Role of pollination in yield and physicochemical properties of tomatoes (Lycopersicon esculentum)

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ABSTRACT

Very little is known about pollination and its effects on the yield and physicochemical properties of flowering plants in tropical countries. Wind and insect pollinators are among our natural resources because pollination is the most important ecosystem service performed by wind and insects, and is vital to the socio-economic status of human beings. In this experiment, different pollination methods for tomato plants were examined. Self-pollination was encouraged by covering the plants with a plastic sheet. Wind and insects were excluded from these plants, and thus only self-pollination was possible. The experiment occurred during the flowering stage. Wind-pollinated plants were covered with a muslin cloth, which excluded insects, and only wind could pass through the cloth. For insect pollination, plants remained uncovered, allowing free access to insects to pollinate the flowers. At fruit maturity, when fruits were completely red, fruits from each treatment were harvested on the same date and under the same conditions. Results illustrated the substantial importance of insects as pollinators of tomato crops. Open field had greater tomato yield and positive effects on physicochemical properties on fruit than under self and wind pollination.

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1. Introduction

The tomato (Lycopersicon esculentum) is the most common and widely used vegetable, being grown worldwide. Suitable temperature and relative humidity in summer increase the production of tomatoes. Tomatoes rely on different methods of pollination for enhancement of yield and better physicochemical properties of their fruit. It is clear from the decline in the achievement of sustainable agriculture that pollination in many areas of agriculture has been reduced (Kevan and Phillips, 2001).

In 2000, Pakistan’s portion of the world’s export of tomatoes was insignificant. The worldwide and national tomato production and export has increased since 2007. Pakistan is now producing approximately 5% of the world’s tomatoes, and the growth rate of tomato export is 8%. Thus, there are opportunities for tomato production and export. At present, Pakistan depends on the Middle East and Afghanistan markets for the export of tomatoes. Therefore, it is essential to search for other markets in the world with increased tomato export (Tahir et al., 2012).

Among cultivated crops, onions, chilies, and tomatoes are the most popular and significant to the human diet in Pakistan. These are baked with meat and with other vegetables, and they are used in salads. Therefore, these vegetables are essential in Pakistan (Bashir et al., 2015; Bashir et al., 2013; Lohano and Mari, 2005).

China is the top tomato producer, producing large amounts of tomatoes, followed by Turkey, India, Iran, and Bangladesh. The tomato production rate for the last decade was designated highest for Sri Lanka (9%) followed by Kazakhstan and Azerbaijan (8%).

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Tomato production in China was 7% and production of tomatoes in India and Pakistan was 5%. Total area for tomato production has increased globally from 4,022,729 ha to 4,837,576 ha from 2000 to 2008 (FAO, 2008).

Pakistan supplies chilies, onions, and tomatoes, which are major vegetable crops and play a vital role in human diet. Therefore, these crops provide substantial benefits to farmers and create opportunities for employment for rural people, because these crops require more labor compared to other crops because they require great care for maximum yield (Abrol et al., 2017; Adgaba et al., 2016; Mari et al., 2007).

In 2004–2005, Pakistan exported fruits and vegetables to many countries, including the United Kingdom, India, Dubai, Saudi Arabia, and Afghanistan (EPB, 2006). In Northwest Europe, approximately 80% of flowering plants depend on insects for their reproduction and pollination, and are responsible for the increase in yield (Kwak, 1994). The pollination success of these plant species depends on the activities of insects that visit and successfully pollinate the flowers. Every insect pollinator has its own pollination efficiency for flowers, based on behavioral features, such as foraging speed, flower constancy, pollen load on the body, pollen collection, and pollen transfer to the stigma (Said et al., 2017; Shaheen et al., 2017; Khan et al., 2012).

In Pakistan, tomatoes are cultivated on approximately 53.4 thousand ha of land, producing approximately 561.9 thousand tons of tomatoes. Of this, the province Punjab devotes 5.6 thousand ha to tomatoes, producing 72.5 thousand tons, which is 12.9 tons/ha higher yield in Punjab compared to the average for the country. The export price of tomatoes is 12,453 thousand rupees and production is approximately 997,147 kg. Similarly, the import price of tomatoes is 502,286 thousand rupees and production is 35,860,265 kg (GOP, 2008).

Tomatoes are usually consumed at their full maturity and when color is red, but before the fruit becomes soft. The color of the fruit is important for fruit picking and usage, and this color is considered the most important external characteristic for fruit selection and for postharvest life. This fruit color plays an important role in the consumer’s decision to purchase the tomato fruits. When the red color of the tomato fruit appears it indicates the degradation of the chlorophyll, as well as production of lycopene and other carotenoids, because chromoplasts are made from the chloroplasts (Fraser et al., 1994). Different products, such as paste, juice, and ketchup are made from tomatoes and are consumed worldwide. Tomato is a rich source of vitamin C and vitamin A, and it is used in various recipes (AVRDC, 1995). The demand for tomatoes is greatly increasing with the increasing human population of the world. It is necessary to produce more tomatoes in the field to fulfill the demand. Increasing fast food production in the country is also having a large influence on the demand for tomato products. It is believed this movement will continue in the near future and the use of tomatoes will rise. The popularity of tomato fruits is based on flavor, physicochemical properties, and nutritive values in terms of human health; thus, the tomato is the main constituent of many recipes (Grierson and Kader, 1986).

Tomato flowers are hermaphrodite, small (1–2 cm in diameter), having a yellow corolla and anthers. Tomato flowers also have five free stamens, whereas the anthers form a cone around the stigma (Minami and Haag, 1989). The seasonal summer crop of tomatoes is grown in open fields. They grow and reach maturity in warm places with there is ample light. Tomatoes are the most widely consumed vegetables worldwide among all vegetables grown under field and greenhouse conditions (Kaloo, 1986).

Lack of pollinators in an area can decrease the yield of tomatoes. Flower pollinators, such as birds, bats, honey bees, and insects play a crucial role in pollination and production for most vegetables and fruits. Without the assistance of pollinators, most plants could not breed and farmers would face great yield losses. In fact, approximately 90% of all the flowering plants depend on animal pollination (Buchmann and Nabhan, 1996; Free, 1993; McGregor, 1976). Many insects play important ecological services to horticulture crops, including pest control and pollination of crops (Losey and Vaughan, 2006; Tscharntke et al., 2005).

In view of the importance of tomatoes, a comprehensive study was designed to determine the efficiency of different pollination methods and their role in the yield and physicochemical properties of the tomato fruit.

2. Materials and methods

The experiment was conducted to determine the effects of different pollination methods (self, wind, and open/insect pollination) in terms of tomato yield and physicochemical properties. All agronomic practices were performed equally and irrigation also occurred on the same date, such that the experimental parameters could be calculated and compared accurately.

2.1. Study area

To determine the influence of pollinator biodiversity on the yield and physicochemical properties of tomatoes, we selected one of the richest vegetable growing area of the Dera Ghazi Khan, which is close to the Indus River, located in the revenue boundary of Mouza Gaddai Gharbi.

2.2. Duration and climatic condition

The study was conducted in different farmers’ fields within the Dera Ghazi Khan agroecological environment. Weather in the area is subtropical with hot summers and cold winters; the mean daily minimum and maximum temperatures and humidity range from 12 °C to 42 °C and 21% to 65%, respectively, with mean monthly summer rainfall of 18 mm. The experiment was performed from February to May 2014, and sampling was conducted every 2 weeks; however, the data were taken on clear sunny days, excluding cloudy and rainy days.

2.3. Comparison of different pollination methods in terms of yield and fruit physicochemical properties

An experiment was conducted to determine the effects of different pollination methods: self-pollination (close pollination) = T3, wind pollination = T2, and insect pollination (open pollination) = T1. To this end, we selected 40 plants for each treatment during their flowering stage. To ensure close pollination, we covered plants with a plastic sheet that allowed no entry of insects or winds. For the wind pollination treatment, we covered the plants with muslin cloth, which allowed the entry of wind while excluding insects. For the insect pollination treatment, plants were uncovered so insects could easily pollinate the flowers. After fruit formation and ripening in each treatment, the fruits were harvested to determine yield differences. To determine the efficiency of different pollination methods regarding yield, various parameters were recorded. These parameters were fruit weight (g), fruit size (length), fruit shape or fruit width, number of seeds/fruit, seed weight/100 seed, and fruit shelf life. Data were analyzed using one-way analysis of variance (ANOVA) and post hoc tests (Duncan’s multiple range test) with alpha set to 0.05. The details of each parameter and data analysis are provided below.
2.3.1. Fruit weight (g)
To evaluate the efficiency of each method, 50 fruits of the same age were harvested at 08:00, and weighed in laboratory at Ghazi University, Dera Ghazi Khan (D.G. Khan) using an electric balance. Each fruit was weighed to the nearest gram.

2.3.2. Fruit size (length)
We measured the fruit length (cm) of tomatoes from each treatment using Vernier calipers and the data were recorded into the data book. Fifty fruits from each treatment were measured.

2.3.3. Fruit shape or fruit width
Fruits from each treatment were measured to determine their widths. Fruit width was measured with a Vernier caliper in laboratory of the Ghazi University. Fifty fruits from each treatment were measured.

2.3.4. Number of seeds/fruit
Fruits from each treatment were dissected with a knife, and seeds were extracted from the placenta of the fruits. Wet seeds were placed in a butter paper bag to be easily cleaned. These thoroughly cleaned seeds were carefully counted in the laboratory to measure the seeds/fruit.

2.3.5. Seed weight (g)/100 seeds
After counting, seeds were washed with water to remove other fruit particles to attain an accurate weight. Washed and cleaned seeds were spread on butter paper for 72 h to dry. Then, 100 seeds from each treatment were weighed using an electronic balance. To maintain accuracy, we weighed 10 replicates for each treatment.

2.4. Comparison of physicochemical properties of tomato fruits based on pollination method
To determine and compare the physicochemical properties of tomatoes, the fruits were sent to the Food Technology Laboratory of BZU, Multan. Fresh fruits from the three treatments i.e. open pollination (T1), wind pollination (T2), and close pollination (T3) were harvested at the same date and time and 0.5 kg of tomatoes from each treatment were packed in a butter paper bag and then sent to the laboratory to determine the physicochemical properties of the fruits. The properties were evaluated on the basis of pH, acidity, moisture content, ash, fruit firmness, total soluble salts (TSS), white color (L), red color (a), and yellow color (b). Color of the fruits were considered a physical characteristic of the fruit. Data were analyzed statistically and results were compared among treatments.

2.4.1. Firmness measurements of fruits
Flesh firmness was measured immediately after color measurement, using a Chatillion DFG-50 penetrometer with an 11 mm plunger (Chatillion and Sons, USA). When the plunger reached the predetermined depth marked by an incision on the piston, the display value was noted. This value represented the resistance of the pericarp to the sinking of the plunger. Triplicate measurements were taken for each treatment with the resultant means calculated and expressed in Newtons (N).

2.4.2. Moisture content
The moisture content was estimated according to AACC official method 44-01 (AACC, 2000) by drying the sample in a hot air oven at 105 ± 5 °C until the weight of the sample was constant.

The moisture content was calculated as:

\[
\text{Dry matter (\%)} = \frac{\text{Wt. of dried sample (g)}}{\text{Wt. of fresh sample (g)}} \times 100
\]

\[
\text{Moisture (\%)} = 100 - \text{Dry matter}
\]

2.4.3. Total ash
Total ash estimation was determined by direct incineration of a sample in a tarred crucible using AACC method 08-01 (AACC, 2000). The crucible was heated on an oxidizing flame until it gave off no fumes and it was then ignited in a muffle furnace at 550 °C until grayish white residue was obtained. Finally, ash was calculated according to the following formula:

\[
\text{Ash (\%)} = \frac{\text{Wt. of ash (g)}}{\text{Wt. of sample (g)}} \times 100
\]

2.4.4. Total soluble solids (TSS)
Total soluble solids (TSS) were determined using the standard method described in AOAC (1998). Abbe’s refractometer was used to measure the total soluble solids of the tomato samples. The instrument was calibrated with distilled water and adjusted to 40 °C. The lens was cleaned with toluene and then 2–3 drops of the tomato (tomato was pressed to make it a paste) were placed on the lens of the refractometer and a reading was taken.

2.4.5. Color tonality of tomatoes
The classification of color by the United States Department of Agriculture (USDA) is widely used for tomato fruits. Colorimeters are used for measuring L*, a*, and b* values. It was stated that colorimeters and humans measure color in a different way (i.e., humans see colors in terms of lightness, hue, and chroma by integrating complex perceptions). Hue differences are much more easily detected than variations in chroma or lightness. Instruments, on the other hand, are capable of seeing pure values of any L*, a*, and b*.

The color of tomatoes was determined using the CIE-Lab Color Meter (CIELAB SPACE, Color Tech-PCM and USA). The lens of the instrument was placed on different sides of the tomato and color values of “L*” (lightness), “a*” (–a greenness; +a redness), and “b*” (–b blueness; +b yellowness) were recorded. The measurements were taken under constant lighting conditions using a white tile control (L*97.46, a*0.02, b*1.72).

3. Results
This research was conducted in the Dera Ghazi Khan region in the farmers’ fields with objectives to determine the role of different pollinators and pollination techniques on the yield and physicochemical properties of tomato fruits.

3.1. Efficiency of different pollination methods regarding yield
To determine the efficiency of different pollination methods regarding yield, various parameters were recorded. These parameters are fruit weight (g), fruit size (length), fruit shape (width), number of seeds/fruit, and seed weight/100 seed. Data were analyzed using one-way analysis of variance (ANOVA) and post hoc tests (Duncan’s multiple range test) with alpha set to 0.05. The details of each parameter and data analysis are provided below.

3.1.1. Fruit weight (g)
The results showed that T1 (open pollination) was significantly different from T2 (wind pollination) and T3 (self-pollination). Open pollinated field tomatoes, which were largely pollinated by insects, wind, and birds, had the largest mean value 109.76 g, which was highly significantly different than that of wind and self-pollinated fruits. Wind-pollinated crops had a mean of 72.97 g, which was significantly higher than that of the self-pollinated fruits (49.03 g), and self-pollinated fruits, thus, had the smallest mean. The percentage values of open, self, and wind-pollinated
fruits are shown in Fig. 1. The plants pollinated by insects had the maximum yield at 47.4% compared to wind (31.5%) and self-pollinated (21.2%) fruits (Fig. 1).

3.1.2. Fruit size (length)

The comparison of treatment means indicated that the fruits harvested from the open-pollination field were of larger (6.90 cm) than the fruits of wind pollination (6.02 cm), and the self-pollination (5.19 cm). The results showed that T1 (open pollination) were significantly different from T2 (wind pollination) and T3 (self-pollination).

3.1.3. Fruit shape or fruit width

Fruits harvested from the open-pollination field were of heavier, and had greater length and width. These fruits were also looked healthier. The average width of open pollinated fruit was 5.14 cm followed by wind 4.47 cm and self-pollinated fruits 3.77 cm (Table 1). Results are highly significant for the open pollination followed by wind and self-pollination. Thus, data analysis for fruit shape showed that fruits that were picked from the open field and were largely pollinated by insects had greater width. Wind pollination and self-pollination resulted in fruits that were smaller in size, although wind-pollinated fruits were larger than the self-pollinated fruits (Table 1).

3.1.4. Number of seeds/fruit

The results showed that the maximum mean value of 65.82 seeds/fruit was obtained from the open-pollination field. This was followed by mean values for wind pollination (63.22 seeds/fruit) and mean values for self-pollination (42.96 seeds/fruit) fruits (Table 1). The data for open pollination were highly significantly different from those of wind pollination, which were significantly higher than those of self-pollination fruit.

3.1.5. Seed weight (g)/100 seeds

The results showed that the weight of seeds from open pollination was greater than that of wind and self-pollination fruits. Mean value for open pollination was 27.66, for wind pollination was 24, and for self-pollination was 22.22. Results showed the highly significant value for open pollination and least significant for wind and self-pollination (Table 1). Seeds obtained from the open pollinated fruits were heavier in weight as compared to wind and self-pollination.

3.2. Physicochemical properties of tomatoes

The results of following parameters were as under.

3.2.1. pH value of the tomato fruit

It was clear from the results that the tomatoes pollinated by insects have lower values for pH compared to that of wind pollination and self-pollination. Self-pollinated tomatoes have more pH (5.00) than the wind pollination (4.97) and open pollination (4.89) (Table 2). Test: Duncan’s, Significance level: .05, Variance: 0.40, Degrees of freedom: 4, LSD 0.05 = 0.45.

3.2.2. Acidity of the tomato fruit

Acidity was measured in the lab and results were compared. Average acidity value of the tomatoes was compared and results showed there was greater acidity for the fruits from the open field of tomatoes (0.61), which were mostly pollinated by insects. This was followed by the wind pollination and close pollination, which both had equal (0.60) acidity values; however, differences were not significant (Tables 2).

Table 1

Comparison of mean treatments for fruit weight, size, shape, seed/fruit and weight/100 seeds.

| Treatments          | Mean fruit weight | Mean fruit size/length (cm) | Mean fruit shape | Number of seed/fruit | Seed weight (g)/100 seeds |
|---------------------|-------------------|-----------------------------|------------------|----------------------|---------------------------|
| T3 (self-pollination)| 49.03c            | 5.19c                       | 3.77c            | 42.96b               | 22.22b                    |
| T2 (wind pollination)| 72.97b            | 6.02b                       | 4.47b            | 63.22a               | 24.00b                    |
| T1 (open pollination)| 109.76a           | 6.90a                       | 5.14a            | 65.82a               | 27.66a                    |

All analyses were performed in triplicate and the mean values are reported. Mean values in the same column but with different letters vary significantly (P > .05).

Table 2

Comparison of mean treatments and replications of tomato fruit pH value, acidity, moisture content, firmness, ash, and total soluble salt.

| Treatments          | pH value factor1/factor2 | Acidity factor1/factor2 | Moisture Content factor1/factor2 | Ash factor 1/factor2 | Firmness factor1/factor2 | Total soluble salt factor1/factor2 |
|---------------------|--------------------------|-------------------------|---------------------------------|----------------------|--------------------------|---------------------------------|
| T3 (self-pollination)| 5.00/5.07               | 0.61/0.61               | 90.96/0.83                      | 0.73/0.74            | 49.27/47.82               | 3.67/3.57                       |
| T2 (wind pollination)| 4.97/4.90               | 0.60/0.61               | 92.44/0.78                      | 0.78/0.79            | 47.78/47.33               | 3.54/3.35                       |
| T1 (open pollination)| 4.89/4.88               | 0.60/0.59               | 92.66/0.79                      | 0.79/0.78            | 45.36/47.25               | 3.06/3.33                       |

All analyses were performed in triplicate, and the mean values are reported.
3.2.3. Moisture contents in the tomato fruit
Moisture content was determined and data were analyzed statistically and means were compared. Results were non-significant. Open field tomatoes had more moisture contents (92.17) than the wind pollination (90.02) and close/self-pollination (91.88) (Table 2). Test: Duncan's, Significance level: .05, Variance: 0.47, Degrees of freedom: 4, LSD 0.05 = 1.55.

3.2.4. Total ash in the tomato fruit
There was more ash in the tomato fruits obtained from the open field, which was open for pollination and was easily reachable by insects. Average of ash in the openly pollinated fruit was 0.79; for wind pollination was 0.78 and for close pollination it was only 0.73 (Table 2). Test: Duncan’s, Significance level: .05, Variance: 0.05, Degrees of freedom: 4, LSD 0.05 = 0.49.

3.2.5. Fruit firmness
Fruit firmness was determined and results were analyzed statistically and means were compared for open pollination method, wind, and close pollination method. Self-pollinated tomatoes have more fruit firmness (49.27) than the wind pollination (47.78) and open pollination (45.36) (Table 2). Test: Duncan’s, Significance level: .05, Variance: 1.09, Degrees of freedom: 4, LSD 0.05 = 2.36.

3.2.6. Total soluble salts (TSS)
TSS was determined and results were analyzed statistically. Means were compared for open pollination method, wind, and close pollination method. TSS was more in the fruits obtained from the close pollination method (3.67) followed by wind pollination (3.54) and the open pollination method (3.06) (Table 2). Test: Duncan’s, Significance level: .05, Variance: 2.64, Degrees of freedom: 4, LSD 0.05 = 3.68.

3.2.7. Colors of the fruits
The results pertaining to color of tomatoes were as under

3.2.7.1. White color (L) of the tomato fruits.
Average value of “L” for open-field tomatoes was 62.87, and for wind pollination it was 58.75, and for close pollination its value was 58.14 (Table 3). Table 3 showed that the all treatments were significantly different from each other. Test: Duncan’s, Significance Level: .05, Variance: 2.64, Degrees of freedom: 4, LSD 0.05 = 3.68.

3.2.7.2. Red color (a) of fruits.
Average value of “a” for open field tomatoes was 36.97, for the wind pollination method it was 40.89, and for close pollination it was 42.76 (Table 3). T2 and T3 were significantly different from T1. Test: Duncan’s, Significance Level: .05, Variance: 1.68, Degrees of freedom: 4, LSD 0.05 = 2.94.

3.2.7.3. Yellow color (b) of the fruits.
The average value of “b” for open field tomatoes was 23.99, for wind pollination method was 23.68, and for self-pollination was 24.91. T1 and T2 were significantly different from T3 (Table 3). Test: Duncan’s, Significance Level: .05, Variance: 5.51, Degrees of Freedom: 4, LSD 0.05 = 5.32.

4. Discussion
Results showed that open pollination, which was largely insect pollination + wind pollination was responsible for an increase in yield and positive effects on physicochemical properties of tomato fruit. In our research three different pollination methods were evaluated on the basis of following yield parameters:

1-fruit weight (g)
2-fruit size (cm)
3-fruit shape (cm)
4-number of seeds/fruit
5-seed weight/100 seeds.

Physicochemical properties such as TSS, fruit firmness, acidity of fruits, pH value, color of fruits (L, a, b), and moisture content were also evaluated and results were compared with different treatments: open pollination, wind pollination, and self-pollination. Results were significant for pH values for the close pollination, followed by the wind and open pollination. Results for acidity were significant for open pollination, followed by the close and wind pollination. There was greater moisture content in the open pollinated fruits, followed by the close pollination and wind pollination fruits. Results were significant for ash in the fruit for open pollination, followed by wind pollination and close pollination fruits.

Results were also significant in terms of fruit firmness for open pollination, followed by the self and wind pollination fruits. Most of the fruits from open pollination were whitish in color, followed by close and wind pollination fruits. Fruits from the wind pollination were of red color, followed by the wind and open pollination fruits.

Three pollination methods i.e., open pollination, wind pollination and self-pollination, were performed in the field and the results were analyzed statistically using Duncan multiple range test. Forty plants were covered with a plastic sheet for self-pollination, which provided less yield and physicochemical properties of fruit was not so improved than the other two methods. Forty plants were covered with a muslin cloth for wind pollination only, and this method provided more yield and good physicochemical properties than the self-pollination method, but less than the open pollination. Forty plants were in the open pollination population and at maturity 50 fruits from each treatment were picked and desired parameters were calculated.

Open pollination was found to be a more efficient method of pollination. Maximum yield was obtained from open pollination and fruits physicochemical properties from this method were improved as compared to the other methods (wind and self-pollination). Fruits picked from the open field were heavier in weight than the fruits picked from the covered plants. Fruit shape and size was also greater in the open field tomatoes. Consequently, there were more seeds in the tomatoes from the open field. Shelf life of the fruit was checked at 25 °C, and the shelf life of the fruits of open field was greater based on daily observation. In the open-pollination field, tomato flowers were clearly visible to attract the insects. Tomatoes that are visible have maximum chances for pollination success by different means, such as wind and animals. If a farmer maintains populations of insects that are helpful in pollination, then he can obtain a higher yield than a farmer who uses pesticides more than required to limit harmful insects visiting flowers.

Our results are similar to those of Chapagain and Weisman (2004), who reported that open field natural pollination for tomatoes had a strong positive effect on the fruit set, yield, fruit weight, size, and seed number, which were extremely higher than those of tomatoes pollinated under muslin cloths. This indicated that prevention of biotic agents play a crucial role in decreasing different
yield parameters and production development for field grown tomatoes, which is a major fruit crop, and a particular concern to producers throughout the world.

Our results are similar those of Klein et al. (2007) who conducted an experiment with greenhouse tomatoes and studied the behavior of pollinators. The results showed that more than 70% of crops in the world are pollinated by bio agents, of which insects are the most important pollinators for crops and vegetables, and increase yield. In several countries, pollinators have declined because of unfavorable conditions, hence pollination efficiency of the crops decreased and yield is also reduced.

Klein et al. (2003) conducted an experiment on pollination and the results indicated increased yield following insect pollination as compared to non-pollination and without insect pollination. It was also reported that the interaction between flowering plants and insect pollinators is necessary for maximum yield.

Our results are similar to those of Wilcock and Neiland (2002), who conducted an experiment on field tomatoes. Tomatoes were grown in an open field for insect pollination and some plants were covered for no or self-pollination. The results showed that fruit quality and quantity was limited if pollinators biodiversity was not encouraged in the field for tomatoes. If insect biodiversity is established in the field or in the greenhouse, then the quality and quantity of fruits of tomatoes will be maximized. Our results are also similar to those of Vaissière et al. (2011), who reported that in Southeast Brazil, the pollination performed by the insects played a vital role in successful pollination of tomato flowers and increased the yield to an optimum level. Hence, quantity and quality of fruits would be increased by insect pollination. If there is a pollination deficiency, it can be improved by manual pollination by hand or with a mechanical vibrator to obtain maximum production from tomatoes. Our results differ from those of Del Sarto et al. (2005), who reported that the two parameters used to evaluate the quality of fruits (the widest circumference and the number of seeds) from the greenhouse, did not differ between fruits resulting from spontaneous self-pollination and supplemental manual cross pollination, which means that no significant difference in quality was observed for fruits originating from self-pollination and from an action simulating pollinators. No difference was recorded for the same parameters regarding fruits pollinated by self, manual vibration, and vibration performed by bees.

There were more a greater number of seeds/fruit obtained from open-field and similar results were reported by Macias et al. (2009). They conducted a field experiment to count the seeds/fruit obtained from open pollination and self-pollination. Their results also showed increased yield and a greater number of seeds/fruit in open field tomatoes compared to self-pollinated tomatoes. Open field tomatoes were pollinated by honey bees and native bees. Our results are similar to those of Al-Attal et al. (2003), who conducted an experiment on the pollination of tomatoes performed by *Bombus* spp. According to the results presented here, the importance of bees is mostly related to the increase in fruit, and consequently on the productivity of this crop. The majority of studies have demonstrated the importance of *Bombus* species on the pollination of tomatoes.

Our results from the open field were significant and were followed by wind pollination and self-pollination. Flower visitors (insects) increased the efficiency of pollination of the tomato flowers and a greater amount of pollen was transferred from anthers to the stigma.

5. Conclusion

Pollination activity was increased because of the favorable season for the insects and ultimately the quantity and the quality of the tomato fruit was increased up to a maximum level as shown by our results. The results showed that insects and wind are the main sources for pollination of tomatoes in Pakistan, especially Dera Ghazi Khan. If the farmers or researchers encourage the population of flower visitors, then they can obtain a greater yield compared to self-pollination. Insecticides can damage the populations of the pollinators and lower their biodiversity, as such the use of insecticides should be minimized to encourage the pollinator biodiversity to obtain maximum tomato production.

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