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FLOWERING BIOLOGY OF EGGPLANT AND PROCEDURES INTENSIFYING FRUIT SET – REVIEW

Grażyna Kowalska
University of Life Sciences in Lublin

Abstract. The paper presents literature data on the flowering biology of eggplant and the influence of flower heterostyly on yielding. Flowers with long–styled pistol are the majority among all flowers on a plant (60%). Number of flowers with medium and short style is lower (10–15% and 22–30%, respectively). Eggplants set fruits from flowers with long style in 49–100% and with medium style in 46–85%. These flower's stigmata have well – developed nodules and well – permissible tissues rich in polysaccharides, proteins styled flowers have small stigmata with underdeveloped nodules and, due to worse absorption, they are not pollinated and do not set fruits. Taking into account the complexity of many factors that make difficult or impossible to self-pollinate the eggplant's flowers, the efficiency of three procedures intensifying the fruit budding has been presented: bunch vibrating, flower harmonization, and natural pollinating by bumblebees. Many authors' studies confirm that flower bunch vibrating has not caused sufficient pollen setting on stomata and has not been sufficient for good eggplant flower pollination. Applying growth regulators appears to be more efficient and significantly affects the improvement of eggplant's yielding. The highest efficiency has been achieved when applying insects as natural pollinators at cultivating the eggplant under covers.

Key words: *Solanum melongena* L., heterostyly, hormonization, pollination by bumblebees, yielding

FLOWERING BIOLOGY

Eggplant (*Solanum melongena* L.) is a vegetable from *Solanaceae* family that originates from warm India and Chine regions [Lawande and Chavan 1998]. Wild and thorny Indian *Solanum incanum* L. or *Solanum insanum* L. Roxb. species are suspected to be the plant ancestors. The eggplant in warm climate is a perennial; its bushy and ligneous plants reach even 3m height. Under moderate climate, it is cultivated as annual

Corresponding author – Adres do korespondencji: Grażyna Kowalska, Central Apparatus Laboratory, University of Life Sciences in Lublin, 13 Akademicka St, 20-950 Lublin, Poland, e-mail: grazyna.kowalska@up.lublin.pl

plant reaching only 0.5–1 m of height. The eggplants begin flowering after forming – depending on a variety – 9 to 12 assimilation leaves, i.e. about 70–90 days after emergence. Eggplant is a self-pollinating plant, although it can be cross-pollinated (6–10%) that results from transferring a pollen by insects such as ants, thrips, and bees [George 1985, Lawande and Chavan 1998]. The eggplant flowers are hermaphrodite; they are single or arranged in inflorescences composed of 2–7 flowers each, and show positive geotropism [Konys 1993]. The flower buds develop in the corners of the same leaves as vegetative buds. At the beginning of flowering stage, eggplant flowers are very close to one another. When internodes are longer, the distances between flowers also increase [Shah and Patel 1970]. Results achieved by Prasad and Prakash [1968] in study upon flowering biology of four eggplant varieties indicate that young flower buds are oval or conical in shape and green in color. In practice, the time of their opening is the same. The largest number of flowers open between 7:00 and 8:00 a.m. At 2:00 p.m. flowers begin to close and late at night they are completely closed. In the morning, flowers open again and the whole cycle repeats for about 1–3 days. Following days, flowers close only in part. The manner flowers open and close depends on the flower's age, and environmental conditions, namely air temperature and relative humidity.

Fig. 1. Flower of eggplant
Ryc. 1. Kwiat oberżyny

The eggplant flowers are quite large 3–5 cm in diameter (fig. 1). The corolla consists of 5–10 accreted petals of purple, pink, or white color depending on a variety. Number of stamens is 5–7. Filaments are short, 6–20 bicameral anthers are yellow and arranged around pistil [Mc Gregor 1976]. When a flower blooms, the pollen grains and germ sack are fully formed. The anthers break in upper direction 15–30 minutes after flower opening. The pollen is quite heavy. It can be spontaneously transferred for up to 1 m distance. The pollination duration depends on air temperature and humidity [Prasad and Prakash 1968].

Fig. 2. Eggplants just before harvest
Ryc. 2. Owoce oberżyny przeznaczone do zbioru

Fig. 3. Transverse section of eggplant fruits at utility ripeness stage
Ryc. 3. Przekrój poprzeczny owoców oberżyny w fazie dojrzałości użytkowej

The eggplant fruits are multi-chamber berries of different shapes. Depending on a variety, they may be: spherical, through oval, ovoid, piriform, to elongated and spiral (fig. 2). Black-purple fruits, in the skin of which anthocyanins are present, dominate in cultivation. There are also white-colored varieties, the skin of which does not contain those pigments. At the stage of utility ripeness, fruits are light yellow to black-purple, while brown-yellow or grey-green at the physiological ripeness stage [George 1985]. The skin and parenchyma color is associated with the fruit color. When the skin is colorless, fruit's parenchyma is white, yellow, or light green. When skin contains pigments, the parenchyma is usually dark – purple (fig. 3). Large, five-section hairy and thorny corolla strongly accreted with the ovary, which makes nursery operations, fruit harvest, and storage difficult, is characteristic for the eggplant fruits [Krug 1991]. Fruit's color, sometimes its growth, depend on the flower's localization in an inflorescence. Side flowers characterized by slower growth rate and less intensive color, set smaller and lighter fruits. Up to 1-25 fruits, about 30-2000 g each, may be set on a single eggplant plant.

HETEROSTYLY AT EGGPLANT FLOWERS AND THE INFLUENCE ON YIELDING

It was reported that eggplant flowers show heterostyly phenomenon [Prasad and Prakash 1968, Rylski et al. 1984, Handique and Sarma 1995, Górecki and Espinosa-Flores 1996, Passam and Bolmatis 1997, Kowalska 2003a, 2006]. The pistil length in eggplant's flowers depends on a plant's age. Studies of Passam et al. [2001] revealed the pistil length between 0.95 and 1.18 cm, which was significantly longer as compared to those flowers shaped after the first fruits formation (0.73 and 0.72 cm). Some aspects of eggplant flower's morphology were examined in India at the beginning of the 20th century [Handique and Sarma 1995]. Later, eggplant's flowers were classified on a base of pistil relative to stamens length. Flowers, in which stigmata were localized above anthers, were called high-pistil ones, while when stigma was at the same level as anthers – medium-pistil, and flowers with rudimentary pistil – low-pistil flowers (fig. 4). In addition, some authors distinguished sub-groups by detailed measuring of pistil length [Prasad and Prakash 1968, Passam and Bolmatis 1997]. At eggplant, the largest number of all flowers is made up by high-pistil ones (over 60%). Number of medium-pistil and low-pistil flowers is considerably lower: 10–20% and 20–30%, respectively. In general, eggplants produce fruits from high-pistil in 49–100% and medium-pistil flowers in 46–85% [Górecki and Espinosa-Flores 1996, Passam and Bolmatis 1997, Kowalska 2003a, 2006]. Rylski's et al. [1984] as well as Handique and Sarma's studies [1995] revealed that these flower's stigmata have well-developed nodules and well-permeable tissues abundant in polysaccharides, proteins, and other nutrients. They are also characterized by high pollen absorption capacity. The low-pistil flowers have small stigmata with undeveloped nodules. Dense tissues of low permeability contain small amounts of nutrients, which makes impossible to germinate for pollen and fruit setting. Studies upon eggplant flower's gynaecium revealed that ovary size was similar: 1.83–0.016 mm for high-pistil and 1.62–0.03 mm for low-pistil flowers. According to Prasad and

Prakash [1968], stigma's sensitivity depends on the flower's age. Maximum absorptivity of stigmata for pollen – about 90% – occurs at the day of flower opening. Along the time, it decreases to be completely reduced after 5 days. Pal and Singh [1943] observed similar cycles in stigma's sensitivity. Maximum absorptivity of the pollen occurs a day after flower opening. Studies upon eggplant's stamina at high-pistil and low-pistil flowers revealed that they did not differ referring to pollen grain number in anthers, as well as shape and size. No differences in stamina fertility between high-pistil and low-pistil flowers were also found [Rylski et al. 1984]. The pollen fertility under low temperatures range from 6% to 45% [Abak and Guler 1994]. The flower development along with low auxins contents and low potassium level due to insufficient flow of nutrients favor producing the low-pistil flowers [Handique and Sarma 1995]. Tendency to form different-pistil flowers at eggplant is characteristic for particular variety [Prasad and Prakash 1968, Kowalska 2003a, 2006], but it also depends on other factors such as fruiting dynamics and plant's age [Lenz 1970], as well as environmental conditions [Sun et al. 1990, Abney and Russo 1997].

OPERATIONS IMPROVING THE FRUIT SETTING AT EGGPLANT

Under worse environmental conditions, the eggplant (*Solanum melongena* L.) is characterized by great variability of fruit setting and yielding. Amoako and Yeboah-Gyan [1991] reported that the plant is partially self-inconsistent and requires cross-pollination for better fruit setting. An appropriate flower pollination is one of the principal conditions for achieving good-quality yields and seeds [Mc Gregor 1976, Polverente et al. 2005]. Ability to flowering and fruit setting at many eggplant varieties depends first of all on environmental conditions [Sun et al. 1990, Kowalska 2003b] and tendency to form low-pistil flowers [Prasad and Prakash, 1968; Kowalska 2003a]. The optimum temperature for pollen germination is 20–27ºC. Below 15ºC or above 30ºC, pollen is unable to germinate. The reason is too low of excessive air humidity – below 50%, pollen gets dry, while above that level, it gets clumped [Dobromilska and Fawceet 1999]. Too wide daily temperature amplitude, low light intensity, and improper N:P ratio in subsoil may influence on small amounts of pollen produced [Gosiewski and Skąpski 1988, Wysocka-Owczarek 1993]. No fruit setting from low-pistil flowers, at which stigmata are not fully developed and contain little sugars making impossible for pollen germination, is another reason that reduces the yielding potential of many eggplant varieties [Rylski et al. 1984, Passam and Bolmatis 1997, Kowalska 2003a, 2006, Mc Gregor 1976].

Assuming the complexity of many factors that make difficult or impossible to self-pollination of eggplant flowers, it is recommended to apply inflorescence vibrating for cultivations under covers [Mc Gregor 1976, Gemmill-Herren and Ochieng 2008], flower hormonization [Olympios 1976, Nothmann et al. 1983, Glapś and Górecki 1989, Krug 1991, Leonardi and Romano 1997, Lawande and Chavan 1998, Kowalska 2006], and natural pollination by a bumble-bee (*Bombus terrestris*) [Mc Gregor 1976, Abak et al. 1995, Kowalska 2003a, 2003b, 2006].

Inflorescence vibrating

Mc Gregor [1976] reported that shaking the inflorescences did not make sufficient pollen setting on pistil stigmata and was not able to pollen the eggplant flowers well. Studies of Sambandan [1964] applying the inflorescence vibrating, only 30–40% of all fruits per plant were set. Gemmill-Herren and Ochieng [2008] reported a positive influence of vibrating the eggplant inflorescences on the number of produced seeds in references to self-pollination. Object with shaken inflorescences produced fruits with significantly larger number of developed seeds as compared to those set due to self-pollination. However, discussed manner of pollination is not so efficient as pollination by insects, which is going to be the subject of further chapters.

Growth regulators

The eggplant flowers can be stimulated for fruit development applying chemicals of growth regulators type. By introducing growth substances such as auxins onto the flowers, fruit setting can be induced before flower pollination. That fact drew to a supposition that pollination leading to fruit and seed formation is associated with production of endogenous growth regulators such as auxins. Further studies allowed for finding that the auxins or similar substances present or synthesized by a pollen or an ovary are the factors that stimulate pollen and ovary growth. After pollination, the level of auxins in ovary suddenly increases, which results in the beginning of a fruit growth. Also a variety of other growth agents were isolated from developing fruits – gibberellins, for instance. Development of partenocarpic fruits can be also stimulated by gibberellins in plants insensitive towards auxins [Buczek 1972].

Olympios [1976], having in mind positive effects of growth regulators mixture applied to induce partenocarpic fruits formation at apple, examined the influence of various combinations of gibberelic acid (GA_3), auxin (2-naphthoxyacetic acid – NOA), and cytokines (benzyloaminopurine – BA) on eggplant's growth and yielding during cold season in Cyprus. He recorded the best fruit setting when NOA, NOA + BA, and NOA + BA + GA_3 combinations were applied. The best results were achieved after application of auxins and cytokines altogether. Applying the auxins had positive effects only when cytokines concentration was optimum. Treating the flowers only with cytokines caused the decrease of early and commercial fruit yields indicating that the presence of auxins is also necessary for an efficient action of other growth regulators. Applying only gibberelic acid did not bring positive results. Perhaps, as Nothmann and Koller [1975] suggested, level of endogenous gibberellins during the cold season was high. Reduction of fruits number and decrease of total yields due to introducing the GA_3 may resulted from the gibberellins excess at low concentrations of auxins and cytokines. Experiments made by Nothmann et al. [1983] revealed that treating the eggplant flowers with 2,4-D at concentration of 2.5 $mg \cdot l^{-1}$ four times every 3 weeks considerably improved the fruit setting. Variety, flower structure, and localization within an inflorescence were important for fruit setting and seed formation processes. Percentage of high-pistil flowers in total fruit setting was 90%. Although hormonization increased the fruit setting from low-pistil flowers four times as compared to the control, maximum fruit setting (8%) was still very poor. Fruits formed from so-called additional flowers were of worse quality than those from main flowers. Auxins stimulated growth of both, but fruits grown from additional flowers were usually smaller than those formed from the main ones. In general, set fruits had no seeds or contained undeveloped seeds. According to Lawande and Chavan [1998], applying the growth regulators (2,4-D and NAA) affected the improvement of fruit setting by 50%. Similar effects were achieved due to seed soaking in growth regulators solutions for 24 before seeding. Glapś and Górecki [1989] reported the increase of early and commercial yields at 'Rodo' eggplant by applying Betokson R (NOA), Betokson Super (NOA), Nasuleaf (2,4-D), Racine (NAA) for developed flowers as well as Nevirol 60 WP for whole plants. Analysis of the yield structure revealed that achieved yield increase mainly depended on fruit weight increase, and not their number. Applied growth regulators did not cause the increase of the deformed or infected fruits percentage in the yield. Leonardi and Romano [1997], when using auxins for growing eggplants, achieved fruits that were characterized by larger weight than those harvested from plants treated with no growth regulator. Experiments made by Kowalska [2003a, 2003b, 2006] confirm positive influence of flower hormonization process on the eggplant's yielding. Significantly higher early and commercial yields of fruits were produced by plants stimulated with growth regulators as compared to those with self-pollination.

Hormones modify flower's heterostyly by influencing on anatomical structure and nutrients transport through pistil's ducts [Handique and Sarma 1995]. Observations of low-pistil anatomy revealed smaller cells as compared to high-pistils, and hormones application affected the enlargement of those cells. At *Solanum sisymbrifolium*, applying the kinetins favored the development of high-pistil flowers, while reduced low-pistil ones; gibberelic acid (GA_3) invoked opposite reaction. Handique and Sarma [1995] applied NAA at 10 ppm concentration and observed the increase of high-pistil flowers number only at some varieties, whereas higher rates (25 ppm) significantly decreasing the number of low-pistil flowers at all tested varieties. Treating the eggplants with kinetins considerably decreased the number of low-pistil flowers; however, higher concentration (40 ppm) was more efficient for all varieties than 20 ppm rate. There is a hypothesis that hormones such as kinetins are more focused on female preferences, while gibberelic acid favors male expression.

In experiments of Passam et al. [2001], application of auxins (IAA) significantly reduced the pistil length in eggplant flowers. Hormonization had negative effects of eggplant's flowering intensification.

Natural pollinators

It is commonly assumed that bees are the most important plant pollinators all over the world. Studies upon the application of honey-bee (*Apis mellifera*) as a natural pollinator at vegetable cultivating under covers began in 1950. Although the insect was very efficient as pollinator of many plant species, it did not play its role in the case of *Solanaceae* plants. At present, bumble-bee (*Bombus terrestris*) in Europe and *Bombus impatiens* Cr. in North America are commonly used for pollinating the flowers of tomato, pepper, and eggplant grown under covers [Van Ravestijn and Van der Sande 1991, Shipp et al. 1994, Abak et al. 1995, Asada 1997, Dobromilska 1997, Dobromilska and Fawcett 1999, Kowalska 2003b, Gemmill-Herren and Ochieng 2008]. Insects applied for plant pollination (bumble-bees and bees) have biting-licking-type mouth, in which the tongue length plays an important role during pollination. *Colletes* family bees have the shortest tongues. They may visit only flowers with accessible nectar and pollen. Bumble-bees have the longest tongues (even 12 millimeters), due to which their application for pollinating in eggplant cultivation under covers gives the best results [Dylewska 1996]. The activity of pollinating insects depends on the daytime and weather. At 15–25ºC, insects are the most active at noon, while in hot days (above 25ºC), they fly to gather pollen in the morning and in the afternoon, when it is cooler. When temperatures remain above 35°C for a longer time, bumble-bees remain in the hive ventilating their nest and giving up the pollen gathering. Bumble-bees, unlike other insects, visit flowers even at lower air temperatures (6–8ºC) and low light intensities, which is important at cultivating thermophilic plants, namely under more sever conditions. Moreover, they pollinate flowers regularly by moving up the plant and they never visit the same flowers [Dobromilska 1997]. In sunny days, these insects start to fly about 8:00 a.m. and end about 5:00 p.m. with their maximum activity between 1:00 p.m. and 5:00 p.m. A single bumble-bee can visit up to 15 flowers per minute, and it pollinates about five of them that time. In cloudy days, bumble-bees start their flights later: about 11:00 a.m., and end before 5:00 p.m. under such conditions, a single insect visits only three flowers per minute [Abak et al. 1995]. Because eggplant flowers are directed down, a bumble-bee that visits them has to hold the stamens with its mandibles very tightly. Specific bumble-bee's jingling makes a flower vibrating, and in consequence, pollen is poured out through the holes in anthers onto insect's body covered with dense hair. Bumble-bee sweeps the pollen and puts it into the baskets localized on the rear leg's shins (fig. 5, 6). Then, it forms the pollen into granules called *corbiculi* (pollen baskets). When a bumble-bee releases its mandibles from the stamens, two brown spots remains – the evidence that the flower was pollinated. Number of pollinated flowers indicates if there is an appropriate number of insects in a greenhouse or tunnel. Four to five bumble-bee families per hectare is sufficient for providing with necessary pollination [Dylewska 1996].

The yield increase and its better quality are considered to be the major benefits from bumble-bee application in vegetable pollination in a greenhouse. It was found that bumble-bees significantly reduce inputs for pollination and nursery. Biological plant protection against diseases and pests is an additional effect of the bumble-bee colony introduction for cultivations under cover [Van Ravestijn and Van der Sande 1991, Wysocka-Owczarek 1993].

In Turkey, Abak et al. [1995] carried out the experiments upon the importance of bumble-bee in eggplant and tomato cultivation in unheated greenhouse. They reported that flower pollination by insects affected the total yield increase by 23% for eggplant and by 1% for tomato. And similarly, number of fruits harvested from 1 m^2 increased by 22% and 6%, respectively for eggplant and tomato from plants pollinated by bumble-bees. The way the flowers were pollinated had not any influence on the quality of produced fruits, whereas seed number increased by 62% and 100%, respectively after bumble-bee introduction.

Fig. 4. Heterostyly phenomenon occurring in eggplant's flowers
Ryc. 4. Zjawisko heterostylii występujące w kwiatach oberżyny

Fig. 5. Hive with bumble-bees at eggplant cultivation
Ryc. 5. Ul z trzmielami w uprawie oberżyny

Fig. 6. Flower pollination by bumble-bees
Ryc. 6. Zapylanie kwiatów oberżyny przez trzmiela ziemnego

Abak et al. [1995], Stępowska [1996], as well as Dobromilska [1997] found that bumble-bee makes effective fruit setting in eggplant and greenhouse pepper cultivations. They have also a positive impact on the total and commercial eggplant's and pepper's yields size. At the same time, earlier fruit ripening was observed, and fruits were heavier than those resulting from self-pollination. The first-selection fruits yield increase in reference to the control plants was also recorded.

Results achieved by Kowalska [2003a, 2003b, 2006] from studies upon the bumble-bee efficiency in eggplant cultivated under covers revealed that flower pollination by insects caused significant increase of early and commercial yields as compared to self-pollinated plants. In object where flowers were pollinated by insects, plants produced considerably more commercial fruits as compared to control ones. It should be emphasized that fruits set with a help of bumble-bee ripened earlier and were heavier than those harvested from control object. Fruits grown from flowers pollinated by a bumble-bee (*Bombus terrestris*) were characterized by higher mean weight, length and diameter.

In Japan, Asada and Ono [1996], as well as Asada [1997] made the comparison of the efficiency of tomato flowers pollination by four local bumble-bee species (*Bombus hypocrita hypocrita* Perez., *Bombus ignitus* Smith., *Bombus ardens ardens* Smith., *Bombus diversus diversus* Smith.) with one imported from England (*Bombus terrestris)*. Experiments revealed that efficiency of tomato flower pollination by all bumble-bee species was the same and high, and fruit setting was 84–100%. Every fruit harvested within commercial yield contained large number of seeds.

Studies carried out in Africa by Amoako and Yeboah-Gyan [1991] indicate great usefulness of a honey-bee (*Apis mellifera adansonii*) under tropical climate conditions to increase the eggplant's, tomato's, and pepper's yields. Number of set fruits in relation to number of formed flowers was significantly larger from plants, that flowers of which were pollinated by insects than self-pollinated ones. The manner of flower pollination had no influence on qualitative parameters of three assessed vegetable species fruits.

Gemmill-Herren and Ochieng [2008] studied the efficiency of different pollination ways on two eggplant varieties yielding. For both of them, a positive influence of bumble-bee pollination on a quality of eggplant fruits was confirmed. Fruits with significantly larger seed number were achieved in object where flowers were pollinated by insects as compared to those set due to self-pollination or inflorescence vibrating.

Reference data fully confirm that pollinating insects, including bumble-bee, play very important yield-forming role at cultivating eggplants under covers. Therefore, their presence on the vegetable plantation should be considered as one of the necessary agrotechnical factors.

The eggplant seed radiation to change the formation of heterostylic flowers should be also mentioned. At *Solanum khsasianum*, the seed treatment with gamma radiation caused considerable reduction of low-pistil flowers number, while increasing the number of high-pistil ones [Handique and Sarma 1995 after Chauhan and Ravindran 1979]. Those results correspond with studies by Handique and Sarma [1995], who found that at *Solanum melongena* L. gamma radiation may reduce number of produced low-pistil flowers and proportionally increase high-pistil ones. It was also reported that varieties of the same species react in different ways towards various radiation intensities. The phenomenon of the high-pistil flowers number increase and reduction of low-pistil flowers resulting from gamma radiation has not been elucidated yet.

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BIOLOGIA KWITNIENIA OBERŻYNY I ZABIEGI INTENSYFIKUJĄCE WIĄZANIE OWOCÓW – PRACA PRZEGLĄDOWA

Streszczenie. W pracy przedstawiono dane literaturowe na temat biologii kwitnienia oberżyny i wpływu zjawiska heterostylii kwiatów na plonowanie. Największą liczbę wszystkich kwiatów na roślinie stanowią kwiaty ze słupkiem wysokim (ponad 60%). Ilość kwiatów ze słupkiem pośrednim i niskim jest zdecydowanie mniejsza, odpowiednio: 10–20% i 20–30%. Większość roślin oberżyny zawiązuje owoce z kwiatów ze słupkiem wysokim w 49–100% i pośrednim w 46–85%. Znamiona tych kwiatów mają dobrze rozwinięte brodawki i dobrze przepuszczalne tkanki bogate w polisacharydy, białka i inne składniki odżywcze. Charakteryzują się również wysoką chłonnością pyłku. Kwiaty ze słupkiem niskim posiadają małe znamiona z nierozwiniętymi brodawkami. Zwarte tkanki z niską przepuszczalnością zawierają niewielkie ilości składników odżywczych, co uniemożliwia kiełkowanie pyłku i zawiązywanie owoców. Mając na uwadze złożoność wielu czynników, które utrudniają lub wręcz uniemożliwiają samozapylenie kwiatów oberżyny, przedstawiono skuteczność trzech zabiegów intensyfikujących zawiązywanie owoców: wibratorowanie gron, hormonizację kwiatów, a także naturalne zapylanie przez trzmiela ziemnego - *Bombus terrestris.* Badania wielu autorów potwierdzają, że potrząsanie gron kwiatowych nie powoduje dostatecznego osadzenia pyłku na znamionach słupka i nie jest wystarczające do dobrego zapylenia kwiatów oberżyny. Stosowanie regulatorów wzrostu jest bardziej efektywne i wpływa znacząco na poprawę plonowania oberżyny. Największą skuteczność uzyskano przy zastosowaniu owadów jako naturalnych zapylaczy w uprawie oberżyny pod osłonami.

Słowa kluczowe: *Solanum melongena* L., heterostylia, hormonizacja, zapylanie przez owady, plonowanie

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