Biological control: A sustainable strategy against invasive citrus snail

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Abstract

Snails are polyphagous pests that cause damage to several crops worldwide. They feed on the leaves and fruits of this crop and transmit certain fungal diseases. The present study aims to elucidate the protective role of the biological control approach against invasive snails. Citriculture in Morocco, particularly in the Gharb region, faces several phytosanitary problems, including snails. Three species, *Theba pisana, Helix aspersa,* and *Eobonia vermiculata*, have been associated with citrus orchards in this region. The current practice to combat these pests predominantly rely on molluscicidal products containing active ingredients such as metaldehyde, abamectin, indoxacarb, chlorfluazuron, and spiromesifen. However, due to the negative effects of chemical control on the environment and non-target species, these products are not a sustainable primary strategy for managing snail invasions. Effective management of invasive snails requires an integrated pest management (IPM) approach, such as i) cultural methods like manual collection from the trunk and branches, ii) Physical control using barrier traps that can be optionally combined with mineral oil, or attractants, and iii) Biological control can be achieved through the use of parasitic nematodes or plant extracts. Promising biological agents such as essential oil extracted from Citrus limon zest, aqueous extract of thyme, as well as lupin extract nanoparticles coated with copper sulfate and starch, which have demonstrated 100% mortality and inhibited egg laying.

Keywords: Invasive Snails, *Theba pisana, Eobonia vermiculata*, Citrus orchards, Biological controls, Sustainable

INTRODUCTION

Morocco is a country with a strong agricultural vocation. For this reason, Morocco's economic policy has given priority to the development of the agricultural sector, with the aim of making agriculture a driver of economic growth. At the national level, citrus farming is one of the key sectors of the Moroccan economy, with an area of approximately 129,333 hectares, of which 31% are in the Gharb region, and an average production of 2.4 million tons during the 2021-2022 campaign, of which 766,500 tons were destined for export (Morocco citrus, 2023). At the dawn of the 21st century, in Morocco where the areas reserved for citrus farming can hardly increase, this crop is called to be increasingly intensified. Such intensification, based on the use of high-yielding varieties, which are demanding in fertilization, water, weeding, and other cultural operations, allows trees to have good vegetative development, humid and shaded, often favorable and conducive to phytosanitary problems, particularly pests and diseases.

In recent years, citrus farming has seen the emergence of a pest that was considered secondary and is increasingly causing significant damage. These are land snails that feed on a variety of living plants and decomposing plant materials. They cause direct and indirect damage, with direct damage manifesting as consumption of foliage and creation of irregular holes on fruits and flowers during the night, only to disappear at sunrise, leaving a slimy trail that becomes shiny when dried (Wilen and Flint, 2018), while indirect damage concerns the transmission of gummosis to phytophthora (Benfradj *et al.*, 2018). As a result, these snails are responsible for significant economic losses that can reach 15% at the packing stations.

To maximize production and obtain high-quality fruits while reducing the extent of damage caused by snails, citrus growers in Morocco, especially in the Gharb region, resort to some cultural and chemical practices. These practices, in addition to being exhausting and expensive, only allow modest minimization of damage and pose problems of resistance, residue management, as well as negative impacts on fauna and flora. It is therefore necessary to resort to other methods of control, including biological control using plant extracts (essential oils, aqueous extracts, etc.) (Elfoudali *et al.*, 2024; Kourime *et al.*, 2025).

To this end, the present work was set to identify the main species of citrus pest snails in Morocco, as well as different methods of control, ranging from cultural practices to biological and chemical control.

CITRUS PEST SNAIL SPECIES IN MOROCCO

Several species have been associated with citrus orchards at the national level since 2007. Studies conducted in the Gharb region have reported the presence of three snail species: *T. pisana, H. aspersa,* and *E. vermiculata* (Elfoudali *et al.*, 2024; Kourime *et al.*, 2025). The three species are eukaryotic mollusks belonging to the class *Gastropoda*, family *Helicidae* (Korábek *et al.*, 2022).

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Theba pisana (Müller, 1774)

Morphology

According to the Helicidae key in Australia, *Theba pisana* is characterized by a relatively high shell, small in size (reaching up to 2 cm in diameter, axial view). The shell is usually white with discontinuous dark brown spiral bands and chevron markings. The juveniles show angular whorls, which become rounded in adults. The umbilicus is narrow, and the aperture is rounded and medium-sized. In adults, the lip of the shell is thickened on the inside and non-thickened or reflected on the outside (Blacket, 2016).

Figure 1: Shell morphology of Theba pisana

Biology and Ecology

Regarding their life cycle, snails estivate when conditions are dry or when temperatures are high, and hibernate in cold conditions. The duration of estivation and hibernation, and thus the length of the cycle, varies depending on the area. For example, in Morocco the cycle is annual, while in some regions of France and Italy, the cycle is biennial (Heller, 2009).

Theba pisana is a cross-fertilizing hermaphrodite. Compared to other *Helicidae* snails, it has a short lifespan (1-2 years), is semelparous (reproduces only once in a season), and produces a large number of small eggs (4566 eggs per couple) (Baker, 1991; Cowie, 1984).

The eggs are laid one or two centimeters below the surface of the soil in cavities dug by the snails (Cowie, 2009).

Distribution

Theba pisana is typically a species of coastal habitats, often found in sandy arid climates regions characterized by hot to warm conditions. Its native range includes almost the entire Mediterranean coastline and extends along the Atlantic coast (Johnson, 2011; Mizrahi *et al*., 2016). It also occurs inland, notably in Morocco, Algeria, Spain, Portugal, western and southern France, although its abundance is frequently in the interior non-coastal localities of these regions, compared to coastal areas (Cowie, 2009). It has been suggested on various grounds that *Theba pisana* original natural range may have been confined to Morocco. Alternatively, at least some, if not most, of its distribution around the Mediterranean and western Europe is the result of human activities in historical times, and therefore, *Theba pisana* should be regarded as invasive in those areas where it can reach extremely high abundances (Elfoudali *et al*., 2024; Mizrahi *et al*., 2016).

Eobonia vermiculata (Müller, 1774)

Morphology

The key of Helicidae species in Australia describes *Eobonia vermiculata* as possessing a relatively depressed shell, medium-sized (reaching up to 3 cm in diameter, axial view). The shell range from light brown to yellow, usually marked by thick, continuous dark brown and white spiral bands, with yellow spots. The whorls are rounded, the umbilicus is usually closed, and the aperture is small, compressed, and shaped. In adults, the lip of the shell thickens in white and strongly reflects (Blacket, 2016; Elfoudali *et al*., 2024; Kourime *et al*., 2025).

Figure 2: Shell morphology of Eobonia vermiculata

Biology and ecology

Eobonia vermiculata is a phytophagous and detritivorous species, active all year round except during cold periods (when hibernation occurs in the north of its range) and during hot and dry periods (when estivation occurs in the south of its range). The lifespan of this species lasts between 2 and 6 years. Mating occurs in autumn after the first rains, provided they are continuous. Subsequently, oviposition occurs 20 days after fertilization and adults that have laid eggs die after 1 to 2 months. During the winter, adults secrete one to three membranous epiphragms and burrow into the soil to a depth of 3 to 5 cm, while young individuals protect themselves under leaves, stones, etc (Kourime *et al*., 2025; Lazaridou-Dimitriadou and Kattoulas, 1983).

Distribution

E. vermiculata is native to the Mediterranean region and has become a very common species in the Mediterranean and the most widespread in the world, except for southern South America and certain Pacific islands (Kourime *et al*., 2025). Non-native populations of *E. vermiculata* have been established in various regions, such as Germany, the Netherlands, Belgium, Hungary, Australia, the United States, Japan, Saudi Arabia, Jordan, Egypt, and South Africa. This species has been established in the United States and is considered a potentially serious threat (CABI.org, 2023).

Helix aspersa (Müller, 1774)

Morphology

The shell is large (up to 4 cm in diameter), thin-walled, with a raised spire, globular, with 4-5 rapidly expanding whorls. It features a strongly flared whorl, a wide and rounded aperture, a closed umbilicus, and a thickened, white and strongly reflected lip in adults. The shell is light brown in color with darker spiral bands and yellow spots.

During estivation, the snail has a thin and transparent or thickened and greenish-gray epiphragm, which is non-convex and situated within the aperture. The body is soft, grayish- green with a pale dorsal band.

Adults are identified by the presence of a thickened reflected lip, indicating maturity and cessation of growth (Blacket, 2016).

Figure 3: Shell morphology of Helix aspersa

Biology and ecology

Helix aspersa is an obligate cross-breeding species. A mature snail mates 2–6 times per season, with each mating event lasting 4–12 hours. It is an oviparous species; fertilized eggs are encapsulated in a partially calcareous shell and laid with little to no embryonic development. Individuals deposit spherical or oval white eggs, approximately 3–5 mm in diameter, into a cavity 4–7 cm deep that they excavate with their foot in moist, loose soil. Egg cannibalism by neonates is common, with around 70% of newborns ingesting at least one egg during their first four days of life while remaining in the natal cavity. Mating and oviposition frequencies are influenced by abiotic factors (e.g., temperature, photoperiod, humidity, soil conditions) and biotic pressures such as population density (CABI.org, 2023).

Like several other snail species, *Helix aspersa* undergoes periods of inactivity, hibernation, and/or estivation, depending on the climatic conditions of its habitat. Studies have shown that the physiological transition between dormancy (estivation/hibernation) and awakening is controlled by enzymes, the main ones being selenium-dependent glutathione peroxidase (Se-GPX) and glutathione S- transferases (GST) (Ramos-Vasconcelos *et al*., 2005).

Distribution

Helix aspersa is widely distributed in Mediterranean countries, Africa, North America, and Europe (Blacket, 2016).

Tree-level dispersion

The distribution of snails at the tree level, both vertically and horizontally, is a very important parameter in determining the orientation of treatments at the tree level. These two types of dispersion vary between species. In the case of *E. vermiculata*, the concentration of snails decreases vertically with tree height, with a maximum of 1 meter from the surface of the ground, so it is recommended to orient treatments towards the surface of the ground and the trunk of the tree (Ismail *et al*., 2017).

Host plants

These three species of *Helicidae* are phytophagous and have a wide range of host plants, including mainly: acacia, onion, white alder, celery, oat, sugar beet, cabbage, cauliflower, turnips, brome grass, citrus, carrot, fennel, legumes, barley, lettuce, alfalfa, date palm, peas, almond, radish, mulberry, raspberry, tomato, cereals, grapevine, maize, etc (CABI.org, 2023).

Damage caused by citrus pest snails

Direct damage

Snails are not linked to a special plant; they consume different crops and decaying plant matter. Their feeding damage is characterized by irregular holes with smooth edges on leaves, fruits and flowers. This type of damage caused by snails can be visually similar to the feeding of other pests such as caterpillars, earwigs, or other chewing insects. The silver mucus trails can confirm that the damage was possibly caused by snails or slugs (Wilen and Flint, 2018).

Figure 4: Damage caused by Helix aspersa on citrus fruit

Indirect damage

Transmission of Phytophthora gummosis: Symptoms of discoloration of the surface of the bark, formation of cankers, and exudation of gum have been observed on citrus treated with snails previously fed on a substrate containing *Phytophthora spp*. These symptoms were exactly the same as those observed in citrus infected naturally with gummosis, including canker formation, bark discoloration, and gum exudation.

Disease symptoms were influenced by seasonal timing. Experiments conducted in May and June resulted in a significant highest infection rate compared to those conducted in August and September. Spatially, infections were most frequently observed in the median third of the trees across all experiments. However, symptoms were only observed in the lower third of citrus plants in May and June trial (Benfradj *et al*., 2018).

CONTROL STRATEGIES USED AGAINST LAND SNAILS

Cultural control

Orchard maintenance

Soil tillage and inversion, tree pruning, good fertilization, and spraying with Bordeaux mixture were applied from November to January in Egypt. These cultural operations resulted in a reduction of 14.6%, 13.4%, and 11.3% in populations of *Theba pisana, Monacha cartusiana,* and *Eobonia vermiculata*, respectively (Rizk *et al.*, 2017).

Manual collection

Snails were collected from the trunk and branches every 15 days from June to September. This method resulted in a reduction of 33.0%, 29.7%, and 31.2% in populations of *Theba pisana, Monacha cartusiana,* and *Eobonia vermiculata*, respectively (Rizk *et al.*, 2017).

Physical control

Barrier traps

Cone barriers are a physical control method that prevents snails from climbing onto the trees. Each device is made of a plastic sheet shaped like a cone, mounted approximately 20 cm above the ground around the tree trunk. Its upper part (cone tip) is attached to the tree trunk with a plastic reinforcement. Its effectiveness can be improved by placing a mineral oil-coated sheet on the outer upper edge. This has a very strong oily odor and can reduce snail percentages on trees by up to 20% (Kheirodin *et al.*, 2012).

Attractive traps

Wheat straw baited traps

An attractive bait was prepared from 5 kg of cereal bran, 0.5 kg of molasses, and 1 liter of water.

0.25 kg of this mixture is used to bait wheat straw covered by a cloth and used as an attractive trap. These traps are placed as 1 trap every 5 trees and 1 trap every 10 trees during winter and spring. When the traps are installed every 5 trees, populations of *Theba pisana, M. cartusiana,* and *E. vermiculata* were reduced by percentages of 51.3%, 48.9%, and 55.0%, respectively, while installing one trap every 10 trees gives reduction percentages of 29.3%, 33.3%, and 32.0%. Thus, the results showed that these traps were more attractive to *E. vermiculata* than the other two species (Rizk *et al.*, 2017).

Fermented bread dough traps

Fermented bread dough (flour, water, and yeast) has been shown to be effective in attracting harmful mollusc species in trials conducted in Hawaii, Oregon, Montana, and laboratory conditions. The dough attracted harmful snails, including major economically important invasive species such as *H. aspersa* and *Ambigolimax valentianus* (Limacidae), than water controls. Adult *H. aspersa* were significantly more attracted to the dough than to water controls. The attraction duration for the dough remains up to 8 days and has been shown to be significantly more attractive than a metaldehyde-based bait, which is widely used against snails (Veasey *et al.*, 2021).

Synthetic lure traps and banana, papaya-flavored oils baited traps

Banana and papaya scented oils were tested to determine if *Lissachatina fulica* (Férussac, 1821) moves towards daytime shelters and feeds on lures dosed with one of the scented oils. The lures were made by saturating standard-sized dental cotton wicks with 4 ml of an emulsion consisting of a 1:1:0,2 mixture of tap water, mineral oil, and Tween80 surfactant. Subsequently, the scented oil was added to each wick. Wicks treated with papaya and banana scented oil emulsions caused Giant African Snails to stop moving towards daytime refuge areas and return to open air (Roda *et al.*, 2019).

Chemical control

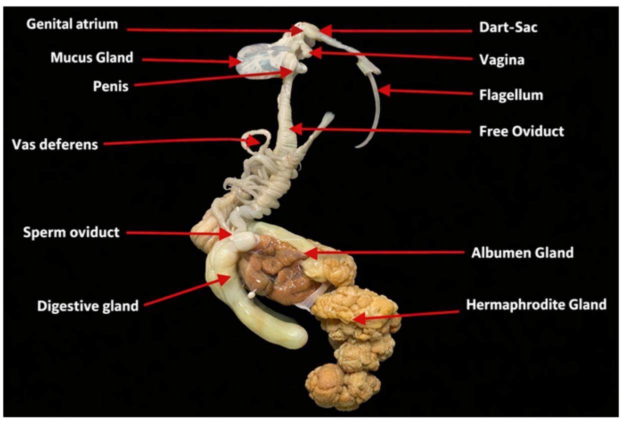
Chemical control using ovicidal products

Imidacloprid and fipronil can be used as active ingredients to significantly reduce the hatching rate of *Eobonia vermiculata* eggs, up to 22.7% and 16.2%, respectively (Hussein and Sabry, 2019). This parameter is calculated using the following formula:

Hatching rate = (Number of hatched eggs/Number of treated eggs) x 100

Chemical control through the use of adulticides

The majority of molluscicide active ingredients target adults. Metaldehyde, abamectin, indoxacarb, spiromesifen, and methyl parathion have been tested against *E. vermiculata*. Indoxacarb was found to be the most effective, followed by abamectin and spiromesifen, with mortality rates of 100%, 73.3%, and 60%, and LD50s of 58.6 ppm, 83.3 ppm, and 280.9 ppm, respectively (Hussein and Sabry, 2019).



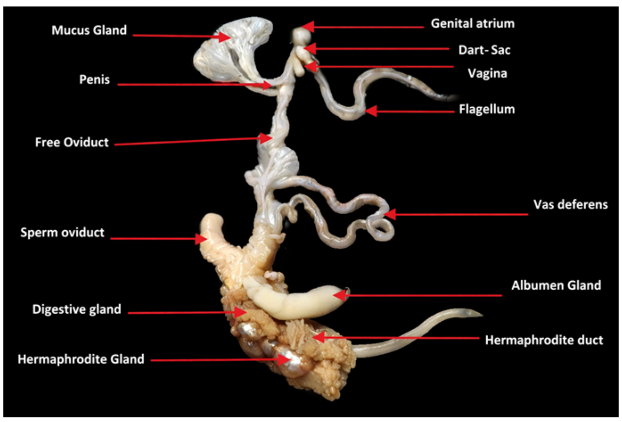


Figure 5: Reproductive system of untreated (left) and treated (right) E. vermiculata

Spraying metaldehyde against *H. aspersa* resulted in increasing mortality rates with increasing concentration. The use of 25% WP metaldehyde resulted in mortalities of 75.5%, 81.2%, and 98.5% with doses of 1.2, 2.4, and 4.8 g/L, respectively, while 50% WP metaldehyde resulted in mortality of 87.8% at a dose of 1.2 g/L (Pappas and Carman, 1961).

Application of 2% metaldehyde baits resulted in reduction percentages of 76.7%, 74.2%, and 73.2% for *T. pisana, M. cartusiana,* and *E. vermiculata*, respectively (Rizk *et al.*, 2017).

In *E. vermiculata*, chlorfluazuron exhibited greater toxicity via contact exposure (LD_{50}: 1528) than as bait (LD_{50}: 1992). On the other hand, chlorfluazuron induced malformations of the reproductive system organs in snails compared to untreated animals, causing significant swelling of the size of the vagina, penis, oviduct, spermiduct, and albumin gland, and led to the absence of eggs in the ovotestis (Figure 5). In field conditions, chlorfluazuron resulted in a 78.7% reduction in snail population (Mobarak, 2016).

The use of abamectin and its nano-derived form induced alterations in certain biochemical pathways, which could lead to significant cellular and metabolic damage. The use of pesticides based on this active ingredient affected vital enzyme activities in *H. aspersa*, where they significantly imposed inhibition of Acetylcholinesterase in ganglion homogenate. This enzyme plays an important role in catalyzing the hydrolysis of the neurotransmitter acetylcholine to maintain normal nerve impulse conduction (Yassin *et al.*, 2021).

Biological control

Use of plant extracts

Use of essential oil extracted from citrus fruits

The essential oil was extracted from the zest of lemon fruits (*Citrus limon*) by hydrodistillation. Chemical analysis by chromatography coupled with spectroscopy shows that this oil is mainly composed of limonene (Table 1). Tests carried out with concentrations of 10, 25, 50, 75, and 100 ppm for molluscicidal activity. In all tests, the percentage of mortality increased with an increase in concentration. Thus, these percentages were higher with a concentration of 50 mg L-1. The LC50 value for molluscicidal activity is 13.0 ppm (Barros Gomes *et al.*, 2019).

Tableau 1: Molluscicide and larvicide activities of the essential oil of Citrus limon

Larvicide activity		Molluscicide activity	
Concentration (mg L^{-1})	Mortality of larvae (%)	Concentration (mg L^{-1})	Mortality of snails (%)
70	100.0 ± 0.0	100	100.0 ± 0.0
50	86.7 ± 0.4	75	100.0 ± 0.0
30	66.7 ± 0.4	50	100.0 ± 0.0
10	36.7 ± 0.4	25	86.7 ± 0.4
5	13.3 ± 0.4	10	26.7 ± 0.4

Use of neem extracts

The effect of commercial neem extract was evaluated against adult snails and the hatching of eggs of two species, *E. vermiculata* and *M. cartusiana,* under laboratory conditions. The study examined the efficacy of the neem extract on egg hatchability, feeding deterrence in juveniles, and adult snail mortality (Ismail *et al.*, 2010).

The results showed that at high concentration (400 ppm), the neem extract decreased the hatching to 50% for *M. cartusiana* and 42.5% for *E. vermiculata*. In addition, the neem extract has a concentration effect against adult *M. cartusiana* snail, the mortality increased with high concentration, reaching 20%, 40%, 55% at the end of the experiment for doses of 0.625%, 1.250%, and 2.5%, respectively.

The extract also showed an anti-feeding effect on juvenile snails of *M. cartusiana*. Feeding consumption reached 9.6 mg (after 3 days) for the highest concentration (200 ppm) against 31.9 mg for untreated juveniles (Ismail *et al.*, 2010).

Use of copper-coated lupin extract nanoparticles

Nanoparticles are prepared from lupin extracts using ethanol, then coated with starch and copper sulfate, through a direct physical gelation encapsulation process. Subsequently, the effect of these nanoparticles on the egg productivity and mortality of two aquatic snails, *Bulinus truncatus* and *Biomphalaria alexandrina,* and a land snail, *E. vermiculata*, was studied (Azzam *et al.*, 2019; Dummee *et al.*, 2015).

The results show that after 24 hours of exposure in dark conditions, nanoparticles coated with copper sulfate and starch caused 100% mortality in the tested species. Furthermore, both aquatic snails (*B. alexandrina* and *E. vermiculata*) showed complete blockage of oviposition. It should be noted that *E. vermiculata* individuals, treated or not, did not lay eggs, as this species had a specific breeding season that did not coincide with its specific reproductive season (Azzam *et al.*, 2019).

Use of aqueous extracts of thyme

The molluscicidal effect of the aqueous extract of *Thymus vulgaris* (thyme) on *E. vermiculata* was tested (Ali and Mohammad, 2017). Chemical analysis by chromatography was carried out to determine the active principles, which showed that the extract used is mainly composed of: 2-bromo dodecane, 3-methylindole, n-tricosane, octadecanedioic acid, and dimethyl ester of tetradecanedioic acid. The highest mortality rate (83.3%) was recorded at a concentration of 12.5 ppm, and the LC30, LC50, and LC90 were 5.832 ppm, 8.029 ppm, and 13.398 ppm, respectively. In addition, the snails showed morphological alterations, such as body swelling due to water retention, which led to a slowdown in snail movement, and protrusion of the tentacles and foot due to their enlargement. Samples of the tegument, mantle edge, digestive gland, and gonads were dissected and prepared for histological examination under an optical microscope. Some morphological abnormalities in the tissues were recorded (Ali and Mohammad, 2017).

Evaluation of the effect of several essential oils on *Helix aspersa*

The effect of several commercial essential oils on the mortality of *Helix aspersa* eggs and adults was evaluated by placing the individuals in Petri dishes containing a filter paper soaked with solutions of 1 ppm concentration (Ahmed *et al.*, 2021; Mc Donnell *et al.*, 2016).

Continuous exposure of *Helix aspersa* eggs and juveniles to eleven essential oils (1%), one terpene (D-limonene, 1%), and the surfactant Tween 80 (2%) resulted in variable mortality rates. Among eggs, several essential oils—including cedarwood, cinnamon, clove bud, garlic, lemongrass, peppermint, pine, and spearmint—induced 100% mortality. Rosemary also showed high ovicidal activity, with a mean mortality of 91.3 ± 15.5%. In contrast, bitter orange (51.9 ± 19.5%), eucalyptus (32.8 ± 27.3%), and D-limonene (16.9 ± 9.3%) exhibited moderate ovicidal effects. No egg mortality was observed with Tween 80 (Mc Donnell *et al*., 2016).

In juveniles, cinnamon, clove bud, garlic, lemongrass, peppermint, pine, and spearmint caused complete mortality (100%). Rosemary also demonstrated strong molluscicidal activity, with a juvenile mortality of 93.3 ± 5.6%. Conversely, bitter orange, eucalyptus, and D-limonene produced no juvenile mortality, while cedarwood showed limited efficacy (20.0 ± 26.5%). Tween 80 caused no mortality, confirming its suitability as a non-toxic control (Mc Donnell *et al*., 2016; Pereira *et al*., 2020).

Use of *Rumina decollata* as a biological control agent

Rumina decollata (Linnaeus, 1758) is an important predator of *Helix aspersa* and can consume both eggs and adults with a preference for snails that are smaller or equal to 14 mm. The average total consumption per individual was 3 eggs per 7 days (Mc Donnell *et al*., 2016).

Use of ducks

A study examined the potential of ducks for the control of the golden apple snail, *Pomacea canaliculata*, in rice paddies. The smaller duck (700 g) attacked snails more than the larger duck (1,300 g). The ducks can attack over 90% of snails by the second day of release. The timing of duck release was more effective at seven days after snail inoculation than simultaneous release (Kim *et al*., 2007).

Use of parasitic nematodes

The parasitic nematode of snails, *Phasmarhabditis* sp. of the family *Rhabditidae*, has shown the ability to generate 100% mortality of adult and egg stages of the species *Eobonia vermiculata*, and therefore, this nematode can play an important role in controlling this pest in all stages of development (Azzam and El-Abd, 2021).

CONCLUSION

Citrus crops are an essential component of Moroccan agriculture. Much effort has been made to improve the production potential of these crops to meet the needs of the population and maximize exports. However, despite all these efforts, yields remain variable compared to the actual production potential. This situation is largely dependent on varying climatic conditions and biotic stress due to attacks by a multitude of diseases and pests, including snails, which are one of the key pests in citrus orchards in the Gharb region. Controlling these Helicidae, namely *Theba pisana, Helix aspersa,* and *Eobonia vermiculata*, is crucial to providing favorable conditions for different varieties to express their potential. Through this review, a diversity of cultural (orchard maintenance, manual picking), physical (barrier traps and attractant traps), chemical (use of ovicides and adulticides), and biological (use of plant extracts, parasitic nematodes, predator snails, etc.) control methods were gathered. In this regard, integrated control technology packages must be developed to reduce economic losses due to snail attacks. These packages should be developed through a better understanding of the biology and ecology of these Helicidae, following field surveys over several years, as well as contextualizing these control methods with the national citrus environment, particularly in the Gharb region, in the hope of finding a better strategy to combat citrus pest snails, ensuring better technical and economic efficiency with minimal negative impact on the environment.

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