Infection of *Ostrinia furnacalis* (Lepidoptera: Pyralidae) by Endophytic *Beauveria bassiana* on Corn

1Itji Diana Daud, 2Elkawakib, 3Kahar Mustari, 3Aris Baso and 3Nuniek Widiayani

1Department of Plant Pests and Diseases, Faculty of Agriculture, Hasanuddin University, Makassar, South Sulawesi, 90245, Indonesia
2Department of Agronomy, Faculty of Agriculture, Hasanuddin University, Makassar, South Sulawesi, 90245, Indonesia
3Department of Agricultural Socio-Economics, Faculty of Agriculture, Hasanuddin University, Makassar, South Sulawesi, 90245, Indonesia

Abstract: The Asian corn borer, *Ostrinia furnacalis* Guenéé (Lepidoptera: Crambidae), is one of the most important pests of corn. Control against this pest is attempted in several ways, including the biological control with entomopathogenic fungi, *Beauveria bassiana*. Infection of *B. bassiana* in different larval phases can cause differences in insect response. This study aims to examine the effect of different larva’s stages when they are inoculated with *B. bassiana* to the growth of *O. furnacalis*. This study was conducted by allowing different larval instars of the pest to feed on corn plants inoculated with different dosages of *B. bassiana* spores. The observed parameters were larval mortality, pupal weight, adult longevity, adult fecundity and number of eggs and larvae infected by *B. bassiana*. The results showed that *B. bassiana* caused mortality to the 1st and 2nd instars of the larvae. The sub-lethal effects of *B. bassiana* on *O. furnacalis* development included reduction in pupal weight, shorter longevity, decreased fecundity of about 50% and reduced number of eggs laid up to 72.3%. *B. bassiana* can be transmitted vertically to the next generation. Up to 88% and 75% of the eggs and larvae were infected by the fungus, respectively. Information provided by this study is very useful for *B. bassiana* conservation efforts in the corn ecosystem and for supporting integrated pest management of *O. furnacalis*.

Keywords: Entomopathogenic Fungi, Endophyte, Larvae, Pupae, Mortality

Introduction

The Asian corn borer, *Ostrinia furnacalis* Guenéé (Lepidoptera: Crambidae) is one of the main pests of corn plant with a wide distribution throughout Southeast Asia, Central Asia, East Asia, and Australasia. The borer attacks all parts and development phases of the corn plants. The pest causes damages on stems, cobs, and flowers of the plant, inflicting yield losses up to 80% (Bato *et al*., 1982). The yield loss occurs the most when the plants are attacked during their reproductive phase of development. The larva is the destructive life stage of *O. furnacalis*. The first instar larvae feed on young leaves and forms small holes in the leaves, the second instar larvae feed on the leaves, especially those that are not yet fully open or developed, the third instar larvae feed on the leaf and stem, and the fourth and fifth instar larvae bore the plant stem (Cook *et al*., 2004; O’Day *et al*., 1998).

Biological controls are alternative management measures that can be developed to control *O. furnacalis*, one of which is using entomopathogenic fungi. The fungus *Beauveria bassiana* has been reported as an endophytic fungus in various plant species and has shown activity against various pests (Bamisile *et al*., 2018). The entomopathogen has been reported effective in controlling many important plant pests, such as *Helicoverpa armigera* on tomato (Qayyum *et al*., 2015), *Hypothemenus hampei* on coffee (Posada *et al*., 2007) and *Lyriomyza huidobrensis* on *Visia faba* and *Phaseolus vulgaris* (Akutse *et al*., 2013). On corn, *B. bassiana* has been reported to control lepidopteran insects such as *Sesamia calamistis* (Cherry *et al*., 2004), *Ostrinia nubilalis* (Bing and Lewis, 1991) and *Spodoptera frugiperda* (Ramírez-Rodríguez and Sanchez-Peña, 2016). There is an evidence that while acting as a plant endophyte, *B. bassiana* can also reduce pest damage (Gurulingappa *et al*., 2010; Akello and Sikora, 2012) by inhibiting insect development and reproduction and may also be antagonistic to plant pathogens (Ownley *et al*., 2008). Another advantage of entomopathogenic fungi is...
the ability to attack all stages of insect development including the eggs and pupae encompassing a fairly wide host range (Anand et al., 2009).

The existence of B. bassiana as an endophyte in insect pest hosts is expected to be sustainable. The ability of B. bassiana to be transmitted vertically and horizontally can support the sustainability of B. bassiana control in the field. Effects of B. bassiana as endophyte to the growth of corn plants and the development of Rachiplusia nu (Lepidoptera: Noctuidae) as a corn pest has been investigated by Russo et al. (2019). However, the role of endophytic B. bassiana in to control and inhibit the growth of O. furnacalis has not been demonstrated. This study aims to observe the effect of B. bassiana as an endophytic fungus on corn in inhibiting the development of O. furnacalis growth and its ability to be transmitted vertically to subsequent offsprings.

Methods

Larva Infection

Test larvae were obtained from eggs laid by adults of O. furnacalis which were free from B. bassiana infection. Larvae were fed with the American diet. The larvae used in the trial were larval instars 1, 2, 3, 4 and 5. The spores of B. bassiana were isolated from homogenized O. furnacalis larvae infected by B. bassiana. Different dosages of B. bassiana spores (0, 100, 200, 400 or 800 spores/mm² of the leaf surface) were applied. stalks of one week old test plants were injected with 0.2 mL B. bassiana aliquots in H₂O per stalk. One larva was then placed on each of test plants that have been inoculated with B. bassiana. Each dosage treatment had five replications of one plant each. The treatment was incubated in a growth chamber with lighting lamps (L:D = 12:12) with a temperature of 27°C and humidity of 70%. After 48 h, the larvae from each treatment were removed from the endophytic stem of B. bassiana and transferred individually into a glass bottle (18x65 mm) containing fresh corn leaves that were not inoculated B. bassiana. The bottles are then covered with cotton plugs and incubated in an insectary to observe the development of insects until the pupae are formed. Sex of the pupae was determined, and female pupae were weighed and put in insect-care containers.

Mating and Oviposition

The newly formed adult females were allowed to mate with uninfected males. Ten pairs of adults were used in each treatment and each pair was placed in a cup (10 cm in diameter, 5 cm in height). waxed paper was placed at the top of the cup which served as a substrate for oviposition. Each day the waxed paper was removed and the eggs on it were counted. Observation of the number of eggs laid in each treatment was carried out for 7 days at a temperature of 27°C and humidity of 70%

Detection of Blastospores in the Eggs and the Larvae

Observation of the blastospore on eggs and larvae began by dividing the waxed paper on which the O. furnacalis eggs were laid into 2 equal parts. One part was frozen for observation of blastospore in eggs and the other part was incubated until the eggs hatched. Instar one larvae were frozen for observation of the blastospores in larvae. The presence of the blastospores in the larvae was observed under a compound microscope (400×).

Observation of B. bassiana infection in eggs was started by immersing a group of frozen eggs into a 2% trypsin solution in a 0.05 M K₂HPO₄ buffer and 0.05 M KH₂PO₄ (pH = 8). This egg group was then incubated at 36-38°C for 45 min to let egg-mass cement dissolve to form individual eggs. Next, the eggs were washed in the filter funnel, four times with ddH₂O and twice with 70% ethyl alcohol. The rate of B. bassiana infection in eggs is estimated by taking 10 eggs chosen at random at each treatment. Then the eggs were observed under a compound microscope (400×).

Experimental Design and Statistical Analysis

The experiment was designed in a randomized complete block with a split-plot arrangement of treatments. The instars were the plots and spore concentrations were the subplots. The experiment was replicated three times. Pupal weight, fecundity and longevity of female moths and blastospore infection rate on eggs and larvae were analyzed using ANOVA and relationships between variables were determined by using contrast coefficients.

Results

Beaververia bassiana infection affected the growth of O. furnacalis larvae differently, depending on the larval instar and the spore concentration applied to the corn. The first and second instars of O. furnacalis larvae died after feeding on the corn inoculated with B. bassiana; while the third, fourth and fifth instars of larvae were able to complete their life cycle. The application of B. bassiana on the third, fourth and fifth instar larvae caused a significant decrease in pupal weight relative to the control. The higher dose of B. bassiana applied to corn plants tended to cause a greater reduction in pupal weight; although this did not occur in the fourth instar larvae applied with 600 spores/mm² of leaf and fifth instar larvae applied with 800 spores/mm² of leaf. The weight of the pupae treated with B. bassiana decreased by 11% to 28% compared to the control (Table 1).

B. bassiana infection also affected the longevity of O. furnacalis. Larvae feeding on B. bassiana inoculated plants had a significantly shorter longevity than the control. In general, the higher dose of B. bassiana was consumed, the shorter the O. furnacalis longevity was. The shortest longevity was found in the treatment of the
third instar larvae fed on plant inoculated with 600 spores/mm² of leaf. It was only 8 days or 4.3 days shorter than the control (Table 1).

Adult females on the control treatment produced up to 345 eggs, while females from the larvae fed on B. bassiana-corn plants laid maximum 221 eggs. Furthermore, adult females from fifth instar larvae fed on leaf treated with 800 spore/mm² produced only 90 eggs. This shows that B. bassiana was able to reduce egg production up to 72.3%. In general, the higher the B. bassiana dose was used, the lower the O. furnacalis fecundity was (Table 1).

Beauveria bassiana infection also affected the number of eggs laid by an adult female of O. furnacalis. Females from uninfected larvae produced up to 74 eggs as shown on the second day, whereas larvae infected with B. bassiana were only able to produce 25 to 37 eggs. The minimum egg laying by O. furnacalis infected with B. bassiana occurs on the fifth day, which was 3 eggs in the 600 spores/mm² leaf treatment. This showed that B. bassiana infection reduced the number of eggs produced. The 800 spores/mm² treatment had the least eggs produced during the seven days of egg laying period (Fig. 1).

B. bassiana is also transovarial in O. furnacalis pest. B. bassiana was able to infect eggs from females infected with B. bassiana. The percentage of eggs infected with B. bassiana increases every day until the seventh day of the egg-laying period. The percentage of B. bassiana infected eggs was the highest in B. bassiana inoculation of 600 spore/mm² of leaf treatment (up to 88%) while the lowest egg infection occurred in B. bassiana inoculation of 200 spore/mm² leaves treatment (up to 68%) (Fig. 2).

![Fig. 1: Effect of different B. bassiana dosage treatments on the number of eggs laid by O. furnacalis imago](image1)

![Fig. 2: Percentage of O. furnacalis eggs infected with B. bassiana from imago that larvae fed from corn inoculated with various B. bassiana concentrations](image2)
The number of the new first instar larvae infected by *B. bassiana* on the first day was found to be very high from fifth instar larvae that fed from corn infected with *B. bassiana*, then followed by the fourth and third instar larvae which were 65%, 60%, 50%, respectively. *Beauveria bassiana* infection in the first instar larvae was the highest on the third day of observation, reaching 75%. Transovarial transmission appears to be more effective when the last instar larvae fed on the corn infected by *B. bassiana* (Fig. 3).

**Discussion**

*Beauveria bassiana* is an entomopathogenic fungus that is effective in controlling insect pests. Generally, this fungus is applied by spraying on the leaves, stems and fruits where the target insects are located, so these spores tend to be exposed to extreme conditions, especially solar radiation. *B. bassiana* which was exposed to UV light at 15 watts with a distance of 30 cm for 1 h, 2 h and 4 h of exposures, showed the ability of spores to germinate by 85.3% to 86.6% but did not cause
death in the test insects. This shows that the pathogenicity of *B. bassiana* is reduced by exposure to UV light, one of which is sun exposure (Daud et al., 1998). * Beauveria bassiana* must be protected from direct sun exposure so that its pathogenicity remains stable. Therefore, in this study, *B. bassiana* was applied by injecting it on corn plant stalks upon which the test insects fed. This method is quite effective because *B. bassiana* is also an endophytic fungus. * Beauveria bassiana* is known to endophytically colonize corn (Bing and Lewis, 1991) and banana (Akello et al., 2008) and it provides protection to the plants against insect pests.

* Beauveria bassiana* significantly influences the growth and development of *O. furnacalis*. Younger larvae will be more susceptible to *B. bassiana* infections. In the present study, first and second instar larvae died while eating from *B. bassiana* infected corn. Some reports mention that most entomopathogenic fungi have chitinase enzymes that are large enough to be very toxic in degrading the insect integument wall (Miranpuri and Khachatourian, 1995; Fang et al., 2005; Zhu et al., 2008). The chitinase of *B. bassiana* CH1 and CH12 enzymes are excreted by *B. bassiana* (Fang et al., 2005; Holder, 2005) and Fan et al. (2007) and highly toxic to integument of Lepidopteran larvae. Larvae instar 1 and 2 have thinner cuticles compared to instar larvae 3, 4 and 5 so that they are more susceptible to *B. bassiana* chitinase degradation.

Effectiveness of *B. bassiana* in controlling insects not only depends on mortality but also on the sub-lethal effects of the fungus on the insect target. The insect instars 3, 4 and 5 fed on corn infected with *B. bassiana* were capable of forming pupae with but lighter body weight compared to the control. Weight reduction of *Costelytra zealandica* larvae fed with *B. bassiana* has also been reported by Lefort et al. (2016). This weight reduction can be caused by decreased appetite of larvae. Characteristics of *B. bassiana* infected larvae are slow movement, decreased consumption and even stopping eating, gradually becoming quiet and eventually die (Daud et al., 1993). Pelizza et al. (2017) reported that *B. bassiana* as an endophytic fungus can influence the level of consumption, fertility, and food preference of *Dichroplus maculipennis*. Significant reduction in the food consumption of *D. maculipennis* nymphs in corn plants inoculated with entomopathogenic *B. bassiana* fungi has also been reported (Pelizza et al., 2017). In addition, some toxins produced by *B. bassiana* namely beauvericin, bassioholide, cyclolepsi-peptide (Tanada and Rich, 1993) and oosporein (Inglis et al., 2001) also play important roles in impeding the development of *O. furnacalis*.

* Beauveria bassiana* also affects various developmental stages of an insect. The longevity and fecundity of *O. furnacalis* are reduced by the treatment of *B. bassiana* as endophytic fungi in corn. Reduction in the longevity and fecundity of *O. furnacalis* can have an impact on the reduction of population in the next generation. Reduction of longevity due to entomopathogenic infections has also been reported in all phases of development of *Liriomyza huidobrensis* (Akutse et al., 2013) and the larval phase of *Tuta absoluta* (Klieber and Rineke, 2016). Decreased longevity of red palm weevil females due to fungal infection has also been reported by Gindin et al. (2006). Reduction in longevity and fecundity of *Plutella xylostella* (L.) due to insecticidal treatment has also been documented by Kumar and Chapman (2006). Entomopathogens as endophytes can also slow down reproduction rates (longer time to reproduction and lower fertility rate), reduce feeding and growth insects (Gurulingappa et al., 2010). Insect fecundity is directly related to the development of the ovary which produces eggs through oogenesis. Fecundity is affected by the age of the insect when infected. Insect fecundity is lower when *B. bassiana* infection occurs in the younger females when the oogenesis process begins (Sánchez-Roblero et al., 2012).

Based on this research, *B. bassiana* can be transmitted vertically. This is due to *B. bassiana* being able to replicate in the host’s hemolymph so that the blastospores can survive on the host’s body up to the eggs produced by the host. The amount of blastospores increased in the host body due to its ability to multiply rapidly after embryogenesis. Infected larvae of *B. bassiana* have high mortality and a slower rate of development than uninfected larvae. Eggs produced by infected adult insects are contaminated with spores inside of the ovarioles. The level of infection and disease damage caused by the host vary, depending on the stage of development since the spores begin to infect and the number of spores infecting the insects.

Vertical transmission to the next generation provides a great advantage in sustaining the control of *O. furnacalis*. Both vertical and horizontal transmissions affected the effectiveness of *B. bassiana* in controlling *O. furnacalis*. Vertically infected larvae can suffer more severe effects than horizontally infected larvae. However, horizontal transmission is very important to transmit *B. bassiana* spores from infected insects with *B. bassiana* to uninfected insects through copulation. Reports that *B. bassiana* can be transmitted horizontally from infected male imago to uninfected female imago of *Anastrepha ludens* (Diptera: Tephritidae) (Toledo et al., 2007) is an opportunity to spread *B. bassiana* in the field. This is very supportive of biological control of *O. furnacalis*, which is environmentally friendly.

**Conclusion**

The effectiveness of *B. bassiana* in controlling *O. furnacalis* is influenced by larval instar feeding on
infected corn plants and spore doses applied. First and second instar larvae are very susceptible to the toxicity of *B. bassiana*. Third, fourth and fifth instars of the larvae were able to develop into pupae but with lower weight, and those became adults had reduced fecundity by 50% and shorter life duration. Data shows that spore transfer occurs at each stage of development. Eggs and first instar larvae on the next generation also remain infected by *B. bassiana*. This is very useful for *B. bassiana* conservation efforts in the corn ecosystem and supports integrated pest management of *O. furnacalis*.

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**Author’s Contributions**

**Itji Diana Daud:** Conceived and designed the study, designed research methodology, manuscript writing and final approval.

**Elkawakib:** Designed the research methodology and variable assessment method.

**Kahar Mustari:** Designed research methodology, data analysis, and interpretation.

**Aris Baso:** Data collection and literature search.

**Nuniek Widiayani:** Data collection, data analysis and manuscript writing.

**Ethics**

No potential conflict of interest was reported by the authors.

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