1.63 ± 0.57	2.25 ± 0.80 A	2.63 ± 0.93	3.88 ± 1.37 A	4.25 ± 1.50 A
	Stansh®	1.00 ± 0.35 AB	1.13 ± 0.40	1.50 ± 0.53 ABC	2.50 ± 0.88	2.50 ± 0.88 ABC	3.63 ± 1.28 AB
	Ultrafit®	1.13 ± 0.40 AB	0.88 ± 0.31	1.88 ± 0.66 AB	2.50 ± 0.88	3.00 ± 1.06 AB	3.38 ± 1.19 AB
	Ultrafat®[y]	0.88 ± 0.31 AB	0.63 ± 0.22	1.13 ± 0.40 BC	2.00 ± 0.71	2.00 ± 0.71 BC	2.63 ± 0.93 B
	Xtracal®	0.63 ± 0.22 B	0.63 ± 0.22	1.00 ± 0.35 C	2.13 ± 0.75	1.63 ± 0.57 BC	2.75 ± 0.97 AB
F	**Cultivar (C; df = 1)**	**3.870^{ns}**	**0.771^{ns}**	**24.500***	**17.294***	**43.852****	**13.664***
	Stimulants (S; df = 6)	**3.431****	**2.535^{ns}**	**6.958*****	**1.6000^{ns}**	**7.920*****	**3.597****
	C × S (df = 6)	**0.271***	**0.259^{ns}**	**1.007***	**1.2000***	**0.600***	**0.578***

[z] For each column, capital and small letters were used to indicate the significant differences between stimulants and the interaction means, respectively. Mean values of stimulant and interaction C × S in each column followed by a letter in common of each season were not significantly different according to Tukey's multiple range test ($p < 0.05$); [y] Applied by adding to soil below the plants; ^{ns} Non-siginificant, *significant at 5%, and *** significant at 0.1% between K186 F_1 and 023 F_1.

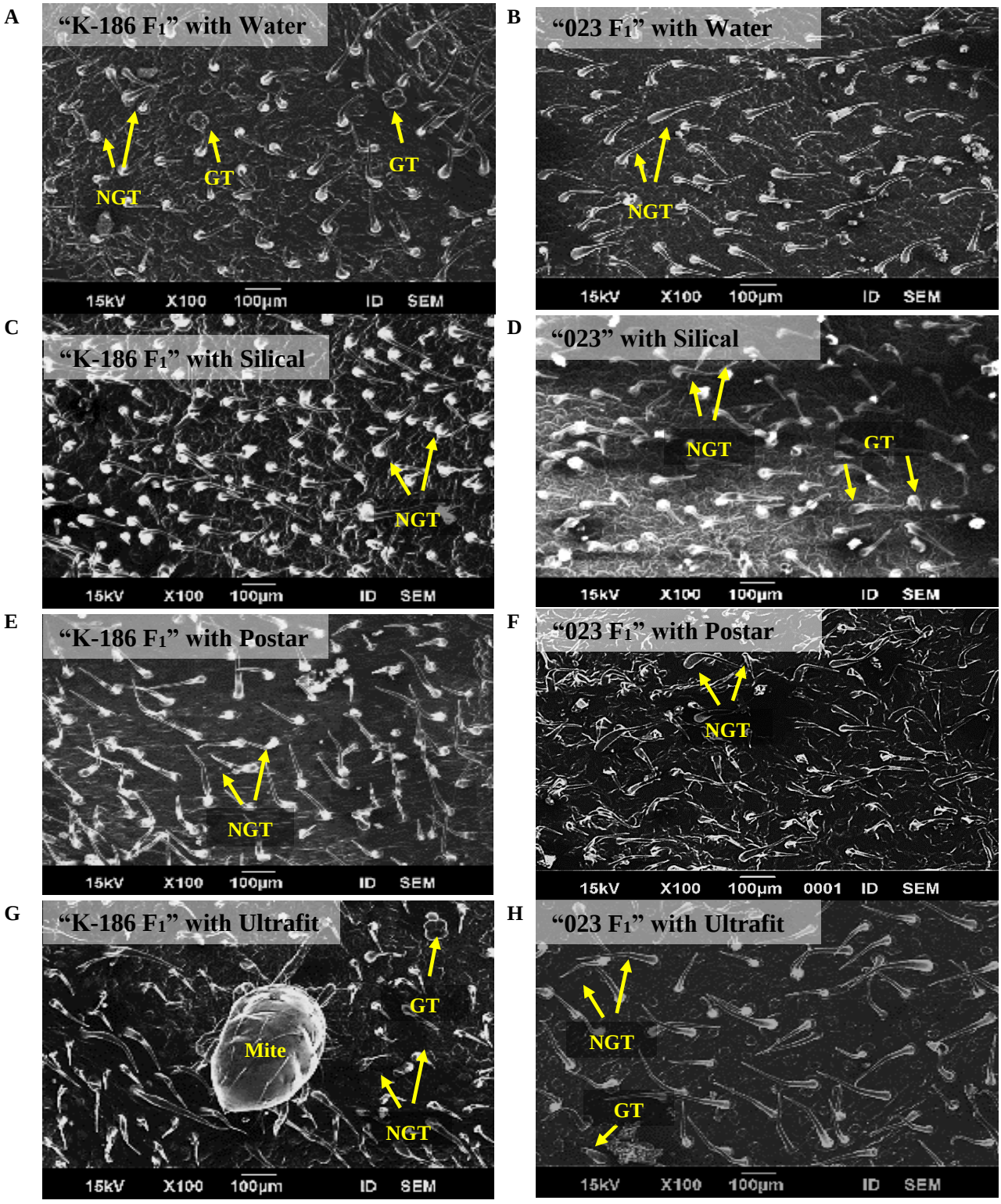

Figure 3. Scanning Electron Microscopy (SEM) images of the lower-surface of leaves sprayed with water (control), Silical®, Postar®, and Ultrafit® to visualize the diversity of trichome types (glandular: GT and non-glandular: NGT) and densities for tomato cultivars K-186 F_1 and 023 F_1.

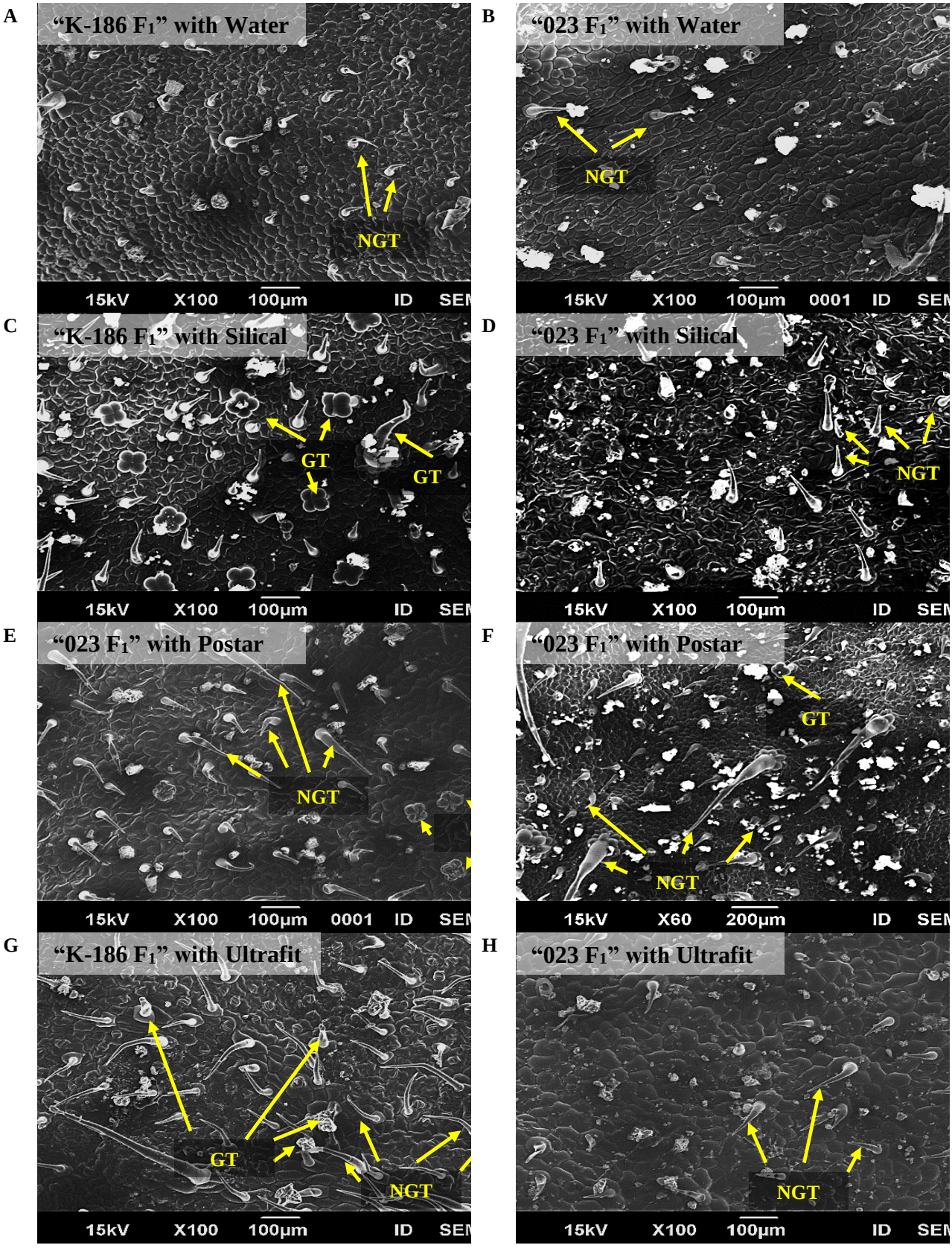

Figure 4. Scanning Electron Microscopy (SEM) images of the upper-surface of leaves sprayed with water (control), Silical®, Postar®, and Ultrafit® to visualize the diversity of trichome types (glandular: GT and non-glandular: NGT) and densities for tomato cultivars K-186 F_1 and 023 F_1.

A total of 20 compounds with K186 F_1 and 15 compounds with 023 F_1 were found in the control treatment (water spray) (Table 5). Silical® spraying produced 20 compounds in K186 F_1, including six new compounds from the control and 21 compounds in 023 F_1, of which 14 were new compounds compared to the control. In comparison, Ultrafit® spraying produced 19 compounds in K186 F_1, including seven new ones from the control, and 22 compounds in 023 F_1, including 11 that were new to the control (Table 5).

Compared to the control group, spraying either of the stimulants on the two cultivars stimulated the synthesis of chlorfenapyr (RT 50.55%) (Table 5). Also, spraying stimulants on 023 F_1 stimulated the synthesis of 2-dehydro-1,8-cineole (RT 5.88%), α-gurjunene (RT 23.35%), β-humulene (RT 26.07%), and heptacosane (RT 57.94%). In addition, spraying stimulants increased the synthesis of some compounds. The synthesis of ß-terpinene (RT 6.07%) and trans-caryophyllene (RT 22.40%) increased in both cultivars, and D-limonene (RT 7.06%), ß-phellandrene (RT 7.14%), and 9-octadecenanmide, Z (RT 55.16%) increased in K186 F_1 only (Table 5).

Table 5. The foliar essential oil composition of tomato cultivars K186 F_1 and 023 F_1 sprayed with Silical® and Ultrafit® stimulants compared to water (control) during the 2018 summer season.

Peak	RT[z] (Min.)	Compounds	Area (%)[y]					
			"K186 F_1"			"023 F_1"		
			Silical®	Ultrafit®	Control	Silical®	Ultrafit®	Control
1	**4.41**	α-Pinene	1.69	–	–	–	0.66	–
2	**5.88**	2-Dehydro-1,8-cineole	–	–	–	0.64	0.53	–
3	**6.07**	β-Terpinene	7.17	4.59	1.62	4.63	2.11	0.54
4	**7.06**	D -Limonene	5.56	5.66	2.99	–	–	–
5	**7.14**	β-Phellandrene	16.81	6.48	5.26	13.80	0.86	4.83
6	**7.59**	Myristyl chloride	–	–	–	–	1.18	3.79
7	**7.79**	Tetradecane	–	–	–	–	–	1.95
8	**8.05**	γ-Terpinene	1.18	1.39	1.16	–	0.61	--
9	**9.22**	Oxalic acid, hexyl neopentyl ester	–	–	–	–	0.74	1.59
10	**9.66**	Linalool	0.94	–	–	–	–	–
11	**9.91**	1-Tridecyne	–	1.41	–	–	–	–
12	**11.56**	Camphor	–	1.21	–	–	–	–
13	**16.19**	2-Pentadecanone, 6,10,14-trimethyl-	–	–	–	–	0.90	–
14	**16.22**	Tetradecane, 2,6,10-trimethyl	–	--	–	–	–	2.17
15	**17.14**	Exobornyl acetate	–	1.22	–	–	–	–
16	**18.21**	Undecane, 4,8-dimethyl	–	–	–	–	0.63	–
17	**18.90**	δ-EIemene	–	–	1.14	1.32	1.24	1.56
18	**22.40**	trans-Caryophyllene	59.25	52.85	48.52	52.86	41.11	36.19
19	**23.35**	α-Gurjunene	–	–	–	1.07	0.60	–
20	**23.92**	α-Humulene	12.48	9.37	10.37	7.03	9.72	10.34
21	**24.94**	1-Iodo-2-methylnonane	–	–	1.21	–	0.81	2.09
22	**25.20**	2H-1-Benzopyran, 3,5,8,8a-tetrahydro-2,5,5,8a-tetramethyl	0.75	1.62	2.08	–	–	–
23	**26.07**	β-Humulene	–	–	–	0.67	0.55	–
24	**26.83**	Z,Z,Z-1,4,6,9-Nonadecatetraene	–	–	1.07	0.96	1.29	2.06
25	**28.08**	1,11-Hexadecadiyne	–	–	–	0.74	–	–
26	**28.80**	Z,Z,Z-1,4,6,9-Nonadecatetraene	–	–	–	0.48	–	–
27	**29.04**	Caryophyllene oxide	4.44	4.84	5.32	3.03	2.93	3.95
28	**30.19**	humuladienone	–	–	–	0.56	–	–
29	**31.00**	(+) spathulenol	0.82	–	1.04	0.53	–	–
30	**31.28**	Tetracyclo[6.3.2.0(2,5).0(1,8)] tridecan-9-ol, 4,4-dimethyl	0.83	2.07	1.83	1.46	0.62	–
31	**32.27**	Ledene oxide-(II)	0.98	–	1.11	–	–	–
32	**32.96**	Nonacosane		–	–	–	0.55	1.28

[z] Retention time; − Not detected; [y] Compound percentage.

Table 5. The foliar essential oil composition of tomato cultivars K186 F_1 and 023 F_1 sprayed with Silical® and Ultrafit® stimulants compared to water (control) during the 2018 summer season.

Peak	RT[z] (Min.)	Compounds	Area (%)[y]					
			"K186 F_1"			"023 F_1"		
			Silical®	Ultrafit®	Control	Silical®	Ultrafit®	Control
33	**34.42**	Undecanal	2.14	–	–	–	–	–
34	**34.57**	Octadecanal	–	–	1.55	–	–	–
35	**34.73**	Hi-oleic safflower oil	–	–	1.72	–	–	–
36	**38.57**	2,15-Hexadecanedione	4.49	2.26	3.08	6.44	0.53	–
37	**39.42**	Isobutyl phthalate	–	–	1.48	–	–	–
38	**45.35**	2H-Pyran, 2-(7-heptadecynyloxy) tetrahydro	–	–	–	–	–	3.72
39	**46.93**	Linolenic acid, methyl ester	1.14	–	–	–	–	–
40	**47.24**	Octadecane, 1-chloro	–	1.19	–	–	–	–
41	**47.30**	Phytol	1.57	–	–	–	–	–
42	**47.79**	Dihomo-γ-linolenic acid	–	–	–	–	–	1.79
43	**49.76**	Docosane, 11-decyl	–	–	–	0.48	–	–
44	**50.55**	Chlorfenapyr	2.11	1.51	–	0.69	0.84	–
45	**52.60**	Docosane	–	–	–	1.07	–	–
46	**55.16**	9-Octadecenamide, (Z)	5.29	8.84	3.94	--	–	–
47	**55.35**	1-Iodo-2-methylundecane	–	–	–	0.97	–	–
48	**57.37**	2,6,10-Dodecatrien-1-ol, 3,7,11-trimethyl-	–	1.62	–	–	–	–
49	**57.94**	Heptacosane	2.83	2.86	3.51	3.30	1.21	–
50	**61.13**	α-Tocopherol	–	2.46	–	–	–	–

[z] Retention time; – Not detected; [y] Compound percentage.

DISCUSSION

Tetranychus urticae is one of the most destructing pests in cropping systems worldwide. Acaricides have been crucial in controlling *T. urticae* populations in plants (Macke *et al.* 2011; Ximenez-Embun *et al.* 2017). Farmers have relied on the extensive spraying of acaricides to control *T. urticae*, which leads to increased costs, environmental damage, and potential harm to the health of both consumers and producers. *Tetranychus urticae* is also notorious for rapidly developing acaricide resistance (De Ponti 1985; Van Pottelberge *et al.* 2008). Plant resistance is one of the modern IPM approaches for reducing pesticide use, production costs, and environmental contamination. Plants have evolved several morphological, biochemical, and molecular mechanisms to reduce the preference (antixenosis) and performance (antibiosis) of herbivores (Smith 2005). The defensive responses are either constitutive (always present in the plant) or inducible by biotic (herbivores or pathogens) or abiotic elicitors (Thakur and Sohal 2013). These elicitors are valuable pest management tools for building a natural defense system against insect herbivores (War *et al.* 2012). These compounds induce resistance when applied to leaves, shoots, or roots (Saikia *et al.* 2003; Wu *et al.* 2012; Papadopoulou and van Dam 2017). The induced resistance generated by chemical elicitors depends on the type of elicitor and the biological processes involved. Tomato resistance to *T. urticae* was caused by foliar spraying of elicitors, such as ET, JA, methyl jasmonate, SA, potassium humates, and potassium silicate (Shivaji *et al.* 2010; War *et al.* 2012; Afifi *et al.* 2015; Ahmed 2018; Pulga *et al.* 2020). Despite much interesting work on induced resistance to arthropods in tomatoes, minimal progress has been made in developing commercial approaches to using induced resistance. In this study, we evaluated the effect of commercial immune-feeding compounds (stimulants) on the induction of resistance in two tomato cultivars to *T. urticae* under open-field conditions. The chemical composition varied among the studied stimulants (Table 1). The main ingredients were silicon oxide in Silical® (45%) and Stansh® (35%), SA in Ultrafit® (38%), potassium oxide in Postar® and

Stansh® (41 and 11.5%, respectively), silicon in Stansh® (13.4%), and calcium in Xtracal® (20%). There were also nutrients including boron, calcium, nitrogen, phosphor, potassium, and silicon.

These stimulants were applied to field-grown tomato plants after observing *T. urticae* individuals. The population of movable stages of *T. urticae* at the start of the application and weekly intervals were counted as a measure of plant resistance. The population of movable stages of *T. urticae* per leaflet should not exceed eight to avoid economic harm to tomato production (Meck *et al.* 2013). The *T. urticae* population can rapidly reach devastating levels in favorable growing conditions and limited plant resistance due to its rapid growth rate and high reproductive potential. The initial population at 3 weeks after transplanting on both cultivars was within the economically safe range (< 1 mite) for both seasons (Table 3). The *T. urticae* population increased gradually with PA (Fig. 1). The *T. urticae* population reached an economically significant injury level at nnine weeks after transplanting, with control over both seasons. The applied stimulants delayed the arrival of the economically significant damage until the 11 weeks after transplanting, especially with the spraying of Silical® and Stansh®. By the end of the evaluation at 13 weeks after transplanting, the *T. urticae* population in both cultivars decreased with stimulants compared to the control. The highest efficacy rate in both seasons occurred in the usage of Silical® (48.0 and 47.6% with K186 F_1, and 47.6 and 52.0% with 023 F_1, respectively) and Stansh® (45.1 and 46.3% with K186 F_1, and 44.8 and 48.1% with 023 F_1, respectively). These findings align with Afifi *et al.* (2015) and Ahmed (2018). These researchers reported that foliar spraying tomatoes with stimulants, such as SA, methyl jasmonate, and potassium silicate, decreased *T. urticae* populations. This was accompanied by morphological and chemical changes in tomato plants, which improved their resistance.

Tomato resistance to arthropods is mainly determined by the presence of plant trichomes (Glas *et al.* 2012; Wang *et al.* 2021). The *Solanum* genus has GT (I, IV, VI, and VII) and NGT (II, III, and V). GT and NGT are responsible for antibiosis and antixenosis resistance mechanisms (Lucatti *et al.* 2013). Trichome function reduces access to the leaf epidermis for feeding and oviposition mechanically by disrupting the movement of insect herbivores on the leaf surface (antixenosis) (Smith 2005; War *et al.* 2012). GT also protects the plant by acting as a chemical barrier and producing toxic substances that are poisonous to the insect (antibiosis) or by producing gummy, sticky, or polymerizing chemical exudates that impede insect movement (antixenosis) (Glas *et al.* 2012). Therefore, the density of GT and NGT on tomato leaves was assessed in all treatments in this study. Significant differences were reported among the different treatments (Table 4). The cultivar effect was limited (significant $P < 0.05$) and observed with only the density of TT and NGT. The stimulants had a critical (significant $P < 0.05$) effect on trichome density. The highest densities were found with Silical®, Stansh®, and Ultrafit® for both cultivars (Table 4, Figs. 3, 4). As the GT density grows, so does the chemical leaf content. Therefore, the foliar essential oil with these stimulants and the control treatment was extracted and analyzed using the GC-MS technique (Table 5). Silical® and Ultrafit® spraying stimulated tomato plants to synthesize some of the compounds that have acaricide activity. Chlorfenapyr ($C_{15}H_{11}BrClF_3N_2O$, RT 50.55%) was synthesized in both cultivars. Chlorfenapyr is a halogenated pyrrole that disrupts mitochondrial oxidative phosphorylation (Hollingworth and Gadelhak 1998). It is a broad-spectrum insecticide-miticide effective against agriculturally important pests, such as *T. urticae* (DeKeyser 2005; Legwaila *et al.* 2021). The components 2-dehydro-1,8-cineole (RT 5.88%), -gurjunene (RT 23.35%), -humulene (RT 26.07%), and heptacosane (RT 57.94%), synthesized in cultivar 023 F_1, are repellent and have toxic effects on mites and some other insects (Afify *et al.* 2012; Salman *et al.* 2015; Ebadollahi *et al.* 2017; Abdel Razik and Heikal 2019; Li *et al.* 2019; Mendoza-García *et al.* 2019; da Camara *et al.* 2020; Choi *et al.* 2021). Silical® and Ultrafit® spraying also increased the synthesis of some monoterpenoids that helped tomato species and other plant species to resist against *T. urticae*. In both cultivars, these monoterpenoids are ß-terpinene (RT 6.07%; Li *et al.* 2021; Weinblum *et al.* 2021) and trans-caryophyllene (RT 22.40%; Antonious and Snyder 2006; Amer *et al.* 2011; Weinblum *et al.* 2021). D-Limonene (RT 7.06%; Li *et al.* 2021; Weinblum *et al.* 2021), ß-phellandrene (RT 7.14%; Li *et al.* 2021; Weinblum *et al.* 2021), and 9-

octadecenanmide, Z (RT 55.16%; Meck *et al.* 2013) only increased in K186 F_1. Likewise, Afifi *et al.* (2015) found that higher trichome density, mainly glandular, induced tomato resistance. This was accompanied by an increase in the quantities of monoterpenoids (i.e., caryophyllene, humulene, β-phellandrene, d-limonene, cis-α-copaene-8-ol, β-spathulenol, eugenol, 8-cedren-13-ol, spathulenol, geraniol, humulene epoxide II, caryophyllene oxide, delta-elemene, linalool, β-elemene, and methyl salicylate) in the foliar essential oil.

CONCLUSIONS

Induced tomato resistance will not eliminate pest problems but will help to reduce pest populations and damage to an acceptable level below the economic threshold. The use of commercial stimulants, especially Silical® and Stansh®, significantly reduced the population of movable stages of *T. urticae* on field-grown tomato plants. Silicon products have been widely accepted, especially in organic farming. It may be considered an appropriate, effective, and ecologically sound strategy to mitigate biotic stresses, such as arthropod pests, under field conditions (Reynolds *et al.* 2009; Frew *et al.* 2018; Laane 2018; Alyousuf *et al.* 2021). As part of IPM programs, this new concept should be wisely chosen for sustainable agriculture.

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کارایی برخی از محرک‌های تجاری در القای مقاومت گوجه‌فرنگی به *Tetranychus urticae* (Acari: Tetranychidae)

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چکیده

اثر برخی از محرک‌های تجاری بر ایجاد مقاومت در ارقام گوجه‌فرنگی K186 F1 و 023 F1 به کنهٔ تارتن دو لکه‌ای (*Tetranychus urticae* Koch) مورد بررسی قرار گرفت. این آزمایش در شرایط فضای باز در طول فصل تابستان ۲۰۱۷ و ۲۰۱۸ انجام شد. پس از مشاهده کنهٔ *T. urticae*، محرک‌ها روی گیاهان گوجه‌فرنگی کشت‌شده در مزرعه به کار برده شدند. جمعیت مراحل متحرک *T. urticae* در شروع کاربرد و فواصل هفتگی به عنوان معیار مقاومت گیاه شمارش شد. جمعیت اولیه در سه هفته پس از نشاکاری در هر دو رقم در محدودهٔ ایمن اقتصادی (کمتر از ۱ کنه در هر برگچه) برای هر دو فصل بود. جمعیت *T. urticae* به تدریج با افزایش سن گیاه افزایش یافت. محرک‌های اعمال شده رسیدن به زیان اقتصادی را تا ۱۱ هفته پس از نشاء به تاخیر انداختند، به‌ویژه با پاشش Silical® (۴۵٪ اکسید سیلیکون، ۹٪ کلسیم و ۰/۹٪ بور) و Stansh® (۳۵٪ اکسید سیلیکون، ۱۱/۵٪ اکسید پتاسیم و ۱۳/٤٪ سیلیکون). تراکم تریکوم‌های غده‌ای و غیرغده‌ای روی برگ‌های گوجه فرنگی برای تیمارهای مختلف در ۱۳ هفته پس از نشاء بررسی شد. محرک‌ها تأثیر مثبت و معنی‌داری بر تراکم تریکوم داشتند. بیشترین تراکم با Silical®، Stansh® و Ultrafit® (۳۸٪ اسید سالیسیلیک، ۲/۸٪ نیتروژن، ٦/۲٪ فسفر، و ۲۳٪ پتاسیم) برای هر دو رقم مشاهده شد. اسانس برگی در تیمارهای Silical®، Ultrafit® و شاهد با استفاده از تکنیک GC-MS تجزیه و تحلیل شد. پاشش Silical® و Ultrafit® باعث تحریک برگ‌های گوجه‌فرنگی برای سنتز برخی از ترکیباتی شد که دارای خاصیت کنه‌کشی هستند. کلرفناپیر در هر دو رقم سنتز شد و ۲-دهیرو-۱،۸-سینئول، -گورجونن، -هومولن و هپتاکوزان در رقم 023 F1 سنتز شدند. همچنین پاشش Silical® و Ultrafit® باعث افزایش سنتز برخی از مونوترپنوئیدها شد که به گوجه‌فرنگی در مقاومت در برابر *T. urticae* کمک کرد. مقاومت القایی گوجه‌فرنگی مشکلات آفات را از بین نمی‌برد، اما به کاهش جمعیت آفات و آسیب پایین‌تر از آستانهٔ اقتصادی کمک می‌کند. ترکیبات سیلیکونی را می‌توان به عنوان بخشی از مدیریت تلفیقی آفات پذیرفت که باید برای پایداری کشاورزی بلند مدت با دقت انتخاب شود.

واژگان کلیدی: GC-MS، سیلیکون، *Solanum lycopersicum*، تریکوم ، کنهٔ تارتن دولکه‌ای.

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