Plant essential oils: the way forward for aphid control?

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DOI: https://doi.org/10.1111/aab.12451

Atanasova, D. and Leather, S.R. 2018. Plant essential oils: the way forward for aphid control? *Annals of Applied Biology*.

9 July 2018

Plant essential oils: the way forward for aphid control?

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Over the past decade or so, there has been an increasing concern that the use of conventional synthetic pesticides may be having a detrimental effect not just on pollinators and other beneficial insects (Goulson *et al*., 2015; Regan *et al*., 2017), but also on insects in general (Sorg *et al*, 2013; Pisa *et al*., 2015; Leather, 2018; Main *et al*., 2018). In addition, the problem of insect resistance to insecticides is a serious problem, with almost 600 arthropod speciesresistant to one or more of the chemical groups commonly used in crop protection products (Sparks & Nauen, 2015). Aphids are particularly good at evolving resistance to insecticides, with the peach-potato aphid, *Myzus persicae* displaying six types of resistance (Simon & Peccoud, 2018). There is obviously a need to develop new crop protection products that are fully compatible with modern Integrated Pest Management approaches. Biopesticides based on entomopathogenic fungi have been used for many decades but their development and use has been hampered by legislation and, in some cases difficulties with formulation and delivery (Chandler *et al*., 2011).

A viable alternative to conventional synthetic pesticides and to entompathogenic fungi and nematodes are the botanical pesticides. Plant essential oils are an environmentally friendly and readily available alternative to synthetic chemical pesticides for pest control (Regnault-Roger, 1997; Isman, 2005; Tripathi *et al*., 2009). Plant products, especially essential oils, have a number of advantages that make them preferable to conventional synthetic pesticides, not least their ease of extraction and low probability of harming beneficial species (Grainge & Ahmed, 1988, Regnault-Roger, 1997; Amoabeng *et al*., 2013). Their use in modern organic crop production as "green pesticides" is becoming increasingly common, although take-up varies btween countries (Bhathal and Singh, 1993; Isman, 2000, 2005; Sampson *et al*., 2005; Digilio *et al*., 2008).

Plant essential oils have long been shown to have contact and fumigant insecticidal action against stored product pests (Shaaya *et al*., 1991; Regnault-Roger *et al.,* 1993; Sarac & Tunc, 1995). A number of investigations (Ho *et al*., 1994, 1995, 1997; Huang and Ho, 1998; Huang *et al.,* 1998) have demonstrated contact, fumigant and antifeedant effects of a range of essential oil constituents including cinnamaldehyde, α-pinene, anethole, extracts of cloves, *Syzygium aromaticum*, and star anise, *Illicium verum* and also eugenol and holy basil, *Ocimum suave*, against these and two other beetle pests, *Sitophilus granarius* and *Prostephanus truncatus* (Obeng-Ofori & Reichmuth, 1997).

Importantly, a number of recent studies have demonstrated the effectiveness and potential of essential oil products to control insect pests in both protected and field cops (Sarac and Tunç, 1995; Tunç and Sahinkaya, 1998, Isman, 2000; Sampson *et al*., 2005, Tomova *et al*., 2005). The possibilities are immense, for example, over fifty essential oils were shown to have significant insecticidal activity against *Trialeurodes vaporariorum* (Westwood) an important pest of various greenhouse grown vegetables in Korea (Choi *et al*. (2003). Twenty essential oils were shown to be toxic to the third instar larvae of *Spodoptera littoralis* (Boisduval) (Pavela (2005) and other plant oils have been shown to have insecticidal activity and suppress the oviposition ability of *Callosobruchus maculatus* (Fabricius) with a significant reduction in damage (Rahman & Talukder, 2006). Similarly, impressive results have been shown against the fruit fly, C*eratitis capitata* (Wiedemann) (Zapata *et al*., 2006), and plant-based essential oils and their constituents have been shown to have both repellent and toxic effects on the Asian citrus psyllid, *Diaphorina citri* Kuwayama (Mann *et al*., 2012).

Aphids are globally important pests attacking a wide range of protected and field crops (van Emden & Harrington, 2017). Many aphid species have developed resistance to conventional synthetic insecticides highlighting the need for viable alternatives (Foster *et al*., 2017). Plant derived essential oils with their novel, highly bioactive compounds can be extremely effective insecticides (Sampson *et al*., 2005) and thus should be considered seriously for control of the aphids. There has been a notable increase over the last twenty years in the number of studies investigating the potential role of essential oils as environmentally friendly aphicides.

Over the last two decades a growing number of plant essential oils have been shown to be very effective aphicides. Tunç and Şahinkaya (1998) found that essential oils of cumin (*Cuminum cyminum* L.), anise (*Pimpinella anisium* L.), oregano (*Origanum syriacum var. bevanii* L.) and eucalyptus (*Eucalyptus camaldulensis* Dehn.) were effective as fumigants against two greenhouse pests - the cotton aphid (*Aphis gossypii* Glover) and the carmine spider mite, *Tetranychus cinnabarinus* (Boisd.). The essential oil volatiles obtained from *Tagetes minuta* L. have been tested against the aphids, *Acyrthosiphon pisum* (Harris), *M. persicae* and *Aulacorthum solani* (Kaltenbach) and significantly reduced the reproduction potential of the tested species (Tomova *et al*., 2005). In addition, rapeseed oil has been shown to significantly reduce damage by black cherry aphid, *Myzus cerasi* (Fabricius) (Jaastad (2007), and oils from *Thymus*, *Veronica* and *Agrimonia* caused significant decreses in the fecundity and survival of the cabbage aphid, *Brevicoryne brassicae* (Görür *et al*., 2008). An additional seven essential oils (*Juniperus excelsa* M. Bieb., *Juniperus oxycedrus* L., *Foeniculum vulgare* Miller, *Pimpinella anisum* L., *Rosmarinus officinalis* L., *Juglans regia* L. and *Laurus nobilis* L.) have, in laboratory studies, also been shown to highly effective against *B. brassicae* (Hemiptera: Aphididae) (Isik *et al*., 2009).

Similarly impressive results have been obtained using the natural essential oils, basil oil (*Ocimum basilicum*), citronella oil (*Cymbopogon winterianus* Jowitt), eucalyptus oil (*Eucalyptus globulus*), juniper oil (*Juniperus communis*) and patchouli oil (*Pogostemon *patchouli*), for the control of foxglove aphid (*A. solani*) even at very low concentrations (Górski & Tomczak, 2010.

Ebrahimi et al. (2013) investigated the efficacy of three plant essential oils, *Azadirachta indica* Adr. Juss. (Meliaceae), *Eucalyptus camaldulensis* Dehn. (Myrtaceae) and *Laurus nobilis* L. (Lauraceae) against *A. gossypii*. They found that *A. indica* possessed the highest lethal activity whereas *L. nobilis* the lowest. These data suggest that essential oils of all the three plants have the potential to be employed in the pest management programmes designed for the control of *A. gossypii* under greenhouse conditions.

Essential oils extracted from *Eucalyptus citriodora* were shown to have moderate insecticidal activity against nymphs of the green peach aphid (*Myzus persicae)* and *F. schultzei* nymphs causing mortality of 85.5 % and 34.8 %, respectively, at 1 % (w v-1) (Costa *et al*., 2015) The major components found in *E. citriodora* essential oil were citronellal (29.31 %), geraniol (27.63 %), *β*-citronellol (14.88 %) and *δ*-cadinene (6.32 %) (Costa *et al*., 2015). Not all aphids are equally susceptible to essential oils. For example, *Aphis nerii* was shown to be more resistant to insecticidal soaps based on sunflower and olive oil extracts than *Macrosiphum rosae* (Ganchev & Atanaosva, 2015).

Biopesticides are often regarded as being less effective than synthetic conventional insecticides, but Attia *et al*. (2016) investigated the essential oil of *Lavandula angustifolia* for its insecticidal activity against *Acyrthosiphon pisum* by fumigation and found that *L. angustifolia* oil can provide valuable pesticide activity with significantly lower LC_{50} values than the more conventional alternatives. Formulations based on essential oils are as effective as commercially available synthetic pyrethroid products (Atanasova & Nenov, 2017; Atanasova *et al*., (2018,) and importantly, have no phytotoxic effects (Atanasova & Nenov, 2017; Atanasova *et al*., 2017). Terpene-based botanical biopesticides seem particularly effective against aphids; orange oil, *Chenopodium ambosioides* and neem oil being shown to as effective as both the synthetic insecticides flonicamid and spirotetramat (Smith et al., 2018).

A commonly cited downside of conventional synthetic insecticides is their potential effects on non-target organisms such as pollinators (Krupke *et al*., 2017). Given that the plant-based products under discussion are also very effective pesticides, do they too pose threats to non-target insects, especially those regarded as important components of integrated pest management systems, *viz*, natural enemies?

Extracts from *Angelica archangelica,* which was shown to be highly toxic to the pea aphid caused only low mortality to ladybird larvae at the same concentrations and no significant negative effects to adults (Pavela *et al*., 2013). Similarly, extracts of nine Ghanaian plants controlled the cabbage aphid *Brevicoryne brassicae* as effectively as the synthetic insecticide emamectin benzoate but were significantly less harmful to ladybirds (Amoabeng *et al*., 2013). A *Chenopdium* based botanical insecticide had little or no residual effect on the adults of two commonly used glasshouse biological control agents, *Orius insdidiosus* and *Aphidius colemani*, and in the case of *O. insidiosus*, also the nymphs, in marked contrast to abamectin, which had high contact toxicity and some residual effects (Bostanian *et al*., 2005). Despite being directly fed three bioinsecticides, Dipel DF (*Bacillus thuringiensis* subspecies *kurstaki*, NeemAzal T/S (*Azadirachta indica)* and Tracer 480 SC (Spinosad), adult *Bracon hebetor* were only affected by the latter (Stoianova *et al*., 2015). Given that direct feeding on insecticides in the field at the concentrations used are highly unlikely, this indicates a high degree of safety.

Currently, as with entomopathogenic biopesticides, the use of botanically based compounds in many countries where synthetic compounds dominate the marketplace, their take-up is being hampered by outdated and inappropriate issues of legislation (Chandler *et al*., 2011). This is particularly true of the EU where far fewer biopesticides are commercially available than in other crop-growing regions (Balog *et al*., 2017). Lacking too, are studies on side-effects, especially in relation to the natural enemies of aphids, pollinators and also potential phytotoxic effects. There is thus an urgent need for further work in these areas with only a handful of studies to date. Without increased work in these areas and much needed changes to regulatory frameworks, the opportunities to progress improvements in sustainable and more environmentally friendly crop production will be severely limited.

Acknowledgements

We are grateful to Tom Pope for his very useful and perspicacious comments.

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