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Spices: A novel source for insect-pest management

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Abstract
In present scenario of agriculture, the methods to manage the insect-pest and diseases are mainly based on the use of synthetics or chemicals pesticides, resulting various hazards i,e. development of insect resistance to particular product, pest outbreak, environmental pollution, pesticidal residue, toxicity to plants, human being and non-target organisms along with high operational cost. These circumstances have created the need for developing alternative approaches to control insect pest and diseases. Furthermore, the demand of organic products, especially fruits and vegetables for the fresh market has greatly increased worldwide. Keeping above in view, essential oils from spices and their derivatives could be an alternative source for insect pest control in the field as well as storage, because they constitute a rich source of bioactive chemicals, are commonly used as flavoring agents in different cuisines. In the last few years, more studies on the insecticidal properties of essential oils from spices and spice derivatives have been published and it seemed worthwhile to compile them. The focus of this review lies on the lethal (Ovicidal, larvicidal, pupicidal and adulticidal) and sub-lethal (antifeedant, repellent, oviposition deterrent and growth inhibitor in progeny) activities of essential oils and their main components from spices and their uses as bio-pesticides. These features indicate that plant protection chemicals from spice crops could be used in a variety of ways to control a large number of insect- pests and diseases. It can be concluded that essential oils and phyto-chemicals isolates from different spices may be efficacious and safe replacements for conventional synthetic insecticides.

Keywords: Spice crops, essential oil, insect pest, bio-pesticides, management

Introduction
In nature, plants have great strategies for protecting themselves. Men through centuries has utilized plants as food to keep him healthy and harness their bountiful potent chemicals to protect himself from diseases. In return, men protected plants through use of non-organic and synthetic chemicals that brought about health and environmental issues. Men have to look back and study that plants can protect themselves and use this insight and knowledge to develop organic pesticides from plants for safer health and the environment. Herbs and spices spike up flavor and aroma of food. Spice is more of a culinary term that refers to extracts from parts of plants, may be roots, leaves, bark, and blooms that are added to food to enhance flavor and smell of food [21]. The American Spice Trade Association (ASTA) considers spices as "any dried plant product used primarily for seasoning purposes covering a wide range of plants like herbs, spice seeds and even dehydrated vegetables and spice blends. The list is numerous and used more commonly as food additives in oriental cuisines. The spices are also known for their medicinal properties [23].
Plants offer an alternate source of insect-control as bio-agents because they contain a range of bioactive chemicals, many of which are selective and have little or no harmful effect on non-target organisms and the environment. Because of the multiple sites of action through which the plant materials can act, the probability of developing a resistant population is very low [34]. Botanical insecticides degrade rapidly in plant system, air and moisture and are readily broken down by detoxification enzymes. This is a very important because rapid breakdown means less persistence in the environment and reduced risks to non-target organisms [35]. The ideal chemical should manage target pests adequately below the economic injury level (EIL) and should be target-specific, rapidly degradable, and low in toxicity to humans and other mammals. Among several natural products, certain highly volatile essential oils currently used in the food, perfume, cosmetic and pharmaceutical and agricultural industries also show promise for controlling insect pests, particularly in confined environments such as greenhouses or granaries. In this context, spices from different origins would rank among the most

important families of plants. Essential oils are complex mixtures of natural flavors and fragrances grouped as monoterpenes and sesquiterpenes (hydrocarbons and oxygenated derivatives), and aliphatic compounds (alkanes, alkenes, ketones, aldehydes, acids and alcohols) that provide characteristic odors [22] may also be applied to food crops shortly before harvest without leaving any excessive residues (Table 1). Moreover, medically safe of these plant derivatives has emphasized also. For these reasons, much effort has been focused on plant essential oils or their constituents as potential sources of insect pest and disease control agents [55] under open field as well as storage conditions.

Plant's essential oils show wide and varied bioactivities against both agricultural pests and medically important insect species, ranging from toxicity with ovicidal, larvicidal, pupicidal and adulticidal activities to sub-lethal effects including ovipositional deterrent, antifeedant and repellent actions as well as they may affect on biological cycles such as growth rate, life span and reproduction [16, 72 & 73]. Accordingly, the use of plant essential oils can lead to the identification of new bio insecticides. Because of this, much effort has been focused on plant essential oils as potential sources of commercial insect control agents. Essential oils are secondary metabolites that plants produce for their own needs other than for nutrition. The aromatic characteristics of essential oils from spices provide various functions for the plants including attracting or repelling insects, protecting themselves from heat or cold; and utilizing chemical constituents in the oil as defense materials. In general, they are complex mixtures of 20-60 organic compounds that give characteristic odour and flavour to leaves, flowers, fruits, seeds, barks and rhizomes [21]. In industrialized countries, essential oils isolated from spices could be useful alternatives to synthetic insecticides in organic food production, while in developing countries; they can be a means of low cost protection [13]. Spices and their extracts are known to have various effects on stored product insects [39, 50]. Spices have characteristic flavors and odours due to the essential (volatile) oils. Essential oils of spices and their constituents have also been reported as a potent source of botanical pesticides. Many essential oils extracted from various plant species belonging to different genera, contain relatively high amount of monoterpenes. Jointly or independently, they may contribute to the protection of plants against herbivores, although some herbivores have counter adapted to them [15, 59].

It has been reported that spices contain chemical principles capable of deterring insect pests from treated plants thus, preventing insects from staying longer on the crop and therefore minimizing the degree of damage [18, 14]. Therefore, the presence of repellent properties in spices has contributed to increased crop production and giving the fact that they are eco-friendly makes them a choice material for replacing synthetic pesticides [19]. Apart from the deterrent and repellent properties in the spices, there could be possible mortality arising from insect contact with the spices and this would further reduce the number of insects attacking cultivated crops [68]. This review gives another perspective to role and use of spices outside the culinary world and into the world of sustainable agriculture (Table 2). Although a number of review articles have appeared in the past on the various aspects of extracts and bio-active compounds from medicinal crops and from few spice crops but the present paper emphasizes on the potentially commercial spices derivatives or extracts in insect-pest management. This paper reviews the research conducted on the phytochemical profiles of common spices, their uses as bio-pesticides with lethal and sub-lethal effects against most of the insect-pests threatening the crops in field as well as under storage after harvest.

Table 1: Phytochemical profile of different spices

Sl. No.	Spice	Botanical name	Family	Part used	Active constituents	Reference
1.	Ajwain	*Trachyspermum ammi* L.	Apiaceae	Seed	Thymol (41.3%), α-terpinolene (17.4%) and ρ-cymene (11.7%).	[60].
2.	All spice	*Pimenta dioica* (L) Merr.	Myrtaceae	Fruit & Leaf	Eugenol and phenols	[17].
3.	Anise	*Pimpinella anisum* L.	Apiaceae	Fruit	Anethole (~ 90%), γ-himachalene (2–4%), p-anisaldehyde (< 1%), methylchavicol (0.9–1.5%) and t, pseudoisoeugenyl-2-methylbutyrate (~ 1.3%)	[57].
4.	Bay leaves	*Laurus nobilis* L.	Lauraceae	Leaf	β-caryophyllene (10%), viridiflorene (12.2%), germacradienol (10.1%), β-elemene (9.7%) and (E)-ocimene (8%)	[24].
5.	Caraway (Shyah jeera)	*Carum carvi* L.	Apiaceae	Fruit & Seed	(R)-Carvone (37.9%), D-limonene (26.5%), α-pinene (5.2%) and cis-carveol (5.0%).	[20].
6.	Cardamom	*Elettaria cardamomum* Maton.	Zingiberaceae	Fruit,Seed	α-terpinyl acetate and 1,8-cineole, myrcene, 1,4-cineole, borneol, 10% terpinylacetate, pinene and sabinene.	[43].
7.	Celery	*Apium graveolens* L.	Apiaceae	Leaf, Fruit & Stem	(Z)-3-Butylidenephthalide (27.8%), 3butyl-4, 5-dihydrophthalide (34.2%) and α-thujene (7.9%).	[62].
8.	Cinnamom	*Cinnamomum verum* Breyn	Lauraceae	Bark, Leaf	α -pinene (11.2%), β-pinene (9.2%), b-caryophyllene (11.0%), a-muurolene (6.1%), γ-cadinene (7.1%), δ-cadinene (13.6%) and a-muurolol (9.8%)	[44].
9.	Clove	*Syzygium aromaticum* (L) Merr.& Perry	Myrtaceae	Flower bud	Eugenol (49–87%), β-caryophyllene (4–21%), eugenyl acetate (0.5–21%), methyl eugenol, flavonoids, galloyltannins, phenolic acids and tri-terpenes.	[17].
10.	Coriander	*Coriandrum sativum* L	Apiaceae	Leaf, Seed	Linalool (57.1%), trans-anethol (19.8%), c-terpinene (3.8%) and geranyl acetate (3.2%).	[40].
11.	Cumin (Jeera)	*Cuminum cyminium* L.	Apiaceae	Fruit	Caryophyllene oxide (6.1%), α-pinene (4.8%), geranyl acetate (4.1%) and âcaryophyllene (3.4%).	[23].
12.	Fennel (Saunf)	*Foeniculum vulgare* Mill.	Apiaceae	Seed	Methyl clavicol (43.5%), α-phellandrene (16.0%) and fenchone (11.8%).	[12].
13.	Fenugreek	*Trigonella foenum-*	Fabaceae	Fruit	Trigonelline (0.13%), choline (0.05%), gentianine, carpaine and	[43].

		graecum L.			Saponins (0.6-1.7%)	
14.	Garlic	*Allium sativum* L.	Alliaceae	Bulb	Sulphur-containing compounds (allicin, alliin, and ajoene, citral, geraniol, linalool, α-phellandrene and β -phellandrene.	[43].
15.	Ginger	*Zingiber officinale* Rosc.	Zingiberaceae	Rhizome	Gingerol, gingeberne, α–zingiberene, citral, vitamin C, β carotene, flavonoids and tannins	[17].
16.	Nutmeg	*Myristica fragrans* Houtt.	Myristicaceae	Seed	Sabinene (32.1), myristicene (2.6%), α-Pinene (13.6%), β-Pinene (12.9%) and terpinen-4-ol.	[52].
17.	Pepper	*Piper nigrum* L.	Piperaceae	Fruit	Piperine (4.6% and 9.7%), piperidine, piperettine, β- pinene (4.92 - 14-33%) and α-pinene (1.11 - 16.20%), δ-Iimonene (16.41 - 24.36%) and β-caryophyllene, linalool oxide and α-terpineol (0.01-0.18%).	[17].
18.	Red chilly	*Capsicum annum* L.	Solanaceae	Fruit	Capsaicin, vanillylamine and 8- methyl-6-nonenoyl CoA.	[17].
19.	Star anise	*Illicium verum* Hook	Illiciaceae	Dried fruit	Trans-Anethole (94.05%), Limonene (1.74%), Estragole (1.45%), α-trans-Bergamotene (0.72%) and Linalool (0.31 %)	[23].
20.	Turmeric	*Curcuma longa* L.	Zingiberaceae	Rhizome	Curcumene 5%, curcuminoids, turmerone, zingiberene andcineole.	[44].

Table 2: Toxicity of essential oils and their derivatives isolated from different spices

Spice crop	Insecticidal activity and tested insect	Reference
Allium sativum L.	*T. castaneum* and *S. Zeamais* Cause mortality against egg, larvae pupa and adults of *Delia radicum* (L.) and *Musca domestica* L. larval, pupal and adult against *Tribolium castanium* H. Lethal and sublethal effects on *Tenebrio molitor* Larvicidal against *Spodoptera litura.* Ovipositional inhibition against *Sitotroga cerealella* (Olivier). Ovicidal against *Spodoptera littoralis.* Larvicidal against *Trichoplusia binotalis* Hiibner	[28]. [54]. [5]. [58]. [46]. [71]. [27]. [56].
Ammi visnaga (L.) Lam.	Lethal to *Tetranychus urticae*	[54].
Anethum graveolense L.	Adulticidal activity on *callosobrucus chinensis* and Fumigant toxicity against *Callosobruchus chinensis*.	[72].
Angelica archangelica L.	Fumigant toxicity against *Callosobruchus Maculatus* adults.	[16].
Carum carvi L.	Antitermitic activity against *Reticulitermes speratus*. Contact toxicity against *Sitophilus zeamais* and *Tribolium castaneum* adults. Adulticidal activity against Sitophilus oryzae and *Tribolium castaneum*. Ovicidal, larvicidal and Adulticidal against C*allosobrucus maculatus* Adulticidal and ovicidal activity against *Callosobruchus maculatus*. Nematicidal activity against *Meloidogyne javanica*	[20]. [60]. [72]. [64]. [49].
Cinnamomum zeylanicum Breyn	Antifeedant activity against *Acanthoscelides oblectus* and *Ceratitis capitata*.	[52].
Coriandrum sativum L.	Adulticidal against *Tribolium confusum* and *Callosobruchus maculatus.* Contact toxicity on *Diaphorina citri* adults. Larvicidal against *Culex quinquefasciatus*. Fumigant activity against *Sitophilus oryzae* adults. Fumigant toxicity against *Callosobruchus chinensis*.	[45]. [65]. [11]. [9]. [73].
Cuminum cyminum L.	Fumigant toxicity against *Callosobruchus maculatus* adults. Inhibits the growth and fecundity potential of *Bactrocera zonata*	[16]. [2].
Curcuma longa L.	Larvicidal action against *Trichoplusia ni* Adulticide against *T. castaneum* and *S. Zeamais*and number of other storage pest. Contact and fumigant toxicity against *Rhyzopertha dominica F.*, *Sitophilus oryzae L.* and *Tribolium castaneum* Herbst adult weevils. Fumigant toxicity against *Sitophilus oryzae* L. and *Ryzopertha dominica* F. Repellent against *Tribolium castaneum* (Herbst)	[70]. [36]. [64]. [25]. [32].
Elettaria cardamomum L.	Fumigant toxicity and oviposition deterrencyagainst *Callosobruchus maculatus*, *Tribolium castaneum* and *Ephestia kuehniella* Contact and fumigant toxicity against the adults of *S. Zeamais* Toxic to egg larvae and adults of *Tuta absoluta*	[1]. [30]. [8].
Foeniculum vulare Mill.	Adulticidal effect on *Lipaphis pseudobrassicae*. Aphidicidial activity against *Brevicoryne brassicae*. Fumigant activity against *Sitophilus oryzae* and *Sitophilus granarius* adults. Fumigant toxicity on *Sitophilus granaries* Fumigant toxicity on *Sitophilus oryzae, Callosobruchus chinensis* and *Lasioderma serricorne* were Acaricidal activity against *Dermatophagoides farinae* and *Dermatophagoides pteronyssinus*	[61]. [33]. [16]. [72]. [39]. [42].
Illicium verum Hook.	Effective control against adults and eggs of *T. Castaneum* and suppressed F1 progeny production.	[28].
Myristica fragrans Houtt.	Larvicidal properties against second stage larvae of *Toxocara canis.* Inhibits oviposition and adult emergence against *Callosobruchus maculatus* Fabricius. Mortality against *Sitophilus oryzae* adults.	[48]. [3]. [37].
Pimpinella anisum L.	Larvicidal activity against *Ochlerotatus caspius*.	[40].
Piper nigrum L.	Mortality and inhibited development of F_1 of *Callosobruches chinensis* under storage condition. Mortality and inhibited development of F_1 of *Rhyzopertha dominica* F. and *Sitophilus granaries* L. Larvicidal activity against *Sitophilus oryzae, Corcyra cephalonica* Acaricidal and Larvicidal activity against *Tribolium castaneum* (Herbst).	[47]. [6]. [38]. [69].

Piper guineense L.	Toxicity, repellency, pod and leaf damage as well as grain yield of cowpea against *Ootheca mutabilis* and *Clavigralla tomentosicollis.* Repellent and mortality against *Sitophilus zeamais*	[68]. [67].
Syzygium aromaticum (L.) Merr.& Perry	*Fumigant toxicity* against *S. zeamais* and eggs of *T. castaneum, S. oryzae* and *T. castaneum*	[27].
Trachyspermum ammi L.	Fumigant toxicity against adults of *Callosobruchus chinensis*. Nematicidal activity against *Bursaphelenchus xylophilus.*	[10]. [51].
Thymus vulgaris L.	Larvicidal activity of *Spodoptera litura* F.	[31].
Zingiber officnale Rosc.	Mortality of *Callosobruchus chinensis* and repellent against *Tribolium castaneum* Ovicidalagainst *Spodoptera littoralis* Larvicidal against *Trichoplusia binotalis* Hiibner.	[28]. [27]. [56].

Conclusion

Elucidation of the mode of action of spices essential oils or their derivatives and their constituents is of practical importance for insect control because it may give useful information on the most appropriate formulation and delivery means. Volatile oil can disrupt communication in the mating behavior of insect by blocking the function of antennal sensilla and unsuccessful mating could lead to a lower fecundity and ultimately lower the insect-pests population. The results obtained from this review article provide a scientific rationale for the use of spices and their derivatives in protection of crop under field and post-harvest grain in storage conditions. Further research on the isolation and mechanism of action of their active constituents may be promising approaches for the management of insect pests of crop plants. However, in vivo insecticidal efficacy of spices extracts and essential oils requires further investigation as well. Based on the results presented in this review paper, spices offer an opportunity for new compounds. These features indicate that plant protection chemicals from spice crops could be used in a variety of ways to control a large number of insect pests and diseases. In fact, the potential insecticidal activity of the spices extracts and essential oils need to be conduct and promote on a commercial scale. It can be concluded that essential oils and their phyto-chemicals isolated from different spices may be efficacious and safe replacements for conventional synthetic insecticides.

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