Colegio de Postgraduados

Production of Saladette-type Tomato (*Solanum lycopersicum* L.) in response to the association with aromatic species

Marroquín-Agreda, Francisco J.[1]; **Osorio-Espinoza, Humberto**[1*]; **Lerma-Molina, José, N.**[1]; **Garza-Hernández Juan M.**[1]

[1] Universidad Autónoma de Chiapas, Campus IV, México. Huehuetán, Chiapas, México. C. P. 30670.
* Correspondence: humberto.osorio@unach.mx

ABSTRACT

Objective: This study analyzes tomato production in response to Volatile Organic Compounds (VOCs) emitted by the foliage and flowers of *Ocimum basilicum*, *Tagetes erecta*, and *Origanum majorana*, intercropped with the vegetable.

Design/methodology/approach: The development of tomato and aromatic plant species (*Ocimum basilicum*[1], *Tagetes erecta*[2], and *Origanum majorana*[3]) was evaluated during both vegetative and flowering stages. Treatments were distributed using a completely randomized block design. Indicators of tomato fruit production and quality were measured and analyzed.

Results: The associations with aromatic plants emitted VOCs based on alkaloids, glycosides, and terpenes, which act as stress regulators and enhancers of tomato plant growth and yield. This demonstrates the importance of aromatic species in improving the quality and size of tomato fruits.

Limitations of the study/implications: During the course of the research, challenges related to VOCs (aroma) arose, as they are difficult to control between experimental units and treatments. The use of 2-meter polyester nylon barriers between treatments prevented the exchange and leakage of VOCs.

Findings/conclusions: The association of aromatic plants with tomato affected fruit yield and quality indicators, resulting in higher production per plant and better fruit quality compared to the control.

Keywords: Yield, Quality, Vegetables, Volatile Organic Compounds.

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INTRODUCTION

Under a semi-controlled exploitation model, such as greenhouses, horticultural production systems are becoming increasingly widespread and demanding in their use of agrochemicals. Tomato is the most in-demand vegetable worldwide, showing a national per capita consumption of 14.1 kilograms per person per year in 2020 (SIAP, 2024); with China positioned as the leading global producer and consumer, the United States as the main importer, and Mexico as the main exporter, placing the latter in the ninth position in the world ranking. This crop exhibited growth in Mexico of around 5.96% between 2017 and 2023, increasing from 3.47 million to 3.637 million tons, and a cumulative global increase of 125.80% is estimated by 2030 (SAGARPA, 2017; SIAP, 2025). This

demand could be met by expanding the cultivation area and improving the technification of greenhouse tomato production, an area that has not seen substantial growth in recent years (2019-2023), with a production yield of 69 t ha^{-1}. However, this is still well below the genetic potential of the crop material (SIAP, 2025). Given the need for food production and climate change resilience, horticultural systems as well as agriculture in general are becoming increasingly dependent on external agricultural inputs, specifically insecticides, fungicides, and mineral fertilizers. In tomato production, 15% of the total production cost is invested in pesticides, 25% in soluble fertilizers, 10% in nutritional foliar products, and 50% in labor expenses over the nine-month greenhouse production cycle; where product safety remains an increasingly complex challenge. In light of the need to offer healthy and safe products, biological diversity —specifically aromatic species offers highly important alternatives to address phytosanitary problems and improve the productivity of vegetables (Gallegos, 2017). The potential of aromatic species for repelling and/or allelopathic effects on various causal agents of phytosanitary issues is well documented, as is their role in human health and cuisine. However, the positive relationship of Volatile Organic Compounds from aromatic plants on the development, growth, and production of vegetables such as tomato, chili, and others is scarcely supported by scientific argumentation. Currently, humanity not only demands more food but also products free of harmful agents; in response to this immense need, the present work analyzes tomato production as a response to the Volatile Organic Compounds (VOCs) from the foliage and flowers of *Ocimum basilicum*, *Tagetes erecta*, and *Origanum majorana*, intercropped with tomato under greenhouse conditions.

MATERIALS AND METHODS

The present study was conducted in the greenhouses of the company "Grupo Agroindustrial Chiapaneco S.C. de R.L. de C.V." (GRACHI), located in the Sierra of Chiapas, Mexico, on the La Trinitaria - Lagos de Montebello highway, km 10, Emiliano Zapata Colony junction, km 3; at the geographical coordinates N 16.16343, W 91.97594, and an altitude of 1,525 meters above sea level. The climate in the area is warm sub-humid with summer rains, with an average monthly temperature of 18.1 °C. The predominant soil types are limestone (77.31%), shale (9.03%), and alluvial soil (7.28%), with an organic matter content of 1.3% (Gallegos, 2017). The topological arrangement designed and implemented consisted of transplanting the aromatic plants at their development and flowering stages between the tomato plant rows, with a spacing of 20 cm between aromatic plants and 110 cm between rows. During the development of the aromatic plants, pruning of the foliage mass was performed every 15 days to promote the release of VOCs. The treatments in this study were randomized using a completely randomized block design over an area of 1,600 m^2 (40 meters wide by 40 meters long), resulting in a total of 70 experimental units. Seven treatments were evaluated, represented by tomato rows intercropped with aromatic plants (*Ocimum basilicum*[1], *Tagetes erecta*[2], and *Origanum majorana*[3]) in development; associations of aromatics (1, 2, and 3) in flowering + tomato, and tomato without association, with 10 replications per treatment. The aromatic seeds were sown in 200-cell trays using peat moss as a substrate, under 70% shade mesh; the tomato seedlings were obtained in the same way. For the field phase, two areas were delineated, each 20 meters wide by 40 meters long, obtaining eight blocks (planting beds of four rows with 100 plants each). Between the tomato rows of each block, 80 basil (*Ocimum basilicum*) plants in development (foliage) were transplanted and 100 basil plants in flowering for the second block; likewise for the treatments with marigold (*Tagetes erecta*), marjoram (*Origanum majorana*), and the control (no association). Each block or area with the aromatic plants was enclosed with 2-meter-high polyester nylon to prevent the exchange and leakage of Volatile Organic Compounds between treatments. Tomato plant production and fruit quality indicators were measured and analyzed: number of clusters, fruits per cluster, fruit weight (g), yield (kg per plant), fruit quality, and aboveground biomass (g). Measurements began 8 days after tomato transplanting and continued until the fruit reached physiological maturity. For this purpose, a measuring tape, caliper (mm), and granataria scale (g) were used for foliar biomass, along with detailed counts for the number of flowers and days to flowering. Ten tomato plants per treatment were selected for data collection.

The data obtained during the research were analyzed using ANOVA (0.05), and based on the calculated F-value, a *post hoc* multiple range test was performed using the Tukey method (0.05). Field data analysis was carried out using the statistical software Statgraphics Centurion XVI.I.

RESULTS AND DISCUSSION

The tomato inflorescence is a cyme with different branching patterns (mono-, di-, and polychotomous), with or without axial bracts; typically having three nodes between each inflorescence (Rick, 1979). Six weeks after sowing, the plant enters its reproductive phase, producing flowers continuously depending on its developmental rate, which is influenced by the plant's physiological conditions and the agroecological environment. The inflorescences are lateral rather than apical, and this type of vegetable features highly developed axillary stems (Villegas *et al.*, 2004). The results show that associations with aromatic plants have a positive effect on the number of floral clusters in tomato plants. The effects were similar during both the vegetative growth (foliage) and flowering phases of the aromatics, with *Tagetes erecta* and *Origanum majorana* demonstrating dominance in both stages (Figure 1). The number of clusters per tomato plant increased by up to two with *Tagetes erecta* and *Origanum majorana*, whereas *Ocimum basilicum* showed results similar to the control (19 and 18, respectively). The number of tomato clusters in the associations ranged from 19 to 21, while the control showed 18 clusters per plant (Figure 1).

For the indicator "number of fruits per cluster," greater dominance was observed with the flowering phase of *Tagetes erecta* and *Origanum majorana*, each with 8 set fruits, followed by *Ocimum basilicum* with 6 fruits, and the control with 5 fruits (Figure 2). The difference in fruit set in tomato as a response to the association with flowering *Tagetes erecta* and *Origanum majorana* was 3 fruits higher compared to the control. Similar results (2 additional fruits) were obtained for the control compared to *Ocimum basilicum*, *Tagetes erecta*, and *Origanum majorana* in their vegetative growth phase. The aromatic species improved the number of fruits set per inflorescence, with the scents emitted by each aromatic plant producing a positive effect, resulting in a 90% fruit set rate.

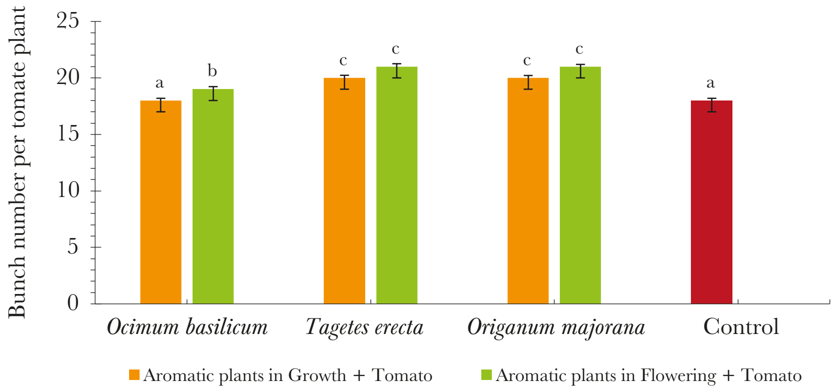

Figure 1. Total flower clusters per saladette tomato plant associated with aromatic plants. Values with the same letter are equal according to Tukey's multiple range test at P≤0.05.

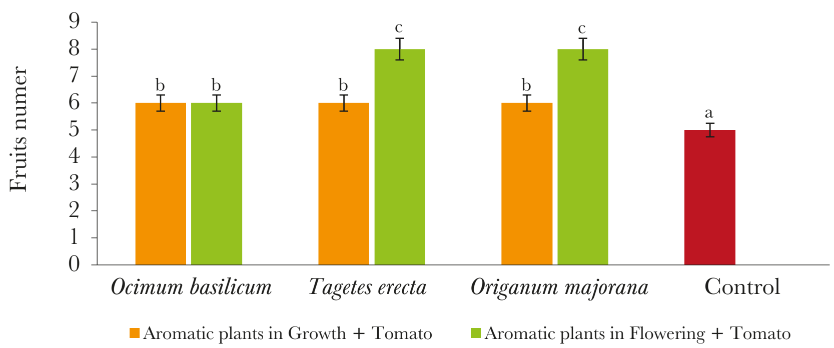

Figure 2. Fruits per flower cluster of saladette tomato plants associated with aromatic species. Values with the same letter are equal according to Tukey's multiple range test at P≤0.05.

There are numerous types of tomatoes such as Saladette, Globe, Cherry, Cocktail, and Grape (SIAP, 2024), and their number continues to grow, with new varieties offering greater disease resistance, higher productivity, and improved fruit quality and shelf life (Navarro, 2011). In contrast, the effects of the phenological phases of the aromatic plants (vegetative growth and flowering) showed greater dominance in the flowering phase of *Origanum majorana*, and in the vegetative growth phase of *Tagetes erecta*, regarding the increase in tomato fruit weight. Tomatoes associated with *Tagetes erecta* yielded a fruit weight of 109 grams, followed by *Origanum majorana* with 108 grams, *Ocimum basilicum* with 107 grams, and finally the control with 97 grams per fruit. Similar results were observed in fruit weight when tomatoes were associated with aromatic plants during their flowering phase: *Origanum majorana* produced the heaviest fruits at 112 grams, followed by *Tagetes erecta* with 110 grams, *Ocimum basilicum* with 108 grams, and the control with 95 grams per fruit (Figure 3). The difference in tomato fruit weight in response to the association with flowering *Origanum majorana* was 17 grams more than the control; similar results (3 grams) were observed in comparison with *Tagetes erecta* during vegetative growth (Figure 3). These findings tangibly demonstrate the importance of aromatic species, which can be used as a form of aromatherapy for economically

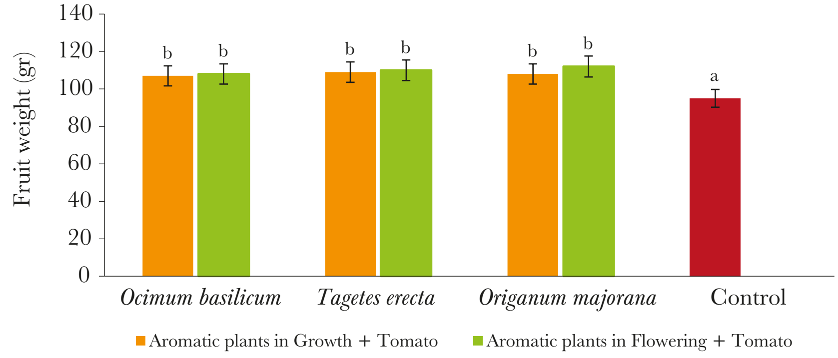

Figure 3. Fruit weight of saladette tomato associated with aromatic plants. Values with the same letter are equal according to Tukey's multiple range test at P≤0.05.

important crops such as tomato, jalapeño pepper, and bell pepper, among others, since their scents help stimulate plant metabolism, improve nutrient and water assimilation, and reduce antagonism between fertilizers present in the soil.

The differences in tomato fruit weight in response to the association with aromatic species are mainly due to the release of scents rich in alkaloids with double aromatic rings, which are found in higher concentrations during the flowering phase. This results in greater assimilation of both soil and foliar nutrients, leading to improved fruit growth.

Tomato fruit production per plant associated with *Origanum majorana* during its flowering stage reached 14.11 kg per plant, followed by *Tagetes erecta* with 13.86 kg per plant, *Ocimum basilicum* with 13.68 kg per plant, and the control with 11.97 kg per plant (Figure 4). Similarly, in the association with aromatics during their vegetative growth phase, *Tagetes erecta* recorded the highest production with 11.77 kg per plant, followed by *Origanum majorana* with 11.66 kg per plant, *Ocimum basilicum* with 11.55 kg per plant, and the control with only 10.476 kg per plant. These values are expressed per plant. From a more commercial-technical perspective, they are expressed in kilograms per square meter (kg/m^2); in this study, the density was 2.87 plants/m^2. These results may vary depending on the planting system (plant density per greenhouse area). Similar and even higher results were reported by Villegas *et al.* (2004), stating that under greenhouse conditions and without pruning, commercial densities range from 2 to 2.5 plants/m^2.

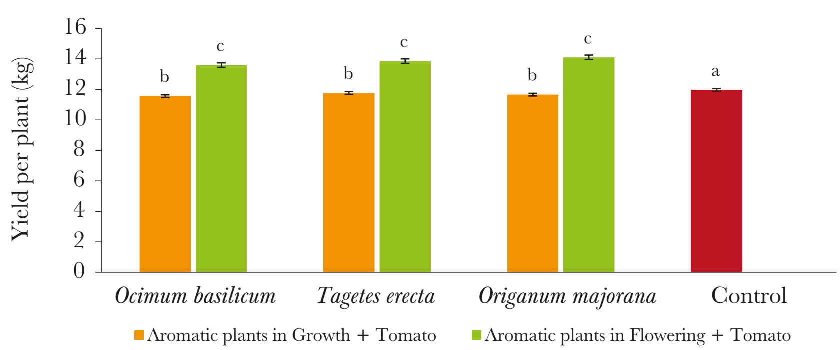

Figure 4. Saladette tomato production per plant associated with aromatic plants. Values with the same letter are equal according to Tukey's multiple range test at P≤0.05.

With an average density of 2.27 plants/m^2, tomato yields a total fruit production of 20.6 kg per plant, equivalent to 46.8 kg/m^2. The quality of most fruits and vegetables is significantly affected by water loss during storage, which depends on temperature and relative humidity. Temperature plays a critical role in maintaining postharvest tomato quality; the effect of storage temperature on the quality and extent of physicochemical changes in tomato fruits is highly dependent on the cultivar, exposure time, and harvest conditions (Peil and Gálvez, 2004).

Fruit quality is assessed in two stages: (1) large tomato quality (fruit weight >95 g), referring to all fruits with suitable values for national market commercialization. In this context, tomato associated with *Tagetes erecta* during vegetative growth produced 246 large fruits, followed by *Origanum majorana* with 237, *Ocimum basilicum* with 208, and the control with 57 fruits. A markedly different outcome was observed in the association with flowering aromatics: *Tagetes erecta* yielded the highest number of large fruits with 282, followed by *Ocimum basilicum* with 203, *Origanum majorana* with 171, and the control with only 104 large fruits. Additionally, medium-sized fruits (60 g-95 g) are classified as such because they do not meet the weight and size criteria for the large category, though they are still marketable at the regional level. Comparing large fruit values, the difference in response to the association with flowering Tagetes erecta was 178 more large fruits than the control; similar results (36 more fruits) were observed with *Tagetes erecta* in vegetative growth (Figure 5). These results demonstrate the importance of aromatic species in the assimilation of foliar fertilizers by reducing plant stress levels, which, along with temperature, relative humidity, and high plant respiration, contributes to achieving larger tomato fruit sizes.

Tomato fruit quality (size) is improved by the association with aromatic species, with differences in fruit quality depending on the species and their phenological stage. The data presented above are consistent with those described by Balaguera and Álvarez (2006), who state that tomato quality is largely determined by its weight, and that fresh weight directly influences its economic value. However, variations in fruit weight have been reported depending on the time of year the crop is harvested. Modifications in tomato quality may be mechanical, physiological, or pathological in

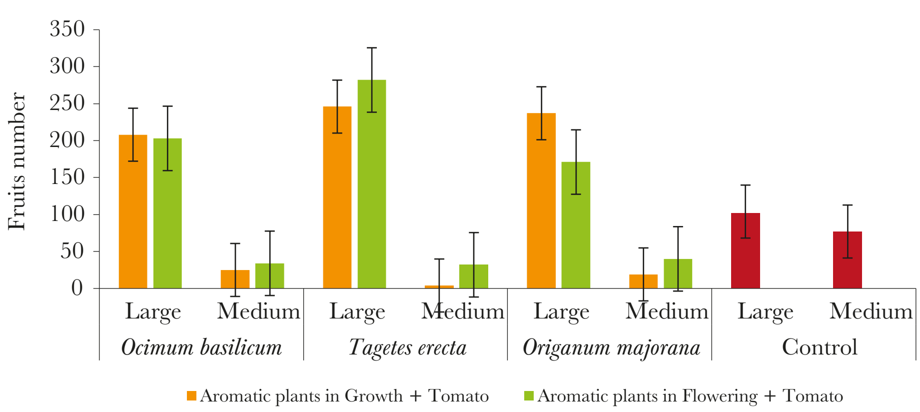

Figure 5. Fruit quality per saladette tomato plant associated with aromatic plants.

nature. Mechanical damage can cause metabolic and physiological alterations, resulting in abnormal internal or external appearance and disruptions in respiratory metabolism, flavor, and firmness. Physical damage may also significantly affect the physicochemical composition of the pericarp and locular tissue in tomato fruits. Other relevant factors influencing the chemical composition of vegetables include climatic conditions, fertilization, production systems, irrigation, and the plant's developmental stage at harvest (Salomé, 2014). Regarding dry biomass production in tomato plants, the effects of the phenological stages of the aromatic plants (vegetative growth and flowering) were more dominant during the flowering of *Tagetes erecta*; the same trend was observed in its vegetative stage. Tomato associated with *Tagetes erecta* yielded 0.710 kg of biomass per plant, followed by *Ocimum basilicum* with 0.600 kg, *Origanum majorana* with 0.420 kg, and the control with 0.280 kg. In the association with flowering aromatics, *Tagetes erecta* produced the highest effect with 0.760 kg of tomato dry biomass, followed by *Ocimum basilicum* with 0.580 kg, *Origanum majorana* with 0.490 kg, and the control with 0.340 kg (Figure 6).

The dry biomass production of the tomato plant (kg) is improved by the association with aromatic species, with differences in biomass influenced by the species and their phenological stages. This difference is statistically significant in the following scenarios: basil-marigold, basil-oregano, basil-control, marigold-oregano, marigold-control, and oregano-control (Figure 6). The yield of a crop is related to the production or accumulation of biomass (fresh and dry matter) in plant organs, which may be allocated to fruit harvest and/or the synthesis of photosynthetic assimilates. As tomato fruits are sink organs for photosynthates, they compete with each other and with vegetative organs for the available assimilates (Castro *et al.*, 2014). However, in indeterminate tomato plants, other factors must be considered, as the dynamics of dry biomass accumulation are different (Ortega *et al.*, 2010). The associations with aromatic plants emit VOCs based on alkaloids, glycosides, and terpenes, which act as stress regulators and growth enhancers in tomato plants. These compounds have potential to be used as phytohormones.

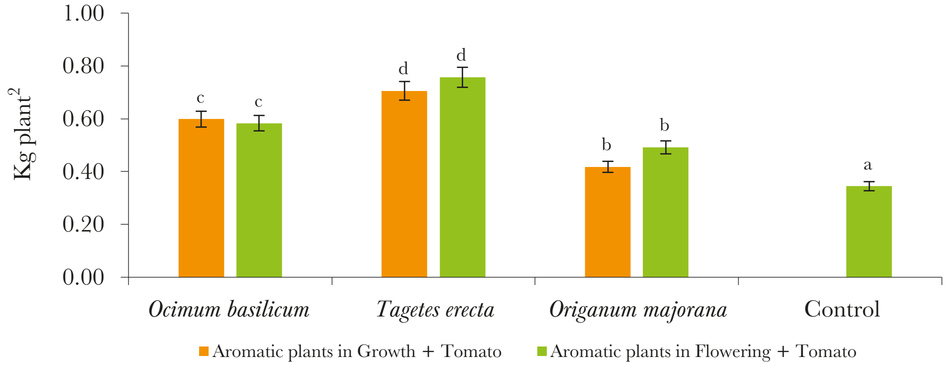

Figure 6. Dry biomass production per saladette tomato plant associated with aromatic plants. Values with the same letter are equal according to Tukey's multiple range test at P≤0.05.

CONCLUSIONS

Tagetes erecta is the aromatic plant with the greatest influence on the production indicators of tomato plants. The flowering of marigold releases alkaloids with a double aromatic ring structure, which the vegetable assimilates, thereby relieving stress in the tomato plant. The scents produced by aromatic plants are composed of terpenes, whose structural base is a double aromatic ring. This property acts as a growth phytohormone, stimulating and enhancing the development of tomato seedlings. Additionally, the alkaloids function as stress regulators, contributing to improved productivity. The association of aromatic plants with tomato had significant effects on yield and fruit quality indicators, as expressed through higher production per plant compared to the control.

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