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REVIEW OF THE CONTROL MEASUREMENTS AGAINTS FLAT-HEADED ROOT-BORER *CAPNODIS TENEBRIONIS* L. (COLEOPTERA: BUPRESTIDAE)

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Abstract

Fruit growing is one of the main sectors in agriculture, both in Bulgaria and in many other European countries. In recent years, the sector has faced a number of challenges, such as climate change, the increasing spread of diseases and pests, and etc.

Capnodis tenebrionis L. (Coleoptera: Buprestidae) is one of the most destructive pests affecting stone and pome fruit orchards in Europe, including Bulgaria. In recent years, its population has increased significantly, with infestations becoming so severe that losses in stone fruit production have reached up to 100%. This can be attributed to several factors: rising ambient temperatures, prolonged drought conditions, and the ban on a large number of insecticides due to their high toxicity and detrimental effects on the environment and human health. Controlling this pest is extremely challenging, as its immature stages develop within the tree roots, where they are protected from all chemical treatments. One of the main pathways for the spread of the pest is through infested nursery planting material.

Various control strategies have been implemented worldwide to protect plants and reduce pest populations. The selection of suitable rootstocks, combined with agrotechnical, chemical, and biological control methods, can effectively protect orchards from infestation. This integrated approach can lead to higher yields and improved fruit quality.

Keywords: agro technical methods, *Capnodis tenebrionis*, chemical control, microorganisms, nematodes

INTRODUCTION

Hosts and damages

The Mediterranean flat-headed root-borer, *Capnodis tenebrionis* (Coleoptera: Buprestidae), primarily attacks species of the family Rosaceae, including apricot (*Prunus armeniaca* L.), peach (*Prunus persica* L.), plum (*Prunus domestica* L.), cherry (*Prunus avium* L.), almond (*Prunus amygdalus*, syn. *Prunus dulcis*), and nectarine (*Prunus persica* var. *nucipersica*) (Mendel et al., 2003; Bari et al., 2019). It also attacks other economically important species such as European crab apple (*Malus sylvestris* L.) (Makhan, 2012), pear (*Pyrus communis* L.), olive (*Olea europaea* L.) (Frézal, 1947; Martin et al., 1998), and pistachio (*Pistacia vera* L.) (Nizamlioglu, 1957).

Adult beetles feed on the buds and leaf petioles of trees, causing the affected parts to dry out and fall off. Females lay their eggs in cracks in the bark or in the soil near the base of trees. The larvae infest the lower parts of the trunk and the roots (Guercio, 1931). The most significant damage is caused by the larvae, which destroy the cambial layer of the roots (Fig. 1–4). Infested trees exhibit delayed development and often die (Lesne, 1917; Garcia del Pino & Morton, 2005).

C. tenebrionis causes serious problems in nurseries and in the production of planting material. A single larva is capable of completely destroying a one- to two-year-old tree. Even older trees in more advanced developmental stages are susceptible to attack by this pest (Ben-Yehuda et al., 2000).

Fig. 1 – 4. Tree damages from *Capnodis tenebrionis* larvae

Chemical control

Chemical control of this pest is extremely challenging, as the larvae remain hidden within the tree roots, making them inaccessible to insecticides. Insecticide treatments can only be effective if applied when the adult borers are active above ground. Therefore, accurate timing of the treatment is critical. Once the larvae have penetrated the roots, they become very difficult to control.

Most chemical control programs are aimed at the adult stage, prior to egg-laying. Larval control is generally achieved through soil treatments with contact insecticides, which usually require multiple applications.

In the 1930s, Rekk (1932) tested paradichlorobenzene, carbon bisulfide, and calcium carbide for protecting apricot trees from *Capnodis tenebrionis*. Paradichlorobenzene provided 95% control of the larvae, while carbon bisulfide and calcium carbide proved to be less effective. To reduce adult populations, Semenov (1945) dusted tree branches with calcium arsenate, achieving a mortality rate between 85% and 100% within five days. For effective protection of young plants, treatments every 15 days were recommended.

Pierre & Marijon (1947) used methyl bromide to reduce pest populations by injecting it into the soil at a depth of 15 cm. Rosella (1948) also employed methyl bromide to protect *Prunus* species from *Capnodis spp*. In trees that were already infested, the same product could be applied, but treatment was recommended in the autumn.

In Morocco, Rosella (1950) observed that HCH (hexachlorocyclohexane) preparations, applied to tree trunks at a specific height above the soil, were very effective against adult beetles.

In the early 1950s, approximately 40,000 stone fruit trees in Bulgaria were damaged by *Capnodis tenebrionis*, necessitating urgent pest control measures. Under laboratory conditions, Kaitazov (1958) tested 18 insecticides to evaluate their effects on adults and larvae. It was found that 2% toxaphene and 0.2% parathion were highly effective against adult beetles.

To reduce larval density and damage, it is recommended to treat young trees while still in nurseries. Dipping the roots of young trees in a slurry composed of soil, stable manure, and 12% BHC (benzene hexachloride) reduced larval infestation to as low as 4%. Additionally, painting the base of tree trunks with parathion, BHC, or paradichlorobenzene was suggested as an effective preventative measure against infestation. In Algeria, Gairaud & Besson (1950) conducted soil treatments using various doses of DDT and BHC against newly hatched larvae of *Capnodis tenebrionis* (L.). BHC showed promising results and remained effective for approximately one month. Similarly, Rivnay (1951) tested the synthetic insecticides DDT and BHC against *Capnodis spp*. Both were applied as fumigants targeting the boring larvae, but the results were largely ineffective. However, when used as contact insecticides against the larvae, both compounds showed satisfactory results.

In 1952, Delmas & Thermes (1953) used dieldrin, the gamma isomer of BHC, and DDT to control adult *C. tenebrionis*. A 25% wettable powder suspension containing 0.25% dieldrin and a 0.2% BHC emulsion were applied to adult beetles. Three days after treatment, 100% mortality was observed on plants treated with dieldrin.

According to Féron (1952), post-harvest treatments with various insecticides—including arsenicals (0.5–1.0% lead arsenate), 2% barium fluosilicate, 1–2% cryolite, 0.5% BHC, and 0.2–0.3% chlordane—significantly reduced pest populations. He also recommended soil treatments using 3 to 5 liters of BHC suspension per tree as an effective control method for the flat-headed root borer. Similarly, Chrestian (1955) advised repeating soil treatments with BHC or dieldrin every two months for optimal results against young larvae.

A few years later, in Georgia, Alavidze (1965) applied a mixture of 0.4% trichlorfon, 0.3% parathion, and 0.4% carbaryl to reduce adult populations. The first treatment was conducted in May, followed by a second application in September. To target larvae, soil treatments were performed using polychlorobutane-4, hexachlorobutadiene, or a 1:4 mixture of paradichlorobenzene and ethylene dichloride. These treatments resulted in a significant reduction in larval density.

For the protection of young stone fruit seedlings, Nasonova (1963) recommended dusting with DDT or BHC. These products were also applied around the trunks of mature trees for additional protection.

Saba (1979) used soil-applied insecticides—Isofenphos, Trichloronate, Chlorfenvinphos, and Lindane to control *Capnodis tenebrionis* larvae in mature cherry orchards. Treatments were applied in May and June, with Isofenphos proving particularly effective in limiting larval populations.

Under both laboratory and field conditions, Garrido et al. (1990) tested the efficacy of fifteen insecticides against *Capnodis spp*. Eight days after treatment, seven of the compounds—Fenthion, Methyl parathion, Azinphos-methyl, Carbophenothion, Triazophos, Pyridaphenthion, and Methiocarb—caused over 90% adult mortality.

In 1995–1996, the effectiveness of Fipronil was evaluated against *C. tenebrionis*. Sekkat et al. (1997) reported promising results, noting that the granular formulation of Fipronil could protect trees for over two months. During the same period in Italy, Colasurdo et al. (1997) conducted field experiments and found that Methiocarb, Azinphos-methyl, and Methyl parathion caused high mortality rates among adult beetles.

In Israel, approximately 480 hectares of deciduous orchards were affected by buprestid beetles (*Capnodis tenebrionis* and *C. carbonaria*). To protect the orchards from these destructive pests, Ben-Yehuda & Mendel (1997) applied three insecticidal dust formulations: Mesurol (methiocarb) 5%, Cutanion (ethylazinphos) 8%, and Marshal (carbosulfan) 2%, applied by dusting around the tree stems. Additionally, foliar sprays of Cutanion (0.2% wettable powder), Mesurol (0.1%), silafluofen (0.2%), Confidor (imidacloprid, 0.05%), and fipronil at concentrations of 0.02%, 0.03%, and 0.04% were tested. The results were satisfactory, and all tested products were recommended for the control of *C. tenebrionis*.

In a subsequent field experiment in stone fruit orchards, Ben-Yehuda et al. (2000) tested nine chemical compounds against both adults and larvae of *C. tenebrionis*. Azinphos-methyl showed the highest efficacy when applied as a foliar treatment, while imidacloprid was the most effective in soil applications.

In Spain, under field conditions, Soler and Dicenta (2012) investigated the efficacy of various active substances against both life stages of the pest. The tested compounds included acetamiprid 20% SP, chlorpyrifos 25% CS, dimethoate 40% EC, imidacloprid 20% OD, thiacloprid 180 OD, and a combination of deltamethrin 2% + thiacloprid 15% OD. Among the tested substances, thiamethoxam 25% WG, imidacloprid 20% OD, cyantraniliprole 20% SC, and chlorantraniliprole 20% SC demonstrated the highest efficacy against larvae.

In Syria, Alkassis (2017) evaluated the effectiveness of three commonly available active ingredients: thiacloprid, deltamethrin, and chlorpyrifos. Thiacloprid was the most effective, followed by deltamethrin. Bufaur et al. (2021) also tested deltamethrin and chlorpyrifos-ethyl, as well as acetamiprid 20%, under field conditions using foliar sprays. Deltamethrin was additionally tested as a dusting powder applied around the tree trunk. The results indicated that chlorpyrifos-ethyl and both deltamethrin treatments were the most effective against adult beetles.

Micro organisms

Numerous studies have investigated the potential of entomopathogenic fungi and bacteria in controlling *Capnodis tenebrionis* at various life stages, including eggs, larvae, and adults. Among the most frequently used fungal genera in the field are *Metarhizium spp*. and *Beauveria spp*. (Roberts & St Leger, 2004). The fungal spores attach to the insect's cuticle and subsequently germinate. The resulting hyphae penetrate the insect’s body, disrupting internal organs and physiological systems, ultimately leading to death. The cadaver becomes covered with fungal mycelium, which continues the infection cycle by releasing conidia (Glare & Milner, 1991). The conidia of both Metarhizium and Beauveria are hydrophobic and are passively dispersed from infected cadavers (Shah & Pell, 2003), facilitating further spread of the pathogen in the environment.

As early as 1930, Guercio (1931) identified a bacterial species belonging to the genus Entomococcus [R.A.E., A, xvii, 687] capable of infecting and killing all developmental stages of *C. tenebrionis*. This discovery highlighted the potential of bacterial agents for successful biological control of this economically important pest.

More recently, Gindin et al. (2014) evaluated the toxicity of δ-endotoxins produced by Bacillus thuringiensis (Bt) against *Capnodis* larvae. Under laboratory conditions, their study demonstrated a high susceptibility of young larvae to Bt toxins, suggesting promising potential for integration into pest management programs.

Aydın & Sezen (2023) successfully isolated 21 bacterial strains from *Capnodis tenebrionis* larvae and adults. The identified species included *Bacillus cereus*, *B. mycoides*, *B. pumilus*, *Paenibacillus xylanilyticus*, *B. flexus*, *B. simplex*, *Raoultella terrigena*, *Enterobacter cloacae*, *Klebsiella oxytoca*, *B. safensis*, *B. amyloliquefaciens*, and *B. aryabhattai*. Several of these bacterial species have been reported to exhibit insecticidal activity and may have potential for controlling other arthropod pests as well.

Entomopathogenic fungi have also emerged as promising biological control agents, particularly for preventing larval infestation of tree roots. Marannino et al. (2006) developed a novel method to evaluate the pathogenicity of *Beauveria bassiana* and *Metarhizium anisopliae* against *C. tenebrionis* larvae. Under laboratory conditions, four isolates from each fungal species were tested. Three isolates of *M. anisopliae* caused 100% larval mortality, while two *B. bassiana* isolates significantly reduced egg hatching rates, achieving reductions of 84.5% and 94.5%. These findings highlighted the strong potential of both fungi in targeting the egg and larval stages of the pest.

Two years later, Marannino et al. (2008) further evaluated the efficacy of *M. anisopliae* strain EAMa 01/58-Su against neonate larvae and adult stages of *C. tenebrionis*, confirming its effectiveness under controlled conditions.

Under laboratory conditions, Marannino et al. (2008) tested two methods to evaluate the efficacy of *Metarhizium anisopliae* against *Capnodis tenebrionis*. In the first method, fiber bands impregnated with fungal conidia were applied, resulting in adult mortality ranging between 85% and 100%. In the second approach, potted plants were treated with *M. anisopliae* via soil application to assess its effect on neonate larvae. The average larval mortality reached up to 85%, demonstrating the potential of soil treatment for larval suppression.

In a subsequent laboratory study, Marannino et al. (2010) evaluated both Spanish and Italian isolates of *M. anisopliae* and *Beauveria bassiana* on *C. tenebrionis* adults. The observed mortality rates ranged from 70% to 100%, depending on the isolate.

In Turkey, Yiğit et al. (2015) investigated the efficacy of *B. bassiana* and *M. anisopliae* against *C. tenebrionis* larvae under semi-field conditions using the apricot cultivar ‘Hacihalioglu’. Three different doses of both fungi were tested. The results showed that the entomopathogens significantly reduced larval penetration into the root zone. Notably, in the treatment with *B. bassiana* applied at a dose of 10^6 spores/cm^2, no larval penetration was observed.

Ment et al. (2020) examined the susceptibility of neonate larvae to *Metarhizium brunneum* (strain Mb7) and *Beauveria bassiana* (strain GHA) under both laboratory and semi-artificial conditions. A dose of 10^8 Mb7 conidia per gram of soil was sufficient to completely prevent infestation of apricot twigs. In a separate semi-artificial experiment using potted rootstocks, applications of 1.6×10^5 Mb7 and 1.3×10^5 GHA conidia per cm^3 of soil—administered several months prior to larval colonization—significantly reduced rootstock infestation.

In a similar study, El-Khoury et al. (2020) tested *B. bassiana* against larvae of *Cossus cossus* and *C. tenebrionis* under laboratory conditions. Chemical control of these pests is notoriously difficult due to their concealed larval stages, which are inaccessible to conventional insecticides. The results confirmed that *B. bassiana* was highly effective, emphasizing the value of microbial agents capable of reaching hidden habitats within the host plant.

Nematodes

Many studies have investigated the effects of entomopathogenic nematodes (EPNs) on the flat-headed root borer, *Capnodis tenebrionis* (Coleoptera: Buprestidae). EPNs from the families *Steinernematidae* and *Heterorhabditidae* are widespread in agricultural ecosystems worldwide and are widely employed as biological control agents against various agricultural pests (Klein, 1990; Morton & García-del-Pino, 2009).

Most entomopathogenic nematodes cause either delayed development or death of their hosts. They penetrate the host through the body wall or the anal opening and parasitize the insect internally. Upon infection, nematodes release symbiotic bacteria that cause the death of the host (Kaya, 1985). The bacterial symbionts associated with *Steinernema* species are *Xenorhabdus*, while those associated with *Heterorhabditis* species belong to the genus *Photorhabdus*. The symbiotic relationship is mutualistic: the nematodes protect the bacteria from external environmental conditions and deliver them into the host, while the bacteria provide nutrients that support nematode reproduction and development within the host (Tarasco et al., 2023).

Entomopathogenic nematodes utilize carbon dioxide (CO_2) as a key chemical cue to locate their hosts. Since all living organisms emit CO_2, nematodes use these emissions as a reliable indicator to find their insect targets in the soil (Nježić et al., 2023).

Environmental factors such as soil moisture and temperature are critical for the successful application and efficacy of EPNs. Kung et al. (1991) found that the optimal temperature range for the development and pathogenicity of *Steinernema carpocapsae* is between 5°C and 25°C, with temperatures exceeding 35°C having detrimental effects on nematode survival and infectivity. Interestingly, lower soil moisture levels are associated with higher nematode viability compared to higher moisture conditions. According to Şahin & Gözel (2022), the persistence of nematodes in the soil ranges between 90 and 150 days, with survival influenced by a complex interaction of biotic and abiotic factors.

Lobatón et al. (1998) reported finding naturally parasitized specimens of *Capnodis tenebrionis* in the field. Subsequently, under laboratory conditions, they isolated the entomopathogenic nematode *Steinernema carpocapsae* from dead larvae and pupae of *C. tenebrionis*. The isolated strain, designated SCG.2, was proposed as a promising candidate for biological control of this pest.

In laboratory bioassays, García del Pino & Morton (2005) tested four nematode species—*Steinernema carpocapsae*, *S. feltiae*, *S. arenarium*, and *Heterorhabditis bacteriophora*—against *C. tenebrionis* larvae. Among these, *S. carpocapsae* caused infection and mortality in larvae more rapidly than the other species. The nematodes primarily penetrated the host through the mouth of neonate larvae. Two days after treatment, insect mortality ranged from 75% to 86%.

Later, Morton & García del Pino (2009) evaluated the virulence of 14 isolates of *Steinernema feltiae*, one isolate of *S. carpocapsae*, and three isolates of *Heterorhabditis bacteriophora* against larvae, pupae, and adults of *C. tenebrionis*. Larval mortality ranged from 50% to 100%, while pupal mortality varied between 0% and 70%. Among adults, *S. feltiae* showed the highest virulence.

Benseddik et al. (2022) evaluated the efficacy of five native Moroccan EPN isolates against neonate larvae and adults of *Capnodis tenebrionis* under laboratory and greenhouse conditions. Their study confirmed previous findings that air temperature and soil moisture critically influence nematode performance. The highest larval mortality was recorded for *Heterorhabditis bacteriophora* (97.5%) and *Steinernema feltiae* (95%) at 10% soil moisture and 25°C temperature. In their adult trials, *Heterorhabditis* species also showed superior efficacy compared to other isolates. These results indicate that Moroccan EPN isolates are promising biological control agents for *C. tenebrionis*.

In Spain, *Steinernema carpocapsae* was applied in apricot orchards, achieving 75% to 90% mortality of *C. tenebrionis* larvae. Furthermore, treated trees demonstrated successful recovery post-application (de Altube et al., 2008).

Morton & García-del-Pino (2008) tested 13 EPN isolates on potted trees, including nine strains of *Steinernema feltiae*, one *S. affine*, one *S. carpocapsae*, and two *Heterorhabditis bacteriophora*. They observed efficacy ranges of 79% to 88% for *S. feltiae*, 71% to 76% for *H. bacteriophora*, and approximately 62% for *S. carpocapsae*. In parallel field trials in cherry orchards, *S. feltiae* (strain Bpa) significantly reduced *C. tenebrionis* populations, with mortality rates between 88.3% and 97%.

Additional studies (El-Khoury et al., 2020) confirmed the strong larvicidal activity of *S. feltiae* under laboratory conditions against larvae of both *Cossus cossus* and *C. tenebrionis*. The biological traits of *S. feltiae*—including its ability to penetrate diverse habitats and transmission through infected hosts—make it a particularly effective biocontrol agent for this pest group. The injection of entomopathogenic nematode suspensions into wood galleries to infect larvae represents a promising preventive control method against wood borer pests such as *Capnodis tenebrionis*. Şahin & Gözel (2021) conducted a two-year study in peach orchards in Turkey to assess native EPN species, including *Steinernema carpocapsae*, *S. feltiae*, *S. affine*, and *Heterorhabditis bacteriophora*, applied using different irrigation techniques. Their results demonstrated that all four nematode strains achieved 100% mortality of *C. tenebrionis* larvae. Additionally, nematode persistence in the soil ranged from 90 to 150 days, highlighting their potential for long-term pest management in orchard ecosystems.

Natural enemies

A limited number of beneficial insect species have been reported in the literature as partial natural enemies of the flat-headed root borer *Capnodis tenebrionis*. In Italy, the ant *Pheidole pallidula* (Nylander, 1849) (Hymenoptera: Formicidae) and the parasitoid *Avetianella capnodiobia* (Trjapitzin, 1968) (Hymenoptera: Encyrtidae) have been recorded as biological control agents against *C. tenebrionis* (Pussard, 1935; Alexeev, 1984). The small ant *P. pallidula* feeds on the eggs and young larvae of *Capnodis* species, while adults of *A. capnodiobia* parasitize the eggs of *C. tenebrionis* (Alexeev, 1994).

The tachinid fly *Billaea adelpha* (Loew), primarily a parasitoid of coleopteran larvae such as cerambycids, but also attacking buprestids and scarabaeids, has been reported as a parasitoid of *C. tenebrionis* larvae (d’Aguilar and Féron, 1949; Tschorsnig, 2017; Torres-Vila and Tschorsnig, 2019).

In Italy, Marannino and de Lillo (2007) identified a small population of *Sclerodermus cereicollis* Kieffer (Hymenoptera: Bethylidae) parasitizing pupae of *Capnodis* species. Furthermore, in apricot and plum orchards in southwestern Sicily, Bonsignore et al. (2008) discovered *Spathius erythrocephalus* (Hymenoptera: Braconidae), an ectoparasitoid that targets large buprestid larvae. Female parasitoids lay their eggs on mature larvae in late autumn, with parasitism rates reaching 35% in plum orchards.

Rootstock

Rootstocks can provide resistance to pests and serve as a valuable tool in integrated pest management. The appropriate choice of rootstock can suppress the feeding, reproduction, or survival of insect pests (Shapiro & Gottwald, 1995).

In Malta, Borg (1936) observed that *Capnodis tenebrionis* does not attack almonds or trees grafted onto almond rootstocks. Frézal (1947) found that quince rootstocks are susceptible to *Capnodis* species. Cuenot et al. (1947) reported that myrobalan plum rootstocks E.F. 74 and Brompton plum showed greater resistance compared to other myrobalans, *Prunus mariana*, and *P. insititia*.

Berville (1948) noted that myrobalan plum, seedling peach, and apricot rootstocks are more frequently attacked by *C. tenebrionis* larvae. He also observed that on calcareous and dry soils, almond is the only rootstock resistant to *Capnodis* species. However, Lozzia (1950) found that almond rootstock is not completely immune to *C. tenebrionis* attack; he suggested that the secretion of resin by almond roots may delay larval development, contributing to a slower progression of infestation.

In cherry orchards, Rosella (1950) found that the Sainte-Lucie rootstock is susceptible to *Capnodis* species, whereas the Mazzard rootstock exhibits greater tolerance to this pest. Chrestian & Guessous (1955) recommended the use of bitter almond as a resistant rootstock.

Malagon & Garrido (1990) investigated the relationship between cyanogenic glycoside content and resistance to *C. tenebrionis* larvae. They established that bitter almond plants have a high concentration of cyanogenic glycosides, which confers resistance to neonate larvae.

Similarly, Cánovas et al. (2001) supported the resistance of almond rootstocks to *C. tenebrionis*. They inoculated almond cultivars ‘Garrigues’, ‘Atocha’, and ‘Desmayo Largueta’ with neonate larvae and found that ‘Garrigues’ seedlings were the most resistant.

Ben Yehuda et al. (2001) evaluated various *Prunus* rootstocks for resistance to *Capnodis* spp. Their results showed that Apricot and Bear plum rootstocks were the most heavily attacked, while Nemagourd, Mariana, and Bitter almond rootstocks experienced less larval damage. The rootstocks Mahaleb (*P. mahaleb*) and Hansen 536 (*P. amygdalus* × *P. persica*) demonstrated the highest resistance against root borers *C. tenebrionis* and *Capnodis carbonaria* (Klug). This study also indicated that resistance to these pests is not solely due to the toxicity of prunasin.

Mendel et al. (2003) examined host selection and oviposition preference in *C. tenebrionis* and *C. carbonaria*. They found that *C. tenebrionis* preferred plum (*Prunus domestica*) and apricot (*Prunus armeniaca*), while *C. carbonaria* showed a preference for peach (*Prunus persica*).

Both *Capnodis tenebrionis* and *C. carbonaria* do not prefer apple (*Malus domestica*) as a host. Apricot rootstock is favored by both buprestid species; however, strong resistance was observed in *P. mahaleb* and in two crosses of *P. persica* × *P. amygdalus*, namely 677 and Hansen. It has been suggested that the resistance of these rootstocks is not due to the toxicity of prunasin.

Dicenta et al. (2003) conducted an in-depth study on the relationship among cyanogenic compounds in kernels, roots, and leaves of trees. They concluded that a high concentration of cyanogenic compounds in almond roots may contribute to resistance against *Capnodis* species.

Soler et al. (2013) evaluated twelve *Prunus* rootstocks for resistance to *Capnodis* species. The rootstocks were planted in the field and artificially infested with *Capnodis tenebrionis* larvae. In winter, the plants were uprooted and examined for larval presence and damage. They found that Rootpac-40 (Nanopac) and PAC 00-05 (AP 65) showed no damage or larvae infestation.

Kokici et al. (2020) conducted experiments to assess the influence of rootstocks on the postembryonic development and adult emergence of *C. tenebrionis*. Using bark flour from the rootstocks Adesoto, CAB6P, Colt, Garnem, GF677, MaxMa60, Montclar, and Myrobalan, they observed that larvae developed poorly on Adesoto, Colt, and MaxMa60.

In a subsequent experiment, Kokici et al. (2020) examined the susceptibility of stone fruit rootstocks to *Capnodis* larvae by monitoring larval development on substrates containing rootstock bark flour and on rootstock twigs. The results showed that larvae developed faster on Montclar and GF677 substrates, whereas development was slower on Adesoto, CAB6P, Colt, and MaxMa60. No significant differences were noted with Garnem and Myrobalan 29C. In the twig infestation trial, Barrier, MaxMa60, and Marianna 26 rootstocks were least infested, while Colt was preferred by young larvae.

Agro technical methods

The main control measures against *Capnodis tenebrionis* include optimal fertilization, regular irrigation, selection of suitable rootstocks, and planting healthy trees (Rosella, 1948). Alavidze (1966) reported that a single irrigation timed during female oviposition and egg hatching could reduce damage by 40%, while an additional irrigation could further reduce damage by 70 to 90%. In stone fruit orchards, Semenov (1945) observed that Buprestidae populations were higher in the absence of irrigation. Interestingly, the primary damage was caused by adult beetles rather than larvae. Malagón et al. (1990) demonstrated that females prefer to lay eggs in dry sites where soil moisture is below 10%. Therefore, regular irrigation is one of the most effective preventive practices to reduce *C. tenebrionis* damage, as moist soil inhibits egg hatching and restricts the movement of neonate larvae. Additionally, mulching with organic materials around the trees helps protect the soil from evaporation, further maintaining adequate moisture levels.

Sharon et al. (2010) investigated host tree selection by adult *Capnodis tenebrionis* and occasionally found that beetles are attracted to nitrogen-rich trees. They suggested that excessive nitrogen fertilization makes trees more favorable for egg-laying by females. This insight could help develop baits to lure females into traps. Talhouk (1966) reported that a combination of regular pruning, soil cultivation, and nitrogen fertilizer applications could reduce damage caused by both *Capnodis tenebrionis* and *C. carbonaria*.

Removing weeds around orchard trees reduces adult beetle density by disturbing their habitat (Baspinar et al., 2017). Borg (1936) discovered that painting tree trunks with a strong milk of lime decreased pest infestation, while Brichet (1945) showed that treating young tree trunks with lead arsenate effectively protected them from insect damage. Additionally, whitewashing trunks reduces egg-laying activity

(Baspinar et al., 2017). Placing polyethylene sheets around tree trunks may also prevent larvae from reaching the trees.

Insect nets have proven successful in protecting trees from various pests. In cherry orchards, Charlot & Weydert (2013) used nets to shield cherry trees from cherry fruit fly (*Rhagoletis cerasi* L.), spotted wing drosophila (*Drosophila suzukii* M.), and flatheaded borer (*Capnodis tenebrionis* L.). Their experiments demonstrated that orchards could be fully protected from aphids, goat moth (*Cossus cossus* L.), wasps, flatheaded borer, and cherry fruit fly.

Direct control of adults includes hand-picking beetles from trees (Féron, 1952; Chrestian, 1955). Furthermore, all infested trees in orchards should be removed and burned, as larvae can continue developing in dead trees (Guercio, 1931; Berville, 1948).

Monitoring

To date, there are no globally available tools such as pheromone traps, repellents, or attractants for the phytosanitary monitoring of *Capnodis tenebrionis* (Kokici et al., 2020). Pest presence and population density assessments are currently performed exclusively through visual field inspections and the sweep net baiting method (Mfarrej & Sharaf, 2010).

Recently, Arapostathi et al. (2023) explored the use of remote sensing, specifically multispectral data from unmanned aerial vehicles (UAVs), for the early detection of *C. tenebrionis*. Remote sensing is the science of acquiring information about an object or phenomenon from a distance, often via sensors on platforms such as satellites or drones. In agriculture, it is employed to monitor plant health, soil fertility, and moisture by measuring the electromagnetic radiation reflected from plants and soil. Healthy plants absorb up to 90% of visible spectrum radiation, whereas stressed or infested plants absorb less blue and red radiation (Roman & Ursu, 2016). The findings of Arapostathi et al. (2023) demonstrated that multispectral remote sensing can accurately detect early infestations in stone and pome fruit trees, highlighting its potential as an effective tool for managing wood-boring insect pests.

CONCLUSIONS

The flat-headed root-borer, *Capnodis tenebrionis* L. is one of the most important pests on stone and pome fruit orchards. Damage caused by this species leads to substantial losses in the fruit-growing sector, and in some regions of the country, it has resulted in the widespread uprooting and destruction of orchards. In recent years, rising temperatures have led to a significant increase in the pest populations, resulting in greater damage in the orchards.

Control of this pest is extremely challenging, which necessitates the implementation of a range of measures, including soil cultivation around the tree trunks, optimal fertilization, irrigation, weed control, the use of chemical pesticides, as well as certain biological methods such as entomopathogenic fungi, bacteria, and nematodes.

This combination of measures succeeds in partially reducing the pest population density, but it does not achieve complete this problem. This necessitates the search for and evaluation of additional control methods to provide a comprehensive solution to this problem and to ensure the preservation of fruit growing in Bulgaria.

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