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REVIEW ARTICLE

Efficacy of botanical repellents on major pests - A review

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Abstract

One of the most common strategies in managing insect pests is repellence. This technology comes from early farming practices. The worldwide evaluation aims to evaluate the current state of research and development on the repellent properties of various botanical products to incorporate them reliably into pest management systems. As a result, many countries are returning to plant-based repellants to combat pest insects and vertebrates. Olfaction and gustatory action are the two mechanisms used by plant-derived repellents. It can be classified by their modes of action, including genuine repellents, attraction inhibitors, contact irritants, antifeedants or deterrents and visual barriers.

Ecologists are concerned about the potential harm contemporary pest control methods may pose to vertebrate wildlife. Therefore, caution is needed in agricultural settings when treating major pest groups, such as beetles, whiteflies, fruit flies, honey bees and vertebrate pests. Botanicals have significant advantages, being eco-friendly, non-phytotoxic and safe for both the agroecosystem and the environment. In modern agriculture, synthetic pesticides or repellents are crucial in helping farmers control pests. However, it may harm non-target insects, cause significant environmental contamination and affect human health.

The current review revisits the urgent and comprehensive needs that must be met to conduct additional research on both known and unknown plants that contain compounds that repel pestiferous taxa throughout agroecosystems. These plants have the potential to be widely utilized as botanical biopesticides, but current research is increasingly focused on their bio-repellent properties, both globally and in India.

Keywords

insect repellence; IPM; insect pests; insecticides; environmental preservation

Introduction

The increasing damage caused by crop pests is a significant issue for global agriculture, driven by climate change, monoculture farming and the spread of invasive species. These challenges lead to substantial crop yield reductions, highlighting the urgent need for effective pest control strategies. Conventional pest management methods have been widely utilized, including mechanical, cultural, biological and chemical techniques (1). Natural and synthetic pesticides play an essential role in modern agriculture, helping manage pests such as insects, weeds and diseases. Pest infestations contribute to approximately 45% of global food loss.

Synthetic pesticides are integral to agricultural production, assisting farmers in controlling weeds, diseases, insect pests and animal pests, leading to significant crop yield increases. The rapid population growth of the 20th century brought about a corresponding increase in food production, with pesticides contributing to roughly one-third of agricultural output. Without pesticides, losses in producing fruits, vegetables and cereals would reach 78%, 54% and 32%, respectively (2, 3). However, the significant increase in pesticide use since the late 19th century has raised serious environmental concerns. In 2022, according to Sharma et al., global pesticide use in agriculture reached 3.70 million tonnes, a 4% increase from 2021 and double the levels recorded in 1990. In India, pesticide consumption reached 61,702 tons in 2020. Uttar Pradesh has the highest percentage of pesticide consumption, followed by Maharashtra, Andhra Pradesh, Punjab and Tamil Nadu, which consumed 1879 tons in 2023 (4). However, synthetic chemicals can harm non-target species and decrease the numbers of birds, fish, beneficial insects, bats, earthworms, aquatic plants and amphibians. Pesticides can contaminate air, water, soil and crops, creating pathways for these chemicals to enter the food chain and affect human health. Pesticide residues frequently spread beyond their target areas, leading to environmental pollution. This dispersion occurs through water runoff, wind drift and soil leaching, causing negative impacts on ecosystems, plants, animals and humans. (4).

Pesticide pollution can negatively impact human health. Synthetic pesticide exposure is linked to several health issues, like cancer, blood disorders, respiratory illnesses, immune system deficits and congenital disabilities. Farm workers, in particular, face higher risks from direct skin contact and inhalation during handling and application. Additionally, pesticide runoff contaminating water sources presents serious health risks to the broader population (5).

Indiscriminate use of pesticides for the control of pests in agricultural and horticultural ecosystems in the recent past has resulted in the development of resistance in many pests and resurgence, in addition to becoming a minor pest into significant threats. This has created a strong need for eco-friendly pest management strategies, such as plant-based pesticides, repellents, attractants and cultural, physical and mechanical methods within integrated pest management (IPM). Botanical pesticides, with different modes of action-poisonous, repellent, or deterrent-have become a key focus in IPM. Many plant-based active compounds are now used to manage agricultural, horticultural and household pests. Plant-based insecticides, used for thousands of years, predate the widespread adoption of synthetic pesticides and are essential to traditional farming and environmentally friendly pest management practices (6). Chemical substances are derived from various plant parts, including leaves, rhizomes, bark, nuts, stems, fruits and seeds. For example, the adult maize weevil, *Sitophilus zeamais* Motschulsky, is repelled or poisoned by both known and novel plants with pesticidal and repellent properties, while extracts from *Datura stramonium* L. seeds effectively repel *Sitophilus oryzae* L. (7). It has been shown that about 2500 plant species and 230 plant families have demonstrated efficacy in suppressing pests affecting crops and stored produce (8). The utilization of botanical repellent in integrated pest management is conceivable due to its low animal toxicity, environmental preservation and reduced likelihood of resistance development. Repellent action prevents pests from landing on or climbing leaf surfaces or interacting with specific chemicals that deter activity, which has enhanced their recognition over time. Although synthetic repellents generally outperform natural ones, some plant-based repellents are similarly effective (9). This reaction can be used as a behavioural control strategy to change the pest's feeding habits, geographic distribution, oviposition pattern, aggregation phenomenon, etc. This review discusses a model plant repellent and its effectiveness against various pest types.

Classification of insect repellents

"repellent" originates from the Latin word *repellere*, meaning "to reject." Thus, a substance is considered repellent in the strict sense if it prompts pests to move in a coordinated manner away from its source (10). Miller et al. (11) describe a repellent as a source that elicits a behavioural response to a stimulus. As a result, some subjectivity distinguishes between repelling phenomena and behavioural responses, including avoiding an odourous source or failing to identify the host. Furthermore, an object that keeps insects away from an odour source should be considered a repellent (12). By applying this broad definition, they can be divided into five categories according to their mode of action. They may act as real repellents, odour masking, contact irritants, deterrents and visual masking repellents (Table 1). A proper repellent, also known as an excellent in medical entomology, is any substance that can influence pests to move away from the source. An odour-masking repellent works by making the host unattractive to pests by obscuring their ability to detect or locate it. These substances hinder pests' ability to locate their targets rather than acting as effective repellents on their own. Contact irritants, on the other hand, drive insects away through physical interaction with the substance. This type of response is commonly known as "landing inhibition" in medical entomology because it keeps insects from landing on a surface or host upon contact. Deterrents, or antifeedants, interfere with or disrupt an insect's feeding behaviour, either

Table 1. Classification of insect repellents of plant origin

Repellent category	Mode of action	Application	Reference
True repellent	Excellent and spatial repellent	Tulsi against, *Rhyzopertha dominic* F. *Tribolium castaneum* Herbst.	10, 65
Odour masking	Attraction inhibition	Tomato volatile against *Bemisia tabaci* Gennadius.	10, 66
Contact irritancy	Landing inhibition (or) Excito-repellent	-	10
Deterrence	Antifeeding, suppressant, Anorexigenic and Anti-appetant	*Peltophorum pterocarpum* DC. and *Ipomoea aquatica* Forssk.against *Pomacea canaliculata* Lamarck.	10, 67
Visual masking	Visual cue	Eggplant against *Bemisia argentifolii* Gennadius.	10, 68

through contact or after ingestion, diminishing the insect's inclination or capacity to continue feeding.

Finally, visual masking repellents alter the appearance or colour of a crop, effectively hiding the host by creating a visual barrier. In pest control, this technique disrupts the pest's ability to recognize and locate the host plant, thereby helping to prevent infestations (13)

Mechanisms of action of insect repellents

Olfaction action: According to Rao et al., olfaction is crucial for communicating pest insects and vertebrates, such as rats, deer, wild boar and Coleoptera (14). Research has shown that wild animals can locate food sources in cultivated crops due to their highly developed olfactory sense. A sensillum contains one to four olfactory receptor neurons (ORNs) (15). The olfactory pathway first activates the olfactory receptors, which are important in sensing the odourant. Every (ORN) expresses a unique mix of olfactory receptors, including olfactory co-receptors. Axons from each ORN project into a single olfactory glomerulus in the antennal lobe (16). Olfaction co-receptors aid in receptor trafficking, targeting and tuning and play a role in signal transduction (17). Repellent odours can interfere with the normal functioning of ORN, which is responsible for detecting substances that typically attract organisms by changing or blocking the response of neurons that are normally sensitive to attractants. For instance, Ditzen et al., showed that applying DEET and odourant compounds to *Anopheles gambiae* Giles, simultaneously, directly reduces the antennal response to both CO_2 and 1-octen-3-ol. This suggests that DEET may cause discomfort and obstruct the perception of host smells (18).

Gustatory action: Animals and insects with well-developed gustatory systems can detect food from a distance and perceive the flavors of various compounds before ingestion. As reported by Vosshall & Stocker, this process contributes to the repellant effect, particularly in insects with various body sections that possess taste organs (19). Due to sensilla on their sensory organs, insects can assess potential food sources by tasting them without the need for consumption. Given the close relationship between the gustatory and olfactory systems, repellent effects like anti-feeding behaviour and irritancy may be attributed to similar physiological mechanisms. (10) As per Altner & Prillinger, gustatory sensilla are uniparous, while olfactory sensilla are multiparous (20).

As stated by Rodrigues & Siddiqi, gustatory systems are made up of two kinds of gustatory receptor neurons cells that can respond to distinct tastes, such as sugar (S cells), tap water (W cells) and bitterness (L2 cells), or they can react to either pleasant or unpleasant tastes. Flies use their gustatory action to respond to different salt concentrations by using distinct types of gustatory receptor neurons (GRNs). Furthermore, it was demonstrated that low-salinity detection is aided by IR76b, a Na^+ channel that belongs to the recently discovered ionotropic glutamate receptor (IR) family (21). According to recent research (22), conflicting behavioural reactions are mainly caused by a complex bimodal switch system with GRNs.

To help with future research, figuring out how different substances work would be useful. A comprehensive review of the mechanisms of action is required to establish a strong foundation for future research in this field. Understanding the workings of these repellents can help overcome current constraints resulting from a lack of knowledge about their mechanisms. Furthermore, using this knowledge, more practical applications of these substances in real-world scenarios can be made and effective tactics can be developed (10).

Visual action: Visual repellent mechanisms utilize visual signals to deter pests or animals from specific areas effectively. This approach may incorporate different objects, such as reflective tapes, scarecrows, or striking colour patterns that are unsettling or alarming to targeted pests, thereby discouraging their presence. The effectiveness of visual repellents is closely connected to the physiological reactions of insects to light stimuli. When insects encounter repellent wavelengths, they may feel discomfort or disorientation, leading them to flee from the source. This behaviour is facilitated by their olfactory and visual systems, where specialized receptors in their antennae respond to variations in light and colour intensity (10).

Limitation of synthetic insect repellents: The worldwide use of pesticides and agricultural chemicals seriously threatens global agricultural ecosystems, compromising ecological stability and the health of living organisms. These chemical compounds frequently lead to environmental contamination, adversely affecting animal and plant life. Humans may be exposed to these substances through skin contact, inhalation, ingestion and eye exposure. According to the researcher, N, N-diethyl-3-methylbenzamide (DEET), a widely used chemical, has been linked to several health issues, including encephalopathy, hypotension, vomiting, nausea and seizures (23). DEET affects people and non-target creatures, especially pollinators, with potentially harmful consequences. Additionally, misuse of such chemicals may lead to insect resistance, such as pyrethroids, making managing home pests more difficult (24).

Synthetic chemicals have significant environmental effects since they can severely deteriorate air, water and soil quality. For example, diethyl phthalate contamination in the Kaveri River disrupts food chains in India, leading to the bioaccumulation and bio magnification of hazardous chemicals throughout the ecosystem. Bioaccumulation occurs when an organism absorbs a chemical faster than it can excrete it, resulting in toxic buildup in its tissues. Bio magnification refers to the increasing concentration of these toxic compounds as they move up the food chain (25). Inhalation of such chemicals can result in serious health issues, including genotoxic effects. Research suggests that combining DEET with permethrin or other insect repellents may heighten the risk of transgenerational epigenetic disorders and cause DNA methylation epimutations in sperm. These harmful effects underscore the urgent need to reassess synthetic chemicals' use in agriculture and develop safer alternatives to safeguard human health and the environment (26). (Fig. 1.).

Sources of natural repellents and their characteristics: Although the historical use of botanical insecticides is not extensively documented, several sources indicate that certain plants have been used as insect repellents in Europe for over 3,000 years. People frequently used extracts from fragrant plants as repellents, particularly against pests that threatened crops or served as vectors (27). Additionally, plant-derived compounds have been employed to combat storage pests for centuries. The repellent properties of plant materials were often utilized by

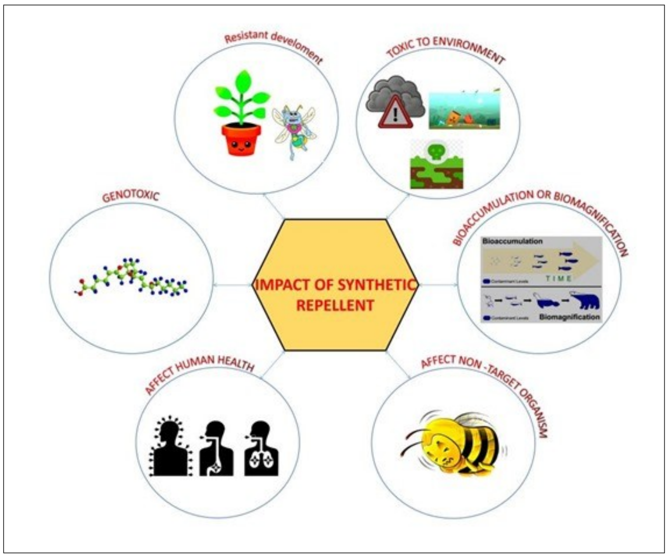

Fig. 1. Environmental impact of the usage of synthetic repellents.

hanging plants in homes to ward off pests (28). Researchers in India and the ancient Greeks and Romans provided detailed records of using plants as insecticides. In addition, aromatic plant materials were strung near granary entrances, alerting people to their unpleasant characteristics for pests (29).

In Ethiopians and Kenyans, people adopted various methods to keep mosquitoes out of their homes at night, including spraying, burning, or hanging *Chrysanthemum cinerariaefolium* L. flowers at doors and around beds. According to folklore, a powder made from dried pyrethrum petals was also used to soothe infants to sleep (30). Botanical repellents can be crafted from various plant parts, including bark, leaves, rhizomes, nuts, cloves, fruits and stems, to create liquid or powder-based repellents (31). Essential oils, produced by plants as secondary metabolites, are volatile, often have a strong smell and can repel insects for a few minutes to several hours, depending on their concentration. These oils contain allelochemicals related to monoterpenes, such as cineole, pinene, eugenol, limonene, citronellol, terpinolene, citronellal, camphor and thymol (32).

Commonly used plants to prepare botanical repellents are shown in Table 2. Plant parts are crushed dried and bioactive compounds are extracted using solvents. The plant extract is then standardized, distilled and tested in laboratory and field settings. Two of the most profitable and successful plant insecticide products are made from pyrethrum (*Tanacetum cinerariifolium* Sch. Bip.) and azadirachtin (*Azadirachta indica* A.Juss.), a neem herb. Numerous other plants can be used as pesticides, including garlic (*Allium sativum* L.), ginger (*Zingiber officinale* Roscoe.), thyme (*Thymus vulgaris* L.), rosemary (*Rosmarinus officinalis* Spenn.), peppermint (*Mentha piperita* L.) and turmeric (*Curcuma longa* L.) (33). Research has been conducted on well-known and lesser-known repellent plant species (7).

While plant-based repellents are a modern method of controlling pests, they have historically been utilized to improve

Table 2. Major sources of natural repellent used against pests

Common Name	Scientific Name and Family	Plant parts used	Target pest	Mode of action	Active Compounds	Reference
Neem	*Azadirachta indica* L. Meiaceae.	Leaf powder and oil	Maize Weevil, *Sitophilus zeamais* Motsch. and Red flour beetle, *Tribolium castaneum* Herbst.	Repellent (Contact and Fumigation)	Azadirachtin	69, 70.
Pepper	*Piper nigram* L. Piperaceae	Seed Powder and oil	Pulse beetle, *Callosobruchus maculatus* F	Repellent and Oviposition deterrent	Caryophyllene Sabinene, α-Pinene and Limonene β-	71
Cironella	*Cymbopogon nardus L.* Poaceae	Leaf	Whitefly, *Bemisia tabaci Gennadius.*	Repellent	Citronellol and Geraniol	72.
Clove	*Syzygium aromaticum*L. Myrtaceae	Oil and plant powder	Pulse beetle, *Callosobruchus maculatus* F.	Repellent	Eugenol, Eugenyl acetate and β-Caryophyllene	73
Lemongrass	*Cymbopogon citratus* Stapf. Poaceae	Leaves	Red flour beetle,*Tribolium castaneum* Herbst. and Rice Weevil, *Sitophilus oryzae* L.	Repellent and feeding deterrent	Geranial	74
Peppermint	*Mentha piperita* L. Lamiaceae	Above-ground plant part	*Tribolium confusum* Jacquelin du Val.	Repellent	Menthol	75
Thyme	*Thymus vulgaris* L. Lamiaceae	Whole plant	Whitefly, *Bemisia tabaci Gennadius.*	Repellent, Oviposition Deterrent	Carvacrol, Thymol and Acetates	50
Sweet flag	*Acorus calamus* L. Acoraceae	Leaf	Pulse beetle, *Callosobruchus maculatus* L.	Repellent	Shyobunone and Isoshyobunone	73
Castor	*Ricinus communis* L. Euphorbiaceae	Seed oil	Red flour beetle, *Tribolium castaneum* Herbst.	Repellent	Ricinolic acid	70
Tobacco	*Nicotiana tobacum* L. Solanaceae	Leaf	Pulse beetle, *Callosobruchus maculatus* F.	Repellent	Nicotine, d-Limonene, Indole and Pyridine.	73
Prickly ash	*Zanthoxylum spp.* Rutaceae	Leaf Powder	Red flour beetle, *Tribolium castaneum* Herbst. and cigerete beetle, *Lasioderma serricorne* F.	Repellent	Germacrene, β-phellandrene and β-myrcene	76
Ginger	*Zingiber purpureum* Roscoe. Zingiberaceae	Rhizome or Root	Red flour beetle, *Tribolium castaneum* Herbst.	Repellent	Sabinene and Terpinen-4-ol	77

environmental conditions and conserve insect ecosystems (34). These substances have multiple functions: they are poisonous, repulsive and control insect behaviour. Plant-based derivatives are harmless for the environment, readily biodegradable and leave behind no residue in food products or soil. The best-desired characteristic for botanical repellents is the longevity of volatile and delayed release of volatile chemicals from plant extract, rather than using easily accessible and inexpensive raw materials (Fig. 2.) (35).

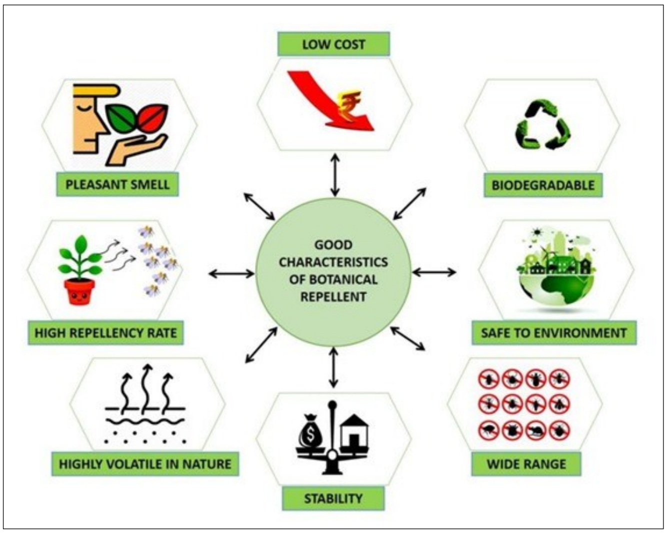

Fig. 2. Advantages of the usage of the botanical repellents.

Efficacy of botanical repellents against the following groups of insects

***Coleoptera*:** Beetles, with approximately 450,000 species, represent the largest group of insects. They account for roughly 40% of all known insect species and about 75% of beetle species are polyphagous, feeding on various stored goods, wood and plants during their larval and adult stages (36). The improper use of botanicals as antifeedants, repellents and contact irritants can lead to unintended consequences, particularly with Coleoptera, as some botanicals have antifeedant effects on this group. Table 3 below provides a list of plants used to combat stored-product pests.

***Lepidoptera*:** Lepidoptera, encompassing both moths and butterflies, are significant global pests that can lead to substantial losses in agriculture and horticulture production. During their caterpillar stage, many can inflict severe damage to crops, potentially leading to complete crop failure. Various non-synthetic insecticides must be used to manage lepidopteran pests in an integrated (37). Recently, some nations have focused on using botanical pesticides, which exhibit various action modes such as stomach poison, repellant, antifeedant, oviposition deterrent and contact poison.

Using plants such as *Azadirachta indica* A. Juss. and *Jatropha carcus* L. to repel insects, primarily with their seeds and leaves, can have highly repellent, antifeedant and toxic effects on lepidopteran species like *Plutella xylostella* L. These plants react with chemo-receptors, so people avoid eating them (38). A low dose of neem and jatropha can decrease feeding rates and induce repellent activity, which may increase mortality rates, depending on concentration differences. A higher concentration can improve the plant's ability to repel (39).Azadirachtin, salanine and Nimbin in neem lowers the intake rate and relative growth of *Spodoptera litura* F. compared to the control. In accord with Koul et al., salanine is a glycoalkaloid repellent that can help prevent a lot of bug infestations (40). To jointly assess the antifeedant and repellent properties of nearby plants, Susmitha et al. compared the antifeedant and insecticidal effects of six local plants on *Plutella xylostella* L. and they found that *Sesbania grandiflora* L. had the highest antifeedant activity (20.82%) when administered after 72 hours, while the antifeedant effect decreased from 24 to 72 hours (41). The antifeedant impact of *Sesbania grandiflora* L. on *Plutella xylostella* L. was also assessed by Sangavi and Edward (42). After two days, evaluating the same dose at different times indicated a 52.31 % anti-feeder effect (43). The fact that other results were discovered in the same plant and pest warned us that the test procedure needed to be standardized. Numerous plants exhibit repulsive properties. Table 4 lists them all.

***Diptera*:** One of the largest groups of insects, dipterans, has two pairs of wings, the front pair of which is fully formed, while the back pair, known as halteres, may be more primitive. They can primarily inflict harm as blood-feeding ectoparasites (e.g., stable flies, *Stomoxys calcitrans* L. and horn flies, *Haematobia irritans* L.) and as vectors of diseases that affect humans and animals (e.g., malaria, dengue, chikungunya, Japanese encephalitis disease.) (44). Alternative plant repellents are required to prevent allergic reactions, because direct application of synthetic repellents, such as DEET, might elicit allergic reactions in some people. Many plants have recently been found to repel some Dipteran species and the most promising ones are included in Table 5 below.

Table 3. Comparative efficacy study on Coleopteran pest using different plant sources

Target Pest	Common Name	Plant Name	Plant part used	Extract Conc. % or µL / mL or µL / L	Efficacy % or EPI		Reference
					TR	A or D	
Callosobruchus maculatus F.	Pulse beetle	*Syzygium aromaticum* L.	Flower bud	0.4	-0.91	-	73
				0.3	80.13	-	78
		Zingiber officinale Roscoe.	Rhizome or Root	2	-	43.9	79
		Acorus calamus L.	Rhizome	0.4	-0.81	-	73
				0.5	90.07	-	78
		Piper Spp L.	Seed	0.3	83.51	-	78
		Nicotiana tobacum L.	Leaf	0.4	-0.81	-	73
		Mentha piperita L.	Leaf	75	-	100	80
Tribolium castaneum Herbst.	Red flour beetle	*Zingiber officinale* Roscoe	Rhizome	2	-0.80	-	73
		Syzygium aromaticum L.	Unopened bud	0.3	61.29	-	81
		Acorus calamus L.	Rhizome	0.5	61.29	-	
		Piper Spp L.	Seed	0.3	64.76	-	
		*Mentha piperita*L.	Leaf	75	-	100	

(EPI- Excess Proportion Index; TR - True repellent; A or D - Antifeedant or Deterrent)

Table 4. The potency of botanical repellent used against Lepidopteran pest

Target Pest	Common Name	Plant Name	Plant part used	Extract Conc. % or µL /mL or µL / L or µg /cm²	Efficacy %		Reference
					TR	A or D	
Plutella xylostella L.	Diamond back moth	*Swietenia macrophylla* King.	Leaf	5	-	15.61	41
		Sesbania grandiflora L.	Leaf	10	-	20.82	
		Prosopis juliflora SW.	Leaf	10	-	58.41	42
		Sesbania grandiflora L.			-	52.31	
		Curcuma longa L.			-	23.10	
Spodoptera litura F.	Tobacco cutworm	*Cassia fistula* L.	Leaf	0.1	-	76.48	43
		Vernonia cinerea L.	Leaf		-	78.69	
		Cerbera manghas L.	Leaf	5	80.37	-	82
Spodoptera frugiperda J.	Fall army warm	*Azadirachta indica* A.Juss	Seed Kernal	1	-	75.17	83
		Tagetes Spp L.	Leaf	1	-	66.70	
Helicovepra armigera Hübner.	Cotton bollworm	*Ageratum conyzoides* L.	Arial part of plant	0.4	-	86.82	84

(TR - True repellent; A or D - Antifeedant or deterrent)

Table 5. Effect of plant extracts on Dipteran pests

Target Pest	Common Name	Plant Name	Plant part used	Extract % or (µl / cm3)	Efficacy %			Reference
					TR	A or D	CI	
Musca domestica L.	Housefly	*Eucalyptus globulus* Labill.	Leaf	0.025	90	-	-	85
		Cymbopogon citratus Stapf.	Leaf	0.01	100	-	-	
		Citrus sinensis L.	Fruit	0.025	90	-	-	
		Mentha piperita L.	oil	0.01 (µl/cm³)	100	-	-	
		Piper nigram L.	Seed	25	66.67	-	-	86
		Allium sativum L.	Bulb	25	80	-	-	
Aedes aegypti	Yellow fever mosquito		Leaf	5	77.7	-	-	87
Bactrocera zonata Saunders.	Peach fruit fly	*Datura alba* Rumph.	Leaf	2	84.14	-	-	88
		Azadirachta indica L.	Leaf	2	-	57.14	-	

(TR - True repellent; A or D- Antifeedant or Deterrent; CI- Contact Irritant)

***Hemiptera*:** Hemiptera, one of the largest insect groups globally, poses significant threats to plants and acts as a vector for various plant diseases. Numerous small hemipteran pests are known for transmitting plant diseases (45). Following Kuhns et al., they pose significant issue with agricultural output (46). Using artificial pesticides to control them is not a sustainable method. Instead, we must adapt natural safeguards (47). Integrating a repellent mechanism is safe for the environment and insect ecosystem. Various plants (e.g., basil, marigold, peppermint, lavender, etc.) can be grown as intercrops since they release volatile organic compounds. Extensive literature on these topics refers to their potential to reduce target pest populations. In their study, Dardouri et al., examined the intercropping of pepper and six other scent plants, including two marigolds, basil, lavender, rosemary and peppermint, against *Myzus persicae* Sulzer. The most effective repellent for aphids was basil, however, the degree of activity, such as attraction or repellence, depends on the chemical concentration (48). Plant extracts were tested against the whitefly *Bemisia tabaci* Gennadius. by Emilie et al., to see whether the plants were repellent or attractant 47. The same plant species showed a repellent or irritating reaction, as indicated in Table 6. Following plant identification, hemipteran pests (such as whiteflies, thrips, tea mosquito bugs, aphids, citrus psyllids, etc.) have been subjected to screening of the plant's chemical compound against pests (50). All of them have employed plant-based repellents as viable botanicals for hemipteran pest management that is sustainable. This includes the application of botanical repellents against novel target pests (such as scale).

***Vertebrates*:** Though not as numerous as arthropod pests, Vertebrates can significantly impact various agricultural systems and cause substantial economic losses worldwide. In Australia, for example, birds alone are estimated to cause approximately $120.8 million in economic losses (51). Despite the availability of

Table 6. Some examples of plants with anti-pest activity

Plant common name	Scientific Name	Mode of action	Reference
Aframomum	*Aframomum pruinosum* Gagnep.	Repellent and Irritant	47
Citronella	*Cymbopogon winterianus* Jowitt ex Bor.	Repellent and Irritant	
Dill	*Anethum graveolens* L.	Irritant	
Cinnamon	*Cinnamomum zeylanicum* J.Presl.	Repellent and Irritant	
Geranium	*Pelargonium graveolens* L 'Hér.	Repellent and Irritant	
Savoury	*Satureja montana* L.	Repellent and Irritant	
Litsea	*Litsea cubeba* Lour.	Irritant	
Lemongrass	*Cymbopogon citratus* DC.	Repellent and Irritant	
Cumin	*Cuminum cyminum* L.	Repellent	

control methods, such as poisonous pesticides, electric fencing, trenching and culling, managing vertebrate pests presents several challenges, particularly given ethical and legal restrictions. In India, legislation under sections 9 and 11 of the Wildlife Protection Act of 1972, which applies to Schedule III (IS 19 No.) animals, provides legal protection to certain species like wild boars, deer and nilgai. As classified by the International Union for Conservation of Nature (IUCN), wild boars fall under the "maximum concern" category, meaning that they cannot be killed for pest control. Botanical repellents, however, can be legally applied as antifeedants or repellents without harming these animals.

For instance, Roa et al. found that a mixture of castor oil, ginger and garlic can repel wild boar with up to 95% efficacy without endangering the health of people or the environment (14). As per Shakthivel et al., ricinoleic acid, a component of plant -based formulations, is used to deter wild boar (52). When applied against rats in enclosed spaces, plant essential oils such as eucalyptus and citronella oil have a repelling effect (53). Since 1948, eucalyptus and citronella oil have been registered and used as botanical-based insect repellents in the United States (54). Numerous research has used essential oils to manage a variety of insect pests (55). There is little research on rats and other vertebrates. Studies on birds that inflict substantial damage, such as crows (*Corvus splendens* Vieillot.) and parrots (*Psittacula krameria* Scopoli.), have been shown to inflict up to 75% to 90% of the damage to sunflowers (56). According to Reddy et al., using repellent technology can help reduce such damage, leading to higher sunflower yields (57).

Status and future of botanical repellents

As botanical-repellent technology does not affect animal ethics, numerous plant-repellent technologies have been developed. The use of botanical repellent against storage pests has been tested and new compounds from various wild and medicinal plants have been identified (58). Numerous studies on botanical repellent technology have been conducted in many countries, including India, to reduce the risk to wild animals (14). In Algeria, three distinct products have been utilized simultaneously against the date palm scale (*Parlatoria blanchardi* Targ), using locally available plants (59).

According to research analysis by BBC, the global market for insect repellents is predicted to rise at a compound annual growth rate (CAGR) of 4.5% from USD 3.7 billion in 2018 to USD 4.6 billion in 2023 (60). In 2022, the market value of insect repellent is USD 4.81 billion to Grand view research (61). With continuous attempts to enhance their safety, efficacy and durability, botanical repellents have a promising future in a global market that is expected to develop at a CAGR of 7.0% from 2023 to 2030 (61). In Finland, future research will concentrate on screening and identifying novel chemicals to protect tick and mosquito. In contrast, ticks are not a big problem in many Asian countries; only 49% of Indian survey participants said they would like protection from mosquitoes and ticks. However, about half of the respondents said they wanted to be protected from mosquito-borne illnesses, as mosquitoes are India's main vector of disease (62).

Future research and development efforts will primarily focus on creating long-lasting formulations, investigating botanical analogues and identifying repellents. Manufacturers of repellents with botanical bases have prospects due to the increased demand for natural and organic products. As research progresses, the potential of botanical repellents to manage pests and improve both human and environmental health will become more evident. Botanical repellents may play an increasingly important part in international pest management techniques, as seen by the increased demand for organic and environmentally friendly farming methods.

The major shortcomings and key research gaps are summarized below

Less persistent or short longevity- Most essential oils are highly volatile, meaning their repellent properties last longer, need longer treatment times or short intervals in greenhouses, which can increase production costs and affect market viablity (62).

Difficult in standardization- It's challenging to develop reliable botanical repellents because of plant composition variations, climate change effects and a lack of established testing procedures. This makes the process of developing uniform standards difficult (63).

Quick or rapid biodegradation- The majority of botanicals are vulnerable to abiotic oxidation (Azadirachtin) and UV (Photodegradation) (64).

Availability of raw material- People frequently turn to botanical repellents rather than traditional synthetic ones for pest management, due to a lack of raw materials and issues with large-scale manufacture (63).

Time taken for activation- One drawback of plant repellents is that they don't work as quickly as synthetic ones on pests (63).

Rules and regulation- Commercialization in regions such as the U.S. and EU is challenging due to lengthy registration and licensing procedures, which can take at least 4 to 5 years after application (62).

Conclusion

The potential application of botanical repellents in pest management has been extensively researched. The effectiveness can vary depending on the concentration and content of active ingredients in the plant material used and variations in the preparation procedure methods. Botanicals may sometimes lack sufficient active components, limiting their widespread use in pest control. Nonetheless, several studies have shown promising results, indicating that various botanicals contain potent anti-feedant or repellent compounds effective against specific pests. However, the efficacy of these botanicals can depend on factors such as the host crop, the target pest species and environmental conditions.

Further research is essential to identify sustainable and effective botanical repellents as scientists continue to explore plants as potential alternatives to synthetic pesticides. In summary, plant-based repellents are promising substitutes for synthetic pesticides, though additional studies are required to understand their effectiveness and safety fully. A comprehensive approach to pest management could incorporate botanicals as a core component.

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Authors' contributions

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References

1. Trivedi TP, Ahuja DB. Integrated pest management: approaches and implementation. Indian Journal of Agricultural Sciences. 2011;81 (11):981-93. https://epubs.icar.org.in/index.php/IJAgS/article/view/12010
2. Sharma A, Kumar V, Shahzad B, Tanveer M, Sidhu GP, Handa N, et al. Worldwide pesticide usage and its impacts on the ecosystem. SN Applied Sciences. 2019;1:1-6. https://doi.org/10.1007/s42452-019-1485-1
3. Tudi M, Daniel RH, Wang L, Lyu J, Sadler R, Connell D, et al. Agriculture development, pesticide application and its impact on the environment. Inter J Environ Res Public Health. 2021;18 (3):1112. https://doi.org/10.3390/ijerph18031112
4. Food and Agriculture Organization of the United Nations. Pesticides use, pesticides trade and pesticides indicators [Internet]. FAOSTAT; 2020 [cited 2024 March 1]. Available: https://www.fao.org/3/cc0918en/cc0918en.pdf
5. Ahmad MF, Ahmad FA, Alsayegh AA, Zeyaullah M, AlShahrani AM, Muzammil K, et al. Pesticides impacts on human health and the environment with their mechanisms of action and possible countermeasures. Heliyon. 2024;10(7):e29128. http://doi.org10.1016/j.heliyon.2024.e29128
6. Stankovic S, Kostic M, Kostic I, Krnjajic S. Practical approaches to pest control: The use of natural compounds. Pests, weeds and diseases in agricultural crop and animal husbandry production. IntechOpen London, UK; 2020. P. 43-59
7. Jawalkar N, Zambare S, Zanke S. Insecticidal property of *Datura stramonium* L. seed extracts against *Sitophilus oryzae* L.(Coleoptera: Curculionidae) in stored wheat grains. Journal of Entomology and Zoology Studies. 2016;4(6):92-96.
8. Qasim M, Islam W, Ashraf HJ, Ali I, Wang L. Saponins in insect pest control. Co-evolution of Secondary Metabolites. 2020:897-924. https://doi.org/10.1007/978-3-319-96397-6_39
9. Jaenson TG, Garboui S, Pålsson K. Repellency of oils of lemon eucalyptus, geranium and lavender and the mosquito repellent MyggA natural to *Ixodes ricinus* L. (Acari: Ixodidae) in the laboratory and field. Journal of Medical Entomology. 2006;43(4):731-36. https://doi.org/10.1093/jmedent/43.4.731
10. Nordlund DA. Semiochemicals: a review of the terminology: their role in pest control. 1981:13-28.
11. Miller J, Siegert P, Amimo F, Walker E. Designation of chemicals in terms of the locomotor responses they elicit from insects: an update of Dethier et al.(1960). Journal of Economic Entomology. 2009;102(6):2056-60. https://doi.org/10.1603/029.102.0606
12. Jaramillo RGI, Logan JG, Loza-Reyes E, Stashenko E, Moores GD. Repellents inhibit P450 enzymes in *Stegomyia (Aedes) aegypti* L. PLOS One. 2012;7(11):e48698. https://doi.org/10.1371/journal.pone.0048698
13. Deletre E, Schatz B, Bourguet D, Chandre F, Williams L, Ratnadass A, Martin T. Prospects for repellent in pest control: current developments and future challenges. Chemoecology. 2016;26:127-42. https://doi.org/10.1007/s00049-016-0214-0
14. Rao NS, Kumar KP, Sakthivel P. Efficacy of botanical repellents against wild boar in field crops. Green Farming. 2019;10:368-71.
15. Dethier VG. The physiology of olfaction in insects. Annals of the New York Academy of Sciences. 1954;58(2):139-57. https://doi.org/10.1111/j.1749-6632.1954.tb54850.x
16. Vosshall LB, Hansson BS. A unified nomenclature system for the insect olfactory coreceptor. Chemical Senses. 2011;36(6):497-98. https://doi.org/10.1093/chemse/bjr022
17. Hansson BS, Stensmyr MC. Evolution of insect olfaction. Neuron. 2011;72(5):698-711. https://doi.org/10.1016/j.neuron.2011.11.003
18. Ditzen M, Pellegrino M, Vosshall LB. Insect odourant receptors are molecular targets of the insect repellent DEET. Science. 2008;319 (5871):1838-42. https://doi.org/10.1126/science.1153121
19. Vosshall LB, Stocker RF. Molecular architecture of smell and taste in *Drosophila*. Annual Review of Neuroscience. 2007;30(1):505-33. https://doi.org/10.1146/annurev.neuro.30.051606.094306.
20. Altner H, Prillinger L. Ultrastructure of invertebrate chemo-, thermo- and hygroreceptors and its functional significance. International Review of Cytology. 1980;67:69-139. https://doi.org/10.1016/S0074-7696(08)62427-4
21. Rodrigues V, Siddiqi O. A gustatory mutant of *Drosophila* defective in pyranose receptors. Molecular and General Genetics MGG. 1981;181(3):406-08. https://doi.org/10.1007/BF00425621
22. Zhang YV, Ni J, Montell C. The molecular basis for attractive salt-taste coding in *Drosophila.* Science. 2013;340(6138):1334-38. https://doi.org/10.1126/science.1234133
23. Dimitroulopoulou C, Trantallidi M, Carrer P, Efthimiou G, Bartzis JG. EPHECT II: Exposure assessment to household consumer products. Science of the Total Environment. 2015;536:890-902. https://doi.org/10.1016/j.scitotenv.2015.05.138
24. Chen-Hussey V, Behrens R, Logan JG. Assessment of methods used to determine the safety of the topical insect repellent N, N-diethyl-m-toluamide (DEET). Parasites and Vectors. 2014;7:1-7. https://doi.org/10.1186/1756-3305-7-173
25. Selvaraj KK, Sundaramoorthy G, Ravichandran PK, Girijan GK, Sampath S, Ramaswamy BR, et al. Phthalate esters in water and sediments of the Kaveri River, India: environmental levels and ecotoxicological evaluations. Environmental Geochemistry and Health. 2015;37:83-96. https://doi.org/10.3390/plants11030463.
26. Manikkam M, Tracey R, Guerrero-Bosagna C, Skinner MK. Pesticide and insect repellent mixture (permethrin and DEET) induces epigenetic transgenerational inheritance of disease and sperm epimutations. Reproductive Toxicology. 2012;34(4):708-19. https://doi.org/10.1016/j.reprotox.2012.08.010

27. Benelli G, Murugan K, Panneerselvam C, Madhiyazhagan P, Conti B, Nicoletti M. Old ingredients for a new recipe? neem cake, a low-cost botanical by-product in the fight against mosquito-borne diseases. Parasitology Research. 2015;114:391-97. https://doi.org/10.1007/s00436-014-4286-x

28. Moore SJ, Lenglet A, Hill N. In: Plant-based insect repellents. Insect repellents: principles methods and use. Boca Raton, CRC Press; 2006. p. 276-96

29. Dubey NK. In: Natural products in plant pest management. CABI; 2010 Nov 18:1-279

30. Abd El Ghany AM. In: Plant extracts as effective compounds pest control. Saarbrucken, LAP Lambert Academic Publishing AG and Co KG; 2012

31. Mustapa MA, Guswenrivo I, Zurohtun A, Khairul INK, Muchtaridi M. Analysis of essential oils components from aromatic plants using headspace repellent method against *Aedes aegypti* mosquitoes. Molecules. 2023;28(11):4269. https://doi.org/10.3390/molecules28114269

32. Nerio LS, Olivero-Verbel J, Stashenko E. Repellent activity of essential oils: a review. Bioresource Technology. 2010;101(1):372-78. https://doi.org/10.1016/j.biortech.2009.07.048

33. Zarubova L, Kourimska L, Zouhar M, Novy P, Douda O, Skuhrovec J. Botanical pesticides and their human health safety on the example of *Citrus sinensis* essential oil and *Oulema melanopus* under laboratory conditions. Acta Agriculturae Scandinavica, Section B-Soil and Plant Science. 2015;65(1):89-93. https://doi.org/10.1080/09064710.2014.959556

34. Paluch G, Bartholomay L, Coats J. Mosquito repellents: a review of chemical structure diversity and olfaction. Pest Management Science. 2010;66(9):925-35. https://doi.org/10.1002/ps.1974

35. Yadav NP, Rai VK, Mishra N, Sinha P, Bawankule DU, Pal A, Chanotiya CS. A novel approach for development and characterization of effective mosquito repellent cream formulation containing citronella oil. BioMed Research International. 2014;2014(1):786084.

36. Patole SS. Review on beetles (Coleopteran): an agricultural major crop pests of the world. Inter J Life Sci Res. 2017;3(6):1424-32. https://doi.org/10.21276/ijlssr.2017.3.6.1

37. Suckling D, Conlong D, Carpenter J, Bloem K, Rendon P, Vreysen MJB. Global range expansion of pest *Lepidoptera* requires socially acceptable solutions. Biological Invasions. 2017;19:1107-19. https://doi.org/10.1007/s10530-016-1325-1329

38. Trematerra P, Sciarretta A. Activity of chilli, *Capsicum annuum* L. var. acuminatum, on stored product insects *Oryzaephilus surinamensis* (L.), *Sitophilus oryzae* (L.) and *Tribolium castaneum* (Herbst). IOBC WPRS Bulletin. 2002; 25(3):177-82.

39. Diabaté D, Gnago JA, Tano Y. Toxicity, antifeedant and repellent effect of *Azadirachta indica* (A. Juss) and *Jatropha carcus* L. aqueous extracts against *Plutella xylostella* (Lepidoptera: Plutellidae). Journal of Basic and Applied Scientific Research. 2014;4(11):51-60.

40. Koul O, Singh G, Singh R, Multani J. Bioefficacy and mode-of-action of aglaroxin A from *Aglaia elaeagnoidea* (syn. A. roxburghiana) against *Helicoverpa armigera* and *Spodoptera litura*. Entomologia Experimentalis et Applicate. 2005;114(3):197-204. https://doi.org/10.1111/j.1570-7458.2005.00259.x

41. Susmitha S, Shanthi M, Murugan M, Senthil K, Mini ML. Antifeedant and insecticidal effect of hexane botanical extracts on diamondback moth (DBM), *Plutella xylostella* L. (Lepidoptera: Plutellidae). 2021;108. https://doi.org/10.29321/MAJ.10.000542

42. Sangavi R, Edward YJT. Anti-Insect activities of plant extracts on the diamondback moth, *Plutella xylostella* (L.). 2017;6(12):28-39. https://doi.org/10.20546/ijcmas.2017.612.004.

43. Arivoli S, Tennyson S. Antifeedant activity of leaf extracts against *Spodoptera litura* Fabricius 1775 (Lepidoptera: Noctuidae) highlighting the mechanism of action. Natural and Formal. 2020;20(4): 67-80.

44. Showler AT. Botanically based repellent and insecticidal effects against horn flies and stable flies (Diptera: Muscidae). Journal of Integrated Pest Management. 2017;8(1):15.

45. Dagulo L, Danyluk MD, Spann TM, Valim MF, Goodrich⍰Schneider R, Sims C, Rouseff R. Chemical characterization of orange juice from trees infected with citrus greening (Huanglongbing). Journal of Food Science. 2010;75(2):199-207. https://doi.org/10.1111/j.1750-3841.2009.01495.x

46. Kuhns EH, Martini X, Hoyte A, Stelinski LL. Repellent activity of botanical oils against asian citrus psyllid, *Diaphorina citri* (hemiptera: Liviidae). 2016;7(3):35. https://doi.org/10.3390/insects7030035

47. Emilie D, Mallent M, Menut C, Chandre F, Martin T. Behavioural response of *Bemisia tabaci* (Hemiptera: Aleyrodidae) to 20 plant extracts. 2015;108(4):1890-901. https://doi.org/10.1093/jee/tov118

48. Dardouri T, Gautier H, Ben IR, Costagliola G, Gomez L. Repellence of *Myzus persicae* (Sulzer): evidence of two modes of action of volatiles from selected living aromatic plants. Pest Management Science. 2019;75(6):1571-84. https://doi.org/10.1002/ps.5271

49. Deletre E, Chandre F, Barkman B, Menut C, Martin T. Naturally occurring bioactive compounds from four repellent essential oils against *Bemisia taba*ci whiteflies. Pest Management Science. 2016;72(1):179-89. https://doi.org/10.1002/ps.3987.

50. Li S, Li H, Zhou Q, Zhang F, Desneux N, Wang S, Shi L. Essential oils from two aromatic plants repel the tobacco whitefly *Bemisia tabaci*. Journal of Pest Science. 2022:1-12. https://doi.org/10.1007/s10340-021-01412-0.

51. Lamelas-López L, Marco F. Using camera-trapping to assess grape consumption by vertebrate pests in a World Heritage vineyard region. Journal of Pest Science. 2021;94(2):585-90. https://doi.org/10.1007/s10340-020-01267-x

52. Rao SA, Rao N, Reddy P. Efficacy of non poisonous castor based repellent against wild boar (*Sus scrofa*) in maize crop around Hyderabad. Pestology. 2013;37:26-29.

53. Singla N, Thind RK. Avoidance behaviour of *Rattus rattus* to odours of eucalyptus and citronella oils under maze experiments: *Eucalyptus* and citronella oils as repellents. Annals of Arid Zone. 2023;62(3):267-74.

54. Atterholt C, Delwiche M, Rice R, Krochta JM. Controlled release of insect sex pheromones from paraffin wax and emulsions. Journal of Controlled Release. 1999;57(3):233-47. https://doi.org/10.1016/S0168-3659(98)00119-9

55. Sheikh Z, Amani A, Basseri HR, Kazemi SHM, Sedaghat MM, Azam K, Amirmohammadi F. Repellent efficacy of *Eucalyptus globulus* and *Syzygium aromaticum* essential oils against malaria vector, *Anopheles stephensi* (diptera: Culicidae). Iranian Journal of Public Health. 2021;50(8):1668. https://doi.org/10.18502/ijph.v50i8.6813

56. Reddy VR. Bird damage to maize crop on the student's research farm at Rajendranagar, Hyderabad, Andhra Pradesh. The Indian Journal of Ornithology. 1998;36(1-2):77-78.

57. Reddy R, Sunitha V, Rajashekhar M, Aruna SI, Baja N, Venkateswarlu P. Reduction of rose-ringed parakeet (*Psittacula krameri*) damage in sunflower crop in Telangana. Agri Assoc Textile Chem Crit Rev J. 2022:6-10.

58. Nkechi EF, Ejike OG, Ihuoma NJ, Maria-goretti OC, Francis U, Godwin N, Njokuocha R. Effects of aqueous and oil leaf extracts of *Pterocarpus santalinoides* on the maize weevil, *Sitophilus zeamais* pest of stored maize grains. African J Agri Res. 2018;13(13):617-26. https://doi.org/10.5897/ajar2018.13014

59. Babaousmail M, Idder MA, Kemassi A. First attempts to repel scale insects using plant extracts: effect on the date palm scale *Parlatoria*

blanchardi Targ.(Hemiptera: Diaspididae). World Journal of Environmental Biosciences. 2018;7(4-2018):59-63.

60. BCC Research. Insect repellent: the global market to 2023 BCC Online; 2019 [Internet]. Available from: https://www.bccresearch.com/market-research/chemicals/insect-repellent-the-global-market.html

61. Grand View Research. Insect repellent market size, Share and rrowth report . Grand View Research Online; 2022 [Internet]. Available from: https://www.grandviewresearch.com/industry-analysis/insect-repellent-market

62. Kumar G, Ojha VP, Pasi S. Applicability of attractive toxic sugar baits as a mosquito vector control tool in the context of India: a review. A Review Pest Management Science. 2021;77(6):2626-34. https://doi.org/10.1002/ps.6226

63. Souto AL, Sylvestre M, Tölke ED, Tavares JF, Barbosa-Filho JM, Cebrián-Torrejón G. Plant-derived pesticides as an alternative to pest management and sustainable agricultural production: prospects, applications and challenges. Molecules. 2021;26 (16):4835. https://doi.org/10.3390/molecules26164835

64. Angioni A, Dedola F, Minelli EV, Barra A, Cabras P, Caboni P. Residues and half-life times of pyrethrins on peaches after field treatments. Journal of Agricultural and Food Chemistry. 2005;53 (10):4059-63. https://doi.org/10.1021/jf0477999

65. Rashmi J, Neeta G. Repellent activity of essential oil from tulsi plant against lesser grain borer, *Rhyzopertha dominica* (Fabricius) (Coleoptera: Bostrichidae) and red rust flour beetle, *Tribolium castaneum* Herbst,(Coleoptera: Tenebronidae). Inter J Curr Microbiol Appli Sci. 2018;7(2):157-60. https://doi.org/10.20546/ijcmas.2018.702.020

66. Togni PH, Laumann RA, Medeiros MA, Sujii ER. Odour masking of tomato volatiles by coriander volatiles in host plant selection of *Bemisia tabaci* biotype B. Entomologia Experimentalis et Applicata. 2010;136(2):164-73. https://doi.org/10.1111/j.1570-7458.2010.01010.x

67. Othman ASAN, Latip SNHM, editors. Antifeedant activity of *Peltophorum pterocarpum* DC. and *Ipomoea aquatica* Forssk. extracts as botanical pesticides against *Pomacea canaliculata* Lamarck. IOP Conference Series: Earth and Environmental Science. IOP Publishing. 2021;685:1. https://doi.org/10.1088/1755-1315/685/1/012028.

68. Smith HA, McSorley R. Potential of field corn as a barrier crop and eggplant as a trap crop for management of *Bemisia argentifolii* Gennadius. (Homoptera: Aleyrodidae) on common bean in North Florida. Florida Entomologist. 2000:145.

69. Perera A, Karunaratne M, Chinthaka S. Bioactivity and volatile profiling of *Azadirachta indica* A.Juss. leaves for the management of maize weevil, *Sitophilus zeamais* (Motsch.) infestations. Journal of Tropical Forestry and Environment. 2018;8:10-24. https://doi.org/10.31357/jtfe.v8i1.3479

70. Rajput LB, Memon SA, Dhiloo KH, Khaskheli NZ, Bhatti QUA, Gilal AA. Repellent potential of medicinal oils against *Tribolium castaneum* (Herbst) under laboratory conditions. Abasyn Journal of Life Sciences. 2021;4(2):7-15.

71. Swamy S, Raja DS. Use of black pepper and clove against pulse beetle *Callosobruchus maculatus* (F.) in green gram. Indian Journal of Entomology. 2018;80(4):1291-95.

72. Saad KA, Roff MM, Idris AB. Toxic, repellent and deterrent effects of citronella essential oil on *Bemisia tabaci* (*Gennadius.)* (Hemiptera: Aleyrodidae) on chili plants. Journal of Entomological Science. 2017;52(2):119-30. https://doi.org/10.18474/JES16-32.1

73. Swamy G, Wesley BJ. Bio efficacy of some botanicals as grain protectants against *Callosobruchus maculatus* (F.) infesting stored blackgram. Swamy. 2017;44(6):663-66.

74. Stefanazzi N, Stadler T, Ferrero A. Composition and toxic, repellent and feeding deterrent activity of essential oils against the stored-grain pests *Tribolium castaneum* Herbst. (Coleoptera: Tenebrionidae) and *Sitophilus oryzae* L. (Coleoptera: Curculionidae). 2011;67(6):639-46. https://doi.org/10.1002/ps.2102

75. Rahdari T, Hamzei M. Repellency effect of essential oils of *Mentha piperita* L., *Rosmarinus officinalis* Spenn. and *Coriandrum sativum* L. on *Tribolium confusum* Jacquelin du Val. (Coleoptera: Tenebrionidae). Chemistry Research Journal. 2017;2:107-12.

76. Zhang WJ, Zhang Z, Chen ZY, Liang JY, Geng ZF, Guo SS, Deng ZW. Chemical composition of essential oils from six *Zanthoxylum* species and their repellent activities against two stored-product insects. Journal of Chemistry. 2017;2017:1-7. https://doi.org/10.1155/2017/1287362

77. Wang Y, You C, Yang K, Wu Y, Chen R, Zhang W, Han J. Bioactivity of essential oil of *Zingiber purpureum* Roscoe. rhizomes and its main compounds against two stored product insects. Journal of Economic Entomology. 2015;108(3):925-32.

78. Madavi PN, Sadawarte A, Undirwade D, Moharil M, Satpute NS. Repellent impact of botanicals against store grain pests pulse beetle (*Callosobruchus chinensis* L.). Journal of Pharmaceutical Innovation. 2022;11:1823-25.

79. Andy EO, Edema AJ. Antifeedant potential of some aromatic plants against cowpea weevil, *callosobruchus maculates* F. World Journal of Agriculture and Soil Science. 2019;2:1-4. https//doi.org/ 10.33552/WJASS.2019.02.000546

80. Rajkumar V, Gunasekaran C, Christy IK, Dharmaraj J, Chinnaraj P, Paul CA. Toxicity, antifeedant and biochemical efficacy of *Mentha piperita* L. essential oil and their major constituents against stored grain pest. Pesticide Biochemistry and Physiology. 2019;156:138-44. https://doi.org/10.1016/j.pestbp.2019.02.016

81. Punam N, Madavi1 AK, Sadawarte DB, Undirwade MP, Moharil NS, Satpute. Insecticidal and repellent effect of botanicals against red flour beetle *Tribolium castaneum* Herbst. Pest of Stored Grains Biological Forum - An International Journal. 2022;14:134-37.

82. Susilo A, Haryanta D, Sa'adah TT. Repellent activity of bintaro leaf extract (*Cerbera manghas* L.) against *Spodoptera litura* L. Systematic Reviews in Pharmacy. 2020;11(5). https://doi.org/10.31838/srp.2020.5.30

83. Prasoona US, Kolhe A, Tathode V, Tidke VN. Antifeedant activity of some botanicals against *Spodoptera frugiperda* (JE Smith) under laboratory condition. Pharma Innov J. 2022;11:101-04.

84. Ragesh PR, Bhutia TN, Ganta S, Singh AK. Repellent, antifeedant and toxic effects of *Ageratum conyzoides* (Linnaeus)(Asteraceae) extract against *Helicovepra armigera* (Hübner) (Lepidoptera: Noctuidae). Archives of Phytopathology and Plant Protection. 2016;49(1-4):19-30. https://doi.org/10.1080/03235408.2016.1147123

85. Chauhan N, Malik A, Sharma S. Repellency potential of essential oils against housefly, *Musca domestica* L. Environmental Science and Pollution Research. 2018;25:4707-14. https://doi.org/10.1007/s11356-017-0363-x

86. Nisar MS, Ismail MA, Ramzan H, Maqbool MM, Ahmad T, Ghramh HA, Farooq S. The impact of different plant extracts on biological parameters of housefly [*Musca domestica* (Diptera: Muscidae)]: implications for management. . Saudi J Biol Sci. 2021;28(7):3880-85. https://doi.org/10.1016/j.sjbs.2021.03.070

87. Hidayatulfathi O, Shamsuddin A, Rajab N, Nor Zafirah A, Nur Hazwani A, Nur Afriza MFO, Nor Azwani MN. Three repellent gels that contain essential oils from local malaysian plants against dengue vector. Tropical Biomedicine. 2017;34(3):540-649.

88. Ilyas A, Khan HAA, Qadir A. Effect of leaf extracts of some indigenous plants on settling and oviposition responses of peach fruit fly, *Bactrocera zonata* Saunders. (Diptera: Tephritidae). Pakistan Journal of Zoology. 2017;49(5). http//doi.org/10.17582/journal.pjz/2017.49.5.1547.1553