

Use of plant-derived products to control household and structural arthropod pests

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Abstract

Plant extracts in water or chemical solvents; crude oil, essential oils and other allelochemicals of several plant species were tested at the laboratory as contact poison and/or fumigant. Most of them acted as repellent to insects and mites. Toxicity effect was dose-dependent and varied as per plant species and organism tested. In some instances, plant-derived products causing mortality were less effective than synthetic pesticides. However, considering possible environmental contamination of synthetics and the eventual toxicity to non-target organisms, plant-derived products against household and structural pests have been recommended by researchers. The major pest species with mode of actions of plant products and integrated strategies for effective, practical and ecofriendly pest control are discussed throughout this review.

Keywords: Allelochemicals; Insects; Mites; Plant Extracts; Mode of Action; Household and Structural Pests.

1. Introduction

Household insect pests are important in dwellings, particularly in urban areas [1]. Currently, these insects are controlled mostly by sprays and aerosols containing chemical insecticides such as, abamectin, fipronil, indoxacarb, imidacloprid, chlorpyrifos, propoxur and chlorfenapyr. Other formulations found in the market include gel, powder, dust, paste and pellets. Structural pests are controlled with oil paints or coating of pesticides at very low concentrations. Few commercial products with low toxic contents have also been promoted by private companies such as, killer bait gel of hydramethylnon (2.15%) used in sticky traps [2]. Generally, the chemical application in residences can be quite hazardous to human health due to contact toxicity, fumigant action and environmental pollution. Therefore, consumer's preference paradigm is nowadays shifting from toxic chemicals to natural products. Nevertheless, fewer toxic chemicals such as, pyrethrins, silica gel, boric acid and hydramethylnon have been generally recommended for quick effects,

Concerning effectiveness, most of the chemicals do not provide long-term control of certain pests. For example, cockroaches taste food before eating and avoid chemically-treated products. In perspective, alternative measures have therefore been developed and applied with varied degrees of control. Baiting and trapping are successful only on a limited scale because if dust in baits gets wet and then dries and cakes, it loses its electrostatic charge and may not be picked up readily by insects. Pheromone traps can facilitate monitoring the presence and incidence, particularly in hiding sites, of the pest species. Essential oils (EOs) as green pesticides being effective and economically profitable could be used against household and structural pests [3-5]. The common EOs experimented in laboratory are shown in Table 1. As such, it is often advised to restrict to biodegradable, residue-free pesticides that are safe for applicators and residents alike. Currently, published information on chemical-free treatments is limited and not easily

available. To fill in this gap, I have compiled literature (2000-2016) and discussed in this review, the use of plant-derived products against important household and structural insect and mite pests with perspective of choice for potential products.

Table 1: Essential Oils Used Against Household and Structural Pests in Laboratory

| Essential oil | Pest species | Essential oil used as | Mode of action | Reference |
|----------------|--------------------------------|-----------------------|----------------|-----------|
| Citral | <i>Periplaneta americana</i> | CON, FUM | IN, RE | [6] |
| Eugenol | <i>P. americana</i> | CON | IN, RE | [6] |
| | <i>Optotermes formosanus</i> | CON, FUM | AF, IN | [26] |
| | <i>Solenopsis invicta</i> | CON | RE | [65] |
| Geranol | <i>P. americana</i> | CON, FUM | IN, RE | [6] |
| Limonene | <i>P. americana</i> | CON | RE | [7] |
| | <i>C. formosanus</i> | CON, FUM | IN | [41] |
| Methyl eugenol | <i>Dermatophagoides furvus</i> | CON | AC | [71] |

AC= acaricide, AF= antifeedant, CON= contact pesticide, FUM= fumigant, IN= insecticidal, RE= repellent.

2. Control of insects and mites

2.1. Cockroaches (Blattodea)

2.1.1. American cockroach

In control of American cockroach, *Periplaneta americana* L. (Blattidae), mint/mentha (*Mentha spicata* L.) oil containing terpenoids, terpenes and phenols (especially, citral, citronellal, gernaniol and eugenol) exerted both repellent and insecticidal activities through fumigant and contact actions when applied to paper at 250 g oil/g [6]. Citrus (*Citrus reticulata* Blanco) oil containing limonene repelled adults up to 98%. However, when it was mixed at 10% with soybean oil, repellency was reduced to 86% [7]. It means soybean oil can act as antagonist. Both oils were toxic

to oothecae with 96.7% egg mortality when mixed with onion (*Allium cepa* L.) 5% extract in water [8]. In another experiment, 10% clove oil exhibited 90% and 100% repellency against nymphs and adults, respectively [9]. When used as fumigant at 7.5 ul/l, 10 ul/l and 8.2 ul/l of air against first instar nymphs, fourth instar nymphs and adults, respectively, it resulted in 100% mortality [10]. Clove oil has also been found stronger surface contact toxic with LC₅₀ of 0.0001-0.0077 ul/cm² than rosemary (*Rosmarinus officinalis* L.) oil with LC₅₀ of 1.92-2.25 ul/cm². In this experiment, first instar nymphs were more sensitive than the fourth instar nymphs followed by adults. Consequently, LT₅₀ values in continuous exposure test correlated negatively with concentration [11].

A dose of 10,000-80,000 ppm (1-8%) of essential oil of *Piper aduncum* L. deterred only nymphs [12] whereas oil of *C. citratus* gave 100% repellency to adults after 24 h of application [13]. Among three local plants from Thailand (clove, lemon grass and *Cymbopogon nardus* (L.) Rendle), essential oils extracted from lemon grass in ethyl alcohol and mixed in soybean oil gave 100% repellency, and this mixture had been recommended as contact poison by Sittichok *et al.* [9]. Insect growth regulatory (IGR) effects were observed with Azadirachtin (AZ, a limonoid from neem) and two other allelochemicals, e.g. quassin (a triterpenoid from *Quassia amara* (L.), and cinnamaldehyde (an organic compound from *Cinnamomum cassia* [Nees & Nees] Presl.). These studies demonstrated that physiological effects of these allelochemicals do not ease the primary insecticidal actions [14]. Mode of action of these two products however needs further studies as they can rather act as repellent only. Conclusively, crude oil (lemon grass, citrus or clove) or essential oils when mixed with vegetable oil (sesame or soybean) were more effective than when used alone. To be cost-effective, water extract (5%) should be recommended as it is easy to prepare and apply to structures and places where cockroaches take shelter.

2.1.2. German cockroach

Against the German cockroach, *Blattella germanica* (L.) (Blattellidae), nearly 80% repellency of acetone extract of catnip (*Nepeta concolor* Boiss. & Heldr. ex Benth.) at 900 ug/cm² [15] or osage orange [*Maclura pomifera* (Raf.) Schneid] at 157 ug/cm² [16] was demonstrated. Ethanol and petroleum ether extract of leaves or fruits of the American pepper (*Schinus molle* L.) when applied topically, adults were not only repelled but later, they were killed [17]. Likewise, crude aqueous extract or acetone extract of pandan leaves initially attracted nymphs but later the repellency was as high as 93% due to musky odor emitted by aromatic compound 2-acetyl-1-pyrroline present in leaves [18].

Sittichok *et al.* [19] tested EO of eight plants at 0.24 ul/cm² of filter paper and noted knock-down effect an hour after treatment and complete mortality after 24 h. The most effective oil was extracted from mint (*Mentha piperita* L.) with LT₅₀ values of 4.17 h. On the contrary, essential oils from *Myristica fragrans* Houtt. Seeds exerted fumigant action resulting in 35-72% mortality [20]. Thus, both adults and nymphs were effectively controlled with EO (1,8-cineole) which was significantly better in bioefficacy than other 11 essential oils. However, any of the EO tested did not prevent hatching of oothecae. Consequently, multiple applications have been recommended in order to eliminate recurrent infestations [21]. Among hundred plants from family Myrtaceae tested for toxicity, EOs of six species of *Eucalyptus* and *Melaleuca uncinata* Br. exhibited strong fumigant action with 100% mortality in male adults whereas EO of five species of genus *Eucalyptus*, *M. uncinata* and *Melaleuca dissitiflora* Muell., were toxic to both male and female adults. Also, an acetylcholinesterase inhibitory activity with LC₅₀ value of 0.22 mg/ml was reported with isoeugenol [22]. Likewise, essential oil of *Eucalyptus robusta* Sm. or *Illicium verum* Hook. leaves, both applied at 5 ppm, and nut grass (*Cyperus rotundus* L.) at 1 ppm repelled nymphs. On the contrary, essential oils of *I. verum* and *Lindera aggregata* (Sims) Kosterm. were found attractive at 1 ppm [23]. Essential oils extracted from osage orange

fruit (raw/ripe) acted as repellent because of content of two isoflavones (osajin, pomiferin), seven ses-terpenoids (elemol/hedycaryol, alpha-copaene, alpha-cubebene, beta-elemene, beta-carpophyllene, alpha-ylangene/valencene, (Z, E)-farnesol) and a green volatile compound (hexyl hexanoate) [24]. In a test of five plants [*Allium sativum* L., *Thymus vulgaris* (L.), *Oregano dubium* (L.), onion and rosemary], only EO from *A. sativum* at 5 ul/l air caused 95% mortality within 48 h [25]. All oils besides their strong repellent action, were toxic and exerted IGR effects resulting in pest mortality.

Contact toxicity of (E)-anethole isolated from *I. verum* fruit was evident to 80% mortality in adults caused at the dose of 0.159 mg/cm² on the first day-after application. It also acted as a fumigant causing 100% mortality at 0.398 mg/cm² making this treatment more effective up to 3 d compared to 2 d for deltamethrin [26]. A monoterpene allyl isothiocyanate isolated from horse-radish (*Armoracia rusticana* Gaertn., Mey. & Schreb.) exhibited fumigant action resulting in 100% mortality at a dose of 2.5 ul/l of air within 18 h whereas other monoterpenoids (eugenol, carvacrol, citronella) did not affect pest survival [25]. Unfortunately, these studies were not continued to know the physiological changes that may take place in insect body.

In topical application of 12 essential oils applied at a dose of 0.04-0.06 mg/insect, thymol was found most toxic to adult males, gravid females and medium nymphs with LD₅₀ values of 0.07, 0.12 and 0.06 mg/cockroach, respectively. On the contrary, trans-cinnamaldehyde was the most toxic component to adult females, and small and large nymphs. In another dose-dependent assay, (-) menthone had the greatest effect on hatching of oothecae with 20.89 nymphs/ootheca compared to 35.21 nymphs/ootheca in control [27]. In overall performance, not a single essential oil completely prevented hatching. In an assay on nut grass rhizome steam distillate constituents and related compounds against female adults, they were effective in closed but not in open containers. Using video-tracking system, Alzogaray *et al.* [28] observed that monoterpenes at 70 ug/cm² produced repellent action but were less effective than N,N-dimethyl-3-methylbenzamide indicating its low bioefficacy. Therefore, essential oils with contact and fumigant activity, particularly, against insecticide-resistant strains, could be recommended to reduce highly toxic synthetic pesticides in indoor environments [29].

As a practical solution, following measures were effective against cockroaches. For example, raw or stewed okra fruits placed under water sink attract cockroaches that can be killed with chemicals. Likewise, bait containing a mixture of citrus pulp + brown sugar + corn meal + boric acid is effective in "attract and kill technique" [30]. Four plants (5% extract in water) from Nigeria, viz. neem (*Azadirachta indica* A. Juss.), *Parquetina nigrescens* (Afzel) Bullock, *Zanthoxylum zanthoxyloides* (Lam.) and clove, were tested as powder mixed with biscuit at 25-100%. Feeding on biscuits (1.5 g/6 adults) resulted in 85-100% mortality in 2 d in *P. americana* adults. [31]. Similarly, Stauffer [30] suggested spraying of rosemary or eucalyptus oil at a conc. of 18 ml/l or spreading crushed leaves of laurel/sweet bay (*Laurus nobilis* L.) on floor surface, to repel cockroaches by strong odor. Application of EOs (20%) derived from kaffir lime, *Citrus hystrix* DC. exhibited cent per cent repellency against both American and German cockroaches resulting in up to 86% reduction in pest populations in residences in Thailand [32]. Recently, potassium alum has been used as controlling agent against *P. americana* in the laboratory [33]. Nymphs and adults died (100% mortality) 4-d and 1-mo respectively, after consuming alum (nymphs 0.3 mg, adult male 1 mg, adult female 2.7 mg). Gravid females are highly susceptible. Alum is cheap and available locally, even in villages, and can be suggested for its use as curative measure.

2.1.3. Asian cockroach

Adult populations of the Asian or flying cockroach *Blattella asahinai* Mizukubo (Blattellidae) were reduced up to 68% at 7 d after treatment with essential oil-based emulsifiable concentrate

(EC) formulation, but control diminished to only 2% by 30 d whereas beta cyfluthrin EC or fipronil granules killed cent per cent pest population at 7d or 30 d, respectively in the USA [34]. In a comparison of five mulches, there was little preference of *B. asahinai* to cypress (*Taxodium distichum* (L.) Rich. Therefore, cypress mulch around home may help to reduce pest populations and limit insecticide exposure to humans and animals [35].

2.1.4. Implications for cockroach management

Essential oils, plant extracts in water or chemical, and crude oil when used through oral, topical or vapor routes, were found less effective than synthetic pesticides as contact poison and/or fumigant. Thus, for an alternative to chemicals, a combination of sanitation with traps or granular baits seems to be effective and economic and may be recommended for practical application in residences. All compounds extracted from plants gave reasonable control but in most of the cases, comparative mortality was not studied. Further, plant products, particularly water extracts are easy to prepare, cheap due to round the year-availability of local plant material, and should be recommended in place of two common insecticides (dichlorvos, deltamethrin). Use of alum needs further investigation for side effects. In all treatments, early instar nymphs would be targeted for effective control.

2.2. Termites (Isoptera)

2.2.1. Formosan subterranean termite

Among chemicals, an IGR hexaflumuron (550-900 mg in bait tubes) [36] or a semisynthetic agent avermectin (3% dust) (20-30 g in monitor devices) [37] eliminated completely the termites from the infesting sites. When 32 extracts, each at 2000 ppm (0.2%) in hexane, ethyl acetate, acetone or methanol of leaves of eight plant species were compared for the control of Formosan subterranean termite (*Coptotermes formosanus* Shiraki) (Rhinotermitidae), highest mortality of 90% was achieved 24 h after treatment with hexane extracts of *Aristolochia bracteolata* Lam., ethyl acetate extracts of *Andrographis paniculata* (Burm. f.) Wall. ex Nees, *Datura metel* L. and *Eclipta prostrata* (L.) or methanol extract of *Andrographis lineata* Nees and *D. metel* [38]. Among leaf extracts and extract derivatives of a Taiwanese plant, *Calocedrus macrolepis* var. *formosana* (Florin) Florin, only T-muurolol caused 100% mortality at 5 mg/g wood after 14 d with LC₅₀ value of 27.6 mg/g [39].

Blaske and Horst [40] studied repellent action by orientation and avoidance behavior, and toxic effects by contact and fumigation actions of plant extracts. In no-choice test, pest mortality did not occur but termites were effectively prevented from penetrating treated soil. The eucalyptus (*Eucalyptus camaldulensis* Dehnh.) leaf oil exhibited both contact and fumigant actions with LC₅₀ value of 12.68-17.50 mg/g. Oil extracted from citrus peel (containing 92% d-limonene) applied at 0.4% caused 96% mortality within 5 days [41]. Similarly, catnip oil (containing E-Z-nepetalactone and Z, E-nepetalactone) at 40 mg/cm² caused 100% mortality one day after application. At a lower dose of 20 mg/cm² of E-Z-nepetalactone, only repellent activity was observed [42]. These examples showed that higher doses of oil are needed for effective pest control.

Essential oils (cedrol, L-cardinol) isolated from heartwood of a Taiwanese plant (*Taiwana cryptomerioides* Hayata) exhibited a maximum antitermitic activity with 100% mortality at a dose of 10 mg/g wood [43]. Between 100 essential oils, each applied at 10 mg/g wood, those extracted from three coniferous plants [e.g. *C. m. formosana*, *Cryptomeria japonica* (Thunberg) Don, and *Chamaecyparis obtusa* var. *formosana* (Hayata)], acted as repellent and gave the cent per cent mortality after 5 d of application. The best treatment was EOs of *C. m. formosana* with LC₅₀ value of 2.6 mg/g [44]. From eight essential oils, clove oil at 50 ug/cm² were most toxic whereas the oil extracted from vetiver, *Chrysopogon zizanioides* (L.) Roberty acted as repellent only at 5ug/g sand, and prevented tunneling at a higher dose of 25ug/g sand [45]. Thus,

essential oils repelled insects just after application and were toxic in a few days later.

Two phytochemicals (β-cymene and terpinene) derived from eucalyptus leaf oil, showed both contact and fumigant actions whereas 1, 8-cineole acted only as fumigant [46] whereas cinnamaldehyde extracted from *Cinnamomum osmophloeum* Kaneh. showed comparatively strongest toxicity at 1 mg/g wood; eugenol and L-terpineol being least effective at the same dose [26]. Boue and Raina [47] studied the effects of oral feeding and topical application on the fecundity, mortality and food consumption in relation to flavonoids of five plants. In these tests, apigenin and biochanin-A fed at 50 ug per reproductive pair proved most toxic. Further, both compounds at 100 ug reduced fecundity and biochanin-A did not elicit phagostimulant activity for adult termites [47]. Mao and Henderson [48] reported antifeedant activity and acute and residual toxicity of alkaloids (matrine and oxymatrine) extracted from *Sophora flavescens* Ait. With filter paper consumption bioassay, Fokialakis *et al.* [49] reported that eight thiophenes isolated from five species of genus *Echinops* gave 100% mortality within 9 d when applied at 2% conc. These findings showed superiority of essential oils over extracts and crude oil.

2.2.2. Eastern subterranean termite

Chloroform extracts of dry leaves of *Lantana camara* L. Applied at 0.016 mg/cm² of filter paper or 0.125 mg/g of sand, exhibited excellent repellent, moderate toxic and antifeedant activities against the Eastern subterranean termite, *Reticulitermes flavipes* (Kollar) (Rhinotermitidae). Higher dose at 0.212 mg/cm² on filter paper resulted in >90% mortality and up to 78% reduction in feeding whereas topical application (4 ug/termite) resulted in a maximum of 60% mortality. Thus, filter paper treatment showed superiority over other methods [50]. More trials may be necessary for practical application in houses. The eastern red cedar (*Juniperus virginiana* L.) oil extracted from heart wood, and ethanol extracts of needles proved lethal and prevented termites from damaging wood [51]. Heartwood was more resistant than sapwood due to presence of essential oils and other allelochemicals. Therefore, there was less pest infestation ((2.1-6.1% versus 44.6%) and termite survival (<24% versus >84%) in cedar wood than in susceptible pine wood [52].

2.2.3. Building termite

Leaf extracts (5%) of *L. camara* in chloroform gave up to 68% mortality 48 h after application of the building termite, *Microcerotermes beasoni* Snyder (Termitidae), and extract of *Ageratum conyzoides* L. leaves in petroleum ether or hexane showed 67% repellency [53]. Further, Kaur and Rawat [54] evaluated extracts in water or chemicals of leaves of six plants, seeds of two plants and root of one plant and finally. They recommended the leaf extracts (0.1%) in petroleum ether of *L. camara*; ethanol extracts (0.1%) of *Murraya keonigii* (L.) Spreng. Or methanol extract (0.1%) of cassia, *Senna (Cassia) occidentalis* (L.) Link. These treatments caused 100% pest mortality within 24 h of application. Similarly, essential oil extracted from *M. fragrans* gave 100% mortality 14 d after treatment at a dose of 5 mg/g wood with LC₅₀ of 28.6 mg/g [55]. Extract in water is comparatively cheaper than chemicals and easy to prepare with readily available local materials. For example, *L. camara* is a weed abundantly found in village surroundings, fallow lands, field bunds and roadside, its extract may therefore be suggested.

In India, Lakshmanan [56] found potential in controlling building termite by spraying water extract (>10%) of *Euphorbia clavarioides* Boiss. var. *truncata* (N.E.Br.) White, Dyer & Sloane, *Aloe lateritia* var. *germinicola* (Reynolds), *Melia azedarach* L., *Lippia javanica* (Burm. f.) Spreng or *Ocimum sanctum* L., and neem oil (NO) mixed in kerosene. Moreover, 20% crude oil of jatropha (*Jatropha curcas* L.) reduced greater weight loss in treated wood (18.8-48.8% compared to oil fractions with 10.5-35.2% loss) or untreated wood (50.8% loss) [57].

2.2.4. Asian subterranean termite

Defatted NO at 7.5% was better than AZ (91% purity) as antifeedant, oviposition deterrent, IGR or contact poison against the Asian subterranean termite, *Coptotermes gestroi* Wasmann (Rhinotermitidae) [58]. Bark powder extracts in ethyl acetate of *Rhizophora apiculata* Blume showed toxic activity due to presence of aromatic carboxylic acids and phenols [59].

2.2.5. Egyptian subterranean termite

In the Middle East, the Egyptian subterranean termite, *Anacanthotermes ochraceus* (Burm.) (Hodotermitidae) was managed by spraying wooden structures with an aqueous extract of four Saharan toxic plants but only (Willd.) Ait. extract in water resulted in a significantly higher pest mortality (maximum of 50%) than with other plants (*Hyoscyamus muticus* L., *Pergularia tomentosa* and *Datura stramonium* L.) [60]. Comparatively, imported wood was resistant to pest attack. Therefore, isolation and characterization of allelochemicals and their use as repellent or antifeedant may lead to improvement in current pest control [61].

2.2.6. Implications for termite management

Subterranean termites are a problem in developing, and less-developed countries where houses are constructed with local material (bamboo, plant stalks, crop residue). Considering easy availability of commercial products in the market, crude oil of neem, jatropha, eucalyptus and jatropha can be a suitable remedy. For example, water extracts (especially of neem and lantana), crude oil and essential oils were found effective against majority of termite species in India [62]. Most of these products showed various modes of action such as, antifeedant, repellent, IGR and toxic. New plant-derived products include coconut shell oil. Its coating reduced termite infestation from 100% in untreated wood to 34.2% in treated wood, and protected wood up to 18 mon [63]. Furthermore, pine (*Pinus* sp.) resin derivatives (diterpene acids) helped to reduce termite damage [64]. Thus, coconut shell oil and resin can be effectively used as protectant (preventive coating) against termites. After evaluating marketed formulations and crude preparations, preference should be given to products based on the indigenous plant species which are readily available in plenty.

2.3. Ants (Hymenoptera)

Not much research has been undertaken on ant control since they are easily managed by boric acid, silica aerogel, aerosol sprays, and diatomaceous dusts or NO sprays. In the digging bioassay, Chen [65] observed that a commercial product containing essential oil when applied to sand at 100 mg/kg, it was repellent to adults of the red imported fire ant, *Solenopsis invicta* Buren (Formicidae). Among compounds tested by Chen [65], eugenol, menthol and methyl salicylate were significantly more effective than camphor and eucalyptol (all applied at 10 mg/kg of sand). These essential oils may be further studied for sand application to prevent ant entry into house premises and can be considered as preventive measure.

2.4. Silverfish (Thysanura)

In the laboratory, essential oils of *Cryptomeria japonica* D. Don leaves (containing eugenol, 16-kaurene, 3-carene and other compounds) exhibited 80% repellency to common silverfish or fish moth, *Lepisma saccharina* Linn. (Lepismidae), at a dose of 0.01 mg/cm² and 100% mortality at 0.16 mg/cm² within 10 h of application [66]. In residences, essential oils (myrtenol, myrtenal, alpha-pinene) extracted from the Formosan cypress plant, *Chamaecyparis formosensis* Matsum sprayed in the air at 0.16 mg/cm³ space completely killed the pest within 8 h of application [67]. Sprays of EO on surface or in air would be appropriate for effective pest control.

2.5. Psocids (Psocoptera)

Essential oil of *Cupressus funebris* Endl. or *Eucalyptus citriodora* at low dose of 10 ppm showed repellent effect to common psocid or book lice, *Liposcelis bostrychophila* Badonnet (Liposcelidae) and was toxic when used at high dose of 20 ppm for fumigation. Action was enhanced significantly when EO were combined with 12% CO₂ + 9% O₂ or balanced N₂ [68]. Between 28 compounds of essential oil extracted from *Kaempferia galanga*, only trans-cinnamaldehyde exerted contact, fumigant and repellent actions [69]. Extraction of essential oils is costly, crude oils may therefore be tested at least for repellency.

Wheat germ and wheat germ oil attract psocids which could be killed with chemical pesticides [70]. This is a practical solution to pest infestation problem in residences and can be recommended while taking proper precautions for pesticide application.

2.6. House dust mites (Acarina)

Acaricidal activity of oil extracted from the clove buds [71], neem or lemon grass [72] has been reported. According to Kim et al. [71], the most effective constituent for contact toxicity is methyl eugenol at a dose of 0.94 ug/cm² and 0.67 ug/cm² against the European house dust mite *Dermatophagoides farina* Huges (Pyroglyphidae) and the American house dust mite, *Dermatophagoides pteronyssinus* (Trouessart) (Pyroglyphidae), respectively. Application of eugenol, acetyl eugenol, isoeugenol or methyl eugenol was effective as fumigant against both mite species and resulted in higher pest mortality than chemical DEET at 17.85 ug/cm² [71]. Traditionally, eucalyptus oil is used to prevent pest infestation. More research is needed to verify bioefficacy of allelochemicals.

3. Looking ahead

!1) Salehzadela and Mahjub [73] reported antagonistic effect of AZ mixed with pyrethroids (0.5% cyfluthrin 10WP or 0.1% permethrin 25WP) against German cockroach. This is possible since these products belong to different groups of pesticides with different modes of action. Further, antagonistic effect might be due to competition for same site or some conformational changes in target sites or receptors. Extensive studies are therefore needed to confirm these findings to include in pest management strategy. Research on structure activity relationship would reveal why some essential oils are toxic and other are not toxic. Similarly, laboratory findings are to be put in practice for effective pest control by undertaking extension activity.

(2) Regulation to harmonize the overall arrangement for authorization of plant products differs in each country and the legislation for execution of rules is under different ministries. Generally, the list of active substances is regularly published by the competent authority. Also, bulletins and gazettes are available with international organizations [74]. In fewer developed and developing countries, standardizations for the content of active ingredients in crude extracts or commercial products are not often followed probably because laboratory facilities are inadequate or non-existing, and procedure is expensive [75]. This aspect is important as the content varies considerably as per ago-climatic zones, collection and processing of raw material and methods of extraction [76]. For marketing, similar official procedure is imposed for registration and for granting license for synthetic pesticides and plant products. Plant products are labelled with green sign or category IV of the pesticides. Therefore, information provided in this paper is essentially scientific or technical in nature and cannot be used without complying current regulations and respecting procedure for any treatment in houses.

(3) Operators sometimes mix locally available products as synergists or adjuvants (particularly kerosene, medicinal herbs) in spray tank and apply against pests and unregistered plant products are used illegally and their use results in partial pest control [75]. Not wearing of protective clothing is another reason for chronic exposure to plant products. Information on category of toxicity, expiry date, antidotes in case of accidental poisoning etc. is clearly

given on the container label and product leaflet [77]. Whenever sprays containing essential oils are used, inhalation can be problematic for human health. Precautions should therefore be advocated during such applications in houses or surroundings. Otherwise, accidental poisoning occurs particularly when operators are not well trained or not fully aware of operations to be carried out. For example, ingestion of unrefined NO [78], purified terpenoid constituents of essential oil [3] or AZ [79] can cause moderate poisoning or mammalian toxicity. Human and animal studies showed that unprocessed material (seed oil, aqueous extracts) are less toxic than non-aqueous extracts and can be applied inside residences with proper care [80]. Essential oils gave promising results but ready-to-use formulations are needed to make them easily available to applicators.

(4) Since NO is commonly used in medical and cosmetic products, it is stored inside houses where hand to mouth exposure can pose health problems. In fact, NO is likely to be carcinogenic and causes toxic encephalopathy [81]. On the contrary, cold-pressed neem oil (CPNO) is comparatively safe to humans, predators and parasitoids of insects, honey bees and other pollinators except it is slightly toxic to aquatic organisms in laboratory, and honey bees have been reported to avoid food that contains >100 ppm of CPNO [82], and its "indoor use" have been approved by EPA in the USA [82]; it can therefore be recommended in other countries against household and structural pests.

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