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# Enhanced Tomato Yield via Bumblebee Pollination: A Case Study in Durres, Albania

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**ABSTRACT**

This study investigated the impact of bumblebee (*Bombus terrestris*) pollination on the yield and quality of greenhouse-grown tomatoes. Control and experimental plots, each spanning 1 ha, were established within glass-enclosed greenhouses, in which tomatoes had previously been planted. The first plot had hives with insect pollinators *Bombus terrestris* from the beginning of flowering, while the other plot was not pollinated by bumblebees. After harvesting, the organoleptic properties of fruits were analysed for 3 clusters of 10 plants from each site and their weight ratio relative to the control. The production activity lasted about 70 days. As a result, it was determined that the fruits formed as a result of pollination with the participation of *Bombus terrestris* were more numerous and larger in size, and their weight was 25% higher ($p$<0.05) than the fruit weight of the corresponding number of plants in the control group. Thus, the use of pollinating bumblebees in greenhouses opens up prospects for simplifying and reducing the cost of industrial cultivation of tomatoes in the closed ground, the implementation of this approach may increase the accessibility of the produce irrespective of the season and enhance the quality of the fruits, thereby potentially elevating their market value.

## 1. INTRODUCTION

Tomatoes, encompassing over 7,500 varieties, are globally significant as a food crop [1]. Originally native to South America, specifically Peru, tomatoes were introduced to Europe around the 16th century [2].

In contemporary agriculture, Albania has emerged as a major player in tomato cultivation. It is ranked among the top 20 nations worldwide for tomato exports. Approximately 37% of all vegetables cultivated in Albania are tomatoes, and as of 2019, nearly half (48%) of all harvested tomatoes were produced in greenhouses [3, 4].

Greenhouse cultivation offers numerous advantages: plants are shielded from many external environmental stressors, microclimate conditions can be regulated, and the yield-to-area ratio is optimized, leading to more efficient resource use [5]. However, this method presents significant costs, and the scarcity of free-pollinating insects, particularly in colder seasons, poses challenges for pollination [6].

Tomatoes, as a species, are naturally pollinated by insects capable of creating vibrations, complicating the search for effective artificial pollination strategies [3]. Various pollination methods for tomatoes, both in open fields and under glass, have been evaluated by researchers. A comparative study by Bashir et al. [7] assessed the efficacy of wind pollination, self-pollination, and open-ground pollination involving abiotic factors and insects. The fruits' shelf life, physicochemical and organoleptic properties, and the number and weight of seeds were examined.

The worst indicators were in the fruits of self-pollinated plants, significantly better in those that were pollinated by wind, and the best in plants that were on free pollination.

However, not all pollinating insects are equally effective. The study by Khalifa et al. [8] analysed the role of bee pollination in agriculture and in comparison, with other pollinators. The researchers concluded that in most cases, bee pollination is more effective than with the participation of other insects and significantly increases fruiting in different crops. Some of them, including tomatoes, although show better results after bee pollination, are much more productive in the presence of vibrating bumblebees. The same conclusions were reached by Cooley and Vallejo-Marin [9] in their theoretical study and comparison of tomato pollination methods. They confirmed that self-pollination is the least effective method and bees that do not buzz and, accordingly, do not cause vibrations during pollination increase yields on a par with artificial pollination using mechanical vibrations and auxin treatment. The highest quality of tomato fruits was observed with bumblebee pollination and free pollination. Studies by Zhang et al. [10] and Vallejo-Marin [11] confirm the possibility of bumblebee pollination in the cultivation of tomatoes in protected ground.

The review of tomato pollinators conducted by Toni et al. [12] identified 5 species of bumblebees that are mainly used for pollination in different parts of the world. Of these, the most typical for Europe is *Bombus terrestris.*

When investigating the use of pollinating insects in the industrial cultivation of crops, it is necessary to consider the specific features of the physiology of these animals. Among the restrictions, the most significant is the minimisation or elimination of the use of pesticides. Both insecticides that act on insects, and other types of these drugs, such as fungicides and herbicides. There is evidence of a significant reduction in the population of natural pollinators living in areas close to agricultural land treated with these chemicals [13]. And studies confirming the negative impact of the use of treatment both on bumblebee populations used as controlled pollinators in greenhouses and on yield indicators [14, 15].

The purpose of this study is to investigate the effect of bumblebee pollination on the quantity, weight, and quality of tomatoes grown in greenhouses compared to plants that were not pollinated with insects and to determine the feasibility of implementing this approach in the coastal zone of Albania (Durres). This study hypothesizes that the introduction of bumblebee pollination in greenhouse cultivation positively affects the quality and yield of tomatoes. Specifically, it is expected that tomatoes pollinated by *Bombus terrestris* will exhibit larger sizes and increased fruit weight compared to those not pollinated by bumblebees.

This study aims to highlight the positive effects that come from the use of the pollination process by bumblebees and promote this method as a positive model that affects the increasing crop production of tomatoes, especially cultivated in greenhouses, focused in coastal areas of Albania (Durres).

The specific objectives of this study are:

1) Implementation of bumblebee pollination protocols in greenhouses cultivated with tomato crops, in the administrative unit of Sukth, Durres.

2) Assessment of bumblebee's pollination effects in fructification and production of the tomato crop in greenhouses.

3) Increasing the awareness of the community of farmers who cultivate the tomato crop, on the use of bumblebees for pollination, in the conditions of the farm.

The research questions are:

a) How to implement bumblebee pollination in tomato crops cultivated in greenhouses?

b) How bumblebee pollination affects tomato production?

c) What about the time intervention and hive amount in the reinforcement mode?

## 2. THEORETICAL OVERVIEW

### 2.1 Tomato pollination

*Solanum lycopersicon L.* – one of the most common tomato varieties. These are plants belonging to the family Solanaceae. According to Vallejo-Marin [11], in nature, they can be pollinated by wind or insects, but the structural features of their flower require special pollinators capable of so-called buzzing pollination, mainly bees. Such pollination is typical for about 6% of all crops, and its essence lies in the mutual adaptation of the morphology of the flower and the physiological data of the insect.

Tomato flowers, as indicated in the study by Wu et al. [16], have a bright yellow colour that attracts pollinators, they do not produce nectar but produce a large amount of pollen. Their stamens are characterised by a porous structure – that is, when pollen matures, the walls of the anther do not crack but are covered with holes. Mechanical vibrations are required to remove pollen through them.

Researchers led by Arroyo-Correa et al. [17] and Cardinal et al. [18] argue that the vibrations generated by bees may have different purposes – pollination, communication, protection – but in all cases, they are created by the pectoral muscles, although they may vary depending on the species and size of the individual. Moreover, the characteristic of vibrations is affected by the flower itself. Currently, it is assumed that the sound that the bee creates is not related to pollination and is its byproduct because the assumption about the effect of acoustic waves on pollen release has not been confirmed.

### 2.2 Bee behaviour and physiology

Bumblebees are social insects that form colonies characterised by an annual cycle. The life cycle of a colony described by Aktürk et al. [19] and Belsky et al. [20] can be divided into four stages: at the first stage, the young queen comes out of hibernation in the spring and initiates the establishment of a new colony, its reproductive functions are activated by pollen that it consumes, then working females develop, building the nest, after which the queen begins to lay unfertilised eggs, from which males develop. In the last stage, working individuals develop into new queens, and mate with males, after which the entire colony, except for young queens, dies, and they fall into hibernation, which lasts for the entire cold period.

### 2.3 Requirements for effective pollination

Pollination itself, according to Arroyo-Correa et al. [17], occurs as follows: the bee sits on a flower, places its abdomen on several anthers, and grabs one of them with its jaws. Vibrations that are created in all directions by circular movements of the pectoral muscles of the insect are transmitted to all parts of the flower and contribute to the release of pollen proportional to the frequency of vibration. Artificial pollination methods, such as auxin spraying, the use of vibrator brushes, and vibration probes, are less effective and degrade fruit quality [16].

*Bombus terrestris* is a species of bumblebee belonging to the family Apidae, the order Hymenoptera, and is used as a controlled species for pollination of various crops [21]. Bumblebees, according to Nayak et al. [21], are the only natural pollinators that can be used in greenhouses, because they can function at low light intensity. The data presented by De Vries et al. [22] and Hautequestt et al. [23] indicate that the effectiveness of pollination depends on some factors such as the number of insects, the number of visits to each flower, the speed of planting, the microclimate in the greenhouse and hive, etc. One insect can pollinate from 500 plants per day and visit up to 1,000 flowers per hour, and high-quality pollination is provided with 3-5 visits to one flower. Dymond et al. [24] showed that attendance and, accordingly, the quantity and quality of fruits improved with increasing insect numbers. Lighting is also an important element – shifting the spectrum to the red-blue side leads to a slowdown in the search for flowers and landing [22].

To effectively use bumblebees as controlled pollinators, it is necessary to ensure certain conditions both inside and outside the hive, maintain a certain level of temperature, humidity, and lighting, and limit the use of pesticides to the lowest possible level.

## 3. MATERIALS AND METHODS

### 3.1 Study location

Tomato plants were used for this study – *Solanum lycopersicon L.*, the Pink Rock variety grown in greenhouse conditions. The fruits of these plants are normally round, regular in shape, rich red in colour, with dense pulp, and an average weight of 220-230 g. They also belong to early-maturing varieties. Hives with bumblebees of the species *Bombus terrestris* (Figure 1) provided by an Albanian commercial company Agro Koni were used as pollinators. This type is typical for the region under consideration. Focusing on Durres, Albania, could be beneficial due to its Mediterranean climate, greenhouse practices, unique microclimates, and potential economic significance for tomato cultivation in the region. These factors make it an ideal setting to study the impact of bumblebee pollination on tomato quality and yield.

The study itself took place in the Durres region (Sukth), Albania. The study area was located near the central coastal region in an area of intensive greenhouse cultivation of tomatoes. This area is characterised by a Mediterranean climate atypical for Albania. The tests were conducted in 2022 during the first growing season of tomatoes, from the beginning of the first flowering to the fruit harvest. The researchers controlled for external factors by maintaining consistent greenhouse conditions, uniform planting, limited pesticide use, continuous monitoring, a control group without pollinators, and objective measurements. Exclusion of other pollinators in the control plot was achieved by physical isolation, control and removal, and by maintaining a closed environment in the greenhouse. The process of setting up the experiment and further work is illustrated by photos (Figures 2-4).

**Figure 1.** *Bombus terrestris*

**Figure 2.** View from experimental greenhouse

**Figure 3.** View of work on monitoring of bumblebee's activity

**Figure 4.** View of work on checking of *Bombus terrestris* activity

### 3.2 Experimental setup

After choosing the location of the experiment, which was laid in an area with a long tradition of growing tomatoes, a covered glass greenhouse was prepared, which was divided with a plastic film into two parts, each with an area of 1 ha, one of which was intended for setting up the actual experiment, and the other for the control version. On both parts, Pink Rock tomato plants were planted in the same way.

For the first option, after the first flowering appeared, immediately after receiving it from the supplier, 7 hives with a pollinating insect *Bombus terrestris*. By situating the hives at the recommended height of 50-60 cm from ground level, the researchers aimed to closely mimic the natural foraging behaviour of these bumblebees. This positioning allows the insects convenient access to the flowering tomato plants, promoting effective pollination. After some time, two more hives were added to increase the efficiency of visits. The distance between the hives was the same. Thus, the beginning of observations coincided with the beginning of the flowering of the first raceme of plants. All this time, the progress of insect activity in the hives and on the territory of the experimental part of the greenhouse was monitored. The second option was a similar plot with an area of 1 ha, where pollinating insects were not used. The conditions of the microclimate, top dressing, watering, application of medicinal preparations, and other factors other than the use of pollinators at the experimental site were the same for both options. During the experiment, special care was taken not to use toxic insecticides on plants. To prevent lethal and minimise the sublethal effects of pesticides, their use and application were limited to the minimum possible doses of fungicides required to control downy mildew and powdery mildew.

### 3.3 Measurement and data collection

To prove the influence of the use of pollinating insects on the efficiency of pollination, it was decided to focus on the weight of fruits as the main criterion. To do this, they were collected according to the following scheme: at 3 points of each variant, 50 plants were taken in 5 different clusters. The fruits of each group of plants were weighed, and then the weight of products obtained from the plants of each variant was compared, both with and without the use of bumblebees for pollination. Moreover, the organoleptic qualities of fruits obtained from plants of each variant were visually and tactilely evaluated: attention was paid to the shape, colour, density, etc.

All production activities, during which products from five clusters of tomato plants were collected and weighed, lasted from May 15 to July 25 2022.

## 4. RESULTS

Pollination is an integral part of the life cycle of angiosperms, without which fruit formation would be impossible. When growing plants in artificially created conditions, it is logical to bring these conditions closer to those that exist in nature [25]. In the case of tomatoes that require specific mechanical influences to release pollen, it is advisable to use controlled colonies of natural pollinators characteristic of the area in which the study was conducted, namely *Bombus terrestris*, or, as this species is also called, buff-tailed bumblebee or large earth bumblebee.

In the course of the study, the physical and organoleptic parameters of the fruits of the Pink Rock greenhouse tomato variety obtained as a result of pollination with the participation of bumblebees were compared with the control option without insect pollination. All tomato plants were grown in protected ground conditions – in a greenhouse. The first flowers appeared around 9 April, at which time 7 hives with commercially bred colonies of *Bombus terrestris* were placed in the experimental greenhouse immediately after receiving them from Agro Koni, according to the terms of the experiment. Bumblebees felt comfortable in the greenhouse and were quite active in pollinating tomato flowers. However, during two weeks of observations of flowers and pollinating bumblebees, it was concluded that the average attendance of most flowers was unsatisfactory, so it was decided to additionally put two more hives obtained from the same supplier. The frequency of attendance increased to the desired level, which is in the range of 3-5 plantings per flower, and the experiment was continued according to the plan. Thus, 9 hives with pollinating insects were placed on an area of 1 hectare. Since the use of pesticides was reduced as much as possible during the study and only fungicides were used, only during periods when this has the least impact on insects, no significant negative impact on bumblebee colonies was observed. This effect should decrease over time, even with the same amount of chemicals as in this study, because pesticides that may have remained in the soil during the experiment from the period of previous treatments will eventually decompose.

The first differences between plants that were pollinated with the participation of insects and control plants became noticeable already at the stage of the fruit set. In the first plants, this process was faster, and the number of fruits in the clusters was higher. At the end of the growing season, after complete reddening, but before the pulp softens, tomatoes from both sites are collected and sorted by plants, clusters, points, and variants. So, for each of the two variants – experimental and control – 5 clusters were selected at 3 points, from each of which 10 plants were selected. Thus, for each variant, the fruits of 150 plants were analysed – 50 at three different points. When visually evaluating the colour and shape, it was determined that tomatoes obtained from pollination involving bumblebees were brighter red and with a more uniform colour. They also turned out to be denser and elastic and had a better, more rounded shape inherent in this variety of tomatoes. The length and width of such fruits were also longer than those of plants that were grown on a site without pollinating insects.

Weight indicators most clearly illustrate the differences between tomato fruits with different types of pollination and allow objectively assessing the advantages or disadvantages of implementing the described method. Thus, Tables 1-3 show the weight indicators of tomatoes that developed after pollination using pollinating bumblebees at each of the three points.

As can be seen from the results obtained, in the first option, in which pollinating insects *Bombus terrestris* were used, the total weight of all fruits was approximately 130.5 kg obtained from 150 plants. At some points, these indicators were divided as 44.04 kg out of 50 plants at point 1 (Table 1), 43.25 kg at point 2 (Table 2), and 43.23 kg obtained from the same number of plants at point 3 (Table 3).

As for the results obtained in the second, control option of the experiment, where no pollinating insects were used for pollination, the weight of tomatoes from all 150 plants was approximately 98 kg, distributed between three points of 50 plants per 33.43 kg (Table 4), 32.95 kg, and 31.72 kg (Tables 5 and 6).

**Table 1.** Measurement of tomato production (kg) of variant 1 (using pollinators), in point 1

| Plant | Cluster 1 | Cluster 2 | Cluster 3 | Cluster 4 | Cluster 5 | Total amount |
|---|---|---|---|---|---|---|
| 1 | 0.7 | 0.82 | 0.93 | 0.9 | 0.97 | 4.32 |
| 2 | 0.85 | 0.79 | 0.87 | 0.93 | 0.94 | 4.38 |
| 3 | 0.98 | 0.95 | 0.94 | 0.87 | 0.82 | 4.56 |
| 4 | 0.77 | 0.87 | 0.9 | 0.82 | 0.86 | 4.22 |
| 5 | 0.69 | 0.74 | 0.88 | 0.89 | 0.92 | 4.12 |
| 6 | 0.97 | 0.82 | 0.86 | 1 | 0.97 | 4.62 |
| 7 | 0.89 | 0.93 | 0.94 | 0.88 | 0.94 | 4.58 |
| 8 | 0.91 | 0.98 | 0.91 | 0.87 | 0.92 | 4.59 |
| 9 | 0.88 | 0.78 | 0.84 | 0.86 | 1 | 4.36 |
| 10 | 0.86 | 0.89 | 0.77 | 0.85 | 0.92 | 4.29 |
| | 8.5 | 8.57 | 8.84 | 8.87 | 9.26 | 44.04 |

**Table 2.** Measurement of tomato production (kg) of variant 1 (using pollinators), in point 2

| Plant | Cluster 1 | Cluster 2 | Cluster 3 | Cluster 4 | Cluster 5 | Total amount |
|---|---|---|---|---|---|---|
| 1 | 0.86 | 0.78 | 0.91 | 0.89 | 0.9 | 4.34 |
| 2 | 0.82 | 0.82 | 0.79 | 0.87 | 0.96 | 4.26 |
| 3 | 0.85 | 0.84 | 0.96 | 0.92 | 0.87 | 4.44 |
| 4 | 0.82 | 0.91 | 0.84 | 0.86 | 0.85 | 4.28 |
| 5 | 0.84 | 0.86 | 0.94 | 0.84 | 0.82 | 4.3 |
| 6 | 0.94 | 0.84 | 0.82 | 0.93 | 0.94 | 4.47 |
| 7 | 0.81 | 0.89 | 0.86 | 0.84 | 0.9 | 4.3 |
| 8 | 0.87 | 0.92 | 0.86 | 0.79 | 0.96 | 4.4 |
| 9 | 0.8 | 0.86 | 0.91 | 0.84 | 0.78 | 4.19 |
| 10 | 0.88 | 0.82 | 0.84 | 0.79 | 0.94 | 4.27 |
| | 8.49 | 8.54 | 8.73 | 8.57 | 8.92 | 43.25 |

**Table 3.** Measurement of tomato production (kg) of variant 1 (using pollinators), in point 3

| Plant | Cluster 1 | Cluster 2 | Cluster 3 | Cluster 4 | Cluster 5 | Total amount |
|---|---|---|---|---|---|---|
| 1 | 0.91 | 0.82 | 0.94 | 0.79 | 0.94 | 4.4 |
| 2 | 0.91 | 0.84 | 0.82 | 0.79 | 0.81 | 4.17 |
| 3 | 0.75 | 0.86 | 0.92 | 0.86 | 0.94 | 4.33 |
| 4 | 0.88 | 0.93 | 0.86 | 0.79 | 0.82 | 4.28 |
| 5 | 0.81 | 0.82 | 0.96 | 0.87 | 0.86 | 4.32 |
| 6 | 0.93 | 0.86 | 0.89 | 0.91 | 0.92 | 4.51 |
| 7 | 0.86 | 0.89 | 0.87 | 0.82 | 0.94 | 4.38 |
| 8 | 0.79 | 0.94 | 0.86 | 0.84 | 0.95 | 4.38 |
| 9 | 0.77 | 0.82 | 0.89 | 0.8 | 0.92 | 4.2 |
| 10 | 0.92 | 0.79 | 0.82 | 0.84 | 0.89 | 4.26 |
| | 8.53 | 8.57 | 8.83 | 8.31 | 8.99 | 43.23 |

Accordingly, Tables 4-6 similarly structured indicators of fruit weight of plants that were not pollinated with insects.

**Table 4.** Measurement of tomato production (kg) of variant 2 (without using pollinators), in point 1

| Plant | Cluster 1 | Cluster 2 | Cluster 3 | Cluster 4 | Cluster 5 | Total amount |
|---|---|---|---|---|---|---|
| 1 | 0.71 | 0.64 | 0.7 | 0.74 | 0.72 | 3.51 |
| 2 | 0.73 | 0.64 | 0.62 | 0.58 | 0.68 | 3.25 |
| 3 | 0.57 | 0.66 | 0.76 | 0.64 | 0.72 | 3.35 |
| 4 | 0.62 | 0.79 | 0.64 | 0.58 | 0.68 | 3.31 |
| 5 | 0.66 | 0.73 | 0.78 | 0.64 | 0.59 | 3.4 |
| 6 | 0.78 | 0.54 | 0.68 | 0.72 | 0.74 | 3.46 |
| 7 | 0.69 | 0.68 | 0.76 | 0.78 | 0.74 | 3.65 |
| 8 | 0.62 | 0.79 | 0.69 | 0.68 | 0.81 | 3.59 |
| 9 | 0.5 | 0.56 | 0.63 | 0.53 | 0.72 | 2.94 |
| 10 | 0.64 | 0.52 | 0.63 | 0.57 | 0.61 | 2.97 |
| | 6.52 | 6.55 | 6.89 | 6.46 | 7.01 | 33.43 |

**Table 5.** Measurement of tomato production (kg) of variant 2 (without using pollinators), in point 2

| Plant | Cluster 1 | Cluster 2 | Cluster 3 | Cluster 4 | Cluster 5 | Total amount |
|---|---|---|---|---|---|---|
| 1 | 0.73 | 0.61 | 0.69 | 0.72 | 0.69 | 3.44 |
| 2 | 0.74 | 0.59 | 0.6 | 0.58 | 0.66 | 3.17 |
| 3 | 0.55 | 0.62 | 0.71 | 0.66 | 0.69 | 3.23 |
| 4 | 0.68 | 0.72 | 0.66 | 0.56 | 0.67 | 3.29 |
| 5 | 0.67 | 0.74 | 0.76 | 0.65 | 0.62 | 3.44 |
| 6 | 0.76 | 0.56 | 0.68 | 0.71 | 0.72 | 3.43 |
| 7 | 0.62 | 0.66 | 0.78 | 0.71 | 0.76 | 3.53 |
| 8 | 0.64 | 0.71 | 0.67 | 0.66 | 0.79 | 3.47 |
| 9 | 0.53 | 0.52 | 0.64 | 0.57 | 0.69 | 2.95 |
| 10 | 0.61 | 0.54 | 0.64 | 0.52 | 0.69 | 3 |
| | 6.53 | 6.27 | 6.83 | 6.34 | 6.98 | 32.95 |

**Table 6.** Measurement of tomato production (kg) of variant 2 (without using pollinators), in point 3

| Plant | Cluster 1 | Cluster 2 | Cluster 3 | Cluster 4 | Cluster 5 | Total amount |
|---|---|---|---|---|---|---|
| 1 | 0.69 | 0.68 | 0.59 | 0.68 | 0.64 | 3.28 |
| 2 | 0.68 | 0.64 | 0.58 | 0.62 | 0.58 | 3.1 |
| 3 | 0.57 | 0.6 | 0.69 | 0.62 | 0.63 | 3.11 |
| 4 | 0.73 | 0.71 | 0.68 | 0.62 | 0.64 | 3.38 |
| 5 | 0.64 | 0.71 | 0.69 | 0.64 | 0.73 | 3.41 |
| 6 | 0.68 | 0.53 | 0.64 | 0.67 | 0.62 | 3.14 |
| 7 | 0.62 | 0.64 | 0.69 | 0.69 | 0.64 | 3.28 |
| 8 | 0.62 | 0.73 | 0.64 | 0.62 | 0.68 | 3.29 |
| 9 | 0.51 | 0.61 | 0.58 | 0.53 | 0.61 | 2.84 |
| 10 | 0.59 | 0.52 | 0.61 | 0.54 | 0.63 | 2.89 |
| | 6.33 | 6.37 | 6.39 | 6.23 | 6.4 | 31.72 |

The differences in the weight of tomatoes between the two variants are indeed statistically significant. Thus, when using *Bombus terrestris* as a pollinator of tomatoes grown in greenhouses, almost 25% ($p<0.05$) more products were obtained than in the area where pollinating insects were not used. In addition, such pollination affected all indicators of productivity and quality of tomatoes, which were evaluated in the course of this study. Ultimately, tomatoes grown using *Bombus terrestris* pollination in greenhouses were larger, had brighter colouration, firmer and more consistent texture, and improved and more uniform shape.

The experiment was conducted for almost four months and included observations of all the main processes of the growing cycle of tomatoes and the behaviour of pollinating bumblebees in a greenhouse, and the results obtained indicate that pollination by *Bombus terrestris* led to an obvious increase in the quantity and quality of tomato fruits grown in the protected ground.

This method is eco-friendly and requires fewer financial costs than artificial pollination methods, which require significant labour intervention to perform monotonous and fairly large-scale work, especially when it comes to industrial tomato cultivation. In addition, distance from natural methods degrades the quality of fruits.

The disadvantages of bumblebee pollination include the difficulty in creating appropriate conditions in the hive and greenhouse, especially in the perspective of winter periods, and the need for periodic monitoring of the situation in nests and with flower attendance. Moreover, this method of pollination limits the possibility of using pesticides to treat plants and protect them from pests. On the other hand, excessive abuse of pesticides leads to a deterioration in the quality of crops, so reducing their use contributes to greater safety and environmental friendliness of products, which makes them more competitive in the world market.

## 5. DISCUSSION

Despite all the advantages of growing crops in protected ground conditions, such as independence from the negative impact of abiotic factors and the time of year, farms face the problem of implementing pollination. In the case of tomatoes, this is complicated by the specific porous structure of anthers, which require specific vibrations to release pollen [26, 27].

In nature, tomatoes are pollinated by wind and insects capable of generating high-frequency vibrations. However, a comparison of different pollination options, implemented by Bashir et al. [7], proved that wind pollination, although gives better results than self-pollination in the absence of external factors, is still significantly inferior to free pollination, which includes stimulation of anthers by various insects, not only capable of vibrations but also others. Moreover, in addition to the weight, size, and shape of fruits, the number and weight of seeds, the content of moisture and dry weight, the content of dissolved salts and acidity indicators are considered. Hardness and colour were determined instrumentally. All indicators, both considered and not in the results of this study, were most optimal in tomatoes that were pollinated, including by insects [7].

In turn, Salvarrey et al. [28] conducted a similar study, but in greenhouses. The researcher compared the number of flowers that appeared after pollination by bumblebees, in the absence of any interventions, and after hormone treatment. The difference between flowers that were pollinated by bumblebees and those that were not exposed to any effects is from 18 to 37%, and when treated with hormones, the percentage of flowers that started was 90% in one experiment, and 60% in the other, with 100% and 73% when pollinated by bumblebees in both cases, respectively. In the first case, unlike the fruits of self-pollinated plants, the fruits of plants treated with hormones, according to the authors, did not differ from those that were pollinated by insects, and in the second – had lower quality. Such contradictory results are probably explained by the fact that the experiments were conducted in different years. However, the advantage of bee pollination has been consistently confirmed from year to year [29].

Another interesting method of pollination was included in the comparison by Zhang et al. [10]. They compared pollination involving bumblebees, treatment with growth-regulating hormones, and manual pollination using a makeshift vibrator made from an electric toothbrush. In addition to the size and shape of the fruit, the chemical composition of tomatoes, which affects sensory sensations important to the consumer, was compared. Thus, they found that the fruits that were pollinated with bumblebees contained more fructose and glucose, although less sucrose, and they also had a lower content of malic and citric acids. Moreover, such fruits have a significantly different profile of volatile substances from those obtained during hormone treatment and mechanical pollination – it is more consistent with natural [30, 31]. Such tomatoes were more popular with consumers when evaluating sensory properties relative to fruit size, this is one of the few studies where it was smaller when pollinated by bees.

Pollinating insects that are capable of vibration are important not only for tomatoes but also for other crops that have similar features of the flower structure. The study by De Vries et al. [22] analysed the literature on avocado pollination. In the end, the researchers concluded that excluding insects from the pollination process negatively affects the quality and quantity of the crop. They also distinguish ways to increase the efficiency of bee pollination an increase in the number of pollinating insects, the selection of alternative species or the introduction of other insects, as an option-wild pollinator. Similar conclusions were reached in another study devoted to the collection and analysis of information from research on this topic, authored by Toni et al. [12]. They also determined the weight as a key indicator and concluded that pollination using bumblebees had the greatest impact on the increase in yield.

Pollination by mixed species, on par with open pollination and pollination by bumblebees, as methods with the most statistically significant weight gain, is also discussed by Cooley and Vallejo-Marin [9]. They analysed the results of 73 experiments related to tomato pollination, in which the weight of fruits was evaluated or compared. In the study, the effects of auxin treatment, mechanical pollination with vibrations, and non-vibrating bees are observed to yield similar results. These approaches demonstrate negligible weight gain, suggesting no significant impact. In addition, it was concluded that different methods of pollination can give different effects on different tomato varieties. The researchers are also inclined to conclude that the frequency of flower visits directly affects the weight of the fruit.

Considering the findings of this study, which are confirmed by numerous papers by other researchers, it can be argued that pollination with the help of bumblebees most contributes to the productivity of tomatoes, both grown in the open ground and in the conditions of protected greenhouse soil. In addition, it reduces costs compared to the use of mechanical pollination with various devices that can simulate vibrations similar to those created by insects and the treatment of flowers with growth hormones that require the use of labour [32-34].

However, the quality of pollination is still largely affected by the conditions created for bumblebees. In particular, the use of pesticides for the treatment of tomato plants can have an extremely negative impact on the condition of both individuals and the colony of these insects. In addition, pesticide residues are found not only in the soil but also in fruits, which poses a danger to the health of consumers and reduces the quality and market value of products [1].

Sponsler et al. [35] identified the most vulnerable stages in the bumblebee life cycle, such as phenology, nesting, and social behaviour, as the most vulnerable to pesticide impact. In a greenhouse that is a limited space, the diameter of natural insect habitats does not matter – if a pesticide is used there, it will steadily accumulate both in the body of each insect and in the hive, which can affect pollinators fatally or sublethally [36]. The paper highlights, in addition to cases of mass extinction of bee and bumblebee colonies after treating significant plant areas with some type of pesticide, that there is also a less obvious negative impact on insects. In particular, they impair learning and the creation of new neural connections or can cause excessive neurostimulation, which causes loss of coordination, and paralysis, and can lead to death [37, 38]. Doses that did not lead to the death of adult insects were also observed to kill larvae that came into contact with poisoned individuals. To more accurately investigate the effects of pesticides on pollinating insects, Banks et al. [39] modelled a bumblebee colony by expressing its structure and the relationships between its constituent parts through differential equations using mathematical methods. They showed that the severity of pesticide exposure depends on the stage of development of the colony at which it encountered it. Thus, the most critical decrease in the number occurred when modelling pesticide treatment in the first month after the beginning of the differentiation of colony workers by function. After 5-6 weeks, toxicant exposure was less critical. However, various sublethal manifestations were observed, mainly realised due to a decrease in reproductive function. Thus, lethal and sublethal exposure to toxicants reduced the size of the simulated colony by half.

Therefore, pollination with bumblebees is the best option for tomatoes grown in greenhouses. It increases the quantity and quality of fruits, is eco-friendly, and does not require such significant investments as artificial pollination options. However, it should be borne in mind that bumblebees are living organisms that require certain conditions for functioning and life. In particular, to achieve the greatest pollination efficiency, it is important to reduce the impact of toxic compounds used in the processing of tomato plants.

## 6. CONCLUSIONS

*Solanum lycopersicon* are plants of the family Solanaceae that are naturally pollinated by insects that can produce characteristic vibrations by contracting the pectoral muscles. Wind pollination and self-pollination are possible but ineffective.

When growing tomatoes as greenhouse crops, there are options for mechanical pollination by treating them with phytohormones, mainly of auxin nature, and using devices that can simulate the vibration required to remove pollen, such as electric toothbrushes. However, these methods are not only expensive and energy-consuming, because they require the involvement of human resources, but also less effective than pollination with bees. Therefore, the use of insects as controlled pollinators can potentially reduce the cost of artificial pollination and at the same time environmentally improve the quantity and quality of tomato fruits.

In Albania, the most common natural pollinator of *Solanum lycopersicon* are *Bombus terrestris*. Representatives of species of this genus are still the only bees adapted to perform the function of pollinators in conditions of insufficient illumination of greenhouses.

The essence of this study was to create equal conditions for Pink Rock tomato plants adapted to growing in greenhouses, with their subsequent division into two groups: experimental and control. Before the first, after the beginning of flowering, beehives with bumblebees were placed to implement pollination, and the second group was not pollinated by any external intervention. At the end of the growing season, tomatoes were harvested at the maturity stage for further analysis. As a result, when comparing the weight, it was shown that at all the points studied, tomatoes formed by insect pollination had a larger weight than those farmed as a result of self-pollination. On average, the results of the weight were almost a quarter better for tomatoes pollinated by bumblebees, and the number of tomatoes in clusters was higher. When checking organoleptic parameters, the fruits formed by self-pollinated tomato flowers were less dense and had a worse, not-so-rounded shape.

The importance of the study is that it is the first scientific study on bumblebee pollination in tomato crops cultivated in greenhouses, in the Durres region. It brings concrete and evident data based on observation and experimentation of the bumblebee's pollination process in tomato crops cultivated in greenhouses, and presents pollination implemented by bumblebees as a choice of manual pollination at the local vegetable grower's community. Among the main limitations in conducting this study, the following can be mentioned: the high price of bumblebee hives for pollination offered by commercial companies which is caused by the Russia-Ukraine War; the lack of technical information in the Albanian language; problems with the arrival time of bumblebee hives for pollination.

Further research should be aimed at determining the physical and chemical characteristics, in particular, to investigate how the pollination method affects the content and composition of organic acids and carbohydrates and, accordingly, the taste of tomatoes. To conduct a study of sensory characteristics and determine consumer expectations for the taste and texture of tomatoes. It also makes sense to compare the cultivation of tomatoes in summer and winter and determine whether pollination using bumblebees can lead to the production of high-quality tomatoes in winter in protected ground conditions.

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## NOMENCLATURE

| | |
|---|---|
| g | gram |
| cm | centimetre |
| ha | hectare |
| kg | kilogram |