Journal of Biodiversity and Environmental Sciences (JBES)
ISSN: 2220-6663 (Print) 2222-3045 (Online)
Vol. 17, No. 2, p. 101-112, 2020
http://www.innspub.net

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REVIEW PAPER OPEN ACCESS

Insights of allelopathic, insecticidal and repellent potential of an invasive plant *Sphaeranthus suaveolens* in pest and weed management

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Article published on August 30, 2020

Key words: Botanical extracts, Secondary metabolites, Sustainable agriculture, Smallholder farmers, Terpene

Abstract

Sphaeranthus suaveolens is a weed from the family Asteraceae, it grows abundantly in wet areas and most common in rice fields. The extracts from plants closely related to *S. suaveolens* have been reported to have allelopathic, insecticidal, antifeedant, repellent, and other biological activities. Currently, the use of synthetic chemicals to control weeds and insect pests raise several concerns related to environment and human health. Extracts from plants with pesticidal properties can offer the best and an environmentally friendly alternative. Some of these extracts have been extensively tested to assess their applications as valuable natural resources in sustainable agriculture. This review article therefore explores the potential of *S. suaveolens* extracts in controlling insect pests and managing weeds by smallholder farmers.

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Introduction

Agricultural production in most part of the world is affected by pests, diseases and weeds among other factors (Nations, 2016; Singh *et al.*, 2003). Majority of the farmers respond to these constraints through the use of synthetic chemicals such as herbicides and pesticide (Kelly *et al.*, 2003). The extensive use of these chemicals in controlling insect pests and managing weeds, however, have alarmed the public on the effects they might bring to human health and the environment at large (Khanh *et al.*, 2005). Such concerns are putting pressure on agricultural sector to reduce the use of chemicals and as a result, much attention is paid to alternative methods and techniques for controlling and managing weeds and insect pests, through non-chemical methods and/or use of natural products such as botanical extracts (Isman, 2006a; Williamson *et al.*, 2008).

Prior to the discovery and commercialization of synthetic pesticides, botanical extracts, among other methods, were used by most farmers in crop protection against insect pests, weeds and diseases (El-Wakeil, 2013). Extracts from plants with allelopathic or pesticidal properties were of great importance in making natural herbicides and pesticides (Benner, 1993; Godfrey, 1994). There is also increasingly evidence from literatures that plant extracts can be manipulated and used as perfect agrochemicals in controlling insect pests and managing weeds (Hoagland, 2001; Macías *et al.*, 2001; Mkenda *et al.*, 2015; Nattudurai *et al.*, 2012; Ngondya *et al.*, 2016; Singh *et al.*, 2003; Stephen *et al.*, 2002; Vyvyan, 2002).

The secondary metabolites in plants are responsible to biological activities that offer defense against predators, fungi and bacteria, also these metabolites may act as natural herbicides by suppressing other plant species (Dewick, 2009; Schoonhoven *et al.*, 2005). These biological activities from the plants secondary metabolites can be exploited and manipulated for various human uses, and in this respect *Sphaeranthus suaveolens* has a considerable potential. *S. suaveolens* is a widespread weed in swampy and irrigated farmlands, and usually infests cultivated fields and reduces crop productivity (Beentje, 2002). A heavy infestation of this weed results in adverse effects on the growth and yield of crops, particularly in rice fields (Fahmy, 1997).

It has been observed that *S. suaveolens* has an ability to overcome and suppress crop plants in a wide range over a short period of time (Ivens, 1989). However, the secondary metabolites involved are largely unknown and weather they can be applied in managing other weeds and controlling insect pests is yet to be determined. Understanding this could considerably justify the practical application of botanical-based weeds and insect pests management techniques for most smallholder farmers in areas where *S. suaveolens* is growing.

This review article therefore highlights the allelopathic, insecticidal and repellent potential of an invasive plant *S. suaveolens* with a focus on its application in controlling insect pests and managing weeds by smallholder farmers.

Overview of S. suaveolens and its spatial distribution in Tanzania

S. suaveolens is an aromatic annual spreading herb from the family Asteraceae with broad sessile leaves covered with glandular hairs (Osman, 2011). The lower stem often trails along the ground and roots at the nodes with thread-like root, flowers are purple, in compound heads ovoid in shape and borne on solitary glandular peduncles with toothed wings (Fayed & Mohamed, 1991).

The head as a whole is surrounded by several rows of bracts, of which only the tips are visible when flowers are fully open, and propagated by seeds which takes about 10-12 days to germinate, and the seedlings attain the height of 5.0 - 6.0cm within 30 days in a favorable environment (Beentje, 2002).

S. suaveolens is widespread in Africa over a range of altitudes from Rwanda, Burundi, Sudan, Ethiopia, Zambia, Malawi, Mozambique, Egypt, Uganda, Kenya to Tanzania (Everard *et al.*, 2002; Fahmy, 1997). It is mostly found growing in wet areas and thrives well in medium clayey soils, but also common in and around irrigation ditches and rice fields and considered as a major weed in most farms (Ivens, 1989). In Tanzania, the plant was first reported in Songea (Brenan, 1960), then Mpwapwa (Launert, 2003), Mkata and Mandela in Wami River Ecosystem (Mligo, 2017). The spatial distribution of *S. suaveolens* in Northern Tanzania particularly Arusha and Kilimanjaro regions however, have not been mapped despite being reported as a weed to most agricultural fields.

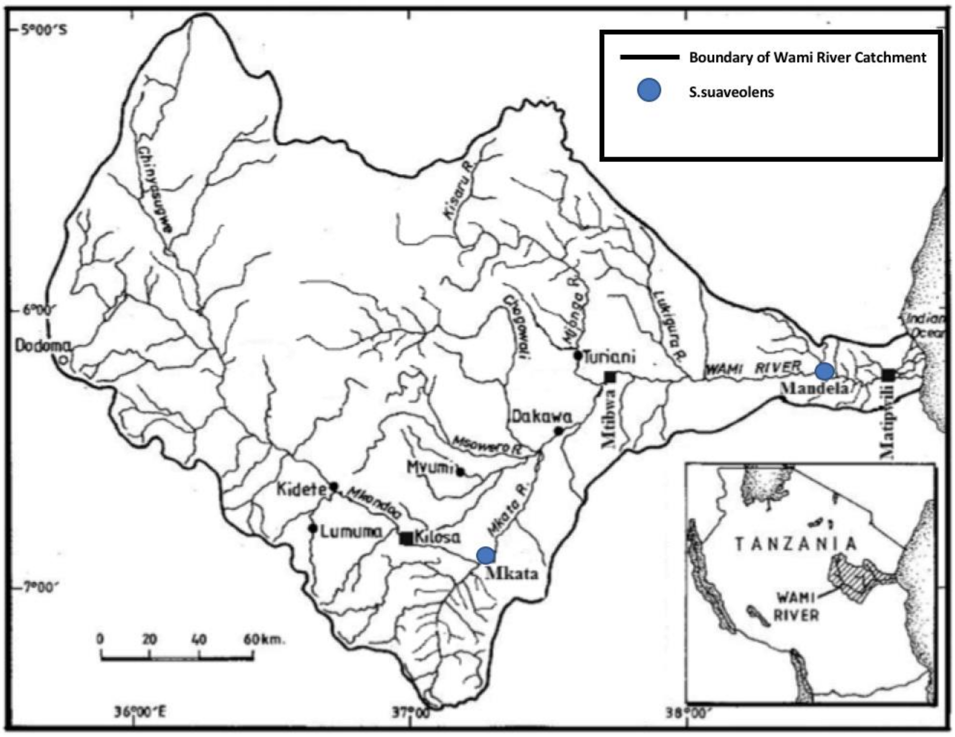

Fig. 1. Distribution of *S. suaveolens* in Wami River Ecosystem in Tanzania.

Allelopathic effects of S. suaveolens on crops

Allelopathy is a phenomenon, whereby one plant influences the growth of another one, including microorganisms by the release of chemical compounds into the environment (Keeley, 2010; Rice, 1983; Whittaker & Feeny, 1971). The allelopathic effects are the result of chemical compounds known as allelochemicals, which are usually plants' secondary metabolites or byproducts of the principal metabolic pathways in plants (Chancellor, 1987; Dayan *et al.*, 2009; Macías *et al.*, 2007). In recent years, allelopathy has become a research hotspot for making comprehensive analysis about the mechanism of weeds and identification of specific chemical compounds responsible for allelopathic effects (Azirak & Karaman, 2008; Bais *et al.*, 2003; Einhellig & Leather, 1988).

Most allelopathic plants have been observed to significantly affect the growth, productivity and yield of other crops by causing soil sickness and nutrient imbalance (Kohli *et al.*, 2008), as well as affecting the microbial population (Batish *et al.*, 2001). Several studies have indicated that, most weeds possess allelopathic effects which play a significant roles in their invasion success (Macías *et al.*, 2014; Qasem & Foy, 2001; Zhou *et al.*, 2013). Numerous weeds from the Asteraceae family have been reported to possess allelopathy and can significantly inhibit crop productivity in agricultural land (Ilori *et al.*, 2010; Kong *et al.*, 2007). The invasive weed, *Sphaeranthus indicus* has been reported to inhibit seed germination and growth of wheat (*Triticum aestivum),* rice (*Oryza* *sativa*) and mung bean (*Vigna radiata*) in different farming systems (Lodha, 2004).

Recently, Mahajan *et al.* (2015) reviewed the allelopathic potential of *S. indicus* and found that the germination and seedling growth of various crops were significantly decreased with increase in concentration of its extract.

Despite of the negative effects on cultivated crops, allelochemicals from allelopathic plants can be manipulated and used to control weeds of various crops. For example, Khanh *et al.* (2006) noted that the allelochemicals contained in tissues of *Passiflora edulis* can significantly suppress the two noxious paddy rice weeds (*Echinochloa crusgalli* and *Monochoria vaginalis*). Other studies have also reported the use of allelochemicals for weed control in the laboratory as well as application under field conditions (Jabran *et al.*, 2015; Ngondya *et al.*, 2016). Jamil *et al.* (2009) described the utilization of allelopathic water extract as an important and useful way of exploiting the allelopathic potential to manage wild oat and canary grass in wheat fields.

The emergence and root length of most rice weeds was inhibited by allelochemical (Lycorine) from the dead leaves of spider lily (Iqbal *et al.*, 2006). The allelopathic crops when used as cover crop, mulch, smother crops, green manures, or grown in rotational sequences maybe helpful in reducing noxious weeds and plant pathogen, improve soil quality and crop yield (Khanh *et al.*, 2005).

Furthermore, the application of allelopathic extracts may give an efficient alternative control over weeds similar to that offered by synthetic herbicides (Xuan *et al.*, 2004). Interactions among potential allelopathic plants, target pests and other non- target organisms in a cropping system also need to be considered and fully realized to avoid detrimental effects to desired crops and non-target species (Farooq *et al.*, 2013).

The allelochemicals involved in weed suppression can serve as basic templates for developing new generation of biopesticides with low or no toxic effects to the environment and human health (Ferguson *et al.*, 2009).

The allelopathic potential of *S. suaveolens*, therefore need to be realized and selectively used to suppress density of other weeds and insect pests population particularly in small farming agricultural systems.

Insecticidal and repellent activities of S. suaveolens to insect pests

Insecticides, weather natural or synthetic are developed to either kill, repel, or interfere with the damaging behavior of insect pests (EPA, 2009). Due to intensity of plant-insect interactions, plants have well developed defense mechanisms against insect pests by producing natural compounds which acts as natural pesticides (Després *et al.*, 2007). The most exciting concept is to isolate and identify such compounds and use them as candidates in making safer pesticides (Maia & Moore, 2011). Plant extracts with pesticidal properties can be active against specific target insects, biodegradable, have low to non-toxic effects, cheap and easy to prepare (Kim *et al.*, 2003; Mkindi *et al.*, 2017). Due to this facts, these plant extracts could lead to the development of new classes of safer pesticides (Céspedes *et al.*, 2014; Tembo *et al.*, 2018).

The Asteraceae family in which *S. suaveolens* belongs, have been reported to contain plants with insecticidal activities (Dhale, 2013; Green *et al.*, 2017; Sosa *et al.*, 2018). These insecticidal activities are mostly linked to presence of secondary metabolites such as terpenes, which can act as larvicides, insect growth regulators and feeding and oviposition deterrents (Miresmailli & Isman, 2014). Terpene is among the most diverse class of plant secondary metabolites found in essential oils of most plants, *S. suaveolens* included (Ahmed *et al.*, 2017; Pagare *et al.*, 2015). This secondary metabolite has been reported to play an important role in plant protection against pathogens (Neerman, 2003), insects (Wu *et al.*, 2016) and toxic to mammals as well (Gurib-Fakim, 2006). Recently, Sosa *et al.* (2018) reported insecticidal activities of the terpene isolated from *Vernonanthura nebularum* against fall army warm (*Spodoptera* *frugiperda)* and fruit fly (*Ceratitis capitate*).

Moreover, two other terpenes from *Inula helenium* were examined by Kaur *et al.* (2017) and reported to significantly inhibit the growth of tobacco leafworm (*Spodoptera litura*).

Other techniques such as use of water extracts from *S. indicus* was also reported to demonstrated toxic effects against insect pests such as rice weevil (Patole *et al.*, 2008), cowpea weevil (Singh & Shrivastava, 2012) and red flour beetle (Pugazhvendan *et al.*, 2012). Furthermore, the extracts from *S. indicus* have been showing larvicidal activities and repellent activities to most of the insect pests (Arivoli *et al.*, 2016; Baby, 1994; Singh & Shrivastava, 2012).

The presence of secondary metabolites with pesticidal properties such as terpene in the essential oil of *S. suaveolens* may give positive insecticidal and repellent activities to most insect pests, hence used for as protective agents against insect pests, but this needs further scientific investigation.

Key allelochemicals from the leaf, stem and root extracts of S. suaveolens

Allelochemicals are secondary metabolites produced by living organisms such as plants that have stimulatory or inhibitory effects upon the growth, health, behavior and distribution of neighboring organisms being another plants, insects or microbes (Haig, 2008). The role played by secondary metabolites is mostly ecological, linked to plant defense against other plants, pests, or diseases (Ramakrishna & Ravishankar, 2011). Allelochemicals undoubtedly pose problems in agriculture, but if well manipulated they can be beneficial and offer great opportunities such as insect pests and weeds control (Einhellig, 1987). Despite the efforts in allelopathic researches, little is known on the potential to exploit the key allelochemicals in agricultural systems and use them as templates in making safer and affordable herbicides and/or pesticides (Kremer & Ben-Hammouda, 2009). Much of the work to date has focused on weather extracts from *S. suaveolens* show biological activities such as antimicrobial, immune stimulating, anticancer, antitumor, anthelmintic, repellency, insecticidal and allelopathy (Ahmed & Mahmoud, 1997; Kleinowski *et al.*, 2016). However, very few literatures have reported the identified compounds found in *S. suaveolens* extracts, none of it has a list of allelochemicals found in *S. suaveolens* despite being the weed of economic importance in many rice and common bean farms in Africa.

Allelochemicals belong to various chemical groups, and can be classified based on their structures and properties into: water-soluble organic acids, straight-chain alcohols, aliphatic aldehydes, and ketones, lactones, long-chain fatty acids and polyacetylenes, quinines (benzoquinone, anthraquinone and complex quinines), phenolics, cinnamic acid and its derivatives, coumarins, flavonoids, tannins, steroids and terpenoids (Li *et al.*, 2010).

Most of these biochemicals are synthesized during the shikimate pathway (Hussain & Reigosa, 2011) or, in the case of essential oils, from the isoprenoid pathway (Rehman *et al.*, 2016). The extract of the aerial parts of *S. suavealens* was reported by Jakupovic *et al.* (1990) to contain eight eudesman-12. 6 β abides, carvotacetone derivatives and a thymohydroquinone glucopyranoside. Later on, Pooter *et al.* (1991) reported extract of the same plant comprise of thymohydroquinone dimethylether, a diacetylene thiophene, inositol and myoinositol esters, and several carvotanacetone derivatives, he went further to examine the essential oil of *S. suaveolens* and noted methyl chavicol, α-ionon,e, dcadinene and p-methoxycinnamadehyde as major constituents, and a-terpinene, citral, geraniol, geranyl acetate, βionone, shaerene, indicusene and sphaeranthol as minor constituents. Ahmed and Mahmoud (1997) examine the extract of aerial parts of *S. suaveolens* and reported three carvotacetone derivatives, together with four monoteroene compounds. Later on, Hassanali *et al.* (1998) reported cis-pinocamphone as the major constituents (63.5%) of the leaf oil of *S. sauveolens*.

The details of these identified compounds are stated in Table 1, however, identifying alone isn't sufficient enough, rather gaining an understanding on which among these compounds are allelochemicals and how to use them in improving crop production though managing weeds and controlling insect pests in sustainable agriculture will be a big advantage.

Table 1. Identified compounds from leaf oil of *S. suaveolens*.

Compound	Ip on RSL-150	Content
α- Thujene	921	0.1
α- Pinene	931	10.6
Camphene	941	0.1
Sabinene	964	1.5
Oct-1-en-3-ol	967	0.3
Myrcene	981	0.6
α- Phellandrene	995	4.1
α- Terpinene	1007	tr
p- Cymene	1011	6.3
1,8- Cineole	1019	6.6
γ- Terpinene	1049	1.1
trans- Pinene hydrate (?)	1131	0.3
Pinocamphone	1139	1.0
Isopinocamphone	1155	33.5
Terpinen-4-ol	1164	0.7
p- Cymen-8-ol	1170	0.4
α-Terpineol	1173	0.6
Methyl thymol ether (?)	1222	0.1
Cuminaldehyde	1228	tr
Thymol	1267	0.2
Carvacrol	1274	0.3
α- Terpinyl acetate	1329	1.2
Eugenol	1330	tr
α- Ylangene	1369	tr
β- Elemene	1382	tr
Thymohydroquinone	1400	16.1
dimethylether	1418	0.9
β- Caryophyllene	1447	0.1
α- Humulene	1449	0.1
β-Farnesene	1461	tr
allo- Aromadendrene	1515	1.2
δ- Cadinene	1547	0.1
Nerolidol	1564	0.7
Spathulenol	1570	0.4
Caryophyllene oxide		

tr = trace (<0.05%); (?) = identification based on the MS and RT

Source: Pooter *et al.* (1991)

Farmers knowledge and perception towards use of S. suaveolens in insect pests and weeds management

The diversity of insect pests and weeds in most agricultural lands need a multi-control strategies to produce satisfactory results in a sustainable manner (Parker *et al.*, 2013). The goals and values of long-term sustainability must be reflected in combinations of practices and methods consistent with an individual farmer's resources, including knowledge and farming practices (Ikerd, 1993). Unfortunately, most smallholder farmers in developing countries have limited knowledge and are resource-constrained. This limits their capacity to manage weeds and insect pests (Whitbread *et al.*, 2010).

Pest management practices by most smallholder farmers are mainly based on use of chemical pesticides, though this alone does not give the desired results (Toda & Morishita, 2009). Few of these farmers have combined such method with some cultural practices such as intercropping and crop rotation (Ajeigbe *et al.*, 2010; Ngowi *et al.*, 2007). Other studies reported that limited technical knowledge among small holder famers and shortage of extension services are among the limiting factors that hinder the adoption of suitable pest management practices (Midega *et al.*, 2012; Mkenda *et al.*, 2020). Most farmers still relying on past experience and farming practices despite the fact that they have not attained fruitful results over the years (Khan & Damalas, 2015). Integrating different pest management practices has long been proposed as the long term solution and future for sustainable agriculture (Pretty & Bharucha, 2015).

For any pest management approach to work and eventually adopted by farmers, their knowledge, perceptions and practices has to be fully realized (Chitere & Omolo, 2008; Hashemi & Damalas, 2010; Huis, 2014). Khan *et al.* reported that some farmers are aware of the role played by companion crops with repellent or toxic characteristics in pests control, as well as harboring natural enemies and in this regard, *S. suaveolens* may have considerable potential (Khan *et al.*, 2010). Isman and Grieneisen (2014) pointed out several plant species from the Asteraceae and other families with pesticidal properties that may be used to control and manage insect pests and weeds, however, very few of these plants are known and used by smallholder farmers despite the increasingly focus in research on plant species with pesticidal potential in Africa.

Conclusion

S. suaveolens is a weed which possesses diverse group of biological activities both in medicine as well as in agriculture.

However, the importance of such activities on the later have been ignored despite its potential in managing insect pests in the field, storage and suppressing other weeds. The wide geographical distribution of *S. suaveolens* give an added advantage and opportunities to small holder farmers as a cheap alternative in managing weeds and controlling pests since they cannot afford the synthetic pesticide. Additionally, the combination of small dosage of synthetic pesticides with botanical extracts may be more effective and environmental friendly compared with standard dose of synthetic pesticides (Isman, 2006b; Joseph *et al*., 2008). The allelochemicals from the plant extracts may be isolated and identified and eventually serves as templates for developing new generation of pesticides with less toxic effect to environment and human health. Extension services and trainings are very important in enhancing the performance and promoting adoption of new strategies and practices to smallholder farmers such as use of botanical extracts particularly from invasive weeds in managing and controlling pests, other weeds and diseases.

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