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Abundance and Population Dynamics of the Key Insect Pests and Agronomic Traits of Tomato (*Solanum lycopersicon* L.) Varieties under Different Planting Densities as a Sustainable Pest Control Method

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Abstract: In Saudi Arabia, the tomato is susceptible to a wide range of insect pests that could destroy this valuable vegetable crop, cause yield losses, and affect fruit quality and quantity. Insecticides are widely applied to protect tomatoes and control pests that develop a resistance to pesticides, but these affect human health and have a negative impact on the environment. The application of Good Agriculture Practices (GAP) is a worthwhile sustainable alternative for controlling insect pests in tomato fields. To investigate the population dynamics of the major pests affecting tomato growth and yield, two commercial varieties (Areenez F1 and Tala F1) were cultivated at three plant spacings (30 × 50 cm, 60 × 50 cm, and 90 × 50 cm) under the conditions of the desert climate. The experiments were conducted in the field in 2020 and 2021 and were laid out in a Randomized Complete Block Design (RCBD) with each treatment repeated for 4 times. A total of 14 major insect pests including *Empoasca fabae*, *Bemisia tabaci*, *Orosius orientalis*, *Acheta domesticus*, and *Lasius niger* were recorded on a weekly basis. The results showed that the mean abundances of *E. fabae*, *O. orientalis*, and *B. tabaci* were higher in the 30 × 50 cm plant spacing, whereas the 90 × 50 cm plant spacing resulted in a higher abundance of *A. domesticus* and *L. niger*. The measured agronomic traits, plant height (cm), plant dry mass (g), and total yield/ha (ton) of both the tomato varieties were significantly increased when the plants were spaced at 60 cm between plants and 50 cm between rows. We recommend that growing tomato plants at 60 cm between plants and 50 cm between rows may reduce the need to apply pesticides given that this plant spacing significantly reduced the abundance of some key insect pests and enhanced the tomato fruit yield.

Keywords: solanaceae crops; plant spacing; IPM; sustainable production; pest control; fruit yield; GAP

1. Introduction

The tomato (*Solanum lycopersicon* L.), from the family Solanaceae, is one of the most important vegetable crops widely cultivated for both the fresh market and processing. Historically, tomatoes are known to originate from the Americas, particularly, Central and South, from Mexico to Peru, and Southern North America, [1]. Due to its high nutritional value in the human diet, the tomato is widely used as the major vegetable in many countries [2]. Tomatoes are rich in several vitamins and minerals [3,4] and these vitamins and beta-carotene act as antioxidants for the neutralization of the detrimental free radicals in the blood [2]. Globally, in 2020, the tomato was found to be the second largest vegetable crop after the potato with 5,051,983 hectares of cultivable land allocated for tomato growing, and the total yield was estimated at 186,821,216 metric tons [5]. Its high nutritional value and low market price means that the tomato is a popular vegetable crop in Saudi Arabia, grown...
both commercially and in home gardens. In 2020, Saudi Arabia dedicated 12,454 hectares of cultivable land to tomato growing with a total production of 3,18,614 metric tons [5].

However, the production of tomatoes has been affected by several abiotic and biotic factors. Crop infestation by several pests (insects, weeds, and diseases) is a major constraint that reduces yields and the quality of marketable fruit [6]. There are numerous key insect pests considered as the critical pests associated with tomato growth and productivity, including: whitefly, *Bemisia tabaci* (Gennadius) (Hemiptera: Aleyrodidae); jassid, *Empoasca fabae* (Harris) (Homoptera: Cicadellidae); tomato leaf miner, *Tuta absoluta* (Meyrick) (Lepidoptera: Gelechiidae); African bollworm, *Helicoverpa armigera* (Hubner) (Lepidoptera: Noctuidae); thrips, *Thrips tabaci* (Haliday) (Thysanoptera: Thripidae); and aphids (Hemiptera: Aphidoidea) [6,7]. Currently, insect pest control is solely dependent on pesticides, which have been used in agriculture for over a century to secure food production and have demonstrated their ability to increase the global food production [8], even though they pose known risks to human health and the environment. The continuous use of chemical pesticides has also resulted in the development of pest resistance and the annihilation of beneficial insects [8,9].

To overcome the human health problems of using pesticides to secure the growth and productivity of the tomato, it is highly recommended to follow sustainable production of tomatoes in the open field and under controlled agriculture, thus the application of pesticides would only be as a last resort [10]. An Integrated Pest Management (IPM) strategy is a global time-dependent issue, which includes: the combined application of cultural control, physical control, mechanical control, trap cropping, biological control, and the proper use of selective pesticides [8]. One of the promising and sustainable IPM procedures to control insect pests is the application of Good Agriculture Practices (GAP) in tomato fields. Adjusting the plant spacing is one of the appropriate GAP methods for pest control that also increases the utilization of space, light, and the uptake of nutrients to promote healthy and vigorous plants, ultimately leading to a high yield and a better quality of tomato production [11–13]. The abundance of the insect pest populations has been reported to be affected by crop plant spacing, and the severity of the insect pest infestation has been found to increase with the increase in planting density [11]. Several empirical studies have found higher insect pest populations at the lower plant spacings due to the higher amount of food availability for the pests compared to a higher plant spacing [11,14,15]. Moreover, the genetic diversity within a single crop could hinder the growth of herbivore pests and their survival [16]. However, to the best of our knowledge, no study has been conducted to investigate the effectiveness of plant spacing and plant diversity on the abundance of insect pests and their relationship with tomato production in Saudi Arabia.

Considering the above view of the economic importance of the tomato and the damage caused by its major insect pests, the current study aimed to investigate the effects of plant spacing, as a sustainable gap method, across two separate varieties of tomato on the abundance and temporal distribution of the main insect pests and their effects on growth and fruit yield of the two tomato varieties.

2. Materials and Methods
2.1. Field Site

The experimental site is located in at Hada Al-Sham (21°48′3″ N, 39°43′25″ E) Al-Jamoom, Saudi Arabia. The soil is sandy loam with a pH of 7.8 and an EC of 1.79 dsm-1 [17]. The soil characteristics are shown in Table 1.
Table 1. Soil physical and chemical properties of the experimental site at the Agriculture Research Station of King Abdulaziz University, Hada AlSham, Al-Jamoom, Saudi Arabia.

| pH (Unit) | EC (ds/m) | Sandy Loam Soil Particle Size (%) | Organic Matter (%) | Organic Carbon (%) | Available Macro Nutrients (%) |
|-----------|-----------|----------------------------------|--------------------|--------------------|-------------------------------|
|           |           | Sand | Silt | Clay | Sand | Silt | Clay | N  | P  | K  |
| 7.83      | 1.79      | 84.21 | 14.05 | 1.74 | 0.453 | 0.500 | 0.215 | 0.070 | 0.781 |

| Total elements (mg/kg) | Cr | Pb | Ni | Cd | Mn | Fe | Ca (%) | Mg (%) | Cu | Zn | Na (%) |
|-----------------------|----|----|----|----|----|----|--------|--------|----|----|--------|
|                       | 0.11 | 4.21 | 0.52 | 0.06 | 144.44 | 239.40 | 1.38 | 1.15 | 4.78 | 32.98 | 0.14 |

2.2. Plant Materials

Seeds of two commercial tomato varieties “Areenez F1” (Enza Zaden, the Netherlands) and “Tala F1” (Sant Martí de Provençals, Barcelona) were obtained from the local market in Jeddah, Saudi Arabia.

2.3. Tomato Field Trials

Seedlings of the two tomato varieties were transplanted in December 2020 and 2021 at plant spacings of 30 × 50 cm (T1–126 plants/plot), 60 × 50 cm (T2–66 plants/plot), and 90 × 50 cm (T3–42 plants/plot) in experimental plots of 3 m × 7 m with 2 m intervals. The experiment was laid out in a Randomized Complete Block Design (RCBD) with four replications. The tomato plants were irrigated using a surface drip irrigation system designed and installed two weeks before the planting. The irrigation dripper capacity was 0.9 gallon/hour and the distance between each two drippers was 0.6 m. The irrigation system operated twice per day for 10 min each time to supply the plants with water. All recommended agricultural practices for growing tomatoes under arid conditions were applied [18].

2.4. Specimen’s Sampling Techniques

Two weeks after transplanting, the levels of the major tomato insect pests were monitored on a weekly basis. The sampling procedure for the collected insects is described in the following two sections (Sections 2.4.1 and 2.4.2).

2.4.1. Pitfall Trapping

The ground-dwelling insect pests were collected by the pitfall trap method as described by Thomas [19]. Two pitfall traps (9-cm-diameter × 10.8-cm-deep) were placed in each managed plot; one at the center of each plot, while another was placed about 10 cm from the edge of the plot. Each trap was filled with 50% propylene glycol and was deployed for one week. The pitfall traps were collected on a weekly basis and the insect pests were preserved in 70% ethanol for further observations [19].

2.4.2. Yellow Sticky Trap

Yellow sticky traps were used for collecting the different foliage-dwelling insect pests. One yellow sticky trap with nonpoisonous gum was placed in the middle of each experimental plot. The yellow sticky trap was collected on a weekly basis and conserved within a fridge at the Lab of Plant Protection, King Abdulaziz University, for further investigation.

2.5. Specimen Identification

The collected samples were enumerated and identified to the genus and species level using taxonomic keys [20–26].

2.6. Measurements

The plant height (cm) and plant dry mass (g) were measured at the end of the growing season using representative samples from each plot. The number and weight of fresh fruits
per plant were recorded every week until the end of the growing season and the data were used to calculate the total number of fruits/plant, the fruit yield, and the total fruit yield (ton/ha).

2.7. Data Analysis

The data captured by the pitfall traps and yellow sticky traps were subjected to an analysis of variance (ANOVA) using SAS version 9.2. The data were transformed by using the formula: \( \ln (N + 1) \), to reach the assumption of the normality and consistency of variance. Following this, a two-way ANOVA was employed to observe the effects of the plant spacing and variety on the mean population of the total number of the studied insects and the interaction between these two factors and the yield of tomatoes. The block was included as a covariate random effect and a post hoc Tukey’s test was conducted for pairwise comparisons among the treatment means, which showed significant effects [27].

To observe the temporal distribution of key insect pests, a separate repeated-measures ANOVA was conducted to evaluate the effect of the following factors: time (12 weeks), variety (two levels), plant spacing treatments (3 levels), and the interaction between these three factors on the mean abundance of the different pests. This design also added the block as a covariate random effect. A correlation analysis was performed using SAS version 9.2 to evaluate the relationship between the total number of pests and the agronomic traits of the tomato as two explanatory variables. Tables and figures were prepared from the untransformed means and standard errors to simplify the interpretation.

3. Results

3.1. Abundance of Insects Pests as Affected by Tomato Genotypes and Planting Spacing

Our findings showed that a total of 20,779 and 21,840 insects under the orders of Coleoptera, Diptera, Hemiptera, Hymenoptera, Lepidoptera, Orthoptera, and Thysanoptera were collected from plots of the tomato varieties ‘Areenez F1’ and ‘Tala F1’, respectively (Table 2). The plant spacing significantly affected the mean abundance of jassid—\textit{Empoasca fabae} (Harris) (Hemiptera: Cicadellidae), brown leaf hopper—\textit{Orosius orientalis} (Matsumura) (Hemiptera: Cicadellidae), whitefly—\textit{Bemisia tabaci} (Gennadius) (Hemiptera: Aleyrodidae), house cricket—\textit{Acheta domesticus} (Linnaeus) (Insecta: Orthoptera: Gryllidae), and black garden ant—\textit{Lasius niger} (Linnaeus) (Hymenoptera: Formicidae). The mean abundance of \textit{E. fabae}, \textit{O. orientalis}, and \textit{B. tabaci} was higher at the plant spacing of 30 × 50 cm, while \textit{A. domesticus} and \textit{L. niger} were extremely abundant at the plant spacing of 90 × 50 cm.

| Abundance of Pests | Total Number | F Values | \( \text{Mean} \pm \text{SE} \) |
|--------------------|-------------|----------|------------------|
| \( 30 \text{ cm} \) | \( 60 \text{ cm} \) | \( 90 \text{ cm} \) |
| \textit{Empoasca fabae} | 11359 | 12.37 ** | 1057.50 ± 29.09 a | 915.50 ± 29.55 b | 866.75 ± 23.95 b |
| \textit{Orosius orientalis} | 1397 | 61.14 *** | 133.50 ± 2.02 a | 112.25 ± 1.65 b | 103.50 ± 2.02 c |
| \textit{Bemisia tabaci} | 5762 | 8.14 ** | 548.75 ± 18.85 a | 458.75 ± 22.99 b | 433.00 ± 21.57 b |
| \textit{Tuta absoluta} | 254 | 0.63 N | 18.25 ± 1.65 a | 21.25 ± 1.70 a | 24.00 ± 4.78 a |
| \textit{Nezara viridula} | 236 | 3.53 N | 22.75 ± 1.38 a | 14.25 ± 1.11 a | 22.00 ± 4.43 a |
| \textit{Heliothrips sp.} | 91 | 0.97 N | 7.50 ± 0.50 a | 6.50 ± 1.04 a | 8.75 ± 1.44 a |
| \textit{Neoceratitis cyanescens} | 145 | 1.44 N | 11.00 ± 0.41 a | 12.50 ± 0.65 a | 12.75 ± 1.11 a |
| \textit{Acheta domesticus} | 462 | 13.15 ** | 29.50 ± 1.94 c | 38.75 ± 3.45 b | 47.25 ± 1.89 a |
| \textit{Melanoplus bispinatus} | 294 | 1.09 N | 23.25 ± 1.11 a | 24.50 ± 1.55 a | 25.75 ± 0.85 a |
| \textit{Trimerotropis pellidipennis} | 61 | 0.56 N | 4.25 ± 1.31 a | 5.25 ± 0.25 a | 5.75 ± 1.31 a |
| \textit{Melanoplus differentialis} | 69 | 1.05 N | 5.25 ± 0.63 a | 5.50 ± 0.65 a | 6.50 ± 0.65 a |
| \textit{Otiorhynchus sulcatus} | 170 | 0.31 N | 13.25 ± 1.49 a | 14.25 ± 2.29 a | 15.00 ± 1.00 a |
Table 2. Cont.

| Abundance of Pests         | Total Number | F Values               | Mean ± SE     |
|----------------------------|--------------|------------------------|---------------|
|                             |              | 30 cm  | 60 cm  | 90 cm  | |
| Lasius niger               | 402          | 121.98 *** | 23.75 ± 0.85 c | 32.75 ± 0.85 b | 44.00 ± 0.91 a |
| Leptysma marginicollis     | 77           | 0.73 N    | 7.00 ± 0.91 a   | 5.75 ± 0.48 a   | 6.50 ± 0.65 a   |

| Variety Tala F1            |              |
|----------------------------|--------------|
| Empoasca fabae             | 12324        | 8.58 **     | 1136.00 ± 36.54 a | 1012.50 ± 37.17 b | 932.50 ± 29.13 b |
| Orosius orientalis         | 1417         | 159.30 ***  | 134.50 ± 1.32 a  | 114.25 ± 1.11 b  | 105.50 ± 1.04 c  |
| Bemisia tabaci             | 5893         | 8.07 **     | 558.75 ± 20.56 a | 470.00 ± 20.73 b | 444.50 ± 20.61 b |
| Tuta absoluta             | 233          | 3.76 N      | 17.50 ± 1.19 a   | 15.50 ± 2.10 a   | 25.25 ± 3.82 a   |
| Nezara viridula           | 253          | 1.67 N      | 19.00 ± 1.58 a   | 21.50 ± 1.44 a   | 22.75 ± 1.49 a   |
| Heliothrips sp.            | 83           | 0.43 N      | 7.75 ± 1.11 a    | 6.50 ± 0.96 a    | 6.50 ± 0.87 a    |
| Neoceratitis cyanescens   | 140          | 0.27 N      | 11.25 ± 0.75 a   | 11.75 ± 0.63 a   | 12.00 ± 0.82 a   |
| Achetia domesticus        | 475          | 6.35 *      | 30.50 ± 2.78 b   | 39.75 ± 3.33 ab  | 48.25 ± 4.80 a   |
| Melanoplus bispinosus     | 284          | 0.77 N      | 22.75 ± 1.11 a   | 23.75 ± 0.85 a   | 24.50 ± 1.04 a   |
| Trimerotropis pellidipennis | 70          | 3.79 N      | 4.00 ± 1.00 a    | 5.75 ± 1.03 a    | 7.75 ± 0.95 a    |
| Melanoplus differentialis | 77           | 1.08 N      | 5.75 ± 1.03 a    | 6.25 ± 0.63 a    | 7.25 ± 0.63 a    |
| Otiorhynchus sulcatus     | 138          | 0.37 N      | 11.00 ± 1.41 a   | 11.00 ± 2.61 a   | 10.50 ± 1.26 a   |
| Lasius niger              | 413          | 170.28 ***  | 24.50 ± 0.65 c   | 33.50 ± 0.65 b   | 45.25 ± 1.11 a   |
| Leptysma marginicollis    | 80           | 3.46 N      | 7.25 ± 0.85 a    | 5.25 ± 0.48 a    | 7.50 ± 0.65 a    |

For F values * = significant at \( p < 0.05 \), ** = significant at \( p < 0.01 \), *** = significant at \( p < 0.001 \), N = non-significant.

The mean with same letter in each row are not significantly different \( (p<0.05) \).

3.2. The Temporal Distribution of Insects as Affected by Tomato Genotypes and Plant Spacing

As shown in Figures 1 and 2, triple significant interactions between plant spacing treatments, tomato varieties, and time of sampling for the insects *O. orientalis* \( (F_{22,143} = 3.33, \ p < 0.0001) \) and *N. viridula* \( (F_{22,143} = 1.69, \ p < 0.0315) \) were observed.

For both tomato varieties, the highest population of *O. orientalis* was observed on 26 December 2020, at the 30 × 50 cm plant spacing, and it instantly decreased on 2 January 2021, and then increased again on 9 January 2021. After 9 January, the abundance of *O. orientalis* started to decrease within the three plant spacings until its further decline on 23 January, following which it started to increase again until its peak on 6 February, but with the plant spacing of 90 × 50 cm. *O. orientalis* sharply decreased on February 13 and kept a nearly straight-line trend until end of the cropping season on 13 March. The only exception was on 26 December 2020 for the tomato variety 'Tala', where the population of *O. orientalis* was extremely low (Figure 1).

For *Nezara viridula* (Linnaeus) (Hemiptera: Pentatomidae) in the three tested plant spacings, the first appearance was on 26 December 2020, after which it slightly increased on 9 January 2021, and its peak was on 27 February (Figure 2). Then, *N. viridula* gradually decreased until the end of the season for the higher plant spacing. For tomato variety 'Tala F1', the abundance of *N. viridula* appeared for the first time on 26 December 2020, and sharply increased until 9 January for the lower plant spacing, and the *N. viridula* population disappeared on 16 January for the higher plant spacings. *N. viridula* fluctuated for all plant spacings until 20 February 2021. The insect abundance sharply increased for plant spacings 30 × 50 cm and 60 × 50 cm until 6 March. Following this, the insect abundance decreased significantly for all three plant spacings until the end of the season on 27 February.
Figure 1. Temporal distribution of *Orosius orientalis* within three plant spacings (30 × 50 cm, 60 × 50 cm and 90 × 50 cm) of two tomato varieties [Areenez F1 (A) and Tala F1 (B)] (the mean of *Orosius orientalis*/week ± SE).
3.3. Tomato Agronomic Traits

The applied plant spacings strongly affected the measured growth and yield traits of both the tested tomato varieties, i.e., plant height (cm), no. of fruits/plant, fruit yield/plant (g), total yield/ha (ton), and dry mass/plant (g) (Table 3). For both varieties, the lower plant spacing (30 × 50 cm) enhanced the heights of the tomato plants. Higher numbers of fruits/plant, fruit yield/plant (g), and dry mass/plant (g) were observed at the highest plant spacing (90 × 50 cm), while the maximum fruit yield (ton/ha) was recorded at the plant spacing of 60 × 50 cm.
Table 3. Plant height (cm), number of fruits/plant, fruit yield/plant (g), total yield (ton/ha), and dry mass/plant (g) as affected by three plant spacings (30 × 50 cm, 60 × 50 cm, and 90 × 50 cm) in two tomato varieties during the winter season of 2020–2021.

| Plant Spacing (T) | Plant Height (cm) | No. of Fruits/Plant | Fruit Yield/Plant (g) | Total Yield (ton/ha) | Dry Mass/Plant (g) |
|-------------------|-------------------|---------------------|----------------------|----------------------|-------------------|
| 30 × 50 cm        | 76.50 ± 2.74 a    | 11.73 ± 0.75 c      | 671.54 ± 36.83 c     | 40.28 ± 2.21 b       | 82.19 ± 3.67 b    |
| 60 × 50 cm        | 69.50 ± 2.62 ab   | 21.85 ± 1.04 b      | 1691.87 ± 42.13 b    | 53.15 ± 1.32 a       | 103.99 ± 3.95 a   |
| 90 × 50 cm        | 65.75 ± 2.24 b    | 24.85 ± 1.55 a      | 1969.99 ± 104.24 a   | 39.38 ± 2.08 b       | 113.76 ± 5.48 a   |
| F-test            | *                 | *                   | ***                  | ***                  | ***               |

LSD 7.6246 2.972 205.56 5.7505 12.482

Variety (V)

| Variety    | Plant Height (cm) | No. of Fruits/Plant | Fruit Yield/Plant (g) | Total Yield (ton/ha) | Dry Mass/Plant (g) |
|------------|-------------------|---------------------|----------------------|----------------------|-------------------|
| Areenez F1 | 69.75 ± 2.26 a    | 17.83 ± 1.71 b      | 1427.35 ± 178.20 a   | 43.73 ± 2.38 a       | 95.67 ± 4.75 a    |
| Tala F1    | 71.42 ± 2.57 a    | 21.12 ± 1.01 a      | 1461.58 ± 175.46 a   | 44.81 ± 2.48 a       | 104.29 ± 5.55 a   |
| F-test     | NS                | *                   | NS                   | NS                   | NS                |

LSD 6.2255 2.4266 167.84 4.6952 10.191

T x V

| T x V      | F-test            |
|------------|-------------------|
|           | NS                |

Means within each column followed by the same letter are not significantly different at level $p < 0.05$. (*) and (***), significant at $p < 0.05$ and $p < 0.001$, respectively; (NS), not significant.

3.4. Correlation between Insect Pests and Agronomic Traits of Tomatoes

The relationship between the insect pests and the agronomic traits of the tested tomato variety Areenez F1 is presented in Table 4. The data showed that *E. fabae* was negatively correlated with the number of fruits/plant at the 30 × 50 cm plant spacing. Also, *O. orientalis* exhibited a significant negative correlation with dry mass/plant (g) at the 30 cm plant spacing. A significant negative correlation was shown between the adult of *Tuta absoluta* (Meyrick) (Lepidoptera: Gelechiidae) and plant height (cm), fruit yield/plant (g), total yield/ha (ton), and dry mass/plant (g) at the 30 × 50 cm plant spacing. Moreover, *A. domesticus* exhibited a significant positive correlation with fruit yield/plant (g) and total yield/ha (ton) at the 60 × 50 cm plant spacing. However, *B. tabaci*, *N. viridula*, *Melanoplus bispinosus* (Scudder) (Orthoptera: Acrididae), and *L. niger* did not have any significant effect on the studied agronomic traits, i.e., plant height (cm), number of fruits/plant fruit yield/plant (g), total yield/ha (ton), and dry mass/plant (g) in the tomato variety Areenez F1.
Table 4. Correlation (r) between the insect pest population and the agronomic traits of the tomato variety ‘Areenez F1’, the plants were grown at three different plant spacings (30 × 50 cm, 60 × 50 cm and 90 × 50 cm) during the winter season of 2020–2021.

| Pests                  | Plant Spacing | Agronomic traits |              |              |              |              |
|------------------------|---------------|------------------|--------------|--------------|--------------|--------------|
|                        |               | Plant Height     | Number of    | Fruit        | Total        | Dry Mass/    |
|                        |               | (cm)             | Fruits/Plant | Yield/Plant  | Yield/Ha     | Plant (g)    |
| Empoasca fabae         | 30 cm         | −0.42            | −0.98 *      | −0.66        | −0.66        | 0.84         |
|                        | 60 cm         | 0.49             | 0.54         | 0.50         | 0.50         | −0.73        |
|                        | 90 cm         | −0.32            | −0.73        | −0.66        | −0.66        | 0.57         |
| Orosius orientalis     | 30 cm         | 0.141            | −0.049       | 0.082        | 0.0815       | −0.016 *     |
|                        | 60 cm         | −0.130           | 0.647        | 0.601        | 0.6009       | −0.484       |
|                        | 90 cm         | −0.001           | −0.580       | −0.605       | −0.6055      | 0.589        |
| Bemisia tabaci         | 30 cm         | 0.75             | −0.14        | 0.06         | 0.06         | −0.02        |
|                        | 60 cm         | −0.05            | 0.20         | 0.14         | 0.14         | −0.62        |
|                        | 90 cm         | −0.20            | −0.80        | −0.63        | −0.63        | 0.49         |
| Tuta absoluta          | 30 cm         | −0.003 *         | 0.249        | −0.021 *     | −0.0208 *    | −0.008 *     |
|                        | 60 cm         | −0.171           | −0.093       | −0.113       | −0.1128      | −0.133       |
|                        | 90 cm         | 0.327            | −0.819       | −0.952       | −0.9529      | 0.996        |
| Nezara viridula        | 30 cm         | −0.126           | −0.529       | −0.799       | −0.8001      | 0.825        |
|                        | 60 cm         | −0.822           | 0.035        | 0.032        | 0.0321       | −0.756       |
|                        | 90 cm         | 0.594            | −0.656       | −0.691       | −0.6905      | 0.665        |
| Acheta domesticus      | 30 cm         | 0.295            | 0.887        | 0.293        | 0.2941       | −0.571       |
|                        | 60 cm         | 0.058            | 0.023        | 0.010 *      | 0.0097 *     | −0.002       |
|                        | 90 cm         | −0.059           | 0.986        | 0.905        | 0.904        | −0.784       |
| Melanoplus bispinosus  | 30 cm         | 0.061            | −0.147       | 0.034        | 0.034        | 0.8 × 10⁻⁵   |
|                        | 60 cm         | 0.061            | −0.674       | −0.625       | −0.6246      | 0.372        |
|                        | 90 cm         | −0.602           | 0.476        | 0.486        | 0.485        | −0.453       |
| Lasius niger           | 30 cm         | 0.219            | 0.250        | 0.590        | 0.5898       | −0.547       |
|                        | 60 cm         | −0.821           | 0.470        | 0.477        | 0.477        | −0.983       |
|                        | 90 cm         | 0.959            | −0.920       | −0.435       | −0.436       | 0.529        |

* = significant at p < 0.05

The relationship between the pests and the agronomic traits of the tomato variety Tala F1 is shown in Table 5. The total abundance of O. orientalis exhibited a significant positive correlation with dry mass/plant (g) at the 60 × 50 cm plant spacing. In addition, B. tabaci showed a significant positive correlation with dry mass/plant (g) at the 90 × 50 cm plant spacing. Moreover, N. viridula showed a significant positive relationship with plant height (cm) and the number of fruits/plant at the 90 × 50 cm and 60 × 50 cm plant spacings, respectively. Moreover, N. viridula exhibited a significant negative correlation with fruit yield/plant (g) and total yield/ha (ton) at the 60 × 50 cm plant spacing, but the total abundance of A. domesticus showed a significant positive correlation with fruit yield/plant (g) and total yield/ha (ton) at the 60 × 50 cm plant spacing. Finally, M. bispinosus exhibited a significant negative correlation with plant height (cm) at the 60 × 50 cm plant spacing. However, E. fabae, T. absoluta, and L. niger did not have any significant effect on the studied agronomic traits, i.e., plant height (cm), number of fruits/plant, fruit yield/plant (g), total yield/ha (ton), and dry mass/plant (g) in the tomato variety Tala F1.
'Tala F1', which are commercial cultivated varieties in Saudi Arabia, at three plant spacings × ‘Tala F1'; the plants were grown at three different plant spacings (30 cm, 60 cm and 90 cm) during the winter season of 2020–2021. The mean abundance of *Neoceratitis cyanescens* (Thripidae), *B. tabaci* (Hemiptera: Aleyrodidae), and *O. orientalis* (Diptera: Tephritidae), was not significantly different for both tested tomato varieties was highly affected by the applied plant spacings. In both tomato varieties, the mean abundance of *E. fabae* was higher in the 30 cm plant spacing, whereas the mean abundance of *A. domesticus* was higher in the 90 cm plant spacing. Moreover, the total cumulative mean abundance of *T. absoluta*, *Heliothrips* sp. (Bouche) (Thysanoptera: Thripidae), *Neoceratitis cyanescens* (Bouche) (Diptera: Tephritidae), *M. bispinosus*, *Trimerotropis pallidipennis* (Burmeister) (Orthoptera: Acrididae), *Melanoplus differentialis* (Thomas) (Orthoptera: Acrididae), *Otiorhynchus sulcatus* (Fabricius) (Coleoptera: Curculionidae), and *Leptysma marginicollis* (Serville) (Orthoptera: Acrididae) was not significantly different between the three plant spacing treatments used and the two tested tomato varieties. These findings were in line with the results of Arif et al. [28] and Momtaz et al. [29], who observed the highest population of *B. tabaci*, *T. tabaci*, and *Amrasca devastans* in a cotton crop with narrow plant spacings. Mesbah et al. [30] also observed the highest number of *B. tabaci*

| Pests                   | Plant Spacing | Plant Height (cm) | No. of Fruits/Plant | Fruit Yield/Plant (g) | Total Yield (ton/ha) | Dry Mass/Plant (g) |
|------------------------|---------------|-------------------|---------------------|-----------------------|----------------------|---------------------|
| *Empoasca fabae*       | 30 cm         | −0.10             | 0.89                | 0.77                  | 0.77                 | −0.14               |
|                        | 60 cm         | −0.79             | −0.82               | −0.89                 | −0.89                | −0.01               |
|                        | 90 cm         | 0.009             | 0.64                | 0.61                  | 0.61                 | 0.17                |
| *Orosius orientalis*   | 30 cm         | 0.388             | −0.760              | −0.828                | −0.828               | −0.083              |
|                        | 60 cm         | 0.694             | −0.059              | −0.002                | −0.002               | 0.003 *             |
|                        | 90 cm         | −0.427            | −0.122              | −0.238                | −0.239               | 0.099               |
| *Bemisia tabaci*       | 30 cm         | −0.10             | 0.89                | 0.77                  | 0.77                 | −0.14               |
|                        | 60 cm         | −0.71             | −0.14               | −0.14                 | −0.45                | 0.55                |
|                        | 90 cm         | 0.26              | −0.49               | −0.47                 | −0.47                | 0.95 *              |
| *Tuta absoluta*        | 30 cm         | −0.172            | −0.362              | −0.132                | −0.131               | 0.148               |
|                        | 60 cm         | −0.693            | −0.61               | −0.731                | −0.731               | −0.002              |
|                        | 90 cm         | 0.323             | −0.664              | −0.502                | −0.501               | 0.726               |
| *Nezara viridula*      | 30 cm         | 0.958             | −0.024              | −0.184                | −0.185               | −0.496              |
|                        | 60 cm         | 0.178             | 0.003 *             | −0.015 *              | −0.015 *             | 0.943               |
|                        | 90 cm         | 0.006 *           | 0.983               | 0.981                 | 0.981                | −0.197              |
| *Acheta domesticus*    | 30 cm         | 0.138             | 0.149               | 0.068                 | 0.068                | −0.895              |
|                        | 60 cm         | 0.397             | −0.024              | 0.021 *               | 0.021 *              | −0.254              |
|                        | 90 cm         | −0.8 E−05         | −0.988              | −0.975                | −0.975               | 0.359               |
| *Melanoplus bispinosus*| 30 cm         | 0.068             | 0.639               | 0.376                 | 0.375                | −0.509              |
|                        | 60 cm         | −0.012 *          | 0.706               | 0.707                 | 0.707                | −0.244              |
|                        | 90 cm         | −0.067            | −0.914              | −0.981                | −0.981               | 0.125               |
| *Lasius niger*         | 30 cm         | −0.618            | −0.083              | −0.6 × 10⁻⁶           | −0.2 × 10⁻⁶          | 0.508               |
|                        | 60 cm         | −0.580            | −0.002              | 0.2 × 10⁻⁵            | 0.2 × 10⁻⁵           | −0.592              |
|                        | 90 cm         | −0.002            | −0.994              | −0.987                | −0.986               | 0.290               |

* = significant at *p* < 0.05

4. Discussion

Plant density is one of the most important Good Agriculture Practices (GAP) that can be a significant variable associated with the abundance of insect pests and crop production [11–13]. Therefore, we planted seedlings of two tomato varieties, ‘Areenze F1’ and ‘Tala F1’, which are commercial cultivated varieties in Saudi Arabia, at three plant spacings to investigate the abundance and population dynamics of insect pests and their relationship with the crop growth and productivity. The mean abundance of *E. fabae*, *O. orientalis*, *B. tabaci*, *A. domestica*, and *L. niger* for both tested tomato varieties was highly affected by the applied plant spacings. In both tomato varieties, the mean abundance of *E. fabae*, *O. orientalis*, and *B. tabaci* was higher in the 30 × 50 cm plant spacing, whereas the mean abundance of *A. domestica* and *L. niger* was higher in the 90 × 50 cm plant spacing. Moreover, the total cumulative mean abundance of *T. absoluta*, *Heliothrips* sp. (Bouche) (Thysanoptera: Thripidae), *Neoceratitis cyanescens* (Bezzi) (Diptera: Tephritidae), *M. bispinosus*, *Trimerotropis pallidipennis* (Burmeister) (Orthoptera: Acrididae), *Melanoplus differentialis* (Thomas) (Orthoptera: Acrididae), *Otiorhynchus sulcatus* (Fabricius) (Coleoptera: Curculionidae), and *Leptysma marginicollis* (Serville) (Orthoptera: Acrididae) was not significantly different between the three plant spacing treatments used and the two tested tomato varieties. These findings were in line with the results of Arif et al. [28] and Momtaz et al. [29], who observed the highest population of *B. tabaci*, *T. tabaci*, and *Amrasca devastans* in a cotton crop with narrow plant spacings. Mesbah et al. [30] also observed the highest number of *B. tabaci*
(Genn.), *Aphis gossypii* (Glov.), *Empoasca lybica debarg*, and *Thrips tabaci*, at a narrow plant spacing (25 x 59.16 cm), while the lowest abundance of these insects was observed at a wider plant spacing (50 x 118.32 cm). Also, the low plant spacings (an increased plant density) enhanced the abundance of jassid, whitefly, and thrips in cotton [31,32], *Tetranychus urticae* in cucumber [33], *B. tabaci* in cucumber [34], sunflower beetle, spittlebug, stem borer, and *P. cordata* in sunflower [11], sweet potato [35], sweet pea [36], and cotton [37]. On the other hand, the highest numbers of sucking insects were observed in the high planting density, while the lowest numbers were observed in the low planting density, which might be due to the high amount of food availability in the high planting density treatments and the lower amount of food availability in the low planting density treatments [11,15]. Solangi et al. [38] reported that the jassid and whitefly populations showed a significant difference in abundance among various studied tomato genotypes, which contrasted with our findings, and might be due to the genetic background and growth habit of the tested tomato varieties. Similarly, higher abundances at lower plant densities (higher planting spaces) were observed for *B. tabaci* in cucurbit varieties [39], and common bean [40], and for whitefly, jassid, thrip, and red-spider mite in cotton [41], thrips and whitefly in cotton [37], and for jassid among okra genotypes [42].

Plant spacing is one of the most important factors, which significantly affects the growth, development, and yield of tomatoes. The appropriate planting density increases the utilization of space, light, and the uptake of nutrients, leading to the high yield and better quality of tomato production [12,13]. The results of our study revealed that for both tested tomato varieties, the maximum yield (ton/ha) was observed when tomato plants were spaced at 60 cm between plants and 50 cm between rows, while the tallest plants were at the 30 x 50 cm plant spacing. The maximum fruits/plant, yield/plant (g), and dry mass/plant (g) were recorded for the plant spacing of 90 x 50 cm. It has been reported that planting tomatoes at 20 cm between plants and 25 cm between rows significantly increased the plant heights, while the maximum yield/plant was obtained at a plant spacing of 30 cm X 35 cm [43]. Our results are partially supported by the findings of Guade [44], Maboko and Du Plooy [45], and Tuan and Mao [46], who reported that a higher plant density gave the minimum yield and a lower plant density gave the highest yield of tomatoes. Moreover, Falodun and Emede [47] reported higher yields (ton/ha) of tomatoes at the 75 x 40 cm plant spacing and 75 x 50 cm plant spacing than that at the 75 x 60 cm plant spacing.

Our results indicated that both tomato varieties differed significantly in the number of fruits/plant, where ‘Tala F1’ produced the highest number of fresh fruits/plant. Additionally, plants of the tomato variety ‘Tala F1’ showed the maximum heights (cm), dry mass (g), fruit yield/plant (g), and total yield (ton/ha) where the differences were not significant. Overall, adjusting plant spacing, as one of the Good Agriculture Practices (GAP), can be considered a sustainable eco-friendly method to reduce the abundance of important insect pests in tomato fields, and thus reduce the reliance on chemical pesticides which leads to the remission of their global risks to human health and the environment.

5. Conclusions

Our study focused on plant spacing, as a Good Agriculture Practice, a sustainable control method of the key insect pests in two tomato varieties ‘Tala F1’ and ‘Areenze F1’, which are widely cultivated in Saudi Arabia. We found that growing tomatoes at a plant spacing of 60 x 50 cm partially discouraged the development of the most abundant pest populations in the tomatoes and produced the maximum yield of fresh fruit. This may add some information for use in the IPM programs, specifically under organic farming for controlling tomato insect pests in Saudi Arabia. We conclude that growing tomatoes at 60 cm between plants and 50 cm between rows may reduce the need to apply pesticides given that this plant spacing significantly reduced the abundance of several key insect pests and enhanced tomato fruit yield.
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