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# Effectiveness of Bumblebee Pollination in Anti-Frost Heated Tomato Greenhouses in the Mediterranean Basin*

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**Abstract:** Turkey has 22,000 ha of greenhouse area, and about 51% of vegetable greenhouses are used for tomato production. In Mediterranean countries generally greenhouses are not regularly heated at optimal levels. Fruity vegetables in winter have a problem of insufficient pollination due to low temperatures and isolated atmosphere. The aim of this study was to investigate the effectiveness of bumblebee (*Bombus terrestris*) pollination in tomato production in anti-frost heated greenhouses in the Mediterranean basin. Three fruit set applications, namely bumblebee, vibration and growth regulator, were used. Bumblebee pollination was compared to 2 other techniques that are commonly used in tomato greenhouses. The tomato varieties F 144, P 198, F 248 and Vivia were grown during the winter cultivation period. The heating system of the greenhouses was only used in the case of emergencies to maintain the temperature above 5 °C. The results showed that the bumblebee can be an efficient pollinator of tomato flowers in anti-frost heated greenhouses during winter in the Mediterranean basin. Bumblebee pollination increased the yield by 90% and 61% over vibration and growth regulator applications. Bumblebee pollinated tomato fruits were heavier than vibrated and growth regulator applied ones by 41% and 9%, respectively. In conclusion, bumblebee pollination should be used instead of growth regulators and vibration for increased yield and more marketable fruits.

Key Words: *Lycopersicon esculentum,* greenhouse cultivation, *Bombus terrestris*, pollination, fruit set

## Akdeniz Bölgesi Anti-Don Isıtılan Domates Seralarında Bombus Arısı Tozlayıcılığının Etkinliği

**Özet:** Türkiye 22 000 ha seracılık alanına sahiptir. Sebze seralarının yaklaşık % 51'inde domates yetiştiriciliği yapılmaktadır. Akdeniz ülkeleri seralarında genellikle bitkilerin optimum istekleri seviyesinde düzenli ısıtma yapılmamaktadır. Kış aylarında yetiştirilen meyveleri tüketilen sebzelerin, düşük sıcaklık ve izole atmosfer nedenlerinden kaynaklanan yetersiz tozlanma problemi vardır. Çalışmanın amacı, don riskine karşı ısıtılan (anti-don) domates seralarında bombus arısının (*Bombus terrestris*) tozlayıcılık etkinliğini incelemektir. Denemede üç tozlama ve/veya meyve tutum uygulaması; bombus arısı, sallama (vibrasyon), ve büyümeyi düzenleyici uygulaması karşılaştırılmıştır. Bitki materyali olarak, domates çeşitleri F 144, P 198, F 248 ve Vivia kış döneminde anti-don seralarda yetiştirilmiştir. Deneme seralarında, sera içi sıcaklığı 5 °C'nin altına düşmeyecek şekilde ısıtma yapılmıştır. Elde edilen araştırma bulguları, Akdenize kıyısı olan ülkelerde (bölgelerde) anti-don (az ısıtılan) domates seralarında bombus arısının kış aylarında da etkin bir tozlayıcı olarak çalışabildiğini göstermiştir. Bombus arısı, sırasıyla vibrasyon ve büyümeyi düzenleyiciye göre toplam ürünü % 90 ve % 61 olarak artırmıştır. Bombus arısı ile tozlanan meyveler vibrasyona gore % 41 ve büyümeyi düzenleyiciye göre % 9 daha ağır olmuştur. Sonuç olarak, sezon dışında kış aylarında üretim yapılan seralarda, domateslerde yüksek verim ve pazarlanabilir meyve kalitesinde artış sağlamak için bombus arısı, sallama (vibrasyon) ve büyümeyi düzenleyici uygulamalarının yerine kullanılmalıdır.

Anahtar Sözcükler: *Lycopersicon esculentum*, sera yetiştiriciliği, *Bombus terrestris*, tozlanma, meyve tutumu

## Introduction

Turkey is a Mediterranean country, with an enormous greenhouse potential. It has over 22,000 ha of greenhouse area. About 51% of that area is used for the production of tomatoes, 17% for peppers, 10% for eggplants and the remaining 22% for cucumbers,

* The article is dedicated to our dear student Ali Oğuz ÖZDOĞAN who lost his life during his military service.

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strawberries, melons and other crops. In open field-grown tomatoes, fruit set is not considered a great problem because solar radiation and temperature are adequate for pollination and fertilization. One of the major problems in greenhouse fruity vegetable production during winter is insufficient pollination due to low temperatures, low light intensity and isolated atmosphere. In Mediterranean countries greenhouses generally are not regularly heated at the level required for optimal plant growth and development. Low night temperatures and solar radiation during the day reduce pollen production and pollen in winter cultivation tends to be sticky and to aggregate under high relative humidity (Ho and Hewitt, 1994; Kinet and Peet 1997; Jones, 1999). Therefore insufficient production of fertile pollen and low pollen dynamism cause serious pollination problems in greenhouses. Although the pollen viability in tomatoes (Daşgan et al., 1995), eggplants (Abak and Güler 1994) and peppers (Abak et al., 1997) in anti-frost heated greenhouses is lower than in the warmer seasons, the limited amount of good quality pollen is sufficient to obtain good yields when effective pollinators are used.

Honeybees have been successfully used for the pollination of many plant species, but they are not effective pollinators for Solanaceae crops (Neisweinder, 1956; Cribb, 1990; Banda and Paxton, 1991; Cervancia and Bergonia, 1991; Winston, 2001). Growers have tried to stimulate fruit set in tomato plants by using vibrators and/or growth regulators. Using growth regulators and vibrators is labor intensive, and growth regulators can give low quality puffy fruits. Recent investigations into the importance of bumblebees for the pollination of greenhouse vegetables showed that the quality of the fruit is improved and growers obtained better prices (Ravestijn and Sande, 1991; Abak et al., 1995; Daşgan et al., 1999; Paydas et al., 2000; Morandin, 2001).

Bumblebees are larger, more robust and furrier than honeybees. They can fly and pollinate flowers at lower temperatures, around 8-10 °C. They grab the tube-like tomato flowers, vibrate them and obtain the pollen from them. Their long tongues allow them to visit and pollinate flowers that have long tubular corollas. Their capacity to forage at low temperatures and low light intensities makes them important pollinators in greenhouse conditions. Therefore, bumblebees have been used as pollinators of tomatoes, peppers and eggplants in greenhouses in many countries, such as the Netherlands, Belgium, France and Israel, since 1988 (Ravestijn, 1990; Sande, 1990; Banda and Paxton, 1991; Kaftanoğlu, 1999; Winston, 2001). However, the effectiveness of bumblebees in anti-frost heated greenhouses in the Mediterranean basin is not known.

The aims of this study were to investigate the effectiveness of the bumblebee as a pollinator of tomatoes grown in anti-frost heated greenhouses, and to compare it with other commonly used fruit set methods.

## Materials and Methods

The study was conducted in two 360 $m^2$ experimental plastic covered greenhouses of the Horticultural Department of the Agricultural Faculty of Cukurova University. Seedlings of 4 $F_1$ hybrid tomato varieties F 144, P 198, F 248 and Vivia, were transplanted in the plastic greenhouses on October 20. Three fruit set applications, bumblebees, vibration and growth regulator, were compared for the tomato crop. Bumblebee plots were placed in one greenhouse and vibration and growth regulator treatments were placed in the other. The heating system of the greenhouses was only used at nights in emergencies to maintain the temperature above 5 °C. Heating was not used during the day. Monthly minimum, maximum and average temperatures inside the greenhouses are shown in Figures 1 and 2. The average minimum temperature recorded during the cultivation period inside the greenhouses was 9.12 °C, and the lowest and highest night temperatures were 6.45 °C and 10.77 °C, respectively. The spacings were 1.0 m and 0.5 m between rows and the distance between the plants was 0.5 m within the rows (2.6 plants $m^{-2}$). The repeated randomized complete block designs method (Mead and

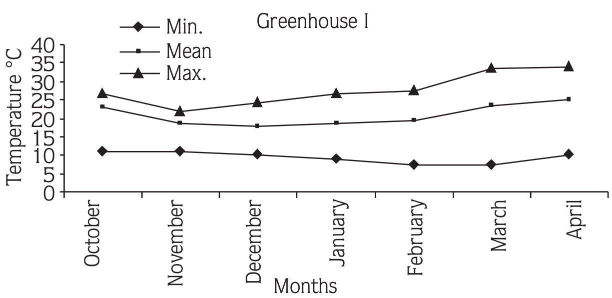


Figure 1. Monthly minimum, maximum and mean temperatures inside the greenhouse in which the tomato flowers were pollinated by bumblebees.

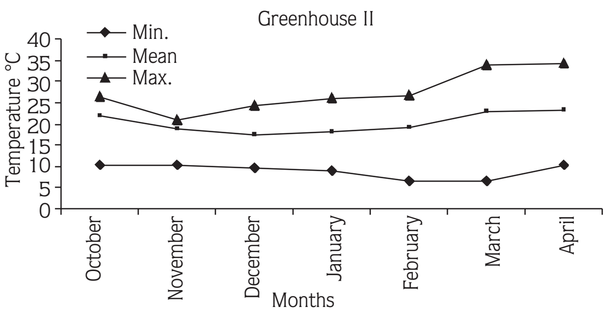


Figure 2. Monthly minimum, maximum and mean temperatures inside the greenhouses in which the tomato plants were treated by vibration and growth regulator.

Curnow, 1983) with 4 replications was used and differences were compared according to Tukey's test. Each plot contained 12 plants. Tomato plants were grown up to the fifth cluster, and then the apical growing points were removed to stop plant growth. We were mainly interested in fruit set in the coldest period, between November and January. In our opinion 5 clusters of fruits are enough to investigate the effectiveness of bumblebee pollination. During the experiment, 175 kg of N, 90 kg of $P_2O_5$ and 300 kg of $K_2O$ $ha^{-1}$ were applied by drip irrigation. The bumblebee colonies used in the experiment were raised at the Faculty of Agriculture, Çukurova University. At the beginning of flowering, one bumblebee colony with 50-60 workers was placed into the greenhouse (December 3) and removed after 65 days (February 7). Daily vibration by a mechanical vibrator was used to shake the stems of tomato plants (Ho and Hewitt 1994; Jones, 1999). Vibration duration with the same degree of shaking was 10 s for each plot every day until the all flowers were fruit set. Time of vibration was between 9:00 and 10:00 AM, which is the optimal time for the self-pollination of tomato flowers, since these open in the morning. However, the mature pollen is ready for transfer at the time of anthesis (i.e. flower opening), and its viability continues for 2-5 days after anthesis. The stigma become receptive about 2 days before anthesis and remain so for 4 days or more (Kaul, 1991; Ho and Hewitt, 1994). Exogenous application of growth regulators (auxin and gibberellin) to the inflorescence at anthesis stimulates the formation of parthenocarpic tomato fruits, and this is one of the fruit set practices under low light and temperature conditions in winter cultivated greenhouses (Mapelli et al., 1979): 4-chlorophenoxy acetic acid (4-CPA) is the most common growth regulator used in tomato greenhouses in Turkey. A concentration of 15 mg $l^{-1}$ of 4-CPA was sprayed onto the flowers during the same period (December 3-February 7) as the vibration and bumblebee applications. The harvesting period was between March 25 and April 16, and the fruit yield (kg $m^{-2}$) was recorded. In order to investigate the effects of the fruit set applications on fruit characteristics, in the middle of the harvesting period 10 fruits were randomly taken from each plot to record the average weight, length, diameter, volume and seed number per fruit. The total soluble solids (TSS) content, acidity and pH of the fruit juice were also measured.

## Results

The effects of bumblebee pollination, vibration and growth regulator applications on the yields of the different varieties, F 144, P 198, F 248 and Vivia, are shown in Table 1. The average tomato yields in bumblebee pollinated, vibrated and growth regulator applied plots were 4.12, 2.17 and 2.56 kg $m^{-2}$, respectively. The highest yield was obtained in bumblebee pollinated plants ($P < 0.01$) with an increased yield of 89.9% and 60.9% over vibration and growth regulator application ($P > 0.05$).

There were also significant differences among the varieties ($P < 0.01$) in terms of fruit yield. The Vivia, F 248, F 198 and F 144 varieties yielded 3.75, 2.96, 2.64 and 2.44 kg $m^{-2}$, respectively. Vivia had the highest and F 144 the lowest yield of all the varieties. Treatment x variety interaction was not significant ($P > 0.05$).

The effects of bumblebees on fruit numbers per $m^2$ in different tomato varieties are given in Table 2. Differences among the treatments were significant ($P < 0.05$). The average fruit numbers per $m^2$ in bumblebee, vibration and growth regulator treatments were 32.79, 21.53 and 19.64 fruits $m^{-2}$, respectively. Bumblebee pollination increased the number of fruits by 52.3% and 67.0% over vibration and growth regulator applications. Since the bumblebees visited the flowers at the proper time, the fruit set and consequently the number of fruits were higher in this treatment. There was no statistical difference between the vibration and growth regulator applications in terms of fruit numbers ($P > 0.05$).

There were also significant differences among varieties in terms of fruit set. The Vivia variety yielded significantly more fruits (32.89 fruits $m^{-2}$) than F 144.

Table 1. The effect of different applications for fruit setting on the yield of different tomato varieties (kg $m^{-2}$)*

| Treatments | | F 144 $F_1$ | F 198 $F_1$ | F 248 $F_1$ | Vivia $F_1$ | FSA** Average |
|---|---|---|---|---|---|---|
| Bumblebee (BB) | | 3.46 | 3.30 | 4.94 | 4.77 | 4.12 a |
| Vibration | | 1.78 | 1.76 | 1.89 | 3.24 | 2.17 b |
| Growth regulator | | 2.08 | 2.86 | 2.05 | 3.25 | 2.56 b |
| % | BB vs. Vibration | 94.4 | 87.5 | 161.4 | 47.2 | 89.9 |
| Increase | BB vs. G. Regulat. | 66.3 | 15.4 | 141.0 | 46.8 | 60.9 |
| Variety Average | | 2.44 b | 2.64 b | 2.96 ab | 3.75 a | 2.95 |
| Probability < Treatment: 0.01, Variety: 0.01, Treatment x Variety: ns | | | | | | |

*Yield values represent only the first 5 clusters of tomatoes
**FSA: Fruit Set Application

Table 2. The effect of different applications for fruit setting on fruit numbers per $m^2$ in different tomato varieties.

| Treatments | | F 144 $F_1$ | F 198 $F_1$ | F 248 $F_1$ | Vivia $F_1$ | FSA** Average |
|---|---|---|---|---|---|---|
| Bumblebee (BB) | | 24.61 | 30.17 | 37.45 | 38.95 | 32.79 a |
| Vibration | | 16.60 | 17.30 | 18.40 | 33.80 | 21.53 b |
| Growth regulator | | 16.40 | 22.93 | 16.30 | 22.93 | 19.64 b |
| % | BB vs. Vibration | 48.3 | 74.4 | 103.5 | 15.20 | 52.3 |
| Increase | BB vs. G. Regulat | 50.0 | 31.6 | 129.8 | 69.9 | 67.0 |
| Variety Average | | 19.20 b | 23.47 ab | 24.05 ab | 31.89 a | 24.65 |
| Probability < Treatment: 0.01, Variety: 0.01, Treatment x Variety: ns | | | | | | |

**FSA: Fruit Set Application

The fruit numbers of F 248 and F 198 were similar, and were between those of Vivia and F 144.

The effects of different fruit set methods on fruit characteristics were also examined. Average fruit weights were 144.49 g in bumblebee pollinated plants, 102.33 g in vibrated plants and 132.51 g in growth regulator applied plants (Table 3). Bumblebee pollination increased fruit weight by 41.2% and 9% compared to the vibration and growth regulator applied plants. However, there were no significant differences between the bumblebee pollinated and growth regulator applied plants with regard to fruit weight ($P > 0.05$), although both were higher than vibrated plants ($P < 0.01$).

As with fruit weight, there were no significant differences ($P < 0.05$) between the bumblebee pollinated plants and growth regulator applied plants in terms of fruit diameter, and these had significantly larger diameters than the fruits of the vibrated plants (Table 4). All the varieties had similar fruit diameters, regardless of the fruit setting methods applied ($P > 0.05$).

There was no significant difference between the bumblebee pollinated and growth regulator applied plants with regard to fruit height ($P > 0.05$) (Table 5). However, both had greater fruit heights than those of the vibrated plants ($P < 0.01$). The Vivia variety had a smaller fruit height than the other 3 varieties ($P < 0.01$).

Table 3. The effect of different applications for fruit setting on the fruit weight of different tomato varieties (g).

| Treatments | | F 144 $F_1$ | F 198 $F_1$ | F 248 $F_1$ | Vivia $F_1$ | FSA** Average |
|---|---|---|---|---|---|---|
| Bumblebee (BB) | | 155.29 | 134.51 | 144.10 | 144.07 | 144.49 a |
| Vibration | | 112.75 | 101.63 | 108.46 | 86.47 | 102.33 b |
| Growth regulator | | 138.95 | 124.16 | 126.05 | 140.88 | 132.51 a |
| % | BB vs. Vibration | 37.7 | 32.4 | 32.9 | 66.6 | 41.2 |
| Increase | BB vs. G. Regulat. | 11.8 | 8.3 | 14.3 | 2.3 | 9.0 |
| Variety Average | | 135.66 | 120.10 | 126.21 | 123.81 | 126.44 |
| Probability < Treatment: 0.01, Variety: ns, Treatment x Variety: ns | | | | | | |

** FSA: Fruit Set Application

Table 4. The effect of different applications for fruit setting on fruit diameters of different tomato varieties (mm).

| Treatments | | F 144 $F_1$ | F 198 $F_1$ | F 248 $F_1$ | Vivia $F_1$ | FSA** Average |
|---|---|---|---|---|---|---|
| Bumblebee (BB) | | 65.76 | 63.85 | 64.11 | 65.44 | 64.79 a |
| Vibration | | 60.82 | 56.51 | 57.48 | 54.33 | 57.29 b |
| Growth regulator | | 65.42 | 62.14 | 60.68 | 66.56 | 63.70 a |
| % | BB vs. Vibration | 8.1 | 13.0 | 11.5 | 20.4 | 13.1 |
| Increase | BB vs. G. Regulat | 0.5 | 2.8 | 5.7 | -1.7 | 1.7 |
| Variety Average | | 64.00 | 60.83 | 60.76 | 62.11 | 61.95 |
| Probability < Treatment: 0.01, Variety: ns, Treatment x Variety: ns | | | | | | |

**FSA: Fruit Set Application

Table 5. The effect of different applications for fruit setting on fruit heights of different tomato varieties (mm).

| Treatments | | F 144 $F_1$ | F 198 $F_1$ | F 248 $F_1$ | Vivia $F_1$ | FSA** Average |
|---|---|---|---|---|---|---|
| Bumblebee (BB) | | 57.25 | 57.14 | 57.29 | 53.48 | 56.29 a |
| Vibration | | 52.91 | 51.61 | 51.68 | 47.01 | 50.80 b |
| Growth regulator | | 54.79 | 53.87 | 55.88 | 50.69 | 53.81 a |
| % | BB vs. Vibration | 8.2 | 10.7 | 10.9 | 13.8 | 10.8 |
| Increase | BB vs. G. Regulat | 4.8 | 6.1 | 2.5 | 5.5 | 4.6 |
| Variety Average | | 54.98 a | 54.21 a | 54.95 a | 50.39 b | 53.63 |
| Probability < Treatment: 0.01, Variety: 0.01, Treatment x Variety: ns | | | | | | |

**FSA: Fruit Set Application

The volume of fruits from bumblebee pollinated plants was significantly higher than those from vibrated and growth regulator applied plants (P < 0.01) (Table 6). Bumblebee pollination increased fruit volume by 19.4% and 22.8% over the vibration and growth regulator applications, respectively. The volume of fruits from the F 144 variety was significantly higher than those from the other varieties (P < 0.01). There were no significant differences among the P 198, F 248 and Vivia varieties in terms of fruit volume (P > 0.01).

The effects of different pollination treatments on the carpel and seed per fruit are given in Tables 7 and 8. Significant differences were observed among different pollination treatments and among varieties (P < 0.01) with regard to carpel numbers per fruit (Table 7). Bumblebee pollinated tomato fruits had significantly more carpels than the fruits pollinated by vibration (P < 0.01). The carpel numbers of the bumblebee pollinated fruits were 14.3% and 6.7% higher than those of the fruits pollinated by vibration and growth regulator application, respectively. The carpel numbers of the fruits from the growth regulator applied plants were between those of the fruits obtained from bumblebee and vibration treated plants.

The effects of different fruit setting methods on the number of seeds per fruit were also significant (Table 8). The highest number of seeds was obtained from bumblebee pollinated fruits (126.3 seeds fruit$^{-1}$), followed by vibration (81.5 seeds fruit$^{-1}$) and growth regulator application (30.4 seeds fruit$^{-1}$). The Vivia

Table 6. The effect of different applications for fruit setting on fruit volumes of different tomato varieties (ml).

| Treatments | | F 144 $F_1$ | F 198 $F_1$ | F 248 $F_1$ | Vivia $F_1$ | FSA** Average |
|---|---|---|---|---|---|---|
| Bumblebee (BB) | | 155.33 | 129.52 | 138.67 | 144.59 | 142.03 a |
| Vibration | | 159.39 | 102.79 | 111.21 | 102.62 | 119.00 b |
| Growth regulator | | 131.95 | 104.36 | 116.22 | 110.17 | 115.68 b |
| % | BB vs. Vibration | -2.5 | 26.0 | 24.7 | 40.9 | 19.4 |
| Increase | BB vs. G. Regulat | 17.7 | 24.1 | 18.3 | 31.2 | 22.8 |
| Variety Average | | 148.89 a | 112.22 b | 122.03 b | 119.12 b | 125.57 |
| Probability < Treatment: 0.01, Variety: 0.01, Treatment x Variety: ns | | | | | | |

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Table 7. The effect of different applications of fruit setting on carpel numbers of fruits in different tomato varieties (carpel fruit$^{-1}$).

| Treatments | | F 144 $F_1$ | F 198 $F_1$ | F 248 $F_1$ | Vivia $F_1$ | FSA** Average |
|---|---|---|---|---|---|---|
| Bumblebee (BB) | | 2.9 | 3.2 | 3.3 | 3.5 | 3.2 a |
| Vibration | | 2.6 | 2.9 | 3.1 | 2.9 | 2.8 b |
| Growth regulator | | 2.8 | 3.2 | 2.9 | 3.2 | 3.0 ab |
| % | BB vs. Vibration | 11.5 | 10.3 | 6.5 | 20.7 | 14.3 |
| Increase | BB vs. G. Regulat | 3.6 | 0.0 | 13.8 | 9.4 | 6.7 |
| Variety Average | | 2.8 b | 3.1 ab | 3.1 ab | 3.2 a | 3.0 |
| Probability < Treatment: 0.01, Variety: 0.01, Treatment x Variety: ns | | | | | | |

**FSA: Fruit Set Application

Table 8. The effect of different applications for fruit setting on seed numbers per fruit in different tomato varieties.

| Treatments | | F 144 $F_1$ | F 198 $F_1$ | F 248 $F_1$ | Vivia $F_1$ | FSA** Average |
|---|---|---|---|---|---|---|
| Bumblebee (BB) | | 134.5 | 123.8 | 140.4 | 106.4 | 126.3 a |
| Vibration | | 91.9 | 83.9 | 90.1 | 60.1 | 81.5 b |
| Growth regulator | | 37.8 | 30.1 | 39.4 | 14.2 | 30.4 c |
| % | BB vs. Vibration | 46.4 | 47.6 | 55.8 | 77.0 | 55.0 |
| Increase | BB vs. G. Regulat | 255.8 | 311.3 | 256.3 | 649.3 | 315.5 |
| Variety Average | | 88.1 a | 79.3 a | 90.0 a | 60.2 b | 79.4 |
| Probability < Treatment: 0.01, Variety: 0.01, Treatment x Variety : ns | | | | | | |

**FSA: Fruit Set Application

variety had the lowest number of seeds regardless of the fruit set method applied ($P < 0.01$). There was no significant difference among the other varieties.

Some fruit juice parameters were also investigated, and the results of TSS content, pH and acidity of juice are presented in Tables 9-11.

The effects of treatments and varieties on TSS content were not significant (Table 9). The 2 other fruit juice parameters, pH (Table 10) and acidity (Table 11), did show some differences among the treatments and varieties.

There were significant differences among the fruit set treatments and varieties with regard to fruit juice acidity ($P < 0.05$). The bumblebee pollinated tomato fruits had lower acidity than the fruits pollinated by vibration. The acidity of the fruits obtained from growth regulator application was between that of those from vibration and bumblebee pollination. The Vivia and F 248 varieties had lower acidity than the other 2 varieties.

## Discussion

The results of this experiment show that in anti-frost heated greenhouses (minimum temperature above 5 °C) in the Mediterranean region, bumblebees can be used as effective pollinators for tomato production. Low pollen production can be caused by low temperatures (below 10 °C) after the meiosis stage of microsporogenesis. The viability of pollen can also be reduced by low temperature

Table 9. The effect of different applications for fruit setting on total soluble solids content of juice in different tomato varieties (%).

| Treatments | F 144 $F_1$ | F 198 $F_1$ | F 248 $F_1$ | Vivia $F_1$ | FSA** Average |
|---|---|---|---|---|---|
| Bumblebee (BB) | 4.2 | 4.2 | 4.1 | 4.1 | 4.1 |
| Vibration | 4.2 | 4.2 | 4.2 | 4.0 | 4.2 |
| Growth regulator | 4.2 | 4.1 | 4.2 | 4.2 | 4.2 |
| Variety Average | 4.2 | 4.2 | 4.1 | 4.1 | 4.1 |
| Probability < Treatment: ns, Variety: ns, Treatment x Variety: ns | | | | | |

**FSA: Fruit Set Application

Table 10. The effect of different applications for fruit setting on fruit juice pH in different tomato varieties.

| Treatments | | $F\ 144\ F_1$ | $F\ 198\ F_1$ | $F\ 248\ F_1$ | Vivia $F_1$ | FSA** Average |
|---|---|---|---|---|---|---|
| Bumblebees (BB) | | 3.87 | 3.88 | 4.00 | 3.87 | 3.91 a |
| Vibration | | 3.82 | 3.84 | 3.84 | 3.83 | 3.83 b |
| Growth regulator | | 3.75 | 3.76 | 3.76 | 3.76 | 3.76 b |
| % | BB vs. Vibration | 1.3 | 1.0 | 4.2 | 1.0 | 2.1 |
| Increase | BB vs. G. Regulat | 3.2 | 3.2 | 6.4 | 2.9 | 4.0 |
| Variety Average | | 3.81 | 3.83 | 3.86 | 3.82 | 3.83 |

Probability < Treatment: 0.01, Variety: ns, Treatment x Variety: ns

**FSA Fruit Set Application

Table 11. The effect of different applications for fruit setting on fruit juice acidity in different tomato varieties (%).

| Treatments | | $F\ 144\ F_1$ | $F\ 198\ F_1$ | $F\ 248\ F_1$ | Vivia $F_1$ | FSA** Average |
|---|---|---|---|---|---|---|
| Bumblebees (BB) | | 0.65 | 0.65 | 0.61 | 0.63 | 0.63 b |
| Vibration | | 0.70 | 0.72 | 0.66 | 0.64 | 0.68 a |
| Growth regulator | | 0.68 | 0.68 | 0.65 | 0.63 | 0.66 ab |
| % | BB vs. Vibration | -7.1 | -9.7 | -7.6 | -1.6 | -7.4 |
| Increases | BB vs. G. Regulat | -4.4 | -4.4 | 6.2 | 0.0 | -4.5 |
| Variety Average | | 0.68 a | 0.68 a | 0.64 ab | 0.63 b | 0.66 |

Probability < Treatment: 0.05, Variety: 0.05, Treatment x Variety: ns

**: FSA: Fruit Set Application

(below 10 °C), which adversely affects subsequent germination (Ho and Hewitt, 1994). In the present experiment, the average of the minimum temperatures recorded during the cultivation period inside the greenhouses was 9.12 °C, achieved by heating on some nights if the minimum temperature fell below 5 °C and by the greenhouse effect during sunny days. This average minimum temperature was enough for the production of viable pollen for bumblebee and vibration pollination. However, the yield from bumblebee pollinated plants was 89.9% higher than that from vibrated plants. This increase in yield shows that bumblebees are effective pollinators in comparison to vibration. Ravestijn and Sande (1991) reported that an active worker bumblebee may visit many tomato flowers and pollinate at least 500 plants per day, i.e., 250 $m^2$ of the greenhouse area. Since the pollen grain viability of 2-5 days and the stigma receptivity of 4 days continue after anthesis (Kaul, 1991; Ho and Hewitt, 1994), bumblebees can pollinate many flowers during this period. Daily pollination of flowers by mechanical vibration for 10 s per day cannot achieve the pollination performance of bumblebees.

Fertilization and fruit set can be disrupted by adverse environmental conditions. Low temperatures and light intensities in particular in greenhouse production result in decreased yields. However, fruit set can frequently be achieved in these conditions by the introduction of artificial parthenocarpy by applying exogenous growth regulators (Ho and Hewit, 1994; Kinet and Peet, 1997; Jones, 1999). In our study, we sought to compare the yields of bumblebee pollinated and growth regulator applied tomato plants, because growers in Turkey who do not have the means to heat their greenhouses commonly use growth regulators for fruit set. The yield increase of bumblebee pollination compared to growth regulator application was 60.9%. Despite the attraction of using exogenous growth regulators to improve fruit set under low temperature conditions, it can pose some problems. Seedless fruits produced by the introduction of growth regulators under low temperatures frequently suffer some type of malformation (Asahira et al., 1982). Puffiness or hollowness has also been reported to accompany parthenocarpic fruit set (Rylski, 1979).

The yield increases of bumblebee pollination compared to vibration and growth regulator applications have been reported in earlier studies on different greenhouse vegetables under similar ecological conditions. Results were reported for eggplants grown in anti-frost heated greenhouses; bumblebee pollination increased the yield by 33% and 25% compared to vibration and growth regulator applications, respectively. Bumblebee activities regarding eggplant pollination during the cultivation period were sufficient to achieve good pollination even in the case of lower pollen production due to low temperatures (Abak et al., 2000). Previous studies on greenhouse tomato (Daşgan et al., 1995), pepper (Abak et al., 1997) and eggplant (Abak and Güler, 1994) production also indicated that even in cold periods it is possible to find a limited amount of fertile pollen, and that this could be sufficient if effective pollinators bumblebees are used. Earlier studies on the production of strawberries in cold weather in greenhouses showed that bumblebees were able to achieve earliness and good yield (Paydas et al., 2000).

The number of seeds (Table 8) from the bumblebee pollinated tomato fruits also confirmed that good pollination occurred in comparison to vibration. Sawhney and Dabbs (1978) demonstrated that seed number is generally positively related to fruit size and shape, which are indirectly related to pollen production and pollination. Seeds are sources of growth regulators that play a significant role in fruit development in assimilate import in both ovary and inflorescence (Sawhney and Dabbs, 1978). In our study, bumblebee pollinated tomatoes had many seeds and the fruit size, symmetry and commercial grade improved with each seed fertilized (Winston, 2001).

An addiiton to the yield increase from bumblebee pollination, fruit quality properties such as weight, diameter, height and volume also increased. The marketable qualities of tomato fruits are enhanced by bumblebee pollination (Banda and Paxton, 1991). Similar enhancements in fruit quality properties in bumblebee pollinated melon (Daşgan et al., 1999), strawberries (Paydas et al., 2000), eggplants (Abak et al., 2000) and peppers (Abak et al., 1997) were reported in previous studies.

Others have also recommended bumblebees as pollinators for greenhouse tomato production (Ravestijn, 1990; Sande, 1990; Banda and Paxton, 1991). In our study we investigated the effectiveness of bumblebees in anti-frost heated greenhouses during winter in the Mediterranean basin. Although low temperatures (below 10 °C) at night are the most damaging factor affecting pollination and fertilization, Mediterranean greenhouses have the advantage of a warmer climate in winter. In anti-frost heated Mediterranean greenhouses, bumblebee pollination was a more efficient technique than vibration and growth regulator applications. It is suggested that bumblebees be used instead of growth regulators and vibration for increased yield and more marketable fruits.

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## References

Abak, K., H.Y. Daşgan, Ö. İkiz, N. Uygun, O. Kaftanoğlu and H. Yeninar. 1997. Pollen production and quality in pepper grown in unheated greenhouses during winter and the effects of bumblebee (*Bombus terrestris*) pollination on fruit yield and quality. Acta Hort. 437: 303-307.

Abak, K., H.Y. Güler and N. Baytorun. 1995. A comparative study in heated and unheated plastichouses of the Mediterranean costal region of Turkey on plant growth, yield dynamics and crop quality. Acta Hort. 412: 335-341.

Abak, K. and H.Y. Güler. 1994. Pollen fertility and the vegetative growth of various eggplant genotypes under low temperature greenhouse conditions. Acta Hort. 366: 85-91.

Abak, K., O. Kaftanoğlu, A.O. Özdoğan and H.Y. Daşgan. 2000. Effectiveness of bumblebees as pollinators for eggplants grown in unheated greenhouses, Acta Hort. 514: 197-203.

Asahira, T., T. Hosaki and K. Shinya. 1982. Regulation of low temperature induced malformation of tomato fruit by plant growth regulators. J. Japan Soc. Hort. Sci. 50: 468-474.

Banda, H.J. and R.J. Paxton. 1991. Pollination of greenhouse tomatoes by bees. Acta Hort. 288: 194-197.

Cervancia, C.R. and E.A. Bergonia. 1991. Insect pollination of cucumber (*Cucumis sativus* L.) in the Philippines. Acta Hort. 288: 278-282.

Cribb, D. 1990. Pollination of tomato crops by honeybees. Bee Craft 72: 228-231.

Daşgan H.Y., K. Abak and N. Baytorun. 1995. İki farklı gece sıcaklığına sahip serada yetişen domates bitkilerinin çiçek tozu canlılık ve çimlenmeleri. Türkiye II. Ulusal Bahçe Bitkileri Kongresi Bildirileri, Cilt II, Adana, 12-16.

Daşgan, H.Y., A.O. Özdoğan and O. Kaftanoğlu. 1999. Comparison of honey bees (*Apis mellifera*) and bumblebees (*Bombus terrestris*) as pollinators for melons (*Cucumis melo* L) grown in greenouses. Acta Hort. 492: 131-134.

Ho, L.C and J.D. Hewitt, 1994. Fruit development. In: The Tomato Crop (Eds.: J.G. Atherton and J. Rudich), Chapman & Hall, pp. 201-239.

Jones, J.B., 1999. Plant characteristics and physiology. In: Tomato Plant Culture: In the Field, Greenhouse and Home Garden, CRC Press, Florida, pp.11-22.

Kaftanoğlu, O. 1999. Domestication of bumblebees (*Bombus terrestris*) and using them in the greenhouses for the pollination of cultivated crops. Final report of TU-Pollination Project under the NATO Science for Stability Program. Adana, Turkey.

Kaul, M.L.H., 1991. Reproductive biology in tomato. In: Genetic Improvement of the Tomato. Monographs on Theoretical and Applied Genetics. (Ed.: Kallo, G.) Vol. 14. Springer-Verlag, Berlin, pp. 39-50.

Kinet, J.M. and M.M. Peet. 1997. Tomato. In: The Physiology of Vegetable Crops. (Ed.: H.C. Wien), CAB International. London and Washington DC, pp. 207-258.

Mapelli, S., G. Torti, M., Badino and G.P. Soressi. 1979. Effects of $GA_3$ on flowering and fruit set in a mutant of tomato. Hort Science 14: 736-737.

Mead, R. and R.N. Curnow. 1983. Statistical Methods in Agriculture and Experimental Biology. Chapman and Hall, London, New York

Morandin, L.A., T.M. Laverty and P.G Kevan. 2001. Effect of bumblebee (Hymenoptera: Apidae) pollination intensity on the quality of greenhouse tomatoes. J. Econ. Ento. 94: 172-179.

Neisweinder, R.B. 1956. Pollination of greenhouse tomatoes by honeybees. J. Econ. Ento. 49: 436-437.

Paydas, S., S. Eti, O. Kaftanoğlu, E. Yasa and K. Derin. 2000. Effects of pollination of strawberries grown in plastic greenhouses by honeybees and bumblebees on the yield and quality of the fruits. Acta Hort. 513: 443-451.

Ravestijn, W. van and J. Sande van der, 1991. Use of bumblebees for the pollination of glasshouse tomatoes. Acta Hort. 288: 204-212.

Ravestijn, W. van. 1990. Bumblebees are good alternatives to truss vibration in round tomatoes. Hort. Abst. 60: 506.

Rylski, I. 1979. Fruit set and development of seeded and seedless tomato fruits under diverse regimes of temperature and pollination. J. Am. Soc. Hort. 104: 835-838.

Sande, J. van der. 1990. Bumblebees are good alternatives to truss vibration for beefsteak tomatoes. Hort. Abst. 60: 506.

Sawhney, V.K. and D.H. Dabbs. 1978. Gibberellic acid induced multilocular fruits in tomato and the role of locule number and seed number in fruit size. Canadian J. of Bot. 56: 2831-2835.

Winston, M. 2001. Bees under glass. Bee Culture 129: 13-16.