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Eggplant production in a protected environment with plant vibration

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Abstract

The aim of this study was to evaluate the production of eggplant fruit according to plant vibration in two types of protected environments, with and without an aphid-proof screen, preventing or permitting the entry of pollinators. Two eggplant hybrids (Roxelle, clear purple color and round shape fruits, and Kokushi, purple color and elongated fruits), two vibration treatments (with or without plant vibration), and two environments (with or without screen) were assessed. The split-plot experiment had a randomized block design, with four replications. The plots consisted of the plants' vibration or non-vibration, and the split-plots consisted of the hybrids. To compare the two environments, a conjoint analysis was performed. The plants were vibrated for approximately 5 s by manually shaking the wire where the plant stick was fixed, twice a day, from the beginning of flowering till the last immature fruit harvesting. The number of seeds per fruit and fruit yield per plant were evaluated. It was concluded that the presence of insects in the open environment increases marketable fruit yield only in hybrid Roxelle (2120 and 1172 g plant^{-1}, with and without insects, respectivelly), the number of seeds per fruit in both hybrids in treatment without plant vibration (average of 584 and 110 seeds, with and without insects, respectivelly), and that plant vibration may partially replace the absence of pollinator insects in a closed environment protected with a screen, with an increase in fruit yield.

Keywords: insects; pollen; pollination; seeds; *Solanum melongena* L.

Introduction

The eggplant (*Solanum melongena* L.) is a Solanaceae originating from the tropical regions of the Eastern Hemisphere and cultivated by Chinese and Arabs for many centuries. Although the cultivated area in Brazil is still small, a little over 1200 ha (ABCSem, 2014), there has been an increase in the consumption of this vegetable driven by a demand from consumers for healthier products with medicinal properties. In this respect, the eggplant stands out due to its cholesterol-lowering properties (Gonçalves et al., 2006). The eggplant has hermaphroditic flowers and reproduction occurs preferentially by self-pollination. However, the percentage of natural cross-pollination varies with the cultivar, with an estimated average of 6%, but it can reach approximately 50%. This rate increases in areas where high populations of pollinator insects occur (Ribeiro et al., 1998). Eggplant flowers contain poricidal anthers, which store pollen inside, releasing it only when vibrated. This vibration can be performed manually, by the wind (when cultivated in an open field), or by insects, in particular bees. Due to the great number of existing cultivars, some controversy exists regarding the need for using pollinators for fruit production and the efficiency of particular species of bees as pollinators (Nunes-Silva et al., 2010). There are reports of various species of bees adapted to the pollination of Solanaceae (Cruz et al., 2005; Hogendoorn et al., 2006; Gemmil-Herren and Ochieng, 2008; Palma et al., 2008) in which pollination occurs by flower vibration (Nunes-Silva et al., 2010). In closed, protected cultivation structures using screens, a decrease in air circulation speed occurs along with the impediment of the entry of insects, which may hinder pollination and fertilization, and therefore affect fruit yield and quality (Higuti et al., 2010). In Brazil, the use of stingless bees for pollination in greenhouses is virtually non-existent (Nunes-Silva et al., 2010), probably due to the unavailability of large numbers of bee colonies (Cortopassi-Laurino et al., 2006) and the limited knowledge concerning this subject (Slaa et al., 2006). Pollination by bee vibration has been described by Nunes-Silva et al. (2010). This type of pollination is particularly important for the cultivation of species belonging to the Solanaceae family, such as tomatoes, eggplants, peppers, and sweet peppers. The mechanical vibration of tomato plants at the flowering phase may increase the pollen grain supply to the stigma, providing a better ripening and quality of fruits, as reported by Higuti et al. (2010). Palma et al. (2008), who studied different pollinators and mechanical vibrations in tomatoes, found that there was an increase in fruit yield in the presence of insects, and that this process was superior to the mechanical vibration treatment. Gemmil-Herren and Ochieng (2008) and Kowalska (2008) reported the inflorescence vibration as an alternative to fruit set in eggplant for cultivation under covers. However, no studies on eggplant production with plant vibration were found, and there is controversy regarding the importance of insects in the pollination of this species.

In view of the above, the aim of this study was to evaluate the production of fruit and seeds of two eggplant hybrids according to plant vibration in a protected environment with or without lateral closing using a screen.

Results and discussion

In the conjoint analysis, the interactions among factors (hybrids, plant vibration and environments) were significants for all traits evaluated. Plant vibration did not influence the

Table 1. Marketable fruit weight (MFW), total fruit weight (TFW), total number of fruits (TNF), number of marketable fruits (NMF) per plant, and number of seeds per fruit (NSF) of eggplants depending on plant vibration and hybrid in the different environments (open and closed greenhouse).

Plant vibration	MFW ($g \cdot pl^{-1}$)		TFW ($g \cdot pl^{-1}$)		TNF		NMF		NSF	
	Open	Closed	Open	Closed	Open	Closed	Open	Closed	Open	Closed
Roxelle										
With	2169 aA	1546 aB	2213 aA	1742 aB	6.62 aA	7.37 aA	5.87 aA	6.25 aA	799 aA	272 aB
Without	2072 aA	798 bB	2252 aA	956 bB	7.00 aA	4.43 aA	6.31 aA	3.75 bB	804 aA	202 aB
Kokushi										
With	458 aA	504 aA	1251 aA	1175 aA	17.68 aA	20.73 aA	5.43 aB	9.00 aA	155 aA	73 aA
Without	548 aA	260 aA	1183 aA	1222 aA	17.18 aA	20.37 aA	7.37 aA	6.06 bA	364 aA	17 aB

Means followed by the same letter for each characteristic and for each hybrid, uppercase in rows and lowercase in columns, were not significantly different at $p \leq 0.05$ using Tukey's test.

Table 2. Marketable fruit weight (MFW), total fruit weight (TFW), total number of fruits (TNF), number of marketable fruits (NMF) per plant, and number of seeds per fruit (NSF) of eggplants depending on plant vibration, environment (open and closed greenhouse), and hybrid.

Hybrids	MFW ($g \cdot pl^{-1}$)		TFW ($g \cdot pl^{-1}$)		TNF		NMF		NSF	
	Open	Closed	Open	Closed	Open	Closed	Open	Closed	Open	Closed
With plant vibration										
Roxelle	2169 aA	1546 aB	2213 aA	1742 aB	6.62 bA	7.37 bA	5.87 aA	6.25 bA	799 aA	272 aB
Kokushi	458 bA	504 bA	1251 bA	1175 bA	17.68 aA	20.73 aA	5.43 aB	9.00 aA	155 bA	73 aA
Without plant vibration										
Roxelle	2072 aA	798 aB	2252 aA	956 aB	7.00 bA	4.43 bA	6.31 aA	3.75 aB	804 aA	202 aB
Kokushi	548 bA	260 bA	1183 bA	1222 aA	17.18 aA	20.37 aA	7.37 aA	6.06 aA	364 bA	17 aB

Means followed by the same letter for each characteristic and for each hybrid, uppercase in rows and lowercase in columns, were not significantly different at $p \leq 0.05$ using Tukey's test.

total and marketable fruit weight of the Roxelle hybrid in the open environment (Table 1). In the closed environment, there was a significant increase in the total and marketable fruit weight with plant vibration. When comparing the environment effect, the Roxelle hybrid had higher fruit weight in the open environment both with and without plant vibration. On the other hand, the total and marketable fruit weight of the Kokushi hybrid was not influenced by the environment or plant vibration. Probably, Kokushi hybrid has a higher rate of self pollination than Roxelle and can be recommended for production in closed environments. The same was observed by Cardoso (2007) that did not obtain an effect from vibration in the weight of sweet pepper fruits in five hybrids, which can be explained by the high autogamy in the sweet pepper hybrids evaluated, which were all recommended for cultivation in protected environments. This difference in results between hybrids confirms the report by Ribeiro et al. (1998) in eggplants regarding the importance of insects in the cross-pollination rate and its variation among varietal differences. For both hybrids, the combinations between environments and plant vibration did not influence the total number of fruits (Table 1). For Roxelle hybrid, the number of marketable fruits obtained in the open environment did not vary as a result of plant vibration; however, in a closed environment, plant vibration significant increased this characteristic. On average, there were 2.5 more marketable fruits in the vibrated plants than the non-vibrated plants. In the absence of plant vibration, the type of environment influenced the number of marketable fruits, in that this number was higher in the open environment. However, when plant vibration was performed, the statistical difference was no longer existed, proving the positive effect of that method in a closed environment for the Roxelle hybrid. Kinet and Peet (2002) reported that the formation of small, defective, non marketable fruits might occur due to flaws in pollination. Similar results were obtained by Higuti et al. (2010) with plant vibration in tomatoes. Kowalska (2008) related that flower vibration had effect in eggplant, but it is not so efficient as pollination by insects. This author did not test plant vibration, just flower vibration. Free (1975) conducted an experiment comparing eggplant fruit production when flowers were either exposed or not exposed to visiting insects, and concluded that, with or without visitation, the fruit set remained at 38%, and reported that self-pollination presented a satisfactory production of fruits. However, this did not occur in this study in both hybrids, probably due to the different cultivars used, which may differ in their level of autogamy and need for insect pollination. In both hybrids, the vibration of plants did not influence the number of seeds per fruit, regardless of the cultivation environment evaluated (Table 1). In sweet peppers, Wien (2000) reported that the shaking of plants probably contributes to pollination, with an increase in the formation of seeds. However, when working with sweet pepper hybrids recommended for cultivation in protected environments, Cardoso (2007) did not obtain differences in the number of seeds with or without plant vibration in a closed environment with screens. On the other hand, Higuti et al. (2010) observed an increase in the number of seeds per fruit with plant vibration in five tomato hybrids. Nevertheless, the Roxelle hybrid produced more seeds per fruit in an open environment, with or without plant vibration, than the closed environment. Without plant vibration, more seeds per fruit were obtained in the Kokushi hybrid in the open environment than in the closed. With plant vibration, the number of seeds per fruit in this hybrid did not differ between the environments. Even in the best treatment, the number of seeds obtained was lower than that obtained by Polverente et al. (2005), in the eggplant cultivar Embu with open pollination (2100 seeds/fruit). These contrasting results were due to varietal and environmental differences, and, probably, the population of pollination insects, since the area used by these authors was located near an apiary of honeybee (*Apis mellifera*). The type of environment influenced the number of seeds per fruit, with the open one resulting in a higher number of seeds, compared to the closed environment (Table 1), except for Kokushi hybrid with plant vibration, showing deficient pollination in the absence of pollinator insects. It was observed intense bee activity, mainly honeybee (*A. mellifera*) and the "irapua" bee (*Trigona* spp.), in flowers, with, at least, five visitations per flower in the opened environment. Various authors have reported on the importance of insects in the pollination of Solanaceae (Cauich et al., 2004; Cruz et al., 2005; Sarto et al., 2005; Hogendoorn et al., 2006; Serrano and Guerra-Sanz, 2006; Palma et al., 2008; Bispo-Santos et al., 2009); however, the majority was on tomatoes and sweet peppers. Abak et al. (2000), Gemmill-Herren and Ochieng (2008), Kowalska (2008) and Nunes Silva et al. (2010) reported on the importance of the different species of bees in the pollination of eggplant flowers. According to Nunes-Silva et al. (2010), the pollinator insects curl themselves over the flowers, contracting their thoracic muscles, which promotes vibrations and causes higher pollen liberation. For this reason, it was expected that the manual plant vibration treatment could favor a higher production of seeds and fruits. However, this was not as efficient in increasing the number of seeds per fruit. In tomatoes, Palma et al. (2008) observed that mechanical vibration resulted in a fruit setting similar to that obtained with insect pollination; however, the latter was more efficient in the production of seeds per fruit and in the increase of the average weight of fruits, as observed in this research (Table 1). Total and marketable fruit weight statistically differed between the hybrids evaluated, in that Roxelle hybrid weight were higher in both the open and the closed environments (Table 2), probably because its fruits are heavier than fruits of hybrid Kokushi. While Roxelle fruits are round shape (diameter of 5-8cm), Kokushi ones are elongated (diameter of 2-3cm). Nevertheless, the total number of fruits of the Kokushi hybrid was higher in both environments. In the closed environment, Kokushi produced more marketable fruits. When cultivated in an open environment, the Roxelle hybrid produced more seeds per fruit, differing from Kokushi. Besides treatments effects, there are varietal differences in seed and fruit production. Probably Kykushi hybrid has a higher rate of self pollinating and production of fruits with few seeds, nearly parthenocarpic ones, because there were fruits, in closed environment, with less than ten seeds. The various differences observed between the hybrids were expected due to the genetic differences among them, since they belong to different varietal groups and do not compete for the same market. Nevertheless, it is important to evaluate whether plant vibration is beneficial in eggplant hybrids of different varietal groups, since these may differ in their level of autogamy (Ribeiro et al., 1998) and need for pollinator insects and/or plant vibration for the production of fruits, as verified in this research.

Materials and Methods

Locality and environments

The experiment was conducted in the São Manuel Experimental Farm, College of Agronomical Sciences (FCA), São Paulo State University (UNESP), Botucatu Campus, located in the municipality of São Manuel, SP, Brazil. The geographical coordinates of the site are 22°44′ S, 48°34′ W, and it has an average altitude of 750 meters. The predominant climate of the municipality of São Manuel is type Cfa, humid subtropical (mesothermal) climate, according to Köppen's classification, with an average temperature in the warmest month higher than 22 °C, and with an average annual precipitation of 1377 mm (Cunha and Martins, 2009). During the experimental period, the average maximum daily temperatures varied from 22 °C to 45 °C, and the average minimum daily temperatures varied from 8 °C to 22 °C. The experiment used two arch-type, metallic unheated greenhouses that were 7.0 m wide, 20.0 m long, and with a floor-to-ceiling height of 2.5 m, and covered with 150-µm thick, transparent, low-density polyethylene film. One of these structures had its laterals totally closed with an anti-aphid screen, which prevented the entry of insects and the incidence of wind, whereas the other was left with opened laterals, allowing the entry of pollinator insects.

Treatments and experimental design

In each protected environment structure, four treatments were evaluated through the combination of two hybrids, Roxelle (fruits that have an external color of clear purple, white pulp, and round shape) and Kokushi (Japanese type, with purple color and elongated fruits), with two treatments, with and without plant vibration. The experimental design was in randomized blocks with the four treatments arranged in sub-plots, and four replications. The plots consisted of plant vibration or non-vibration, and the sub-plots consisted of the hybrids used. Each sub-plot contained six plants, from which the first four were used to evaluate the production of immature fruits, and the remaining two were used to evaluate seed production per fruit by leaving them on the plant until ripening. The seeding was performed in expanded polystyrene trays with 128 cells using a commercial substrate. Once seedlings had four leaves they were transplanted at 1.0 × 0.5 m spacing. The staking was performed using bamboo sticks individually and independently in each plot so that there was no interference from a plot with vibration to a plot without vibration. The sprouts arising below the first flower were removed. Plant vibration stimulation was performed manually, and initiated when the plants presented the first floral bud about to reach anthesis and finished when the last fruit were harvested. Vibration treatments were performed during the morning (7:30) and afternoon (4:30) periods by manually shaking the wire where the plant stick (bamboo) was fixed for approximately 5 s, with the aim of liberating as much pollen as possible, according to the methodologies used by Cardoso (2007) for sweet peppers and by Higuti et al. (2010) for tomatoes. After first harvesting, it was measured the insect visitation in a sample of ten flowers per subplot.

Traits measured

The immature fruits were collected when they reached market size (25–30 cm) and the typical shape for each cultivar. The following characteristics were evaluated: fruit yield (number and weight) of total fruits and marketable fruits (with no apparent defects) per plant. The fruits that were left in the plants until ripening were collected and left to rest for seven days to standardize seed maturation and facilitate seed extraction. This way, the number of seeds per fruit could be evaluated, which is an indirect measure of pollination efficiency. For the extraction of seeds, the fruits were cut and washed in a sieve, separating the pulp from the seeds. The seeds were dried in the shade for 72 hours and stored in a dry chamber (20 °C and 40% RH). The cleaning process to remove the hollow and damaged seeds was performed using a density-based separation device, model "De Leo Type 1," and only the good seeds were counted.

Statistical analysis

The statistical analyses were performed using the statistical program SAS (Statistical Analysis System), version 9.1.3, and the means were compared using Tukey's test (5%). The environments (with or without screen) were compared by conjoint analysis, considering each environment as one experiment.

Conclusions

The presence of insects in the open environment increased the number of seeds per fruit and the production of eggplant fruits, total and marketable, in hybrid Roxelle. In hybrid Kokushi, the presence of insects in the open environment increased the number of seeds per fruit just in treatment without plant vibration. Plant vibration may partially replace the absence of pollinator insects in eggplants cultivated in a closed environment with a screen, with an increase in fruit yield.

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