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REVIEW

Sweet potato pests: Perspectives on the use of pheromones for control and monitoring

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Abstract

Sweet potato production is mainly concentrated in tropical and subtropical regions, especially in developing countries in Africa, Asia and Latin America. It is a rustic crop fundamental to the population's food security. More research needs to be conducted on the crop, especially on the chemical ecology of insects that affect the plant. This review shows the main pests that affect sweet potato production and presents insect pheromones and their efficiency in semi-field and field tests with different releasers. Small farmers use cultural, biological, and chemical methods to reduce insect pest damage. With the advancement of new research, behavioral control is a growing practice, e.g., sex pheromones are used to monitor and control pests. This practice is possible because of studies on the chemical ecology of insects. There is a need to use specific and safe low-cost strategies associated with IPM. This review aimed to present a compilation of the leading pheromone options for controlling insects that affect sweet potato production, in order to assist in decision-making in the study of new pheromones from known pests and a combination of pheromones with other control strategies.

Keywords: chemical ecology, IPM, pest control, pheromone, semiochemicals

Introduction

The sweet potato, *Ipomoea batatas* (L.) Lam., (Solanales: Convolvulaceae) is an important food crop in tropical regions. Many pest species create significant challenges to its productivity and quality (Kays 2005; Okonya *et al.* 2014). Despite its worldwide importance, sweet potato cultivation still lacks investment in research and development by public institutions, especially in areas such as pest control (Xiao *et al.* 2022).

Chemical ecology, which investigates the chemical interactions between organisms and their environment, has proven to be an effective and practical approach to pest management. It offers alternatives to traditional control methods and should be developed for crop pests.

In this review, the chemical ecology of sweet potato pests was examined, focusing on identifying these individuals and research priorities for pheromone use. The attack of soil and foliage pests affects tuberous roots' productivity and quality. Defoliator insects promote the reduction of leaf area by limiting photosynthesis and causing injuries that facilitate the entry of disease-causing pathogens.

The primary insects that attack the inner part of sweet potatoes are weevils of the Curculionidae family, especially *Cylas formicarius* (Fabr.) (Coleoptera: Brentidae), *Cylas puncticollis* (Boheman) (Coleoptera: Brentidae) and *Euscepes postfasciatus* (Fairmare) (Coleoptera: Curculionidae). In the foliage, the complex of chrysomelids, *Diabrotica speciosa* (Germar) (Coleoptera: Chrysomelidae), *Diabrotica balteata* (LeConte) (Coleoptera: Chrysomelidae), *Diabrotica bivittula* (Kirsch) (Coleoptera: Chrysomelidae), *Sternocolaspis quatuordecimcostata* (Lefèvre) (Coleoptera: Chrysomelidae), *Typophorus nigritus* (F.) (Coleoptera: Chrysomelidae), *Paraselenis flava* (L.) (Coleoptera: Chrysomelidae), *Systena* spp. (Coleoptera: Chrysomelidae), *Epitrix* spp. (Coleoptera: Chrysomelidae) and *Chaetocnema apricaria* (Suffrian) (Coleoptera: Chrysomelidae), and caterpillars of the Lepidoptera order and Noctuidae family (*Spodoptera* spp. and *Megastes* spp.) are mainly responsible for the injuries.

Underground pests are considered the most problematic and challenging to control. They cause economic losses even in low numbers because they live underground and continue to attack even during storage (Kapsa 2008). Most of these insects belong to the order Coleoptera, which in the larval stage, cause direct damage to the commercial part of the crop by feeding on the roots, making them unfit for consumption.

Climate change which intensifies the occurrence of crop disease can impact the food security of the world's population (Halsch *et al.* 2021; Skendžić *et al.* 2021; Yasin 2021). Increasing temperatures and changing rainfall patterns can accelerate the life cycle of several species of insect pests, resulting in a more significant number of generations in a shorter period and their rapid dispersion to new areas. Thus, specific and safe integrated pest management (IPM) strategies are needed.

The integrated pest management of sweet potato crops combines cultural, biological, and chemical strategies to minimize damage caused by insect pests. Among cultural practices, crop rotation with grasses interrupts pest reproductive cycles and increases annual yields, while mulching significantly reduces the population of certain species (Mansaray *et al.* 2013; Gurr *et al.* 2016).

Biological control is also a relevant tool in IPM, employing parasitoids and entomopathogenic nematodes against subterranean pests. Nevertheless, chemical control remains widely used, with pyrethroids, neonicotinoids, and organophosphates being the most common active ingredients. In this context, pheromone traps have gained prominence as an ethological strategy within IPM, enabling precise pest population monitoring, mass insect trapping, and mating disruption, thereby reducing reproduction rates.

Using pheromones for IPM in sweet potato culture is a promising strategy for facing the challenges posed by climate change since they reduce the dependence on insecticides and promote more sustainable agricultural practices. The focus in this review of this highly relevant crop was to understand the pests that attack sweet potato crops, by gathering studies on their inter nd intraspecific interactions. At the end of this review, the insect species that affect the sweet potato crop, the available pheromone options, and the perspectives and priorities related to this research topic are discussed.

Importance of sweet potato culture and main limitations to cultivation

Sweet potato (*I. batatas*) is one of the most versatile and economically relevant crops globally, having a strategic role in food security and income generation, especially in developing countries. It can be used for human consumption, animal feed, and as a raw material for food and energy industries. Small farmers represent the majority of producers (Jansson and Raman 2019). In 2020, global sweet potato production was estimated at 92.1 million tons, cultivated in more than 100 countries (FAOSTAT 2021). China leads production, accounting for more than 50% of global supply, at 48.9 million tons. The global sweet potato planting area is estimated to be around 7.2 million hectares. Beyond its direct economic value, sweet potato stands out for its rusticity, high productivity in poor soils, and resistance to adverse weather conditions. It was considered the sixth most important food crop in the world (Alam 2021).

About 821 million people worldwide suffer from malnutrition due to the various impacts of climate change on food security, which necessitates strategies such as low-cost crop production (Wheeler and von Braun 2013). Increasing temperatures can expand pests' geographical distribution, as well as increasing the number of generations per year and the evolutionary process. This in turn hastens the development of insecticide resistance and increases crop damage (Skendžić *et al.* 2021). In this context, sweet potatoes have high nutritional value and resilience to diverse growing conditions, which is essential for food security. However, pest-related challenges which limit yield and quality increasingly threaten their cultivation.

Sweet potatoes have high genetic diversity due to their sexual mode of propagation and the introduction of plants from different origins. Farmers generally select plants with desirable characteristics for reproduction and cultivation using material obtained from previous harvests, seedlings purchased from nurseries or other farmers, and materials from germplasm banks that store and conserve the genetic diversity of plants. These materials have different colors, formats, textures and production yields (Firon *et al.* 2009). Farmers face several production-limiting factors, including a lack of access to financial resources to obtain inputs and production technologies, a lack of information and education on efficient agricultural practices, adverse climate changes and low availability of quality seed (Okonya *et al.* 2014).

For sweet potato crops, the anticipated appearance of insects and diseases in agricultural environments and the emergence of insects not previously present in the area will require more frequent insecticide applications to reduce production losses. It is estimated that a 2°C increase in temperature can increase insect reproduction from 1 to 5 generations per crop cycle. Warmer periods are associated with an increase in insect abundance in subsequent years, causing significant production losses (Yamamura and Kiritani 1998; Halsch *et al.* 2021).

Global warming affects the dynamics of insect populations, promoting an increase in pests and a decrease in beneficial insects. This scenario leads to the need for alternative strategies for the intensive use of insecticides, such as pheromones. Pheromones can attract and capture pests or interfere with their reproductive behaviors, reducing the need for chemicals. In a warming climate, using pheromones may become even more crucial to sustainably control insect populations and minimize negative impacts on crops and the environment (Deutsch *et al.* 2018).

Use of pheromones in agriculture

IPM aims to control pests efficiently, safely and sustainably. Taking into consideration the characteristics of the environment, culture, and insect population density, it combines different control methods. A modern and widely used method in IPM is the behavioral control of insects using pheromones. This mechanism is considered safe, efficient, and ecologically correct for monitoring and controlling insects. Pheromones have specificity and do not leave residues in the environment. Thus, they are valuable tools for pest control, as they minimize the negative impacts of using traditional synthetic insecticides (Goulart *et al.* 2015). In agriculture, pheromones are used to monitor insects for decision-making when carrying out management. In this phase, a small number of traps are installed per unit area to detect the presence or absence of an insect and monitor its population fluctuation after data collection in the field. The farmer or technician verifies whether the insect is causing economic damage, whether there is population stability and whether natural enemies are present (Goulart *et al.* 2015; Santi *et al.* 2015).

Another way of using pheromones is to control pests, which can be done by mass trap collection to attract the most significant number of individuals to the collection site, consequently reducing the population. An example of success in agriculture is the use of Rhynchophorol®, the aggregation pheromone of the eye borer of the coconut tree *Rhynchophorus palmarum* L. (Coleoptera: Curculionidae), and the primary agent of dissemination of the nematode *Rhadinaphelenchus cocophilus*, the causal agent of red ring disease of the coconut tree (Navarro *et al.* 2002; Goulart *et al.* 2015; Oehlschlager 2016).

Pheromone traps containing Rhynchophorol® can achieve reductions of over 80% in pest populations in treated areas. The effectiveness of control depends on such factors as the pheromone release rate and the type of trap used, with bucket traps being widely adopted for their efficiency and cost-effectiveness. Additionally, capture efficiency is enhanced when traps are combined with sugarcane pieces, coconut palm stems, or pineapple fruits. Moderate release rates (approximately 4.3 mg/day) have been found to be the most economical and effective for capturing *R. palmarum* (Navarro *et al.* 2002).

Sweet potato pests

Considering pest diversity, Jansson and Raman (2019) stated that more than 300 arthropod species can attack sweet potatoes. However, despite this impressive number, only some can cause economic damage.

The pests that attack the sweet potato crop can be divided into two categories: those that attack the foliage and those that attack and feed on tuberous roots. Pests attacking the foliage feed exclusively on leaves, causing significant losses when present in high incidence, especially during the initial stages of the plant. Pests attacking tuberous roots are considered the most notorious because they directly affect the production and commercial value of the crop.

The primary insects attacking the inner part of the sweet potato are weevils of the Curculionidae family, especially *C. formicarius*, *E. postfasciatus* and *C. puncticollis*, which are the most reported in the literature.

In the foliage, the primary pests include the complex of chrysomelids (*D. speciosa*, *D. balteata*, *D. bivittula*, *S. quatuordecimcostata*, *T. nigritus*, *P. flava*, *Systena* spp., *Epitrix* spp. and *C. apricaria*), which competes with several species of defoliating caterpillars of the Lepidoptera order, specifically of the Noctuidae family (*Spodoptera* spp. and *Megastes* spp.), among other secondary pests.

IPM in sweet potato cultivation combines different strategies to minimize damage caused by insect pests. Among cultural practices, crop rotation, mulching, and proper management of crop residues stand out. Studies show that rotations that included grasses, such as bahiagrass *Paspalum notatum* Flügge (Poaceae) and sweet corn *Zea mays* (L.) var. rugosa (Poaceae), result in higher annual sweet potato yields and significantly reduce pest incidence by interrupting their reproductive cycles, while mulching contributes to reducing the population of *C. formicarius* (Guertal *et al.* 1997; Mansaray *et al.* 2013; Devi *et al.* 2016).

In biological control, the parasitoids *Telenomus remus* and entomopathogenic nematodes of the genera *Heterorhabditis* and *Steinernema* have shown effectiveness against larvae and adults of underground pests, reducing populations by up to 90% under experimental conditions (Ekanayakei *et al.* 2001; Gapasin *et al.* 2016; Fanou *et al.* 2019).

Chemical control is the most common, but its excessive use can lead to pest resistance and negative impacts on non-target organisms. The most commonly used active ingredients include: pyrethroids effective against chrysomelids and other foliage pests, neonicotinoids used for underground pest control, and organophosphates for the control of *D. speciosa*, although their use is being restricted in many countries due to environmental concerns. (Salles and Grutzmacher 1999; Huseth and Groves 2014; Molnar and Rakosy-Tican 2021).

Integrated pest management practices can be employed to regulate insect populations. However, the methods widely adopted in agriculture are relatively new, and the use of insecticides as the primary approach is predominantly highlighted. To promote more sustainable practices from an environmental point of view, it is crucial to adopt ecologically correct procedures, such as behavioral control, which is already used in crops of greater economic relevance.

Pheromones of sweet potato insects

Coleoptera

Weevil larvae are considered a significant problem in culture; however, little is known about their ecology, biology, and forms of control. The larvae penetrate the tuberous roots of the sweet potato, piercing the surface and digging tunnels. This activity causes direct mechanical damage to the roots, weakening their structure and impairing their ability to absorb nutrients and water. Perforations and galleries also allow the entry of pathogens, such as fungi and bacteria, which interfere with root growth and cause yield losses.

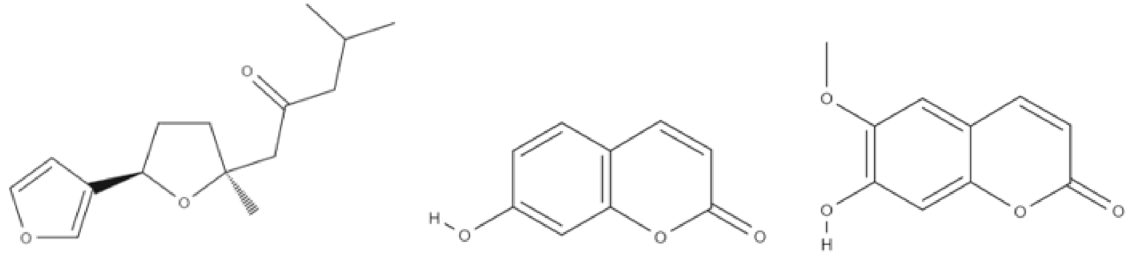
Under attack by borers, the sweet potato plant reacts and produces furanoterpenoid ipomeamarone and coumarins Umbelliferone and Scopoletin (Fig. 1) (Uritani *et al.* 1975). Under high infestation, the production of these compounds is increased, causing a characteristic odor and bitter root taste, which reduces its commercial value (Uritani *et al.* 1975; Wang and Kays 2002).

Cylas formicarius

For sweet potato cultures, weevil *C. formicarius* is the most serious pest in the world. Females produce a sex pheromone determined by Heath *et al.* (1986) as (Z)-3-dodecen-1-ol (E)-2-butenoate (Table 1). Glass slides and rubber septa showed similar results in attracting male weevils in the field. Furthermore, higher doses of synthetic pheromone resulted in greater attraction efficiency; in rubber septa, a dose of 1000 ng · 100 μl^{-1} was superior for insect capture.

Yasuda *et al.* (1992) studied the synthetic pheromone of *C. formicarius* in sweet potato fields in Japan. The pheromone effectively attracted male sweet potato weevils for over a month, and the traps were more efficient when placed downwind. Pheromone activity was highest in the late afternoon and early evening and declined rapidly at dawn. Traps set directly on the ground more effectively captured males than those installed above the ground.

Another study evaluated the impact of the sweet potato weevil and the effectiveness of sex pheromone raps in Java, Indonesia. Damage was higher in the dry season, reducing productivity from 3.32 to 2.50 kg · m^{-2}. Pheromone traps showed variations in weekly captures but did not significantly impact losses,



A B C

Fig. 1. Compounds with high production in sweet potato tubers after *E. postfasciatus* attack. A – furanoterpenoid ipomeamarone and coumarins: B – umbelliferone and C – scopoletin

with damage of 2.7% and 4.7% caused by the weevil and other pests, respectively. Field trials resulted in an average yield of 2.41 kg · m^{-2}, with captures ranging from 46 to 584 weevils/week, depending on the location (Braun and Van De Fliert 1999).

Cylas puncticollis and C. brunneus

The life cycle and some characteristics of *C. puncticollis* and *C. brunneus* are similar to those of *C. formicarius* (Skoglund and Smit 1994). On average, the incubation period lasts 3–4 days, and the larval instars last 11–14 days. The pupal period ranges from 5 to 7 days, with a total developmental period of 19–24 days. *C. brunneus* has a longer developmental cycle than other species (Musana *et al.* 2016). At 27°C, *C. formicarius* has a total developmental time of about 35–40 days, while *C. brunneus* takes about 44 days to complete its cycle.

Experiments carried out in Uganda and Indonesia led to the identification of the sex pheromones of females of *C. puncticollis* and *C. brunneus* as the compounds decyl (E)-2-butenoate and dodecyl (E)-2-butenoate, respectively (Table 1). Decyl (E)-2-butenoate attracts only *C. puncticollis* males, while dodecyl (E)-2-butenoate attracts males of both species, indicating lower specificity (Table 1) (Downham *et al.* 1999; Vasquez *et al.* 2009).

The effectiveness of pheromone traps for *C. puncticollis* and *C. brunneus* varies depending on the type of dispenser, polyethylene vial or rubber septum. For *C. puncticollis*, polyethylene vials were more effective, while for *C. brunneus*, rubber septa were more selective, capturing fewer *C. puncticollis* individuals. The rate of pheromone release, which is slower in rubber septa, may influence selectivity, but this explanation is not entirely conclusive. Selectivity for *C. brunneus* did not consistently increase with lower initial concentrations and slower pheromone release kinetics, suggesting that factors other than release rate, such as differences in the sensitivity of the two species' olfactory receptors to pheromones, the presence of other unidentified semiochemical compounds, and behavioral and ecological factors, may influence pheromone selectivity (Downham *et al.* 1999).

Pheromone identification represents an advance in the management of these pests, but the lack of specificity of dodecyl (E)-2-butenoate and the influence of the type of dispenser on attracting insects indicate the need for additional research resources to optimize the use of pheromones to control these species.

Euscepes postfasciatus

The sweet potato borer, *E. postfasciatus*, is an essential and vital pest widely reported in South America, Central America, the South Pacific and the Caribbean basins (Shimoji 2011). Its larvae can burrow deep into tubers, similar to *C. formicarius*, promoting high production of the furan-terpenoid ipomeamarone 1-[(2S,5R)-5-(furan-3-yl)-2-methyloxolan-2-yl]-4-methylpentan-2-one and the coumarins umbelliferone 7-hydroxychromen-2-one and scopoletin 7-hydroxy-6-methoxychromen-2-one (Fig. 1). The potato has an unpleasant smell and bitter taste, making it challenging to commercialize (Uritani *et al.* 1975).

Table 1. Pests that attack sweet potato crops and their pheromone compounds

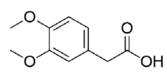
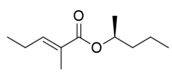
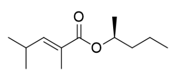
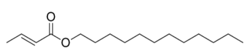
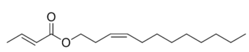
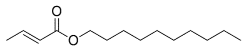
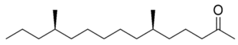
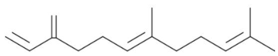
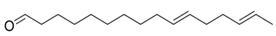
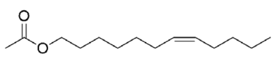
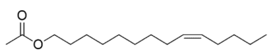
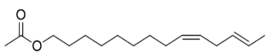
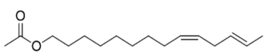
Order/Family/Specie	Pheromones		References
		Coleoptera	
		Bostrichidae	
Rhyzopertha dominica (Fabricius, 1792)		3:4-dimethoxyphenylacetic acid	Williams *et al.* (1981)
		(S)-(+)-1-methylbutyl (E)-2-methyl-2-pentenoate (S-dominicalure-1)	
		(S)-(+)-1-methylbutyl (E)-2,4-dimethyl-2-pentenoate (S-dominicalure-2)	
		Brentidae	
Cylas brunneus (Fabricius)		dodecyl (E)-2-butenoate	Musana *et al.* (2016)
Cylas formicarius (Fabricius, 1798)		(Z)-3-dodecen-1-ol (E)-2-butenoate	Heath *et al.* (1986); Mithran and Subbaraman (1999)

Table 1. Pests that attack sweet potato crops and their pheromone compounds – continuation

Order/Family/Specie	Pheromones		References
Cylas puncticollis (Boheman, 1883)		decyl (E)-2-butenoate	Downham *et al.* (1999); Vasquez *et al.* (2009)
Chrysomelidae			
Diabrotica balteata (LeConte, 1865)		(6R,12R) dimethylpentadecan--2-one	Chuman *et al.* (1987)
Diabrotica bivittula (Kirsch, 1883)		unidentified	Melo *et al.* (2020)
Epitrix sp.	–	unidentified	França and Ritschel (2002)
Sternocolaspis quatuordecimcostata (Lefèvre, 1877)	–	unidentified	Melo *et al.* (2020)
Curculionidae			
Euscepes postfasciatus (Fairmaire, 1849)	–	unidentified	Capinera (2020)
Scarabeidae			
Phyllophaga ephilida (Say, 1825)	–	unidentified	Diagne (2004)
Hemiptera			
Aphididae			
Aphis gossypii (Glover, 1877)		*trans*-β-farnesene	Bowers *et al.* (1972)
Lepidoptera			
Crambidae			
Omphisa anastomosalis (Guenée, 1854)		(10E,14E)-hexadecadienal; (10E,14E-C16Al)	Wakamura *et al.* (2010)
Noctuidae			
Pseudoplusia includens (Walker, 1857)		(7E)-dodecenyl acetate; (7E-12OAc)	Berger and Canerday (1968)
Spodoptera albula (Walker, 1857)	–	unidentified	Broglio *et al.* (2011)
Spodoptera cosmioides (Walk., 1858)		(9Z)-9-tetradecenyl acetate; (9Z)-14:OAc	Blassioli-Moraes *et al.* (2016)
Spodoptera dolichos (Fabricius, 1794)		(9Z,12E)-9,12-tetradecadienyl acetate; (9Z,12E-14:OAc)	Mitchell and Tumlinson (1973)
Spodoptera eridania (Stoll, 1782)		(9Z,12E)-tetradecadien-1-ol acetate; (9Z,12E-14: OAc)	Jacobson *et al.* (1970)
Pyralidae			
Megastes pusialis (Snellen, 1875)	–	unidentified	–
Megastes grandalis (Guenee, 1854)	–	unidentified	–
Sphingidae			
Agrius cingulata (Fabricius, 1775)	–	unidentified	Halder *et al.* (2018)

The tunnels formed can be gateways for other pathogens attacking the crop (Capinera 2020).

The sweet potato weevil demonstrates a weak attraction to LEDs, including chemiluminescent and ultraviolet lights (Katsuki *et al.* 2012; Nakamoto and Takushi 2001). The effectiveness of capture with LEDs is still insufficient to monitor pests effectively, requiring association with more effective techniques.

E. postfasciatus males exhibit "guarding" behavior both before (pre-copulation) and after (post-copulation) mating. This means that the male remains close to the female, both to guarantee exclusive access to her (before) and to prevent other males from copulating with her (after) (Sato and Kohama 2007; Kumano *et al.* 2009).

Sweet potato weevil males responded to extracts of waxy components obtained from the body surface, exhibiting prolonged mating behavior in glass spheres covered with extracts from females. These responses suggest that body surface lipid components can be used as semiochemicals for pest management (Isa *et al.* 2019). However, the specific compound that generates this response for *E. postfasciatus* has yet to be described.

Phyllophaga ephilida

The white larva *Phyllophaga ephilida* (Say) (Coleoptera: Scarabaeidae) is another crop pest. Adult beetles of the genus are nocturnal and feed on tree leaves, mainly hardwood.

Adult females lay eggs in the soil at 2.5–20 cm depths. After hatching, larvae feed on the roots and stems of plants, including sweet potatoes, and form tunnels that affect the quality and marketing of tubers (Diagne 2004).

Thus far, pheromones against *P. ephilida* have not been identified (Diagne *et al.* 2006).

Chrysomelidae

Members of the chrysomelid beetle complex Coleoptera of the family Chrysomelidae are phytophagous beetles that can cause severe defoliation in the larval and adult stages. Some members of the subfamilies Cassidinae, Eumolpinae and Galerucinae are species that attack sweet potato crops. Chrysomelids have similar behaviors, life cycles and injuries, which makes it challenging to define the impact of each species. Thus, they are divided into a complex composed of the species *D. speciosa, D. balteata, D. bivittula, S. quatuordecimcostata, T. nigritus, P. flava, Systena* spp., *Epitrix* spp. and *C. apricaria* (França and Ritschel 2002; Melo *et al.* 2020).

Of the chrysomelids that affect sweet potato crops, sex pheromones are reported only for *D. balteata*, a minor pest. Therefore, further studies are needed to identify active compounds in the communication of this complex of beetles, aiming at their use in IPM techniques, such as monitoring and control.

Diabrotica balteata

D. balteata is a polyphagous pest. Adults oviposit close to the roots of host plants. After hatching, the larvae feed on the roots, while the adults feed on the leaves, flowers, and fruits. This species does not present diapause in its eggs and has several continuous generations throughout the year, making it a tricky pest to control (Cabrera *et al.* 2020).

Chuman *et al.* (1987) identified the sex pheromone of *D. balteata* as (6R,12R) dimethylpentadecan-2-one (Table 1). Field tests were performed by incorporating the formulated material into filter paper or rubber septum and using it in wing-type traps (Pherocon, California, USA), showing a significant response to the formulation.

Field tests were carried out on sweet potato and pumpkin plantations, with traps containing different concentrations of the synthetic pheromone (1, 4, 10, 100 and 1000 µg on filter paper and 0.03, 0.1, 0.3, 1, 3, 10 and 30 mg in rubber septa). The natural material and a control (hexane) were compared. The optimal dose of synthetic pheromone was 10 µg, which captured an average of 104.2 males per trap, surpassing lower doses (1 µg: 65.5 males) and higher doses (100 µg: 37.2 males; 1000 µg: 8.7 males). In traps with rubber septa, doses between 30 and 300 µg were more effective, with a maximum capture of 24.8 males at 300 µg. It is essential to highlight that research on insect pheromones is complex and requires the combination of different approaches, including chemical, behavioral and ecological studies. The study did not investigate the interaction of the pheromone with other volatile compounds potentially present in the species' chemical communication. Mclaughlin *et al.* (1991) found that the bioactive form of the female sex pheromone of *D. balteata* is (6R,12R) dimethylpentadecan-2-one. The other three stereoisomers ((R,S), (S,R), and (S,S)) did not attract males and did not inhibit the capture of males by the bioactive isomer. Field tests revealed that a 300-µg load of the RR isomer in a rubber septum effectively captured the male. However, capture decreased significantly with bait containing more than 300 µg of the RR isomer.

This result is crucial for developing more efficient pheromone traps for managing *D. balteata*. This indicates that the ideal concentration of the pheromone in the bait is essential to maximize the capture of males. Furthermore, this study highlights the importance of using the correct bioactive form of pheromone, as the other stereoisomers were ineffective. The ideal dose and the influence of stereoisomers still need to be further explored to optimize its practical application.

Lepidoptera

In sweet potato production, lepidopterans are hardly considered more severe than borers because the larvae generally do not reach the commercial part and feed on the crop's leaves. Defoliations cause yield reductions only in severe attacks (Lugojja *et al.* 2001). According to Lugojja *et al.* (2001), it takes more than one defoliation event during the crop cycle for significant yield loss.

Megastes pusialis and M. grandalis

Megastes pusialis (Snellen) (Lepidoptera: Crambidae) and *M. grandalis* (Guenee) (Lepidoptera: Crambidae) are moths from the Crambidae family. The larvae excavate galleries in the collar and stems of plants, especially sweet potatoes, causing significant damage (Cavalcante *et al.* 2013). The females lay eggs at the base of the plant, and the larvae, pink in color with black dots, feed internally, forming galleries. The life cycle lasts around 57 days, and the adults are dark brown moths.

Symptoms of attack include swelling, cracks, and holes in the stems as well as wilting and drying of the branches. The lesions mainly affect the sap-conducting vessels and, occasionally, the roots, resulting in leaf loss, branch wilting and reduced production, which can vary from 30 to 50%. The death of stems is a strong indication of the presence of the pest in the crop (Sorensen 2009).

Omphisa anastomosalis

The caterpillar *Omphisa anastomosalis* (Guenée) (Lepidoptera: Crambidae), which predominantly occurs in Asia, pierces the main stem of the plant and occasionally reaches the storage organ, causing cavities, wilting and eventual plant death (Ohno *et al.* 2010). It is considered the second most important pest of sweet potatoes in areas where it coexists with sweet potato weevils. Infestations by *O. anastomosalis* can cause significant production losses, ranging from 30 to 50%. Controlling the pest is difficult because its immature stages feed inside the plant's branches (McQuate *et al.* 2019). For *O. anastomosalis*, Wakamura *et al.* (2010) identified an active compound obtained from the extract of pheromone glands taken from the abdomens of virgin females (10E,14E)-hexadecadienal (Table 1). In field tests, the synthetic sex pheromone was less attractive than the use of virgin females.

McQuate *et al.* (2019) investigated the efficacy of a combination of sex pheromones (10E,14E)-10,14-hexadecadienal (Type I) and (3Z,6Z,9Z)-3,6,9-tricosatriene (Type II) to monitor and control the *O. anastomosalis* in Hawaii. Field tests demonstrated that adding the Type II component significantly increased the capture of males in traps by up to 13 times compared to using the Type I component alone. The ideal Type I: Type II ratio ranged between 1 : 5 and 1 : 10. Additionally, the 12-week weathering study revealed that bait attractiveness persisted throughout this period, gradually decreasing the Type I: Type II ratio.

Family Noctuidae and the Spodoptera Complex

The Noctuidae family constitutes one of the most diverse groups of moths, and most pests of agricultural importance are included in this family. When small, the caterpillars scrape the leaves, causing superficial damage without loss of production. However, they can evolve into lesions with regular edges. Reaching their last instar, they can destroy the leaves and even the thinnest stems (Rabieh 2018).

In South America, the Spodoptera complex is formed by essential pests for several commercial crops, such as corn, soybean and cotton. The main species of the complex include *Spodoptera albula* (Walker) (Lepidoptera: Noctuidae), *Spodoptera cosmioides* (Walker) (Lepidoptera: Noctuidae), *Spodoptera eridania* (Stoll) (Lepidoptera: Noctuidae), and *Spodoptera frugiperda* (J.E. Smith) (Lepidoptera: Noctuidae). *Spodoptera dolichos* (Fabr.) (Lepidoptera: Noctuidae), *S. albula* and *S. cosmioides* have been reported in sweet potato crops. Despite the large number of species present and their importance in other crops, these are considered secondary pests for sweet potato, as they do not attack the commercial part of the sweet potato, hardly causing any economic damage.

Among the reported species of the Noctuidae family, the sex pheromones of have been identified as follows: *S. dolichos*: (9Z,12E)-9,12-tetradecadienyl acetate (Mitchell and Tumlinson 1973), *S. cosmioides*: (9Z)-9-tetradecenyl acetate (Blassioli-Moraes *et al.* 2016), *S. eridania*: (9Z,12E)-tetradecadien-1-ol acetate (Jacobson *et al.* 1970), and *P. includens*: (7E)-dodecenyl acetate (Table 1).

Other defoliating caterpillars of the Noctuidae family have been identified in sweet potatoes in Brazil: *Pseudoplusia includes* (Walk.) (Lepidoptera: Noctuidae) and *Agrius cingulata* (Fabr.) (Lepidoptera: Noctuidae) (Broglio *et al.* 2011).

Hemiptera

Aphis gossypii

Aphis gossypii (Glover) (Hemiptera: Aphididae) is an aphid that damages sweet potato crops, as it transmits phytoviruses and reduces plant vigor by sucking sap and injecting toxins. Although not considered a key pest, its chemical control can be counterproductive, since it eliminates the natural enemies that regulate its population. Therefore, it is essential to know the biology and ecology of this insect to develop IPM strategies (Ames *et al.* 1997).

The sex pheromone of *A. gossypii* has not yet been described. However, an alarm pheromone has been reported for aphids, triggering the dispersal and evasion of individuals of the same species when attacked by another, such as a natural enemy. They identified the compound as trans-β-farnesene (Table 1) (Bowers *et al.* 1972).

(E)-β-Farnesene triggers dispersal and evasion responses. This characteristic can be exploited in pest control strategies, using the alarm pheromone to manipulate the behavior of aphids, inducing colonies' dispersal and reducing crop infestation. Furthermore, (E)-β-farnesene can also act as a kairomone, recruiting natural enemies of aphids, such as ladybugs and lacewings, aiding in biological control (Bushra and Tariq 2014).

Storage pests

Pests that attack sweet potatoes in storage are a severe problem due to the resulting economic losses. Without monitoring and control measures, the injuries can be even greater than those incurred in the field. Some studies have reported the identification and use of pheromones to monitor and control these species (Hackman *et al.* 1948).

Rhyzopertha dominica

Rhyzopertha dominica (Fabr.) (Coleoptera: Bostrichidae) is a pest that attacks stored grains and has a reddish brown to dark brown color (Edde 2012). It can attack dried sweet potato roots and affect their quality (Mihale *et al.* 2009). *Rhyzopertha dominica* is a holometabolous insect, and its life cycle lasts an average of 60 days, with an egg incubation period of 15 days, a larval period of approximately 22 days, a pupal stage of 5 days and an adult stage of around 29 days (Reddy 2015).

Hackman *et al.* (1948) determined the phenolic substances released through the cuticle in six arthropod species, including *R. dominica*. The observed compound was 3:4-dimethoxyphenylacetic acid (Table 1). Further research has revealed that the main components of the aggregation of pheromone in *R. dominica* are comprised of (S)-(+)-1-methylbutyl (E)-2-methyl-2-pentenoate and (S)-(+)-1-methylbutyl (E)-2,4-dimethyl-2-pentenoate, named dominicalure 1 and 2, respectively (Williams *et al.* 1981).

Sweet potato resistance to pest attack

Weevils are the primary pests attacking the commercial parts of sweet potatoes. Therefore, it is necessary to adopt control measures associated with IPM and to determine the plant's defense mechanisms against attacks by these pathogens. Some studies have investigated the chemical basis of sweet potato resistance to weevil attacks to identify the compounds responsible for this resistance present in different cultivars (Muyinza *et al.* 2012; Anyanga *et al.* 2013, 2017).

Chemical analyses of sweet potato varieties have shown differences in the levels of certain compounds, such as flavonoids and alkaloids, between resistant varieties (New Kawogo and Tanzania). Compounds present in sweet potato latex and on the root surface can cause oxidative stress and impair weevil protein absorption, consequently affecting their development. This study provides important insights into the chemical basis of sweet potato resistance. It has potential applications in developing new strategies to control sweet potato weevil *C. puncticollis* (Stevenson *et al.* 2009).

Field trials and laboratory bioassays comparing seven resistant and three susceptible sweet potato varieties have revealed that resistance is not just a way to avoid damage but an active process. Higher concentrations of caffeic and coumaric acid esters, including hexadecyl, heptadecyl, octadecyl and quinic acid, are correlated with resistance in sweet potato varieties.

Octadecyl coumarate and octadecyl caffeate compounds are esters of hydroxycinnamic acids found on the surface and in the root epidermis of sweet potato varieties resistant to the weevils *C. puncticollis* and *C. brunneus* (Anyanga *et al.* 2013). These compounds act as insect repellents or inhibitors of feeding and oviposition. Surface applications on susceptible sweet potato varieties significantly reduced weevil damage in laboratory tests, suggesting that weevils are involved in plant resistance (Anyanga *et al.* 2013).

Currently, the New Kawogo and Tanzania varieties stand out in research and are considered the most resistant (Stevenson *et al.* 2009; Anyanga *et al.* 2013). Despite several studies on the resistance of sweet potato varieties to weevils, none are effectively immune to insect attacks. The compounds present in resistant varieties help to reduce damage. The presence of high hydroxycinnamic acid ester concentrations in the epidermis and root surface indicates their relationship to resistance to attack and oviposition by adult insects due to its restriction to the root surface; the larvae are not affected, and therefore, the internal area that suffers the most damage is not protected by the presence of these compounds (Anyanga *et al.* 2021).

Hydrocinnamic acid esters are organic compounds found in many plants, including fruits, grains, vegetables, and herbs, and are an essential part of plant defense systems. They are formed by combining cinnamic acids, such as caffeic acid and ferulic acid, with hydroxylated esters, such as methyl esters (Sova and Saso 2020). They can protect plants from environmental stress and pathogen attacks and have antimicrobial, antifungal and deterrent properties against herbivores.

Phytoalexins are organic compounds produced by plants in response to biotic (such as pathogen attacks) or abiotic (such as environmental stress) stimuli. These compounds are produced at sites of infection or damage and are essential for defense against pathogens and protection against damage caused by abiotic stress. Several biosynthetic routes make phytoalexins, which can be classified into terpenoids, flavonoids and alkaloids. Occasionally, their biosynthesis occurs via multiple pathways (Akagi *et al.* 2014; Kariya *et al.* 2020).

The main compounds identified in the roots and associated with weevil resistance are hexadecyl caffeic acid, hexadecyl coumaric acid, heptadecyl caffeic acid, octadecyl caffeic acid, octadecyl coumaric acid, and the furan-terpenoid phytoalexin ipomeamarone (Uritani *et al.* 1975; Stevenson *et al.* 2009; Anyanga *et al.* 2013). The information presented highlights the importance of organic compounds, such as phytoalexins and hydrocinnamic acid esters, in protecting plants against pathogens (Figure 1).

Conclusions and future perspectives

It is essential to consider farmers' perceptions and practices when developing insect control solutions for root tuber production. This work guides future research aimed at pest recognition and identifying, synthesizing, and using semiochemicals for pest monitoring and control as part of integrated crop management.

Using pheromones in sweet potato pest management has shown promising results, but significant challenges remain. Identifying pheromones for critical species, such as *E. postfasciatus* and *P. ephilida*, is a priority. Furthermore, studies are needed that address the optimization of traps and releasers, the combination of pheromones with other control strategies and the evaluation of the effectiveness of these approaches under different field conditions. The successful implementation of these technologies requires a deeper understanding of pest-specific life cycles and behaviors.

The main pheromone options currently available are highlighted for the management of pests that affect sweet potato crops, such as *C. formicarius*, *C. puncticollis*, *C. brunneus*, *O. anastomosalis*, *S. cosmioides*, *S. eridania*, *S. dolichos*, *P. includens*, *D. balteata,* and *A. gossypii*. The identification and synthesis of pheromones for other vital pests, such as *E. postfasciatus*, represent current research priorities. Furthermore, studies on the optimization of traps, releasers, the combination of pheromones with other control strategies and the evaluation of effectiveness in different field conditions are necessary to obtain more robust results.

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