DOI: 10.29050/harranziraat.1407990
Harran Tarım ve Gıda Bilimleri Derg. 2024, 28(2):192-200

Research Article/Araştırma Makalesi

New Approaches to the Control of *Neodiprion sertifer* (Geoffroy, 1785) (Hymenoptera: Diprionidae)

Neodiprion sertifer (Geoffroy, 1785) (Hymenoptera: Diprionidae)'in Mücadelesinde Yeni Yaklaşımlar

Hilal TUNCA COSİC[1*] Damla ÇAYCI[2]

[1,2]Ankara University, Faculty of Agriculture, Department of Plant Protection, 06110, Ankara, Türkiye

[1]https://orcid.org/0000-0003-3073-6628; [2]https://orcid.org/0000-0003-2918-7609

To cite this article:
Tunca Cosic, H. & Çaycı, D. (2024). New approaches to the control of *Neodiprion sertifer* (Geoffroy, 1785) (Hymenoptera: Diprionidae). Harran Tarım ve Gıda Bilimleri Dergisi, 28(2): 192-200

DOI: 10.29050/harranziraat.1407990

Address for Correspondence:
Hilal TUNCA COSIC
e-mail:
htunca@ankara.edu.tr

Received Date:
21.12.2023
Accepted Date:
13.05.2024

ABSTRACT

Neodiprion sertifer (Geoffroy) (Hymenoptera: Diprionidae) is a major pest on *Pinus* spp. in Europe. In this study, new control methods were tried to control *N. sertifer*. The effectiveness of *Bauveria bassiana* (Nostalgist, Bb %1.5 1 x 10 8 kob /ml min, 250 ml/100L), azadirachtin (Nimbecidine, 0.3g azadirachtin/l, 500 ml/da-100L; Nimiks4.5, 40g azadirachtin /l, 200 ml/100L; Neem Azal ®-T/S, 10 g azadirachtin /l, 300ml/100L) and spinosad (Oread, 480 g spinosad/l, 10ml/100L) was tested on *N. sertifer* larvae. In addition, the effect of the idiobiont parasitoid *Bracon hebetor* (Say) (Hymenoptera: Braconidae) venom was evaluated. *Bauveria bassiana*, spinosad and azadirachtin were applied to the larvae by spraying method. Different numbers of *B. hebetor* females (1-5 females) were also tested on *N. sertifer* larvae. All experiments were carried out at 25 ± 1°C, 60-70% relative humidity and 16L:8D h photoperiod. After *B. bassiana* application, the survival rates were 71.66% and 61.66% at the 6th day and 7th day. The maximum efficacy was obtained with azadirachtin in Nimiks 4.5 (40 g azadirachtin/l). The highest mortality (100.0%) was found at 24 h after the application of spinosad (10ml/100l). The most effective combination of *B. hebetor* female venom on *N. sertifer* larvae is 5 females and 7 days duration. The study shows that spinosad, azadirachtin and *B. hebetor* female venom can achieve effective control of *N. sertifer* larvae.

Key Words: *Neodiprion sertifer*, *Bauveria bassiana*, spinosad, azadirachtin, *Bracon hebetor* venom

ÖZ

Neodiprion sertifer (Geoffroy) (Hymenoptera: Diprionidae) Avrupa'da Pinus spp.'nin en önemli zararlısı konumundadır. Bu çalışmada *N. sertifer*'in mücadelesi için yeni mücadele yöntemleri denenmiştir. *Bauveria bassiana* (Nostalgist, Bb %1.5 1 x 10 8 kob /ml min, 250 ml/100L), azadirachtin (Nimbecidine, 0.3g azadirachtin, 500 ml/da-100L, Nimiks4.5, 40g azadirachtin /l, 200 ml/100L; Neem Azal ®-T/S, 10 g azadirachtin /l,300ml/100L) ve spinosad'ın (Oread, 480 g spinosad/l, 10ml/100L) etkinliği *N. sertifer* larvaları üzerinde denenmiştir. Ayrıca idiobiont parazitoit *Bracon hebetor* (Say) (Hymenoptera: Braconidae)'un venomu da değerlendirilmiştir. *Bauveria bassiana*, spinosad ve azadirachtin larvalara püskürtme yoluyla uygulanmıştır. Farklı sayıdaki *B. hebetor* dişisi de (1-5 dişi) *N. sertifer* üzerinde test edilmiştir. Bütün denemeler 25 ± 1°C, 60-70% orantılı nem ve 16:8 saat aydınlık:karanlık koşullarda gerçekleştirilmiştir. *Bauveria bassiana* uygulamasından sonra larvaların yaşam oranı 6. ve 7. günde %71.66 ve %61.66 olarak bulunmuştur. Azadirachtinde maksimum etkinlik Nimiks 4.5 (40 g azadirachtin/l)'de elde edilmiştir. En yüksek ölüm oranı (%100) spinosad (10ml/100l) uygulamasından 24 saat sonra bulunmuştur. *B. hebetor* dişi venomunun *N. sertifer* larvaları üzerinde en etkili olduğu kombinasyon 5 dişi ve 7 gün süredir. Bu çalışma spinosad, azadirachtin ve *B. hebetor* dişi venomunun *N. sertifer* larvaları üzerinde etkili bir kontrol sağlayabileceğini göstermiştir.

Anahtar Kelimeler: *Neodiprion sertifer*, *Bauveria bassiana*, spinosad, azadirachtin, *Bracon hebetor* venom.

Introduction

Neodiprion sertifer (Geoffroy) (Hymenoptera: Diprionidae) is a European diprionid species which is the most widely distributed in the world. It was recorded in New Jersey, USA in 1925 and in Ontario, Canada in 1939 (Lyons, 1964; Pschorn-Walcher, 1965; 1982, Griffiths et al., 1984). The larval stage feeds on the needles of pines such as *Pinus banksiana* (jack pine), *Pinus sylvestris* (Scots pine), *Pinus cembra* (Arolla pine), *Pinus contorta* (lodgepole pine) and *Pinus densiflora* (Japanese umbrella pine) (Baş, 1973; Tosun, 1975; Şimşek & Kondur, 2006; Aksu, 2010). *Neodiprion sertifer* can reach epidemic population levels in pine forests (Larsson & Tenow, 1984; Virtanen et al., 1996; Lyytikainen-Saarenmaa & Tomppo, 2002).

Chemical insecticides have long been used for controlling *N. sertifer* population. However, they cause a many negative health and environmental problems (Yaman et al.,2001). The use of environmentally friendly control methods against *N. sertifer* have been started many years ago. It was first described by Escherich (1913) as natural nucleopolyhedrosis virus (NPV) (Baculovirus) that reduces *N. sertifer* populations. Cunningham & Entwistle (1981) noted that virus infection spreads rapidly in *N. sertifer* population via defecation of larvae. Nevertheless, due to the virus activity, the population of *N. sertifer* was decreased very rapidly. Göktürk &Tozlu (2019) applied different doses of *Bacillus thuringiensis* subsp. kurstaki ABTS-35 and Natural-Pyrethrum (obtained from *Chrysanthemum cinerariaefolium*) to *Diprion pini* L. (Hymenoptera: Diprionidae) and *N. sertifer* larvae. Dipel (Bt) 500g/100 l dose was found to be the most effective dose on *N. sertifer*. However, it has been reported that a dose of 600 ml of Spruzit Neu (Pyretrum) has a significant effect on *N. sertifer* larvae.

Azadirachtin is a tetranortriterpenoid obtained from the seed of neem tree [Azadirachta indica A. Juss (Meliaceae)], is very known commercialized biopesticide and the most successful botanical pesticide that is used against agricultural pests in the scope of Integrated Pest Managment programmes. Azadirachtin has an antifeeding, repellent, adult sterility and insect growth regulator effect on the pest. However, it is considered that it has low residual effect and low side-effect on biocontrol agents, predators, and parasitoids (Tunca et al., 2012; Biondi et al., 2013; Abedi et al., 2014, Cura et al., 2019; Kilani-Morakchi et al., 2021).

Beauveria bassiana was first obtained from silkworm cadavers, and it is effective on more than 200 insects (Nakahara et al., 2009). *B. bassiana* produces numerous toxins (beauvericin, bassianin, bassianolide, beauverolides, tenellin, oosporein, oxalic acid, calcium oxalate crystals, and many beauvericin analogs) that cause infection in insects (Chelico &Khachatourians, 2008; Naqqash et al., 2016; Wang et al., 2021).

Spinosad is a nerotoxic (effective on the nervous system) insecticide. Saccharopolyspora spinosa, an actinomycete bacterium of soil origin, naturally produces metabolites of Spinosyn A (85%, $C_{42}H_{67}NO_{16}$) and Spinosyn D (15%, $C_{41}H_{65}NO_{16}$) as a result of fermentation under airless conditions. Spinosad has demonstrated high levels of efficacy against lepidopteran larvae, as well as some Diptera, Coleoptera, Thysanoptera, and Hymenoptera, has a range of effects on insects including as a contact, stomach poison effect, repellent, antifeedant, and growth and mating inhibitor (Anastas et al., 1999; Copping & Menn, 2000; Cisneros et al., 2002; Williams et al., 2003; Mayes et al., 2003; Isman, 2006; Matthews, 2006; Joseph, 2020).

Bracon hebetor Say (Hymenoptera: Braconidae) is a gregarious, idiobiont ectoparasitoid that attacks larvae of several species of Lepidoptera (Brower et al., 1996; Hagstrum & Smith, 1997). *Bracon hebetor* females paralyze their host before oviposition and then may deposit a different number of eggs near or on the paralyzed hosts. Meanwhile, female parasitoid caused ırreversible paralysis of the host insects. (Ghimire, 2008). There have been no studies on the effects of azadirachtin, *B. bassiana*, spinosad and B. hebetor venom on the *N. sertifer*. The objective of this study was to evaluate their potential efficacy for future IPM program options.

Materials and methods

Insect

Third instar larvae of *Neodiprion sertifer* were collected from Konya-Hüyük provence (37.93023°Lat, 31.71091°Long) and transferred to the laboratory. Larvae were reared to the insect rearing box (25 x 35 x 17 cm) with fresh black pine needles and placed in the climate room (25 ± 1°C, RH 65 ± 5% and L : D 16 : 8 h photoperiod).

Insecticides

In our study, three biorational insectides, *Beauveria bassiana* (Nostalgist, Bb %1.5 1 x 10 8 kob /ml min, application of dose is 250 ml/100L), azadirachtin (Nimbecidine, 0.3g azadirachtin/l, application of dose is 500 ml/da-100L; Nimiks4.5, 40g azadirachtin /l, application of dose is 200 ml/100L; Neem Azal ®-T/S, 10 g azadirachtin /l, application of dose is 300ml/100L) and spinosad (Oread, 480 gspinosad /l, application of dose is 10ml/100L) were used. However, 1-5 females of *B. hebetor* were used to test the efficacy of *B. hebetor*'s venom.

Bioassays

For this purpose, one third instar larvae were placed in petri dishes (6.5 cm) with blotting paper. Application doses of each insecticide were applied to 20 third instar larvae using the hand spray bottle. After treatment, the larvae were placed to the climate room (25 ± 1°C, RH 65 ± 5% and L: D 16: 8 h photoperiod) and provided with black pine needles. Each treatment was carried out in triplicate with 20 larvae. A total of 60 larvae were used for one application. 660 larvae were used for 11 treatments, including control. The alive larvae were checked daily during 7 days.

Statistical analyses

Survival data was calculated as a percentage and were normalized using an arcsine transformation ($p' = \arcsin \sqrt{p}$, Zar, 1999). Transformed data were analysed using ANOVA ($\alpha=0.05$) and Tukey's mean separation ($\alpha=0.05$). Statistical analyses were carried out using MINITAB computer software Release 17.

Results and Discussion

All biorational insecticides had adverse effects on *N. sertifer* at different incubation period after the treatment in this assay (Table- 1) (df=76; F=71.65; $P \leq 0.05$). Oread (Spinosad) induced 100% mortality and it was significantly greater than all other treatments (Fig. 1). The highest mortalities of this pest were obtained with Nimiks (40 g azadirachtin /l). The mortality rate increased with the increase of incubation period (Figure 1). The survival rates of *N. sertifer* larvae were found 63.33 %, 78.33 %, 90.00 % at seventh day, in Nimiks, Neem Azal (10g azadirachtin /l) and Nimbecidine (0.3g azadirachtin/l), respectively.

Table 1. Survival rate (%) caused by different treatments to third instar *Neodiprion sertifer* larvae after 1-7 day incubation at 25±1°C.

Treatments	***Days***						
	1	2	3	4	5	6	7
Nostalgist 250 ml/100l	100**A**	100**A**	91.67**AB**	86.67**BC**	85**BC**	71.67**DE**	61.66**EF**
Nimbecidineb500ml/100l	100**A**	100**A**	98.33**A**	95**AB**	95**AB**	91.66**AB**	90 A**BC**
Nimiks 200 ml/100l	91.67**A**	86.67 **BC**	85.00**BC**	80 **CD**	80**CD**	70**DE**	63.33**EF**
Neem Azal 300ml/100l	100**A**	96.67 **AB**	93.33**AB**	91.66**AB**	88.33**BC**	85 **BC**	78.33**D**
Oread 10 ml /100l	0	0	0	0	0	0	0
Bracon hebetor (1 dişi)	96.67**AB**	93.33 **AB**	88.33**BC**	88.33 **BC**	86.66**BC**	86.67 **BC**	83.33**BC**
Bracon hebetor (2 dişi)	93.33**AB**	88.33 **BC**	88.33**BC**	88.33 **BC**	88.33 **BC**	83.33 **BC**	78.33**D**
Bracon hebetor (3 dişi)	80**CD**	73.33**DE**	71.67**DE**	66.67 **EF**	65**EF**	63.33**EF**	58.33**FG**
Bracon hebetor (4 dişi)	53.33**FG**	48.33**GH**	46.67**GH**	38.33**HI**	36.67**HI**	33.33 **IJ**	33.33**IJ**
Bracon hebetor (5 dişi)	30**IJ**	23.33**JK**	18.33**KL**	13.33**KL**	11.66**KL**	10**L**	8.33**L**
Control	100**A**	100**A**	100**A**	100**A**	95**AB**	95**AB**	95**AB**

*Means followed by a different uppercase letter are significantly different (P< 0.05, ANOVA, Tukey).

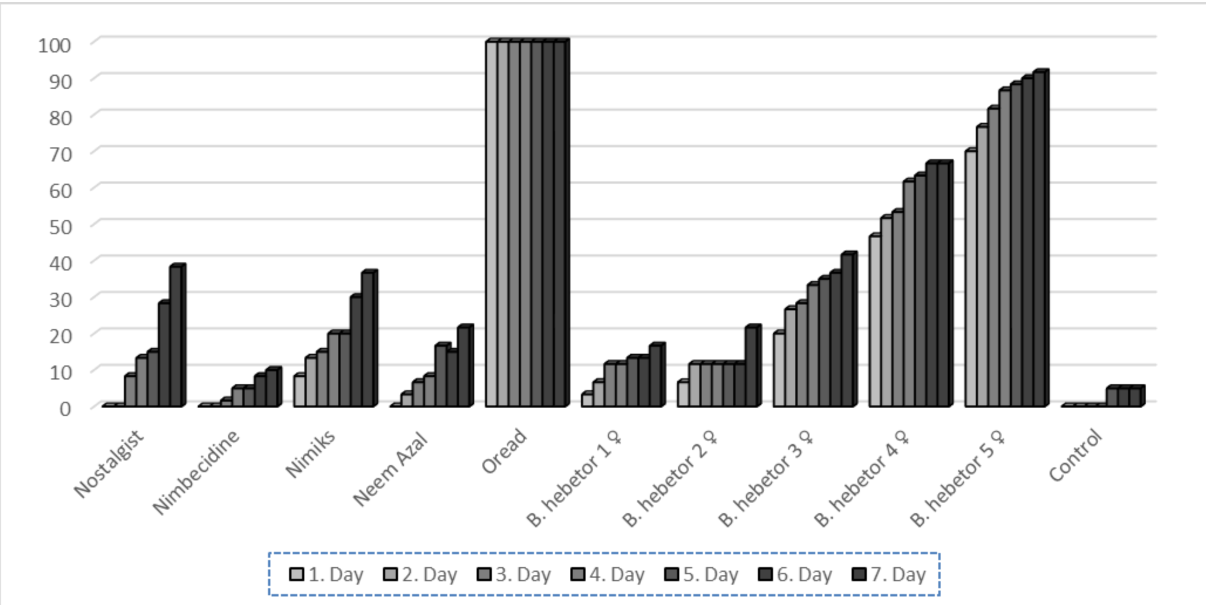

Figure 1. Percent mortality of *Neodiprion sertifer* larvae at different treatments and at 1, 2, 3, 4, 5, 6 and 7 days interval.

The mortality induced by the *B. bassiana* after 144 h of incubation. The highest mortality level (38.34%) for the *N. sertifer* larvae was recorded after 7 days with treatment of *B. bassiana* (Figure 1). *Bracon hebetor* venom had a strong effect on the survival of larvae of *N. serifer* (Table 1). The mortality rate was found significantly higher with increased of the incubation period and the number of females. Mortality rates increased with the treatment of 4 and 5 females (Figure 1). After Oread, *B. hebetor*'s venom has been found to be most effective treatment for *N. sertifer*. However, mortality rate never exceeded 5% in the control (Figure 1).

Biorational insecticides known as "third-generation insecticides" or "reduced- risk insecticides" are derived from natural compounds and have low or no side effects on the environment or beneficial organisms (Hara, 2000; Horowitz & Ishaaya, 2004; Kapoor & Sharma, 2020). Studies on the impact of biorational insecticides on the *N. sertifer* are limited to baculovirus and pyrethrum (Cunningham & Entwistle, 1981; Podgwaite et al., 1984, Yaman et al., 2001; Göktürk &Tozlu, 2019). In this study, the most effective result was obtained with spinosad among the tested insecticides. All larvae were dead within the first 24 hours (Table 1, Figure 1). Spinosad treatments were also toxic to *Mamestra configurata* Walker (Lepidoptera: Noctuidae), *Phyllotreta cruciferae* Goeze (Coleoptera: Chrysomelidae) (Elliot et al., 2007). Kowalska (2008) noted that all concentrations of spinosad (0.2%, 0.1% and 0.05%) caused mortality both *Leptinotarsa decemlineata* (Say) (Coleoptera: Chrysomelidae) adults and larvae depending on the temperature. Maral (2021) reported that, the highest mortality rate of *Stefanitis pyri* (Fabricius) (Heteroptera: Tingidae) adults was found in spinosad after that azadirachtin and kaolin.

In this study, the effect of azadirachtin varied depending on the rate of active substance, dose and incubation period. Nimiks (40 g azadirachtin/l) was also found to be the more effective than the other azadirachtin insecticides (Table 1). It can be preferred in the control of *N. sertifer.* Kraiss & Cullen (2008) noted that two neem insecticides (neem seed oil and azadirachtin) were effective in causing nymphal mortality of *Aphis glycines* (Matsumura) (Heteroptera: Aphididae) (77% by neem oil and 80% by azadirachtin). Neem oil formulation also presented significant efficacy on *Idioscopus clypealis* (Lethierry,) (Hemiptera: Cicadellidae), a mango pest (Adnan et al., 2014). Lin et al. (2021) noted that azadirachtin was effective on *Spodoptera litura* (Fabricius) (Lepidoptera:Noctuidae) and *Rhopalosiphum maidis* (Fitch) (Heteroptera: Aphididae).

Beauveria bassiana is the most studied birational insecticides. Like azadirachtin, *B. bassiana* was applied for the first time against *N. sertifer*. The highest mortality was obtained on the 7th day (38.34 %) (Table 1, Figure 1). A high case mortality rate was not observed in *N. sertifer* larvae. Studies on *Beauveria* have focused especially on the order Lepidoptera. Wraight et al. (2010) reported that *Obstrinia nubilalis* (Hübner) (Pyralidae), *Helicoverpa zea* (Boddie) (Noctuidae) and *Spodoptera frugiperda* (Smith) (Noctuidae) (Lepidoptera) are highly susceptible of *B. bassiana* strains. Mortality of *Galleria mellonella* (L.) (Lepidoptera: Pyralidae) was %0, %8 and %10 at 24, 72 and 120 h, respectively (Tunçsoy et al., 2020). Gao et al. (2022) reported that *B. bassiana*-PfBb can be used as a bio-insecticide to control young larvae of *S. frugiperda*. *B. bassiana* (BMAUM-M6-4) isolate was caused significant infection in early and late instar larvae of pine processionary (Gök et al., 2018). In another study, it was determined that nymphs and adults of *Palomena prasina* L. (Heteroptera: Pentatomidae) were susceptible to *B. bassiana* (Yiğit and Saruhan, 2022). Besides, side effect studies were mostly conducted on parasitoids in the Hymenoptera order, such as *Encarsia formosa* (Gahan) (Hymenoptera: Aphelinidae) (Labbé et al., 2009), *Trichogramma cacoeciae* (March) (Hymenoptera: Trichogrammatidae) (Tunçsoy et al., 2020), *Coptera haywardi* (Oglobin) (Hymenoptera: Diapriidae) (Martínez-Barrera et al., 2020), *Trichogramma dendrolimi* (Mastumura) (Kandil, 2022). However, no study was found on a pest belonging to the order Hymenoptera.

Parasitoid venoms compose of a complex mixture of proteinaceous and non-proteinaceous components that thought as agrichemicals to improve pest management (Morreau &Asgari, 2015). The main effect of toxin (venom of ectoparasitoid) is the influence of short and long-term paralysis in the host during the larval and nymphal stages to start developmental block. On the other hand, toxin might have different roles during induction, such as restraining the immune system or disrupting development (Edwards et al., 2006; Price et al., 2009; Tian et al., 2010; Kryukova et al., 2011).

Idiobiont parasitoid *Bracon hebetor* causes paralysis of host (Quistad et al., 1994). Three proteins were determined in the venom, two of them (Brh-I and -II) being insecticidal when injected into lepidopteran larvae (Ferber et al., 2001). The constituents of the venom, which comprise of proteins from 3.4–200 kDa have not been well characterized (Gnatzyet al., 2000). In this study, effect of *B. hebetor's* venom was investigated on another Hymenopter species, *N. sertifer*. It was found that *B. hebetor* paralyzed larvae of *N. sertifer* larvae but did not deposit eggs. The level of paralysis was increased by the number of parasitoid females. Mortality rates were found to be 66.67 % and 91.67%, respectively with application of 4 and 5 females at 7th day (Table1, Figure 1). Parasitoid female venom has a highly toxic effect on *N. sertifer*'s larvae.

Conclusion

As a result, spinosad and *B. hebetor* female venom can offer effective control of *N. sertifer*'s larvae and prevent serious damage to *Pinus* spp. Azadirachtin and *B. bassiana* can be used with the combination of the *B. hebetor* venom of in an integrated pest management program.

Acknowledgements: All authors acknowledged the Konya General Directorate of Forestry, for their support in providing necessary facilities for the study.

Conflict of Interest: There is no conflict of interest.

Author Contributions: Hilal TUNCA COSİC contributed to investigations, writing, editing, and data analysis; Damla ÇAYCI helped in methodology and contributed to the rearing of insects. All authors have read and approved the final manuscript.

References

Abedi, Z., Saber, M., Gharekhani, G., Mehrvar, A., Kamita, S.G., 2014. Lethal and Sublethal Effects of Azadirachtin and Cypermethrin on *Habrobracon hebetor* (Hymenoptera: Braconidae). Journal of Economic Entomology, 107(2):638-45. doi: 10.1603/EC13227.

Adnan, S., Uddin, M., Alam, M., Islam, M., Kashem, M., Rafii, M, et al., 2014. Management of mango hopper, *Idioscopus clypealis*, using chemical insecticides and neem oil. Science World Journal, 709614. doi: 10.1155/2014/709614

Aksu, Y., 2010. Ağaçlandırma Sahalarında Pinus sylvestris'lerde Önemli Zararlar Yapan Neodiprion sertifer (Geoff.) (Hymenoptera; Diprionidae) Üzerine Yapılan Araştırma. Çevre ve Orman Bakanlığı, Orman Genel Müdürlüğü Orman Koruma ve Yangınla Mücadele Dairesi Başkanlığı Yayınları, Ankara

Anastas, P., Kirchchoff, M., Williamson, T., 1999. Spinosad a new natural product for insect control. Green Chemistry Award, http://pubs.rsc.org/en/content/articlepdf/1999/GC/A906794I

Baş, R., 1973. Türkiye'de Orman Ağaçlarına Zarar Yapan Zar Kanatlılar (Hymenoptera) Üzerine Araştırmalar. Orman Genel Müdürlüğü, Ankara.

Biondi, A., Zappalà, L., Stark, J.D., Desneux, N., 2013. Do Biopesticides Affect the Demographic Traits of a Parasitoid Wasp and Its Biocontrol Services through Sublethal Effects? PLoS ONE 28(9): e76548. https://doi.org/10.1371/journal.pone.0076548

Brower, J.H., Smith, L., Vail, P.V., Flinn, P.W., 1996. Biological control In B. Subramanyam, & D.W. Hagstrum (Eds). Integrated Management of Insects in Stored Products. (pp. 223- 286) Marcel Dekker, New York, USA.

Chelico, L., Khachatourians, G.G., 2008. Isolation and characterization of nucleotide excision repair deficient mutants of the entomopathogenic fungus, Beauveria bassiana. Journal of Invertebrate Pathology, 98: 93–100. doi: 10.1016/j.jip.2007.10.006

Cisneros, J., Goulson, D., 2002. Derwent LC, Penagos DI, Hernandez O, Williams T Toxic effects of spinosad on predatory insects. Biological Control, 23: 156-163. https://doi.org/10.1006/bcon.2001.1000

Copping, L.G., Menn, J.J., 2000. Biopesticides: a review of their action, applications and efficacy. Pest Management Science, 56: 651-676. https://doi.org/10.1002/1526-4998(200008)56:8<651::AID-PS201>3.0.CO;2-U

Cunningham, J.C., Entwistle, P.F., 1981. Control of sawflies by baculovirus. In: Burges H.D., editor. Microbial Control of Pests and Plant Diseases 1970–1980. Academic Press, New York,. p. 379–407.

Cura, M.S., Gençer, N.S., 2019. Side Effects of Azadirachtin on Some Important Beneficial Insects in Laboratory. Journal of Biological & Environmental Sciences, 13(37): 39-47.

Edwards, J.P., Bell, H.A., Audsley, N., Marris, G.C., Kirkbride-Smith, A., Bryning, G., Frisco, C., Cusson, M., 2006. The ectoparasitic wasp *Eldophus pennicornis*

(Hymenoptera: Eulophiclae) uses instar-specific endocrine disruption strategies to suppress the development of its host *Lacanobia oleracea* (Lepidoptera: Noctuidae) Journal of Insect Physiology, 52:1153–1162. doi: 10.1016/j.jinsphys.2006.08.003.

Elliott, R., Benjamin, M., Gillott, C., 2007. Laboratory studies of the toxicity of spinosad and deltamethrin to *Phyllotreta cruciferae* (Coleoptera: Chrysomelidae). Canadian Entomologist, 139: (4) 534-544. https://doi.org/10.4039/n06-070.

Escherich, K., 1913. Neves uber polyaderhrankheiten. Naturut Z Land Forstwirtsch, 11: 86.

Ferber, M., Horner, M., Cepok, S., Gnatzy, W., 2001. Digger wasp versus cricket: Mechanisms underlying the total paralysis caused by the predator’s venom. Journal of Neurobiology, 47:207–222. doi: 10.1002/neu.1028.

Gao, Y.P., Luo, M., Wang, X.Y., He, X.Z., Lu, W., Zheng, X.L., 2022. Pathogenicity of *Beauveria bassiana* PfBb and Immune Responses of a Non-Target Host, *Spodoptera frugiperda* (Lepidoptera: Noctuidae). Insects, 13: 914. https:// doi.org/10.3390/insects13100914.

Ghimire, M.N., 2008. Reproductive Performance of the Parasitoid *Bracon hebetor* Say (Hymenoptera: Braconidae) On Various Host Species of Lepidoptera. Ph D Thesis.

Gnatzy, W., Volknandt, W., 2000. Venom gland of the digger wasp *Liris niger*: Morphology, ultrastructure, age-related changes and biochemical aspects. Cell and Tissue Research, 302:271–284. https://doi.org/10.1007/s004410000282

Gök, S., Güven, Ö., Karaca, İ., 2018. Entomopatojen fungus Beauveria bassiana’nın çam keseböceği (Thaumetopoea wilkinsoni Tams)’nin farklı dönemlerine etkileri. Türkiye Biyolojik Mücadele Dergisi, 9 (1): 7-19.

Gökturk, T., Tozlu, G., 2019. The Effect of Pyrethrum and *Bacillus thuringiensis* Biopesticides on *Diprion pini* L. and *Neodiprion sertifer* (Geoffr.) (Hymenoptera: Diprionidae) Larvae. Pakistan Journal of Zoology., 51(3): 989-994. https://doi.org/10.17582/journal.pjz/2019.51.3.989.994

Griffiths, K.J., Cunningham, J.C., Otvos, I.S., 1984. *Neodiprion sertifer* (Geoffroy), European pine sawfly (Hymenoptera: Diprionidae). In: Kelleher JS, Hulme MA, editors. Biological control programmes against insects and weeds in Canada 1969-1980. Slough, UK: Commonwealth Agricultural Bureau, 1984, p. 331-340.

Hara, A.H., 2000. Finding alternative ways to control alien pests - Part 2: New insecticides introduced to fight old pests. Hawaii Landscape, 4 (1): 5.

Hagstrum, D.W., Smith, B.J.,1997. Host finding ability of *Bracon hebetor* and its influence upon adult parasite survival and fecundity. Environmental Entomology, 6: 437-439. https://doi.org/10.1093/ee/6.3.437

Horowitz, A.R, Ishaaya I.,2004. Biorational Insecticides – Mechanisms, Selectivity and Importance in Pest Management Programs. In: A.R. Horowitz, & I. Ishaaya (Eds.) Insect Pest Management- Field and Protected Crops (pp.1-28) Springer, Berlin, Heidelberg, New York.

Isman, M.B., 2006. Botanical insecticides, deterrents and repellents in modern agriculture and an increasingly regulated world. Annual Review Entomology, 51 (1): 45-66. https://doi.org/10.1146/annurev.ento.51.110104.151146

Joseph, S.V., 2020. Repellent effects of insecticides on Stephanitis pyrioides Scott (Hemiptera: Tingidae) under laboratory conditions. Crop Protection., 127: 104985. https://doi.org/10.1016/j.cropro.2019.104985

Kandil, C., 2022. Researchs on the Effect of Some Biorational Preparations on the Biological Characteristics of *Trichogramma dendrolimi* (Matsumura) (Hymenoptera: Trichogrammatidae) Ankara University, Graduate School of Natural and Applied Sciences, Department of Plant Protection, Master Thesis.

Kapoor, B., Sharma, K., 2020. Biorational Pesticides: An Envirosafe Alternative to Pest Control. Indian Farmer, 7(08): 722-731.

Kilani-Morakchi, S., Morakchi-Goudjil, H., Sifi, K., 2021. Azadirachtin-Based Insecticide: Overview, Risk Assessments, and Future Directions. Frontiers in Agronomy, 3:676208. https://doi.org/10.3389/fagro.2021.676208.

Kowalska, J., 2008. Laboratory Studies of the Activity of Spinosad against *Leptinotarsa decemlineata* (Say) Depending on Different Temperature. 16th IFOAM Organic World Congress, Modena, Italy, June 16-20.

Kraiss, H., Cullen, E.M., 2008. Insect growth regulator effects of azadirachtin and neem oil on survivorship, development and fecundity of *Aphis glycines* (Homoptera: Aphididae) and its predator, *Harmonia axyridis* (Coleoptera: Coccinellidae). Pest Management Science, 64, 660–668. doi: 10.1002/ps.1541

Kryukova, N., Dubovskiy, I., Chertkova, E., Vorontsova, Y., Slepneva, I., Glupov, V., 2011. The effect of *Habrobracon hebetor* venom on the activity of the prophenoloxidase system, the generation of reactive oxygen species and encapsulation in the haemolymph of *Galleria mellonella* larvae. Journal of Insect Physiology, 57:769–800. https://doi.org/10.1016/j.jinsphys.2011.03.008

Labbé, R.M., Gillespie, D.R., Cloutier, C., Brodeur, J., 2009. Compatibility of an entomopathogenic fungus with a predator and a parasitoid in the biological control of greenhouse whitefly. Biocontrol Science Technology, 19: 429–446. https://doi.org/10.1080/09583150902803229.

Larsson, S., Tenow, O., 1984. Areal distribution of a *Neodiprion sertifer* (Hym, Diprionidae) outbreak on Scots pine as related to stand condition. Ecography, 7 (2):81-90. https://doi.org/10.1111/j.1600-0587.1984.tb01108.x

Lin, S., Li, S., Liu, Z., Zhang, L., Wu, H., Cheng, D., Zhang, Z., 2021. Using Azadirachtin to Transform *Spodoptera frugiperda* from Pest to Natural Enemy. Toxins, 13:541. https://doi.org/10.3390/ toxins13080541

Lyons, L.A., 1964. The European pine sawfly, *Neodiprion sertifer* (Geoff.)(Hymenoptera: Diprionidae). A review with emphasis on studies in Ontario. Proceedings of the Entomological Society Ontario, 94:5-37.

Lyytikainen-Saarenmaa, P., Tomppo, E., 2002. Impact of sawfly defoliation on growth of Scots pine *Pinus sylvestris* (Pinaceae) and associated economic losses. Bulletin Entomology Resesearch, 92: 137–140. DOI: 10.1079/BER2002154.

Maral, H., 2021. Effect of spinosad, azadirachtin and kaolin on *Stephanitis pyri* (Fabricius, 1775) (Hemiptera: Tingidae) under laboratory conditions. Türkiye Entomoloji Dergisi, 45 (1): 87-97. https://doi.org/10.16970/entoted.770859

Martínez-Barrera, O.Y., Toledo, J., Cancino, J., Liedo, P., Gómez, J., Valle-Mora, J., Montoya, P., 2020. Interaction Between *Beauveria bassiana* (Hypocreales: Cordycipitaceae) and *Coptera haywardi* (Hymenoptera: Diapriidae) for the Management of *Anastrepha obliqua* (Diptera: Tephritidae). Journal Insect Science, 20(2):6. doi: 10.1093/jisesa/ieaa010. PMID: 32186740; PMCID: PMC707178

Matthews, G.A., 2006. Pesticides: Health, Safety and the Environment. Blackwell Publishing, Oxford, UK,

Mayes, M.A., Thompson, G.D., Husband, B., Miles, M.M., 2003. Spinosad toxicity to pollinators and associated risk. Environmental Contamination and Toxicology, 179:37-71. doi: 10.1007/0-387-21731-2_2. PMID: 15366583.

Moreau, S.J., Asgari, S., 2015. Venom Proteins from Parasitoid Wasps and Their Biological Functions. Toxins, 7(7):2385-412. doi: 10.3390/toxins7072385

Nakahara, Y., Shimura, S., Ueno, C., Kanamori, Y., Mita, K., Kiuchi, M., et al., 2009. Purification and characterization of silkworm hemocytes by flow cytometry. Dev. Comp. Immunol. 33: 439–448. doi: 10.1016/j.dci.2008.09.005

Naqqash, M.N., Gökçe, A., Bakhsh, A., Salim, M., 2016. Insecticide resistance and its molecular basis in urban insect pests. Parasitology Research,115: 1363–1373. doi: 10.1007/s00436-015-48989

Quistad, G.B., Nguyen, Q., Bernasconi, P., Leisy, D.J., 1994. Purification and characterization of insecticidal toxins from venom glands of the parasitic wasp, *Bracon hebetor*. Insect Biochemistry and Molecular Biology, 24: 955-961. doi: 10.1016/0965-1748(94)90132-5.

Podgwaite, J.D., Rush, P., Hall, D., Walton, A.S., 1984. Efficacy of the *Neodiprion sertifer* (Hymenoptera: Diprionidae) Nucleopolyhedrosis Virus (Baculovirus) Product, Neochek-S. Journal of Economic Entomology, 77(2): 525-528. https://doi.org/10.1093/jee/77.2.525

Price, D., Bell, H., Hinchliffe, G., Fitches, E., Weaver, R., Gatehouse, J.A., 2009. venom metalloproteinase from the parasitic wasp *Eulophus pennicornis* is toxic towards its host, tomato moth (Lacanobia oleracae) Insect Molecular Biology, 18:195–202. doi: 10.1111/j.1365-2583.2009.00864.x.

Pschorn-Walcher, H., 1965. The ecology of *Neodiprion sertifer* (Geoffr.)(Hym.: Diprionidae) and a review of its parasite complex in Europe. Technical Bulletin, Commonwealth Institute of Biological Control, 5:33-97.

Pschorn-Walcher, H., 1982. Suborder Symphyta, sawflies. In: Schwenke W, editor. Die Forstschaedlinge Europas. 4. Hautflügler und Zweiflügler. Hamburg, Germany: Paul Parey, 66-129.

Şimşek, Z., 2006. Kondur Y. Çankırı Ormanlarının Zararlı Böcekleri ve Mücadele Yöntemleri. Gazi Üniversitesi, Orman Fakültesi Dergisi, 6(1): 105-107.

Tian, C., Wang, L., Ye, G., Zhu, S., 2010. Inhibition of melanization by a *Nasonia defensin*-like peptide: Implications for host immune suppression. Journal Insect Physiology, 56:1857–1862. doi: 10.1016/j.jinsphys.2010.08.004.

Tosun, İ., 1975. Akdeniz Bölgesi İğne Yapraklı Ormanlarında Zarar Yapan Böcekler ve Önemli Türlerin Parazit ve Yırtıcıları Üzerinde Araştırmalar. Orman Bakanlığı Orman Genel Müdürlüğü Yayınları, İstanbul.

Tunca, H., Kılınçer, N., Özkan, C., 2012. Side-effects of some botanical insecticides and extracts on the parasitoid, Venturia canescens (Grav.) (Hymenoptera: Ichneumonidae). Türkiye Entomoloji Dergisi, 36 (2): 205-214.

Tuncsoy, B.S., Bueno-Pallero, F., Dionisio, L., Neto, L., Ozalp, P., 2020. Effect of *Beauveria bassiana* on *Galleria mellonella* L. (Lepidoptera: Pyralidae) and Its Parasitoid *Trichogramma cacoeciae*. Karaelmas Fen ve Müh Dergisi, 10(2):131-136.

Virtanen, T., Neuvonen, S., Nikula, A., Varama, M., Niemela, P., 1996. Climate change and the risk of *Neodiprion sertifer* outbreaks on Scots pine. Silva Fennica, 30: 169–177.

Wang, H., Peng, H., Li, W., Cheng, P., Gong, M., 2021. The Toxins of *Beauveria bassiana* and the Strategies to Improve Their Virulence to Insects. Front

Microbiology, 12:705343. doi: 10.3389/fmicb.2021.705343

Williams, T., Valle, J., Vinuela, E., 2003. Is the naturally derived insecticide spinosad® compatible with insect natural enemies? Biocontrol Science Technology, 13 (5): 459-475. https://doi.org/10.1080/0958315031000140956.

Wraight, S.P., Ramos, M.E., Avery, P.B., Jaronski, S.T., 2010. Vandenberg JD. Comparative virulence of *Beauveria bassiana* isolates against lepidopteran pests of vegetable crops. Journal of Invertebrate Pathology, 103: 186–199. doi: 10.1016/j. jip.2010.01.001

Yaman, M., Nalçacıoğlu, R., Demirbağ, Z., 2001. Viral Control of the European Pine Sawfly, *Neodiprion sertifer* (Geoffroy) in Turkey. Turkish Journal of Biology, 25 419-425.

Yiğit, Ş., Saruhan, İ., 2022. Entomopatojenik funguslar; *Beauveria bassiana*, *Isaria fumosorosea* ve *Metarhizium anisopliae*'nın *Palomena prasina* L. (Heteroptera: Pentatomidae)'ya karşı etkileri. KSÜ Tarım ve Doğa Dergisi, 25 (5): 1051-1060. https://doi.org/10.18016/ksutarimdoga. vi. 938399

Zar, J.H., 1999. Biostatistical analysis. – Prentice-Hall, upper Sadle River, NJ,.