Green Pesticides Handbook
Essential Oils for Pest Control

Leo M.L. Nollet, Hamir Singh Rathore

Essential Oils and Their Constituents as Novel Biorational Molluscicides for Terrestrial Gastropod Pests

Publication details

https://www.routledgehandbooks.com/doi/10.1201/9781315153131-25

Rory Mc Donnell

How to cite :- Rory Mc Donnell. 30 May 2017, *Essential Oils and Their Constituents as Novel Biorational Molluscicides for Terrestrial Gastropod Pests from:* Green Pesticides Handbook, Essential Oils for Pest Control CRC Press

Accessed on: 20 Mar 2023

https://www.routledgehandbooks.com/doi/10.1201/9781315153131-25

25

Essential Oils and Their Constituents as Novel Biorational Molluscicides for Terrestrial Gastropod Pests

Rory Mc Donnell

CONTENTS

25.1 Background

Invasive species are found in most taxonomic groups, and the Mollusca are no exception. Bivalves and both terrestrial and freshwater snails have been linked with many invasive events throughout the world, and these invasions are typically initiated by either deliberate or inadvertent introductions by humans (Cowie and Robinson 2003). In fact, terrestrial mollusks have been associated with the transport of goods by humans for thousands of years (Welter-Schultes 2008). In the 1850s, *Cornu aspersum* was introduced to California as a potential source of food (escargot), and it is now a very serious pest of citrus and ornamentals (Dekle and Fasulo 2011). In more recent times, the deliberate introduction of the carnivorous rosy wolf snail, *Euglandina rosea*, from subtropical North America to control the invasive giant African land snail, *Lissachatina fulica*, on Pacific and Indian Ocean islands, is widely regarded as being an ecological disaster (Civeyrel and Simberloff 1996). This invasion is thought to have resulted in the extinction of greater than 60% of the endemic Hawaiian land snails (Solem 1990) and the extinction of partulid tree snails (family Partulidae) on the French Polynesian island of Moorea (Clarke et al. 1984).

The management of snail and slug pests throughout the world relies heavily on the use of molluscicides, which are underpinned by only four active ingredients (metaldehyde, iron phosphate, sodium ferric EDTA, and methiocarb). However, the activity of these products is very variable and heavily influenced by environmental conditions. Baits containing the active ingredient metaldehyde are most commonly used, but metaldehyde is very toxic to many nontarget organisms, such as dogs and cats (Studdert 1985; Bates et al. 2012). There is hence an urgent need to develop new molluscicidal products that are more reliable and have less impact on nontarget organisms. One such option is the development of biorational products that have plant extracts as their active ingredients.

25.2 Studies Investigating Essential Oils and Their Constituents as Novel Molluscicides

Essential oils and/or their constituents are known to have a broad spectrum of activity against insect and mite pests, fungi, and nematodes. For example, certain oils and their constituent terpenes are known to be lethal to the American cockroach (*Periplaneta americana*) (Ngoh et al. 1998), the German cockroach (*Blattella germanica*), and the common housefly (*Musca domestica*) (Coats et al. 1991; Rice and Coats 1994). However, their efficacy against terrestrial mollusks has been largely overlooked, except for a small number of papers that have focused on two general areas: the potential use of essential oils or their constituents as antifeedants and repellents, and their use as novel molluscicides.

25.2.1 Essential Oils as Antifeedants and Repellents

Many past studies concerned with the antifeedant and repellent properties of plant extracts did not specifically identify the active compounds involved. For example, Barone and Frank (1999) examined the antifeedant properties of methanol extracts of nine plants on the invasive slug *Arion lusitanicus*. The extracts of only two species (*Saponaria officinalis* and *Valerianella locusta*) significantly deterred feeding in the laboratory, but no attempt was made to isolate and identify the actual repellent compounds involved. Similarily, Ali et al. (2003a) determined that the raw plant materials and extracts of the bark of *Detarium microcarpum*, the bark and leaves of *Ximenia americana*, and the shoots of *Polygonum limbatum* were repellent to the slug *Deroceras reticulatum* in both labotatory and field bioassays, but the active compounds were not identified.

Other studies involving terrestrial mollusks have examined the efficacy of essential oils from various plants, but again, the actual repellent compounds were not determined. For example, Ali et al. (2003b) showed that saw dust coated with the essential oil of *Commiphora guidottii* helped reduce wheat seedling damage by *D. reticulatum* in laboratory bioassays. Likewise, Lindqvist et al. (2010) determined that birch tar oil had repellent properties against the slug *A. lusitanicus* and the snail *Arianta arbustorum*. Although the repellent compounds were not identified, when mixed with Vaseline®, birch tar oil prevented the land snails from crossing over treated Perspex® fences (height 40 cm) for up to several months in the field.

Vokou et al. (1998) investigated the interaction of commonly occurring aromatic plants in the Mediterranean region of Europe and the snail herbivores, *C. aspersum*, *Helix lucorum*, and *Eobania vermiculata*. The authors found that the presence of the crude essential oil blend extracted from *Origanum vulgare* subsp. *hirtum* placed in food at naturally occurring concentrations had a repellent effect on all three snail species, but the essential oil blend from subsp. *vulgare* did not. Although the authors did not identify the active compounds, they did state that the main essential oil constituents, carvacrol and thymol, accounted for ~60% of the constituents in subsp. *hirtum* extracts, while in subsp. *vulgare*, these phenols were only present in trace amounts, which suggests that carvacrol and thymol were the active snail repellent compounds. This theory is supported by the work of Linhart and

Thompson (1995), who demonstrated that foods containing carvacrol and thymol were fed on the least by *C. aspersum.*

Rice et al. (1978) compared the differential palatability of monoterpenoid compositional types of *Satureja douglasii* to the slug *Ariolimax dolichophallus*. The authors found that types containing a high proportion of bicyclic monoterpenoids (e.g., camphene and camphor) were more palatable to the slug than those containing high proportions of *p*-menthane monoterpenoids (e.g., isomenthone, pulegone, and carvone). In the case of individual monoterpenoids characteristic of these types, pulegone was the least palatable, and carvone and isomenthone were intermediate.

Dodds (1996) assessed the effects of plant extracts on the feeding behavior of *D. reticulatum*, and extracts of hemlock (*Conium maculatum*), rock sapphire (*Crithmum maritimum*), and curled chervil (*Anthriscus cerefolium*) caused the greatest reduction in feeding. Two active antifeedants, (+) fenchone and 4-allylanisole, were identified in *A. cerefolium*, and a new antifeedant compound (later identified as RESCO-1 by Clark et al. 1997) was responsible for most of the activity in *C. maculatum.* These compounds were not tested by Dodd (1996) under field conditions.

Scott et al. (1977) examined the antifeedant potential of extracts of 60 plant species against *D. reticulatum*, and two showed high activity. These were the root extract from horseradish (*Armoracia rusticana*) and the leaf extract of scented geranium (*Pelargonium graveolens*). The activity of the former was accounted for by 2-phenylethyl isothiocyanate, but field trials with this compound did not protect wheat seedlings because it was phytotoxic. The active compound in *P. graveolens* was the monoterpenoid alcohol, geraniol, but field use was limited by its instability to oxidation. To follow on from this work, Airey et al. (1989) tested the activity of 30 related compounds, primarily monoterpenoids, but only the bicyclic monoterpenoid ketone, (+) fenchone, was active. Furthermore, (+) fenchone was effective in protecting wheat seeds in boxes, but the high volatility and low persistence of the compound were seen as limiting factors to widespread use. Interestingly, the (–) isomer of fenchone was inactive, suggesting that different isomers of the same compound can have variable toxicity to terrestrial mollusks.

Clark et al. (1997), in designing a standard method for screening materials that influence feeding in *D. reticulatum*, tested a range of plant extracts. The authors found that a methanol extract of tarragon (*Artemisia dracunculus*) reduced consumption by 82% (±7.5), and the monoterpenoid alcohol geraniol at 1.5% concentration reduced feeding by 83% (±4.3). The fenchone enantiomers were also both significantly antifeedant at 1.5%, but only (+) fenchone reduced feeding at 0.5%, suggesting that this isomer is more repellent than the (–) isomer. This supports the earlier findings of Airey et al. (1989) that (–) fenchone is less active than (+) fenchone, at least in relation to *D. reticulatum.*

25.2.2 Essential Oils as Molluscicides

Research on essential oils as novel molluscicides has also focused on the activity of crude oil blends or on the activity of actual terpenoid compounds. For example, Mc Donnell et al. (2016) investigated the toxicity of 11 essential oils and d-limonene against the eggs and juveniles of the pest snail *C. aspersum*. Clove bud oil was identified as the most toxic oil (LC_{50} 0.027%), and in glasshouse trials with potted *Hosta* “Royal Standard,” emulsions of this oil were not phytotoxic when applied as a drench and foliar spray at a concentration of 0.116%. The authors suggest that eugenol was the likely active compound.

Amirmohammadi et al. (2012) investigated the toxicity of the essential oil of *Artemisia annua* on the slug *Deroceras agrestis* under controlled laboratory conditions by presenting starved test animals with radish leaves (*Rhaphanus sativus*) soaked in various concentrations of the oil and then air dried. The calculated LC_{50} was 5.81%. The authors also showed that the essential oil has physiological impacts on *D. agrestis*. For example, there was an increase in cytochrome P450 monooxygenase, likely because of the detoxifying role of this enzyme. Increases in phosphatases in the test slugs are also likely linked to the breakdown of toxins present in the essential oil.

Ferreira et al. (2009) showed that exposure to thymol (at concentrations of 2 and 5 g/L) in laboratory studies killed 97.50% of the eggs of the snail *Subulina octona*. The authors also investigated the effect of thymol at these concentrations on 10-day-old juvenile snails, but there was no significant difference in mortality with an untreated control. Using 30-day-old snails, mortality (55% after 120 days of exposure) was significantly higher using thymol at 5 g/L compared to the control.

Abdelgaleil (2010) investigated the fumigant and contact toxicity of 11 monoterpenes against adults of the pest snail, *Theba pisana*. (–) Fenchone had the highest toxicity (LC_{50} 2.51 mg/ml), but myrcene (3.88 mg/ml) and 1,8-cinerole (4.17 mg/ml) also exhibited strong fumigant toxicity to the test species. Cuminaldehyde, geraniol, and (–) menthol were not active. However, in the contact bioassays, cuminaldehyde (LD_{50} 28.37 μg/snail) was the most toxic, followed by geraniol (LD_{50} 42.29 μg/snail) and (–) limonene (LD_{50} 60.27 μg/snail). In fact, eight of the tested monoterpenoids were more toxic to adult *T. pisana* than the synthetic molluscicide methiocarb, highlighting their potential importance as novel biorational molluscicides.

Eshra et al. (2016) also evaluated the fumigant toxicity of four plant extracts against *T. pisana*, and as did Abdelgaleil (2010), the authors found that fenchone (isomer not specified) (LC_{50} 3.3 μl/L of air) was most toxic, followed by the essential oil of *Lavandula dentata* (LC_{50} 16.3 μl/L), limonene (LC_{50} 19.8 μl/L), and carvone (LC_{50} 33.2 μl/L). In fact, fenchone was significantly more toxic to the test snail than the other plant extracts. Esra et al. (2016) also determined that fenchone was a significantly better inhibitor of acetylcholinesterase (AChE) than carvone and limonene, but the authors suggested that the inhibition of AChE by monoterpenes is not the primary mode of action for these compounds because of the high concentrations required for inhibition. Fenchone was also twice as toxic to *T. pisana* than the commercial fumigant, methyl bromide, highlighting its potential commercial importance in snail management.

Radwan and El-Zemity (2007) tested the molluscicidal activity of 10 naturally occurring compounds against *T. pisana* and found that thymol (LD_{50} 120.61 μg/snail) was most effective, followed by eugenol (LD_{50} 125.82 μg/snail) and pulegone (LD_{50} 361.79 μg/snail). Interestingly, this is the only study to the best of the author's knowledge that investigated the potential synergism of molluscicidal plant extracts with a synergistic compound. The authors found that the toxicity of thymol and eugenol alone was less than that of methiocarb (LD_{50} 107.34 μg/snail), but mixing these monoterpenes with the synergist piperonyl butoxide (1:2 ratio) more than doubled their toxicity (LD_{50} thymol, 34.96 μg/snail; LD_{50} eugenol, 50.13 μg/snail) and resulted in both compounds being more toxic to *T. pisana* than methiocarb.

Iglesias et al. (2002) tested the ovicidal efficacy of a number of molluscicides, herbicides, insecticides, and some plant extracts against the eggs of *D. reticulatum* in the laboratory. The active ingredient of neem (*Azadirachta indica*) oil, azadirachtin, killed all the slug eggs at a dose of 0.020 mg/cm^2 after 24 h of exposure, while a dose of carvone at 0.063 mg/cm^2 also caused 100% egg mortality. In the only other study that examined the effect of azadirachtin on terrestrial gastropods, Ploomi et al. (2009) demonstrated that azadirachtin at concentrations of 0.3% and 0.03% was repellent to *A. arbustorum* in field trials in Estonia.

25.3 Synthesis of Previous Studies

Although many of the studies above provide encouraging results, it is important to remember that research involving the use of essential oils and their constituent compounds as novel products in managing terrestrial gastropods is still in its infancy. Nevertheless, by synthesizing the above studies, it is possible to provide some valuable conclusions and directions for future research.

Research on the monoterpene fenchone has shown that different isomers can have varying efficacies against different gastropod species. For example, (+) fenchone is known to be more active in repelling *D. reticulatum* than (–) fenchone (Airey et al. 1989; Clark et al. 1997), but (–) fenchone has a strong fumigant toxicity to *T. pisana* (Abdelgaleil 2010). In addition, the mode of action of individual active compounds can be very different. For example, cuminaldehyde is known to be a contact toxin to *T. pisana* but was not active as a fumigant toxin against the same snail species. These studies highlight the importance of investigating both the fumigant and contact toxicity of the same compound, but also the molluscicial potential of different isomers. It will also be beneficial to remember that some compounds can be repellent at certain concentrations and act as phagostimulants at other concentrations. For example, at concentrations of more than 5%, sucrose increasingly deters feeding, but between 2.5% and 5%, it stimulates feeding in *D. reticulatum* (Henderson et al. 1992). It would be wise to be mindful of this concentration effect when working with other repellent compounds, be they plant extracts or not.

One of the main disadvantages with using essential oils and their constituents in pest management is that they can be phytotoxic at those concentrations required to kill the target pest (Isman 2000). It is therefore surprising that the phytoxicity of candidate oils and compounds has been largely overlooked in previous research. Exceptions include Scott et al. (1977), who demonstrated that the gastropod repellent 2-phenylethyl isothiocyanate was phytotoxic to wheat. Mc Donnell et al. (2016) demonstrated that the concentration of clove bud essential oil necessary to kill the eggs and juveniles of *C. aspersum* was not phytoxic to *Hosta* “Royal Standard,” which highlights the potential value of this oil as a novel biorational molluscicide. However, future trials with clove bud oil should consider phytotoxic effects on a range of plant species.

Another potential disadvantage with using essential oils and their constituents is their cost in comparison with other management approaches. For example, Mc Donnell et al. (2016) showed that drenches of clove bud oil were >100 times more expensive than using a synthetic molluscicide product (Slug Fest® All Weather Formula). However, the high cost of alternative approaches to managing slugs and snails has not been a significant impediment to their use by stakeholders. For example, the biological control product Nemaslug® is a high-cost management strategy for gastropod pests in Europe, but it is widely used by growers to protect a diverse range of crops (Rae et al. 2007). Furthermore, it may be possible to reduce the overall cost of using essential oils or their constituents by using synergists. Synergists have been used commercially for about 50 years and have contributed significantly to improving the efficacy of insecticides (Bernard and Philogène 1993), but to the best of the author’s knowledge, only one study has investigated their potential with biorational molluscicidal compounds. Radwan and El-Zemity (2007) demonstrated that inclusion of piperonyl butoxide (1:2 ratio) more than doubled the toxicity of eugenol and more than tripled the toxicity of thymol and cinnamyl aldehyde against *T. pisana.* The addition of the synergist also resulted in both thymol and eugenol being more toxic to the test snail than the commercially available molluscicide methiocarb. Therefore, it may be possible to use synergists to increase the toxicity of essential oils or their constituents, which in turn will decrease the quantity of active ingredient required for effective pest control, thereby reducing the per treatment cost.

Most of the studies on terrestrial gastropods to date have focused on laboratory bioassays, with few considering the efficacy of identified active compounds against pest species under field conditions, which ultimately is required for identifying truly effective products. Those studies that did progress to field testing therefore provide useful data for helping to select priority oils and compounds for more thorough future investigations. For example, clove bud oil proved to be an effective potted plant drench for *C. aspersum* (Mc Donnell et al. 2016), and birch tar oil, when mixed with Vaseline, repelled *A. lusitanicus* and *A. arbustorum* for up to several months in the field (Lindqvist et al. 2010), but the authors of these studies did not identify the active compounds in the oils, and this should be a priority for future research. In addition, (+) fenchone was effective in protecting wheat seeds from *D. reticulatum* (Airey et al. 1989), but the high volatility and low persistence of the compound were seen as limiting factors. However, future work with this monoterpene should consider the use of slow-release systems to prolong field life. Such slow-release systems have been identified for other pesticides (Sinclair 1973; Rudzinski et al. 2002).

Finally, research with insects has shown that there is little overlap among species with respect to the most toxic essential oils and constituents, indicating that these substances are generally active against a range of pests, but interspecific toxicity of oils and their constituents may be highly idiosyncratic (Sarac and Tunc 1995; Isman 2000). Unpublished results by the author suggest that a similar pattern exists for terrestrial gastropods. Therefore, it will be critical to test oils and their active components on a variety of pest snail and slug species before widespread adoption as molluscicides. Also, it may ultimately be prudent to test combinations of two or more active compounds or oils with the hope of targeting multiple pest species with the same biorational product.

Acknowledgment

I am grateful to Veronica Puig Sanvicens for her comments and suggestions on this chapter.

References

Abdelgaleil, S.A.M. 2010. Molluscicidal and insecticidal potential of monoterpenes on the white garden snail, *Theba pisana* (Müller) and the cotton leafworm, *Spodoptera litroalis* (Boisduval). *Applied Entomology and Zoology* 45:425–433.

Airey, W.J., Henderson, I.F., Pickett, J.A., Scott, G.C., Stephenson, J.W., Woodcock, C.M. 1989. Novel chemical approaches to mollusc control. In *Proceedings, British Crop Protection Conference—Slugs and Snails in World Agriculture*, 301–307. Guilford, United Kingdom.

Ali, A.Y., Müller, C.T., Randerson, P., Bowen, I.D. 2003a. Molluscicidal and repellent properties of African plants. In *Proceedings, British Crop Protection Conference—Slugs and Snails: Agricultural, Veterinary and Environmental Perspectives*, 135–141.

Ali, A.Y., Müller, C.T., Randerson, P., Bowen, I.D. 2003b. Screening African plants for mollusk repellency. In *Proceedings, British Crop Protection Conference—Slugs and Snails: Agricultural, Veterinary and Environmental Perspectives*, 319–324.

Amirmohammadi, F., Sendi, J.J., Zibaee, A. 2012. Toxicity and physiological effect of essential oil of *Artemisia annua* (Labiatae) on *Agriolimax agrestis* L. (Stylommatophora: Limacidae). *Journal of Plant Protection* 52:185–189.

Barone, M., Frank, T. 1999. Effects of plant extracts on the feeding behavior of *Arion lusitanicus. Annals of Applied Biology* 134:341–345.

Bates, N.S., Sutton, N.M., Campbell, A. 2012. Suspected metaldehyde slug bait poisoning in dogs: A retrospective analysis of cases reported to the Veterinary Poisons Information Service. *The Veterinary Record* 171:324.

Bernard, C.B., Philogène B.J. 1993. Insecticide synergists: Role, importance, and perspectives. *Journal of Toxicology and Environmental Health* 38:199–223.

Civeyrel, L., Simberloff, D. 1996. A tale of two snails: Is the cure worse than the disease? *Biodiversity and Conservation* 5:1231–1252.

Clarke, B., Murray, J., Johnson, M.S. 1984. The extinction of endemic species by a program of biological control. *Pacific Science* 38:97–104.

Clark, S.J., Dodds, C.J., Henderson, I.F., Martin, A.P. 1997. A bioassay for screening materials influencing feeding in the field slug, *Deroceras reticulatum* (Müller) (Mollusca: Pulmonata). *Annals of Applied Biology* 130:379–385.

Coats, J.R., Karr, L.L., Drewes, C.D. 1991. Toxicity and neurotoxic effects of monoterpenoids in insects and earthworms. *American Chemistry Society Symposium Series* 449:306–316.

Cowie, R.H., Robinson, G.D. 2003. Pathways of introduction of non-indigenous land and freshwater snails and slugs. In *Invasive Species. Vectors and Management Strategies*, ed. G.M. Ruiz and J.T. Carlton, 93–122. Washington, DC: Island Press.

Dekle, G.W., Fasulo, T.R. 2001. *Brown Garden Snail, Cornu aspersum (Müller, 1774) (Gastropoda: Helicidae).* Gainesville, FL: Institute of Food and Agricultural Sciences Extension, University of Florida.

Dodd, C.J. 1996. The control of slug damage using plant-derived repellents and antifeedants. In *Proceedings, British Crop Protection Conference—Slug and Snail Pests in Agriculture*, 335–340. Canterbury, United Kingdom.

Eshra, E.H., Abobakr, Y., Abddelgalil, G.M., Ebrahim, E., Hussein, H.I., Al-Sarar, A.S. 2016. Fumigant toxicity and antiacetylcholinesterase activity of essential oils against the land snail, *Theba pisana* (Müller). *Egyptian Scientific Journal of Pesticides* 2:91–95.

Ferreira, P., Gonçalves Soares, G.L., D'ávila, S., de Almeida Bessa, E.C. 2009. The influence of caffeine and thymol on the survival, growth and reproduction of *Subulina octona* (Brugüière, 1789) (Mollusca, Subulinidae). *Brazilian Archives of Biology and Technology* 52:945–952.

Henderson, I.F., Martin, A.P., Perry, N.J. 1992. Improving slug baits: The effects of some phagostimulants and molluscicides on ingestion by the slug, *Deroceras reticulatum* (Müller) (Pulmonata: Limacidae). *Annals of Applied Biology* 121:423–430.

Iglesias, J., Castillejo, J., Ester, A. 2002. Laboratory evaluation of potential molluscicides for the control of eggs of the pest slug *Deroceras reticulatum* (Müller) (Pulmonata: Limacidae), *International Journal of Pest Management* 48:19–23.

Isman, M.B. 2000. Plant essential oils for pest and disease management. *Crop Protection* 19:603–608.

Lindqvist, I., Lindqvist, B., Tiilikkala, K. et al. 2010. Birch tar oil is an effective mollusk repellent: Field and laboratory experiments using *Arianta arbustorum* (Gastropoda: Helicidae) and *Arion lusitanicus* (Gastropoda: Arionidae). *Agricultural and Food Science* 19:1–12.

Linhart, Y.B., Thompson, J.D. 1995. Terpene-based selective herbivory by *Helix aspersa* (Mollusca) on *Thymus vulgaris* (Labiatae). *Oecologia* 102:126–132.

Mc Donnell, R.J., Yoo, J., Patel, K. et al. 2016. Can essential oils be used as novel drench treatments for the eggs and juveniles of the pest snail *Cornu aspersum* in potted plants? *Journal of Pest Science* 89:549–555.

Ngoh, S.P., Hoo, L., Pang, F.Y., Huang, Y., Kini, M.R., Ho, S.H. 1998. Insecticidal and repellent properties of nine volatile constituents of essential oils against the American cockroach, *Periplaneta americana* (L.). *Pesticide Science* 54:261–268.

Ploomi, A., Jõgar, K., Metspalu, L. et al. 2009. The toxicity of neem to the snail *Arianta arbustorum*. *Sodininkystė ir daržininkystė Mokslo darbų* 28:153–158.

Radwan, M.A., El-Zemity, S.R. 2007. Naturally occurring compounds for control of harmful snails. *Pakistan Journal of Zoology* 39:339–344.

Rae, R., Verdun, C., Grewal, P.S., Robertson, J.F., Wilson, M.J. 2007. Biological control of terrestrial molluscs using *Phasmarhabditis hermaphrodita*—Progress and prospects. *Pest Management Science* 63:1153–1164.

Rice, P.J., Coats, J.R. 1994. Insecticidal properties of monoterpenoid derivatives to the house fly (Diptera: Muscidae) and red flour beetle (Coleoptera: Tenebrionidae). *Pesticide Science* 41:195–202.

Rice, R.L., Lincoln, D.E., Langenheim, J.H. 1978. Palatability of a monoterpenoid compositional type of *Satureja douglasii* to a generalist molluscan herbivore, *Ariolimax dolichophallus*. *Biochemical Systematics and Ecology* 6:45–53.

Rudzinski, W.E., Dave, A.M., Vaishnav, U.H., Kumbar, S.G., Kulkarni, A.R., Aminabhavi, T.M. 2002. Hydrogels as controlled release devices in agriculture. *Designed Monomers and Polymers* 5:39–65.

Sarac, A., Tunc, I. 1995. Toxicity of essential oil vapours to stored product insects. *Zeitschrift für Pflanzenkrankheiten und Pflanzenschutz* 102:69–74.

Scott, G.C., Griffiths, D.C., Stephenson, J.W. 1977. A laboratory method for testing seed treatments for the control of slugs in cereals. In *Proceedings, British Crop Protection Conference—Pests and Disease*, 129–134. Brighton, United Kingdom.

Sinclair, R.G. 1973. Slow-release pesticide system. Polymers of lactic and glycolic acids as ecologically beneficial, cost-effective encapsulating materials. *Environmental Science and Technology* 7:955–956.

Solem, A. 1990. How many Hawaiian land snail species are left? And what we can do for them. *Bishop Museum Occasional Papers* 30:27–40.

Studdert, V.P. 1985. Epidemiological features of snail and slug bait poisoning in dogs and cats. *Australian Veterinary Journal* 62:269–272.

Vokou, D., Tziolas, M., Bailey, S.E.R. 1998. Essential-oil mediated interactions between oregano plants and Helicidae grazers. *Journal of Chemical Ecology* 24:1187–1202.

Welter-Schultes, F.W. 2008. Bronze Age shipwreck snails from Turkey: First evidence for oversea carriage of land snails in antiquity. *Journal of Molluscan Studies* 74:79–87.