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ANTI-TERMITE EFFICACY OF VARIOUS PLANT ESSENTIAL OILS WITH SPECIAL REFERENCE TO FAMILY RUTACEAE

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ABSTRACT

The present review article emphasizes anti-termite efficacy of various plant natural products for control of Indian white termite and its associating species. The Indian white termite, *Odontotermes obesus* (Rambur) (Isoptera: Odontotermitidae), is highly destructive polyphagous insect pest in Eastern Uttar Pradesh. It damages commercial wood, food crops, orchard plants and house hold articles. Though, several methods have been used to control this termite species in field, but present article explains most recent developments happened in termite control. Present article clarifies seasonal cycle of termite species and suggests use of natural plant products as termiticides to replace synthetic pesticides. As there are reports that residues of synthetic pesticide persist for longer duration in soil system and in aquatic habitat. These enter into the food chain and kill non target organisms. This article found plant essential oils from the family Rutaceae as new alternatives of synthetic pesticides if used in blends or with other natural products. Essential oils are highly volatile at a very low temperature and could be used as fumigants to control household termite population mainly reside inside tunnels, crevices, wood spaces and holes. Plant essential oils and its constituents are safe for the environment and medium. They inhibit metabolism in termites and kill them due to anti-feedant, repellent and toxic action. This article also explains cultural, behavioral, microbial, genetical and biological control of termites to minimize the use of synthetic pesticides so as to save the ecological food chains from poisoning.

KEYWORDS: Termite, Synthetic pesticides, Non target organisms, Biomagnifications, Essential oils.

INTRODUCTION

Termites are detritus feeders and feed on dead leaves, stems, barks, field crops. Termites are known as silent destroyers because of their ability to chew wood, clothes and harm to crop fields. Termites are major pests causing considerable damage to agriculture, forestry, house materials and buildings round the globe except few cold regions. Termites cause economic damage to commercial wood, fibers, cellulose, sheets and papers. They also cause harm to clothes, woolens and mats, and woody building materials. These infest green standing foliages, cereals stored in godown. The Indian white termite, *Odontotermes obesus* (Rambur) (Isoptera: Odontotermitidae), is highly destructive polyphagous insect pest, it lives in huge mounds, feeds on cellulose material and almost anything which contains carbohydrate (Photograph 1). Both worker and soldier termites cause harm to non seasoned commercial wood and its formed materials. Termite damage approximately $30 billion in property damage annually. Termites of the genus *Reticulitermes* are some of the most significant pests of commercial wood and timber tree. These mostly attack old trees in farming areas of the northern hemisphere and causing losses in the billions of dollars annually. There are about 2000 termite species are known in the world. Termites digest plant litter in garden soil and form humus (Photograph 1). Termites are the natural food of reptiles, birds and mammals. Termites are used as feed for poultry. Fungus gardens and soil of termiterium is used to culture mushrooms.

Termites make huge mounds in forests up to a height of 5 m. These have ethnological value as these are used as burying places for dead bodies. Termites make holes which regulate the internal climatic conditions within their nests. For which they built gallaries and chambers insides termitaria or mound. They make holes in mounds east-west face to keep the internal temperature cool and within the requirement of the colony. *C. oculatus* make mushroom shaped mounds for their role in thermal regulation within their nests (Aiki et al., 2019). Colonies are composed of casts: a queen, a king, soldiers and workers. Some species of termite cultivate specialized fungi to digest cellulose. Termites constitute 10% of all animal biomass in the tropics. But four types of termites found all over the world. i.e. (1) subterranean (2) drywood (3) dampwood (4) powderpost. Subterranean termites are responsible for about 95 percent of the damage in all over world. Most of the area of eastern U. P. in tarai belt, relative humidity remains high through out the year, it favors termite population growth that results in termite menace in different local regions, mainly in crop fields, household and forests (Photograph 1). In this area the main species of termite is

Odontotermes obesus (Indian white termite and red termite *Coptotermes* sp.) Similarly at the global level in both tropical sub-tropical countries major infestation is carried by drywood termite *Cryptotermes brevis* (Kalotermitidae) (Walker, 1853). This is one of the most important wood structural pest in the world (Santos et al.,2017).

Termites play a key role as ecosystem engineers in numerous ecological processes, though they degrade the wood in tropical dry forests, particularly the level of the crown canopy. Termites invade standing dead trees in forests. Termites major role in peoples' lives, they make huge mounds which are used by some tribes for funeral as well as spiritual aspects (Huis., 2017). Termites could play a key role in the decomposition of above ground dead wood, mediating the incorporation of suspended and standing dead wood into the soil (Calderon-Cortes et al.,2018). The present article signifies insecticidal potential and target specificity of plant essential oil against termite. Essential oil components are used as synergists will be applied in the form of poison baits which successfully exploit feeding, tunneling (Xie et al., 2013) and reproductive behavior in termites (Cheng et al., 2012). Few natural products such as flavonoids (Park et al., 2014), sesquiterpenes (Seo et al., 2009) and thiophenes (Hagel et al., 2008) isolated from different plants species were found effective against termites.

Whether it is a rural area or an urban domestic site, termite menace is everywhere. In the past, for control of termite population in the field various synthetic pesticides such as chlordane (Karchesy et al., 2018) cypermethrin (Santos et al., 2017) hydroquinone and indoxacarb have been used (Abdullah et al., 2015). But all such synthetic pesticides are highly toxic and present for longer periods in the form of residues. They enter into the food chain and kill non target organisms. These have been banned and its new alternatives are discovered in the form of natural pesticides. Termite mound soil is used as fertilizer, making bricks, geochemical prosperity, pottery and plastering of houses.

TERMITE CONTROL:

(1) Synthetic pesticides:

Over the past 8-9 decades, organochlorines and organophosphates, the two prominent classes of termite control agents, have been massively used. Though, synthetic pesticides show unique modes of action and kill termites in large numbers after treatment (Spomer et al., 2009). But over use of synthetic chemicals caused heavy losses to the environment and severely affected human health. Synthetic pesticides created potential risks to the urban environment and human beings, due to biological magnification and persistent residual effects. The use of synthetic termiticides is very harmful to environmental health mainly for soil as their derivatives reach deeper into the soil after application (depth, 20-30 cm) and kill soil microbiota (Ying et al., 2006). It results in massive loss of fertility. Bound residues of synthetic pesticides usually seep into groundwater that is highly harmful to human health.

Fipronil is a termiticide belongs to phenyl-pyrazole class of chemical compounds. It has broad-spectrum killing power against house hold pests such as cockroaches, mosquitoes, locusts, ticks, and fleas at both larval and adult stages. It is also used to control subterranean termites in buildings. Its two metabolites viz. desulfinyl and sulfide-fipronil was detected in soil samples after much longer time after application. Fipronil residues seep inside earth up to 60 cm depth (Sharma et al., 2008). Farmers massively use phenylpyrazoles, pyrethroids, chloronicotinyls and pyrroles as termite control agents. These pesticides cause mammalian toxicity. Both indoxacarb and fipronil display slow action and nonrepellency against the two termite species i.e. eastern subterranean termite, *Reticulitermes flavipes* (Kollar), and the Formosan subterranean termite, *Coptotermes formosanus* Shiraki (Hu., 2005). Imidacloprid shows higher water solubility and in used with less water-soluble termiticides in poison baits (Sapkota et al., 2020). Imidacloprid foam is found to be more toxic against *C.formosanus* (Osbrink et al., 2005). Boron compounds & borate show 90% mortality against *C. acinaciformis* (Petres & Fitzgerald.,2006). Isoborneol shows repellent activity against *C. formosanus* (Blaske et al., 003)(Table 1).

Microencapsulated fenobucarb is a fast-acting termiticide; it shows reduced repellent activities and prohibits entry of termites into treated soil (Kubota et al., 2007). Photo-immobilization of bifenthrin-embedded chitosan on the surface of PVC substrates are used for termite control. This is a novel and environmentally friendly technique for termite control (Zhang et al.,2016). For achieving effective chemical control of termites silk fibroin is used as a carrier to embed bifenthrin (Guan et al., 2011).

Due to rapid increase spread of termite infestation, new effective termite control agents should discover which should be environmentally friendly and safe termite control agents with minimal mammalian toxicity (Meepagala et al., 2011). Thiamethoxam and fipronil were examined for their termiticidal properties against the Formosan subterranean termite, *Coptotermes formosanus* Shiraki, and the eastern subterranean termite, *Reticulitermes flavipes* (Kollar). Thiamethoxam was found to be more toxic against *C. formosanus* than *R.*

flavipes whereas fipronil showed similar toxicity for both species. High toxicity and horizontal transmission of thiamethoxam was observed against the workers of the Asian subterranean termite *Coptotermes gestroi* (Acda., 2014). It successfully killed termites inside the soil upto 5-cm depth due to percolation inside soil (Remmen et al.,2005).Chlorpyrifos, an organophosphorus insecticide, also control termite workers in the field (Jitsunari et al., 1989) (Table 1).

(2) Essential Oils

Essential oils are complex mixtures of diverse chemical constituents such as lectins, polypeptides, alkaloids, phenols, quinines, flavones, flavonoids, terpenes, tannins, coumarins, benzene derivatives, various hydrocarbons and straight chain compounds. Essential oils possess mixed functional groups, too complex in their structure and are highly volatile at a very low temperature. Essential oils (EOs) are lipophilic secondary metabolites obtained from plants. These are obtained in pure form or a complex mixture of several components without making any change in their chemical composition (Jones et al., 1997). These are obtained by fractionation or rectification and steam distillation of various plant parts in Clevenger apparatus. Due to high volatility essential oils easily spread in the environment and medium. Due to their fast diffusion and volatile action these could be used as fumigants to control household termite population mainly resides inside tunnels, crevices, wood spaces and holes.

Plant essential oils show least residual effect in the non-target organisms, inhibit metabolism in termites and kill them due to antifeeadnt, repellent and toxic action. Essential oils (EOs) are used for making soaps, lotions, shampoos, hair styling products, cologne, laundry detergents, and even insect repellents. These are used for a wide variety of purposes such as flavoring, perfuming (Mishra et al., 1994) aromatherapy and food preservation (Faid et al., 1995).

Agathosma betulina limonene, pulegone ,α-pinene, β-pinene,p-cymene, linalool act as feeding deterrant in termites (Moolla et al., 2008) (Table 2). *Aegle marmelos* also contains limonene, α-phellandrene ,β-ocimene, α-pinene, (E)-caryophyllene , β-elemene ,germacrene (Verma et al., 2014); sesquiterpene hydrocarbons, germacrene D , (E)-caryophyllene from *Casimiroa edulis* (Mille et al., 2009); E-ocimenone, Z-ocimenone, gamma-terpinene, germacrene D from *Clausena anisata* (Yaouba et al., 2011); 2-tridecanone, beta-caryophyllene, 2-pentadecanone, caryophyllene oxide ,germacrene D. from *Pilocarpus microphyllus* (Taveira et al., 2003) (Table 2). Limonene from *Pilocarpus spicatus* (Nogueira et al., 2020); β-myrcene, (Z)-β-guaiene, (Z)-β-ocimene, β-caryophyllene, bicyclogermacrene, α-terpinyl acetate, geijerene and β-copaene-4α-ol from *Boenninghausenia albiflora* (Padalia et al., 2012); dictagymnin, feniculin estragole from *Dictamnus albus* (Baser et al., 1994) (Table 2).

Essential oil showed strong insecticidal activity against the Japanese termite, *Reticulitermes speratus* Kolbe, in fumigation bioassay. Responses varied with source, exposure time and concentration (Seo et al., 2009). Similarly, leaf essential oil and its main constituents isolated from *Calocedrus formosana* Florin (Cupressaceae) shows antitermitic activities against *Coptotermes formosanus* at a very low LC50 value of leaf essential oil i.e. 27.6 mg/g (Cheng et al., 2004) (Table 3). *Jatropha curcas* oil shows anti-feeding effect causes reduction in tunneling activity and increased mortality in *Coptotermes vastator*. Behavior of termites exposed to sand treated with *J. curcas* oil shows repellent activity against the Formosan subterranean termite. The essential oil of aerial parts of maca (*Lepidium meyenii*) and its components i.e. Phenyl acetonitrile (85.9%), benzaldehyde (3.1%), and 3-methoxyphenylacetonitrile (2.1%) showed antitermite activity. The oil shows complete growth inhibition at 100μ/ml. It shows high mortality in *Formosan* subterranean termite, *Coptotermes formosanus* (Tellez et al., 2002). Essential oils from Coniferous plants showed anti-termitic activities against *Coptotermes formosanus* Shiraki at a dosage level of 10 mg/g. Similarly chemical constituents of leaf essential oils of *Cryptomeria japonica* displayed high antitermitic efficacy against *Coptotermes formosanus* Shiraki. Among these constituents, β-elemol andα-terpineol achieved 100% termite mortality at the dosage of 1 mg/g after 7 d of testing.Thus, *C. japonica* leaf essential oils as well as β-elemol and α-terpineol possessed commendable antitermitic activity (Cheng et al., 2012) (Table 3).

Vetiver oil proved the most effective repellent because of its long-lasting activity. Vetiver oil decreased termite tunneling activity. Thus, Vetivor oil is a promising novel termiticide with reduced environmental impact for use against subterranean termites (Zhu et al., 2001). Essential oils of Vetiver grass, cassia leaf, clove bud, Cedarwood, *Eucalyptus globules*, *Eucalyptus citrodora*, lemongrass and geranium gives repellent and toxic action against the *Formosan* subterranean termite, *Coptotermes formosanus* Shiraki. Essential oils obtained from the leaves of two *Cinnamomum osmophloeumclones* (A and B) and their chemical ingredients show antitermitic activities against *Coptotermes formosanus* Shiraki (Chang et al., 2002). The heartwood and sapwood essential oils of *Calocedrus macrolepis* var.

formosana and *Cryptomeria japonica* and the leaf essential oil of *Chamaecyparis obtusa* var. formosana showed 100% mortality in field termites after 5 d of test. The termiticidal effect of heartwood essential oil was toxic and repellent in action (Cheng et al., 2007).

Clove bud essential oil was toxic, killing 100% of termites in 2 days. *Cinnamomum camphora* leaf essential oil is shown insecticidal activity in midge and butterfly larvae and kill adults fruit flies, and fire ants. *C. glaucescens* fruit essential oil showed notable anti termite activity (Satyal et al., 2013). The essential oils from *Cinnamomum camphora* (L) Presl showed strong fumigant toxicity against *Tribolium castaneum* and *Lasioderma serricorne* adults. The essential oils of *C. camphora* and its individual compounds can be considered a natural resource for the two stored-product insect management (Guo et al., 2016). The essential oil of catnip, *Nepeta cataria* (Lamiacae) gives behavioral effects on two populations of subterranean termite, *Reticulitermes flavipes* (Kollar) and *R. virginicus* (Banks) (Isoptera: Rhinotermitidae) at some extent (Peterson et al., 2003) (Table 3). Antitermitic activities of essential oils from different tissues of chinese cedar contains ferruginol, y- cadinene and kaurene as major components. Both leaf and heartwood essential oils from chinese cedar might be considered as a potential source of natural termiticide (Xie et al., 2014). The essential oil from Chinese cedar leaf and α-terpineol might be considered as a potent source for the production of effective, environmentally friendly and safe termiticides (Xie et al., 2013).

Citrus is a wood protective natural substance.This is a mixture of *citrus* fruit epicuticular waxes and essential oils.It shows antitermite activity against the termite *Cryptotermes brevis* Walker (Isoptera: Kalotermitidae).It also shows strong antifeedant activity (Sbeghen-Loss et al., 2011). Vetiver oil and its components nootkatone and cedrene disrupt food recruitment in *Coptotermes formosanus* Shiraki (Maistrello et al., 2001). Similar antifeedant activity has been found in essential oil at very low dose (250-700 ppm) of *Alpinia galanga* against two species of termites, *Coptotermes gestroi* (Wasmann) and *Coptotermes curvignathus* (Holmgren) (Isoptera: Rhinotermitidae). Due to presence of 1,8-cineol, it also shows termiticidal activity at 945 -1102 mg/kg LD50 value (Abdullah et al., 2015). Patchouli oil obtained from *Pogostemon cablin* (Blanco) Benth and its main constituent, patchouli alcohol. This oil shows strong repellency and toxicity against *Formosan* subterranean termites (*Coptotermes formosanus* Shiraki) (Zhu et al., 2003). *A. trilobata* EO and its constituents, especially the limonene showed repellent and termiticidal activity against *N. corniger*. This oil also shows repellent action and detterant activity from feeding (Santos et al., 2019).

Insecticidal activities of so many plant essential oils i.e. *Melaleuca dissitiflora*, *Melaleuca uncinata*, *Eucalyptus citriodora*, *Eucalyptus polybractea*, *Eucalyptus polybractea*, *Eucalyptus radiata*, *Eucalyptus dives*, *Eucalyptus globulus*, *Orixa japonica*, *Cinnamomum cassia*, *Allium cepa*, *Illicium verum*, *Evodia officinalis*, *Schizonepeta tenuifolia*, *Cacaliaroborowskii*, *Juniperus chinensis* var. horizontalis, *Juniperus chinensis* have been established against the Japanese termite, *Reticulitermes speratus* Kolbe, in fumigation bioassay. These plant essential oils showed potential fumigant action on termites (Park et al., 2005; Seo et al., 2014). Similar results were obtained after treatment of termites by oriental sweetgum (*Liquidambar orientalis*) and valerian (*Valeriana wallichii*) essential oils against the Japanese termite (*Reticulitermes speratus*). Fumigant toxicity varied with plant essential oils or constituents, exposure time, and concentration (Park et al., 2014). Essential oils, those from *Chamaemelum nobile* exhibited the strongest fumigant toxicity against termites (Seo et al., 2014) (Table 3).

Essential oils from family Rutaceae

Essential oils isolated from various species of *Citrus* possess highly effective bio-organic constituents like monoterpene, limonene, β-pinene; geranyl acetate and verbenone from *Citrus maxima* (Varkey et al., 2014); citronellal and citronellol from *Citrus grandis* (Tsai et al., 2017); germacrene isomers, pinene, linalool dimmer, bornane, citral , anethole, anisole, safrole, demitol from *Citrus aurantifolia* (Adokoh et al., 2019) and limonene, β-myrcene , α-pinene from *Citrus aurantium* (Teneva et al., 2019) (Table 2). Few important constituents like d-limonene, linalool, geraniol, nerol, monoterpene aldehydes, alpha- and beta-pinene, myrcene, sesquiterpenes in most of the *Citrus* plant species (Geraci et al.,2017); (Othman et al., 2016);(Gabriele et al., 2009); Alpha-terpinene, alpha-pinene and sesquiterpene have been isolated from *Citrus paradisi* (Njoroge et al., 2005), *Citrus latifolia* (Ruiz-Perez et al., 2016) and *Citrus limon* (Amorim et al., 2016), germacrene and hexane from *Citrus japonica* (Nouri et al., 2016) and sabinene from *Citrus hystrix* (Othman et al., 2016)(Table 2).

Bergamot peel essential oil contains flavonoids (Mandalari et al., 2006). For taking better production, yield and beneficial components from citrus byproducts are more effective and sustainable (Yang et al., 2017).

Leaf essential oil of *Citrus x limon* contains beta-Pinene, myrcene, neral, geranial, neryl acetate, geranyl acetate, and beta-caryophyllene (Vekiari et al., 2002). The *citrus* fruit is rich in d-limonene, a cyclic terpene, phenolics, vitamins, minerals, dietary fiber, essential oils and carotenoids (Gonzalez-Molina et al., 2010). The chemical composition of EOs contains four chemical classes of compounds hydrocarbons, oxygenated monoterpenes, sesquiterpenes, and fatty alcohol esters (Simeone et al., 2020). It shows strong biological activity (Viviana Negro et al., 2016) and good antimicrobial activity (Hamdan et al., 2013). *Citrus limon* (lemon) is used for culinary and pharmacological benefits (Klimek-Szczykutowicz et al., 2020). *Citrus* genus is the most important fruit tree crop in the world and lemon is the third most important *Citrus* species. A potential use of *Citrus* oils as valuable new flavor functional properties of food or nutraceutical products with particular relevance to supplements for the elderly (Tundis et al., 2012).

Ruta genus is constituted by ten species, of which the most commonly described are *R. chalepensis* and *R. graveolens*. The family Rutaceae has great economic importance of its numerous edible fruits and essential oils. *Ruta* plants are perennial shrubs belonging to the family Rutaceae, which are traditionally used in folk medicine. The phytochemical composition of these plants consists mainly in the essential oil (EO), but phenolic compounds were also reported, like coumarins and flavonoids, as well as alkaloids. *Ruta* species products like extracts and EOs have shown broad pharmacological activities, such as antimicrobial and antifungal activities, as well as, antiviral and antiparasitic. *Citrus* EOs is an economic, eco-friendly and natural alternatives to chemical preservatives and other synthetic antioxidants, such as sodium nitrites, nitrates or benzoates, commonly utilized in food preservation. *Citrus* based EOs is obtained mainly from the peels of *citrus* fruits which are largely discarded as wastes and cause environmental problems (Mahato et al., 2019). *Ruta* plant oils are also used as bio- insecticides in the control of different insect pests showing to be able to reduce infestation (Coimbra et al., 2020).

Essential oils of seven plants of the family Rutaceae, *Aegle marmelos, Murraya koenigii, Citrus reticulata* Blanco, *Zanthoxylum armatum, Skimmia laureola, Murraya paniculata*, and *Boenninghausenia albiflora*, all have insecticidal, toxicological and medicinal properties (Liaqat et al., 2018). *Citrus aurantifolia* (Christm.) Swingle (syn. *C. medica* var. *ACIDA Brandis*) essential oil is safe, it can have mild hematotoxic, nephrotoxic and hepatotoxic effects (Adokoh et al., 2019). It also shows antibacterial activity against cariogenic bacteria

(Lemes et al., 2018). The essential oils of sweet orange (*Citrus sinensis*), bitter orange (*Citrus aurantium*), neroli (*Citrus aurantium*), orange, petitgrain (*Citrus aurantium*), mandarin (*Citrus reticulata*), lemon (*Citrus limon*), lime (*Citrus aurantifolia*), grapefruit (*Citrus × Paradisi*), bergamot (*Citrus bergamia*), Yuzu (*Citrus junos*), and kumquat (*Citrus japonica*) have the important biological activities and safety (Dosoky et al., 2018). Volatile components of citrus fruit essential oils show inhibitory action on *P. digitatum* and *P. italicum* growth. *P. digitatum* is more sensitive to the inhibitory action of the oils (Caccioni et al.,1998). The leaf and root essential oil composition of *Boenninghausenia albiflora* Reichb and Meissner (family: Rutaceae) contains β-myrcene, (Z)-β-guaiene, (Z)-β-ocimene and β-caryophyllene as major oil constituents found in leaf essential oil whereas bicyclogermacrene, α-terpinyl acetate, geijerene and β-copaene-4α-ol were identified as the major constituents of the root essential oil (Padalia et al., 2012).

Citrus essential oils (CEOs) consist of some major biologically active compounds like α-/β-pinene, sabinene, β-myrcene, d-limonene, linalool, α-humulene, and α-terpineol. These compounds possess several health beneficial properties like antioxidant, anti-inflammatory, anticancer, and antimicrobial properties (Bora et al., 2020). These plants also contain beta-pinene/limonene; limonene/geranial/neral;limonene/linalool/citronellal which also showed multiple biological activities (Lota et al., 2002). Essential oils from *C. reticulata* Blanco generate cytotoxicity in P. italicum and P. digitatum by disrupting cell membrane integrity and causing the leakage of cell components (Tao et al., 2014). Bergamot fruit essential oil is used in perfumes, cosmetics, food, and confections. It is used in aromatherapy for reducing anxiety and stress (Navarra et al., 2015) (Table 3).

Essential oil constituents β-thujene, β-pinene, γ-terpinene, myrcene, sesquiterpenes from *Citrus* species showed termiticidal effects (Gabriele et al., 2009). Few other bio-oraganic active compounds such as linalool , linalyl acetate from *Ocimum basilicum* (Rezzoug et al., 2019); α-terpinyl acetate , neryl acetate , α-pinene from *Thymus algeriensis* (Rezzoug et al., 2019); thymol , 1,8-cineole, umbellulone , α-bisabolol, camphor from *Tanacetum walteri* (Ghaderi et al., 2019); sesquiterpenes, β-eudesmene, *β*-bisabolene from *Helichrysum italicum* (Oliva et al., 2020); eugenol from *Syzygium aromaticum* (Pinto et al., 2009); carvacrol, thymol, eugenol,cinnamaldehyde from *Eugenia caryophyllata* showed multiple biological activity including termiticidal effects in major of them (Chaieb et al., 2007) (Table 3).

Eucalyptus camaldulensis essential oil contain 1,8-cineole , α-pinene , α-phellandrene, p-cymene (Gakuubi et al., 2017); *Thuja occidentalis* essential oil contains alpha-pinene, 4-carene α-cedrol, terpinolene , β-myrcene , β-pinene, sabinene , D-Limonene (Qureshi et al., 2016); caryophyllene oxide, p-caryophyllene, spathulenol are isolated from *Tagetes patula* which showed deterrent effects (Ali et al., 2016) (Table 3). Components like α-pinene, verbenone, terpinolene, α-terpineol isolated from *Helianthus annuus* (Liu et al., 2020) neophytadiene, phytol, trans-pinane, 6,10,14-trimethyl-2- pentadecanone, citronellyl propanoate isolated from *Jatropha curcas* shows anti-oxidant and anti-inflammatory activity (Adeosun et al., 2017). Few components menthol, menthofuran, menthyl acetate, menthone, 1,8-cineole extracted from *Mentha piperita* (Marwa et al., 2017). Moreover, cinnamaldehyde, linalool, β-caryophyllene, eucalyptol, eugenol isolated from *Cinnamomum zeylanicum* (Behbahani et al., 2020); α-thujone,1,8-cineole, α-pinene, camphor, camphene from *Ricinus communis shows* antimicrobial (Zarai et al., 2012) (Table 3).

(3) Plant natural products

In nature, both plants and animals possess diverse natural bio-organic constituents. Environmental and soil conditions generate chemotypic variations which are acquired after every cycle of development and reproduction inside genome at a very slow rate and finally displayed as adaptability. This information is coded inside genes which control or regulate synthesis of species specific biomolecules which act as chemotypes or chemical variants. This chemotypic specificity found in diverse plant groups show wide array of primary and secondary metabolites which are used as bio-insecticides and alternative medicines (Ozaslan et al., 2018).

Flavanoids mainly alkaloids showed antifeedent (Ohmura et al., 2000) and repellent activity against *C.formosanus* (Mao & Henderson., 2007; Watanabe et al., 2005). Seeds of *Withania somnifera*, *coroton tiglium* & *Hygrophilia auriculata* distrupt the activity of their gut microflora in *Microtermes Obesi* (Duke et al., 2010); while leaf of *Rhazya stricta Decne*, *Lantana camara* showed antifedent activity against *Psammotermes hybostoma* (Yuan et al., 2012). *Azadirachta indica* oil shows 100% mortality against *Macrotermes* sp (Duke et al., 2010).

Plant species synthesize thousands of active biomolecules and so many of them have been extracted and identified for its insecticidal activities (Upadhyay et al., 2009). Few of them act at cellular and physiological level (Arnao et al., 2018). Plant-derived compounds are used as an alternative of synthetic pesticides for termite control. *Capparis decidua* and its combinatorial mixtures are used to control the Indian white termite *Odontotermes obesus (*Upadhyay et al., 2010a); and stored grain insects (Upadhyay et al., 2011). Solvent extracts of *Capparis decidua* alter function of few metabolic enzymes and shows termiticidal effects (Upadhyay et al., 2010b). Plant natural products are used in ecofriendly control of termites and its management (Upadhyay and Jaiswal., 2009).

Few of plant derived bio organic compounds and other natural products are as following:

(i) Plant-derived compounds

Plant secondary metabolites including alkaloids, flavonoids and phenolics were found highly useful to control insect pests, pathogens in eco-friendly ways (Zaynab et al., 2018). Flavonoids are widely distributed as secondary metabolites produced by plants and have a variety of potential biological benefits such as antioxidant, anti-inflammatory, anticancer, antibacterial, antifungal and antiviral activity (Zakaryan et al., 2017). These secondary metabolites (SMs) make plant defense against pathogenic attacks, environmental stresses and have significant biological activity (Yang et al., 2018). Phenolics play an essential role in the defense reaction of crop plants against pathogens (Dadakova et al., 2020). Terpenoid metabolites are used in variety of basic functions like growth and development but majority of terpenoids participate in more specialized chemical interactions. Traditionally, plant-based terpenoids have been used by humans in the food, pharmaceutical, and bio organics industries for making bioinsecticides and biofuel products (Tholl., 2015).

Limonoids are a group of highly oxygenated terpenoid secondary metabolites found mostly in the seeds, fruits and peel tissues of *citrus* fruits. Limonin, the aglycones and glycosides of limonoids show insecticidal activity (Gualdani et al., 2016). *C. sinensis* natural products are also found beneficial for human health and used to develop new drugs (Favela-Hernandez et al., 2016). Cannabis and cannabinoids isolated from *Cannabis sativa*, or hemp shows several medicinal properties (ElSohly et al., 2017). These plant-origin natural pesticides control wide range insect pests efficiently and cut down the pest population even applied in very low quantity. These are much safer, low cost and easily biodegradable in the medium and show no residual effect. This plant chemical diversity is also used to control specialized natural enemies (Salazar et al., 2018).

(ii) Plant Latex

Latex is a milky sap produced and secreted by cells called laticifers. Latex contains a broad range of specialized metabolites such as terpenoids, cardenolides, alkaloids, and phenolics, which are partly responsible for their antifeedant, insect-repellent activities. Latex-bearing plants are important sources of medicine in many countries due to their characteristic latex ingredients. Latexes contain many secondary metabolites alkaloids, flavonoids, glycosides, phenols, saponins, steroids, tannins and terpenoids (Sibi et al., 2013). Latex peptidases shows defense against herbivores or pathogens (Ramos et al., 2019). Which show insecticidal activity (Salome Abarca et al., 2019). Latex of *Synadenium grantii* a Euphorbiaceae plant found in Brazil is traditionally used for control of termites and nematodes (Gomes et al., 2019). *Chelidonium majus* L (Papaveraceae) latex is used in traditional folk medicine to treat papillae, warts, condylomas, which are visible effects of human papilloma virus (HPV) infections (Nawrot et al., 2017).

(iii) Plant extracts

Plants produce a variety of useful bioactive products. The crude methanolic extract and various fractions of *Zizyphus jujuba* showed significant antitermite activity against *Heterotermes indicola* (Ahmad et al., 2011). *Flourensia* species exhibit insecticidal, antifeedant, antibacterial and antitermite activities (Rios et al., 2015). Organic extracts of *Flourensia* species contains sesquiterpenes, flavonoids, benzofurans, chromenes, coumarins, lupantriterpenes, aliphatic lactones, and aromatic and acetilenic compounds.The chemical components of tarbush (*Flourensia cernua*) leaves were fractionated by extracting successively with hexanes, diethyl ether, and ethanol. Plant extracts, prepared from *Pyllanthus niruri, Azadirachta indica, Leucaena leucocephala* and *Andrographis paniculata* exhibit a high degree of antitermite activity (Tellez et al., 2001). These extracts inhibit tunneling behaviour in subterranean termites, *Globitermes sulphurues* and *Coptotermes gestroi*. There is a strong termiticidal activity of plants extracted with methanol against *C. gestroi* and *G. sulphureus* (Bakaruddin et al., 2019).

BIOLOGICAL CONTROL:

Natural enemeies are employed for termite control. Ants are the greatest predators of termites. Mammals, reptiles and birds feed on termites in crop field and potentially regulate termite population (Culliney et al., 2000). Few fungal metabolites (siderophores) show repellent and insecticidal activity against termites (Culliney et al., 2000). Insecticidal proteins secreted by entomopathogenic bacterium *Photorhabdus luminescens* subsp. *laumondii* TT01, a symbiont of the entomopathogenic nematode *Heterorhabditis bacteriophora* is also used for termite control. It is highly useful alternative method for sustainable control of the Formosan subterranean termite (*C. formosanus*) and other social insects (Zhao et al., 2008). Fungus *Metarhizium anisopliae* are used as biological control of subterranean termites (Chouvenc et al., 2012). Endophytic fungus-based biopesticides are used to control *Odontotermes* spp. workers. Fungal conidia and its suspension is directly sprayed on termite worker population (Ambele et al., 2020).

Termites are the natural food of some mammals (myrmecophagy) (Redford., 1987) and reptiles (Keri Gardner). Bearing birds feed upon field termites. Some other animals such as scarlet tanager (*Piranga olivacea*) eat termites. Termites are important food resource for birds around the world (Eisenmann, et al., 1961; Ruth de Jauregui) (Table 4). Few bird species silently feed on termites and directly collect them from Termitaria (termite nests) by making holes in mud (Hardy et al., 1963). Smaller animals such as genets, civets, mongooses, bats and numbats eat termites. Moles and shrews also eat termites. Dwarf mongoose live in social groups live inside caves and eat termite from mounds. Armadillos live in warm climate excavate termites by using deep into a termite mound and collect termites by using long tongue. Edentate animals also possess long tongue and consume 35,000 ants and termites each day. So many reptilian animals such as Blind snake, legless lizard, Naked-toed geckos, Armadillo girdled lizard, Frill -necked lizard feed on termite colony. Few insects like Wasps, Fire ants, Praying Mantis, Spiders and Back ground Beetles are also eats termites (Paul Parsons., 2017) (Table 4). *Oogpister* Beetle (ground beetle) preys exclusively on ants and termites. Blind snake eats Termite *C.formosanus* Alates & workers (Petrakova et al., 2015).

MICROBIAL CONTROL:

Insect pathogens can be utilized in a variety of pest management approaches, from inundative release to augmentation and classical biological control *Metarhizium anisopliae c-4-B strain spores* cause rapid mortality against *C.formosanus Alates & workers* (Wright et al.,2005); *Beauveria bassiana & M.anisopliae* semiochemicals & fungal metabolites (Siderophores) are employed with bait against *C. formosanus(*Culliney & Grace., 2000*).* Natural entomopathogen populations show detrimental pest suppression effects in termites. The insecticidal activity depends on the pathogen type; its mode of competition, and operation for biological control. Target hosts can exhibit considerable variation in their susceptibility to entomopathogens, and cases of field-evolved resistance have been documented for *Bacillus thuringiensis* and *baculoviruses*.

Microbial control of insects is the concerted use of insect-specific pathogens and nematodes for the biological control of insects. Microbial pesticides have a number of advantages over conventional chemical pesticides. Social insects make a range of behaviors to protect their colonies against disease (Davis et al., 2018). *Incistermes Scwarzi* shows cumulative mortality against Drywood termite (Calleri et al., 2010); *Isaria fumosorosea, Metarhizium anisopliae & Bacillus thuringiensis show* 100% Mortality against *C.formosanus* (Wright et al., 2012); *Metarhizium Anisopilae & Beauveria bassiana gives.* Fungal infesction in nest *Subterranean termites(*Hussain et al., 2017*); Saccharum officinarum bagasse & pennisetum purpureum* shows 70% mortality against *C.*formosanus (Guerrero et al., 2015) (Table 1).

BEHAVIOURAL CONTROL:

Termites maintain social behavior in colonies via chemical communication by using pheromones (Gao et al., 2020).Termites reach to food source by using pheromones. This process can be used for termite control (Oberst et al., 2018). Trail pheromones play important roles in foraging behavior and building tunnels and nests in termites. They can be dettered from food and communication. The termite, *Coptotermes formosanus* Shiraki (Isoptera: Rhinotermitidae), protects itself from entomopathogenic fungi by mutual grooming behavior. The termite removes and discards foreign organisms, such as fungal conidia, from the body surface of its nestmates by mutual grooming behavior. The allogrooming behavior can fast remove fungal conidia from termite cuticles and then decrease their physiological investment in individual innate immunity (Liu et al., 2019).The antennae play important roles in the mutual grooming behavior of the termite (Yanagawa et al., 2009). Termites show choice in food preference, they select cellulose based materials for feeding in field.

Termite soldiers produce a vibratory alarm signal to warn conspecific workers. If signals are abrupted. It shows 100% mortality in these termites that is used for self protection (Inta et al., 2009). WPS E1-09 is also used to stop feeding preference of Formosan subterranean termites (Little et al., 2012).Diatomaceous earth (DE) affect penetrating tunneling behavior in termite,100% mortality its 6 hours treatment shows subterranean termite *Reticulitermes chinensis* (Gao et al., 2018)

Termites are eusocial insects which use pheromones for making communication among the members of the colony. Pheromones are volatile chemicals secreted from exocrine glands located all over the termite body (Costa-Leonardo et al., 2010). The termite pheromones are composed of a blend of chemical substances, these are used to coordinate different social interactions or activities, including foraging, building, mating, defense, and nestmate recognition. Failure of communication process prevents the worker termites to become reproductive adults. A number of pheromones are known in termites. Contact pheromones are released when workers are engaged in trophallaxis or grooming and make alarm. The alarm pheromones are defensive chemicals that are secreted from the frontal gland. These are secreted in subterranean termite, *Reticulitermes flavipes* and are called royal recognition pheromones (Funaro et al., 2019). Among the termite pheromones few are hydrocarbons which are used to recognize of nestmates.Trail-following pheromones shape the cohabitation of *Constrictotermes cyphergaster* and *Inquilinitermes microcerus*.Cohabitation is a conflict-avoiding strategies in termites (Cristaldo et al., 2014).

Termites use a range of semiochemicals to maintain the organization and integrity in their colonies. Among these semiochemicals, the trail pheromones in termites are secreted by exocrine gland. These are also secreted by sternal glands present in the abdominal sternites of all termite species and developmental stages (Sillam-Dusses et al., 2020). Trail pheromones are produced in the hindgut, Dufour's gland, the venom gland, and the tibial, tarsal, sternal and abdominal glands of termites. Trail pheromones of *Mastotermes darwiniensis* (Mastotermitidae), and two other basal termites, the Termopsidae *Porotermes adamsoni* (Porotermitinae) and *Stolotermes victoriensis* (Stolotermitinae) are very useful in behavioural communication. Trail pheromones are produced primarily by social insects that forage on the ground, such as termites and ants, although a few nonsocial insects also use them (Cristaldo et al., 2009). In the majority of termite species, trail pheromone comprises a single compound. Trail pheromones orient termite wokers between the nesting and foraging sites. This orientation and recruitment of nestmates from the nest to the food sources collectively called ecological success. In some myrmecine and ponerine ants, the venom gland is the source of trail odors. The major component of the pheromone appears to be the same in the three basal species: the norsesquiterpene alcohol (E)-2,6,10-trimethyl-5,9-undecadien-1-ol. This represents a new chemical category of trail-following pheromones for termites (Sillam-Dusses et al., 2007). The trail pheromone components of *T. subterranea* include both E- and Z-citrals. Trail-laying behavior regulates the amount of pheromone deposited on a trail, which in turn controls a colony's response. After deposition on the substrate, a trail pheromone diffuses. The distance between the food source and the nest is retrieved, with the help of trail pheromones that are highly useful for colony's foraging (Klowden et al., 2013.). Differences in pheromone composition between species may reduce interspecific trail following in stingless bees (Zablotny et al., 2009). These also assist termite species show variations on the theme of mass communication and depicts foraging ecology of individual species (Traniello et al., 2009). Insects also use pheromones for associating with their nests to identify and return to the nest entrance. Argentine ants use (Z) -9-hexadecenal, which lasts about 4 h before the signal fades for use by other workers if it is not replenished (Klowden et al., 2008).

Soldiers of *Prorhinotermes canalifrons* secrete (E)-1-nitropentadec-1-ene and (E,E)-alpha-farnesene, (E,E)-alpha-farnesene from frontal glands. These trigger alarm reactions in *P. canalifrons*, whereas (E)-1-nitropentadec-1-ene did not affect the behavior of termite groups. By alarm reactions termites move faster and send an to alert activate other members of the group (Sobotnik et al., 2008) (Table 5). Trans-8-dodecatrienol & Z, Z E-3,6,8-dodecatrien-1-ol are trail- pheromones of *Macrotermes annandalei, R. virginicus, R. speratus &R.santonensis* (Raina et al., 2005). Termites use Z- dodec-3 en-1-ol induces orientation & recruitment secreted by sternal glands of *Macrotermes annandalei (*Peppuy et al., 2001). Juvenile hormone-mimicking compound cause disruption of the social structure and ultimately the death of the colony due over induction and differenesion of caste expression (Hrdy et al., 2004) (Table 5).

POISON BAITS:

For control of subterranean termites *Coptotermes curvignathus* (Holmgren) and *Coptotermes gestroi* (Wasmann) (Blattodea: Rhinotermitidae) poison coated bait matrices are used. These are supplemented with various sugars, amino acids, and cassava.These bait formulation can be added with termiticides that can use to seek wider control of subterranean termite colonies (Castillo et al., 2013). Noviflumuron is used in poison baits to kill molting worker population of Formosan subterranean termite, *Coptotermes formosanus* Shiraki inside nest (Kakkar et al., 2018) (Table 1). Polyacrylamide/attapulgite composite baits are also applied in agricultural soils.These attracts termite population for foraging (Xie et al., 2019). Systemic posions or pesticides could be added to these gels to kill termites. Carbon dioxide (CO2) relealse attract termites, It improves effectiveness of an insecticide to kill termites in nests

(Bernklau et al., 2005). Termite worker population can be regulated or suppress by using poison bait and killed in pre-adult developmental stages (Hex-1 and Hex-2) (Zhou et al., 2006).

Summon disks and filter paper disks coated with few chitin synthesis inhibitors, i.e. diflubenzuron, hexaflumuron, and chlorfluazuron are used to control forests and field termites (Sbeghen loss et al., 2011). It obstructs the aggregation, feeding, and recruitment behavior in *Coptotermes obesus* termites**.** Noviflumuron causes 77% mortality in *C. formosanus* (Eger et al., 2012). 2- Deoxy – Glactose causes 70% mortality against *C.formosanus* (Veilon et al., 2010). Bistrifluron causes 83% mortality against *C.formosanus (*Evans et al., 2010). Feeding behavior is also inhibited by using bait supplements in Summon Preferred Food Source disks (Cornelius et al., 2009; Xiong et al., 2018) (Table 1).

GENETICAL CONTROL:

Termite colonies are developed from a single pair of nestmates.The reproductive plasticity of termite workers provides colonies with tremendous flexibility to respond to environmental changes, which is the basis for evolutionary and ecological success. Although it is known that all colony members share the same genetic background and that gene retardness, if created in termites it will stop pattern of the specific expression of genes involved in the differentiation of workers into reproductives castes. Once it is being failed may it will cut down numbers of workers and decrease the number of reproductive castes. Thus, inhibition of molecular mechanisms underlying the reproductive plasticity of workers can successfully control population by changing molecular-genetic mechanisms (Chenxu et al., 2019). Similarly, termite population can be controlled in regulating the action of structural genes during its development. By blocking the action of few structural genes they will affect testicular development that may create significant discrepancies in reproductive capacity among the reproductive that results in loss of fertility in male indivduals. They show loss of male gametes during early spermatogenesis apoptosis (Su et al., 2015).

Other genetic method which can be used to kill termites by making gene knockout, and make termites inoperative to feed on wood items, crop plants and cellulose paper. Gene knock down will generate sterile nest mates that will stop colony formation in termites.The separation of reproductive and non-reproductive roles based on caste differentiation is the most prominent characteristic of termites. Genome sequenacing can suggest such new genes, which regulate organ formation in insects; it could be exploited to develop new pest control methods. Once gene activity activity is inhibited, the deveopment in termites will hold up and will generate potential development related effects (Poelchau et al., 2016).

CULTURAL CONTROL:

There are so many methods which have been used to control field and garden termites. For eradication of termite menace older trees are replaced by new healthy saplings. Similarly, decaying plant litter, wastes and leaves are collected from the field and burn to finish the infection. Clean cultivation is also one of the effective methods for control of termites. Normally termites have a nature they select green saplings to feed and house inside the old ones. Plants which are suffering from disease or lack of water are generally more susceptible to termites than healthy plants. It is therefore important that plants should keet healthy and watered. In dry areas seed treatment and systemic bio-pesticides are used to stop the termite population increase. Use of poison baits, dry powder and ash and phosphate dust repel termites to leave the field (Huis et al., 2017). Treatment of termites with fumigants in dry regions is an effective method (Sun et al., 2013). In addition, therse is a need to train farmers to use and apply safe agronomical practices regarding ploughing, manuring, watering and harvesting at a proper time will provide good results. Farmers should follow crop rotation to fix and revive the fertility of soil. Planting the same crop on the same land year after year reduces soil fertility and its structure. Crops growing in such conditions will be weaker and susceptible to termites. Crop rotation can play an important role in reducing termite attack.

Mixed species cropping is often perceived as a viable tool to increase on-farm biodiversity in organic agriculture and is a potentially important component of any sustainable cropping system. In a mixed crop system one plant assists the growth of other plant, for example growing wheat with pulses, keeps on nitrogen fixation on static and field remain always rich in nitrogenous residues. Roots of crop plants supply good nitrogen amount due to decaying of nodules under the top soil or the active plant growth region is being enriched only by growing mixed crops. Vegatable crops mainly *Amaranthus hybridus*, *Ceiosia argentea* and *Corchorus olitorius*, grown support each other. This mixed-cropping is an important component of integrated pest management of vegetables (Okunlola et al., 2011). Adding compost or well-rotted manure to the soil and growing green manures helps to increase the organic matter in the soil. Where possible, green manure crops can be ploughed into the soil. Adding organic material to the soil, crop rotation, physical barriers, encouraging predators, plant parts and plant extracts can be used effectively for control termite population (Kumari et al., 2013). It also assists in pest management and disease control in organic farming systems (Ramert et al., 2002).

Neem, tree is well known source of natural compounds mainly azadirachtin that shows potent insecticidal, feeding deterrent and insect growth regulator activity (Ahmad & Grainge., 1986). Neem oil is environmentally safe , cheap and bestfor termite control (Nwilene et al., 2008).It is easily available to farmers as a natural pesticides. Some specific components like Azadirachtin,Nimbin, Nimbidin , Meliantrol and Salanin have shown strong repellent, growth inhibiting and insecticidal potentials against *coptotermes formosanus* (Delate et al., 1995b) Termites prefer to eat dead plant material. If plant litter contains green biomass manily standing field crops are ploughed for green manuring can be ploughed into the soil.

Termites prefer to eat dead plant material. Their attacks are thought to be related to soils with low organic matter content. Green organic matter attracts the termites and prevents them from attacking the target crop. Ridges are usually made along contours and the soil is finally shaped into a ridge form. In these operations, termite colonies are destroyed or exposed to predators such as birds. Only healthy plants should be transplanted into the field, infected, dead, half digested and abnormal plants must burn according to season. Great care should be taken during transplanting and pruning (leaves and roots) as termites may enter plants through scar tissues. If there is a polythene bag around the root of a tree seedling, it is recommended that it should not be completely removed when transplanting as it can act as a barrier against termite farmers cultivate castor (*Ricinus communis*) crop in severely termites infested field and doing so, they found that the termite infestation has substantially been decreased in the next cropping season (HDRA Report, 2001). This can prevent pest and disease buildup and also help the soil to recover nutrients. Irrigation is also used to minimize the effect of the termites. When the farm is regularly irrigated, the activities or damages of termites are reduced.

Termites are major soil macrofauna and are one of important indicator of environmental sustainability (Anyango et al., 2020). Worker and soldier of termites contain endoglucanase and β-xylanase which are the main cellulase and hemicellulase, respectively. Termites efficiently digest the main components of lignocellulosic materials stimulate the purification of gut enzymes. It could be harvested by using recent biotechnological methods to produce these enzymes by using their gut symbionts (Lima et al., 2014). It will strengthen the organic and conventional farming systems on pest control, productivity, profitability and sustainability.

USE OF MODERN METHODS AND TECHNOLOGY FOR TERMITE CONTROL

1. Chitin synthesis inhibitor baits:

CSI baits more succefully eliminate termite colonies. The lethal time of a chitin synthesis inhibitor (CSI) -baited colony of *Coptotermes formosanus* Shiraki largely depends on the time taken for workers to molt after consuming a lethal dose. Termites died during molting after biochemical changes. CSI baits are durable and require less-frequent site inspection and target termite population in large numbers (Su., 2019). Noviflumuron eliminate the foraging population over a 30 m-long foraging area within 9 weeks. While CSI bait eliminate termite colonies in two weeks time (Kakkar et al., 2018).

2. Use of insect growth regulators (IGRs):

Insect growth regulators (IGRs) are synthetic insect hormones. IGRs are generally less toxic to humans and used as insecticides to regulate the populations of harmful insect pests. IGRs prevent an insect population from seeking maturity by interfering with the molting process. Many IGR products are mixed with other insecticides that kill adult insects (Agrawal et al., 2020).

3. Non-toxic heat treatments:

Heat treatment effectively kill all the life stages of insects—egg, larva, pupa, and adult, without needing to go over 56–60°C, which is high enough to kill the pests rapidly. Termites can not withstand or sustain in hepyethermia and low hypothermia both (Agrawal et al., 2020).

4. CRISPR technology to control pests:

This is more effective, efficacious, safe, self-limiting, and scalable control method which control population of a specific species. In this method disease vector is potential developed and used against a plethora of insect pests. This technology can be safely used in the field to suppress and even destroy target species. In CRISPR technology gene editing is done that acts as a tool to alter function of key genes that regulate the fertility and sex determination of insects (Agrawal et al., 2020).

5. Fly baits:

For field control of termites fly bait stickers can be used near the food storage area or where the flies congregate. The small sticker is coated with insect food and an insecticide that has the ability to knockdown flies in just 1 min upon contact (Agrawal et al., 2020).

6. Thermal Imaging Technology:

Thermal imaging can be an extremely effective way to locate and identify pest related problems. This technology makes use of thermal detection instruments capable of picking up the sources of heat. This helps detect the source of pests, even if they are hidden behind walls or other similar surfaces (Agrawal et al., 2020).

7. Drone Pest Control:

Drones are extensively used these days to check for pest infestation in areas that are difficult to reach. This reduces the risk factor, saves time, and allows the pest control professionals to work out an effective extermination plan.

8. Disruption of communication behaviour:

It is an electronic data surveillance system in which infectivity is observed in relation to presence of adults or larval stages. The mobile data-capture devices can be introduced for pest control, termites can be controlled by obstruction its biological communication system by using electronic devices which send electronic multiple signals and fail neurological corrective actions in termites and safely deter them from life activities and target pest population.

9. Ultrasonic Pest Repeller:

It is modern electronic method for termite control. It is very effective and ecofriendly technique for termite control. Ultrasonic waves are shows repellent activity against termite population.

10. Radio wave pest control:

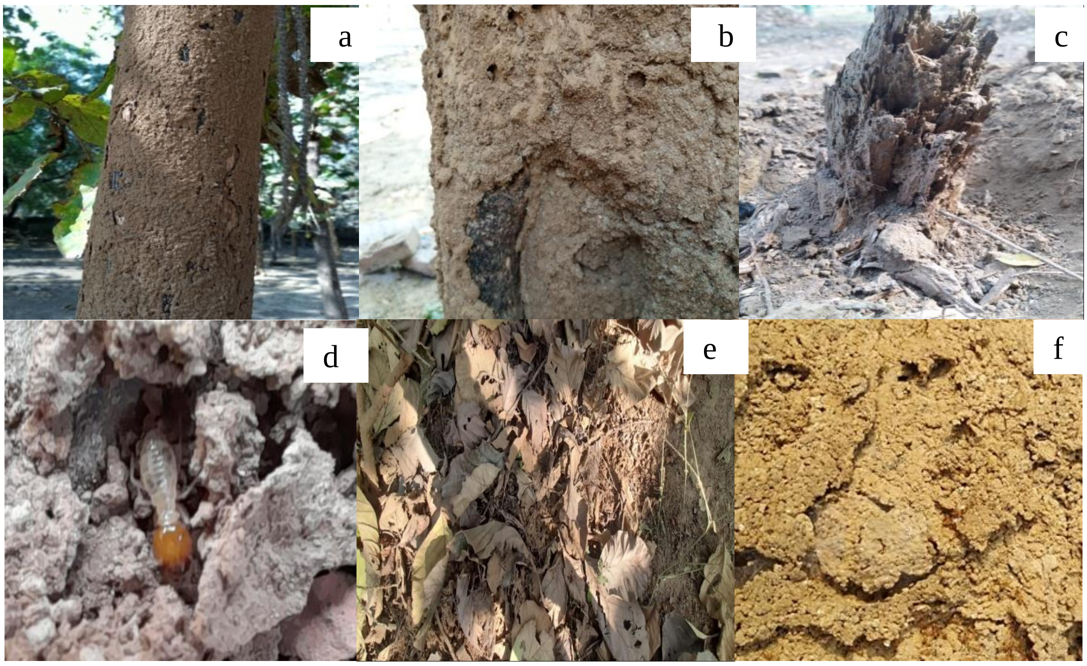
In modern electronic pest control technique, radio waves are very useful, sustain and effective to check the termite population. The concept of a radio wave (RW) or radio frequency (RF) to control the behavior of living organisms has shown promise. Since RF energy generates heat through agitation of bound water molecules, it generates heat through ionic conduction and agitation of free water molecules in insects. As a result, more thermal energy is converted in insects.

CLIMATE CHANGE AND TERMITES POPULATION:

Various climatic factors also play important role in control of termite population. In extreme climatic conditions large population of termites is being killed, but in normal climatic conditions termite population remains on rise. If temperature increases sharply and rises up to 45-46^{0}C, termites avoid foraging, both thermal and heat waves dried the chitin layer and due to heavy losses of water heavy mortality occur in termites in summer season. Due to high heat colony could not search and find foraging grounds, numbers of workers and soldiers died due to hunger. In condition of heavy rains termite's termitaria get filled with rain water and result in loss of termites. Climate also regulate invasion of termites into new territories that also decreases infestation. Most invaders are also dettered during day light and high humidity invaded natural forest habitats ((Photograph 1).

Besides, old traditional methods, new standard methods are employed against invasive termites. For a successful operation against termites two eradication attempts be followed against (Theodore et al., 2013). Like other control methods where economic expenditures are usually high, nature mainly climatic kill termites in huge numbers, but post disasters scenario again put termite population on steep rise. Positive and significant correlation was found among atmospheric temperature, precipitation and both subterranean termite species i.e., Microtermes obesi and *Odontotermes lokanandi*. This correlation is non-significant and negative between relative humidity and foraging activities of both termite species. Only temperature alterations cause large mortality and cut down number of workers of *M. obesi*; but normal temperature induce and support termite population much higher than death rate. This significant difference atmospheric temperature equally affects population of all termite species homogenously and reagulate number in workers of *O. lokanandi*. Similar negative and significant correlation was also noted in varying states of relative humidity that also reduce numbers of workers of *M. obesi*; and *O. obesus* (Sattar et al., 2013). Light radiation in hot summers affect phototrophic bevhaviorus in termites, Radiation help control this pest (Ferreira et al., 2011).

Wood moisture content plays significant role in the survival and reproduction in dry wood termites. Reduction in moisture contents also decrease the survival time in termites (McManamy et al., 2008). Temperature rise in urban areas is also responsible for low reproductive potential in *C. gestroi* and *C. formosanus* that is strongly linked to urban development. It will increase population growth and biotic distribution of termite species in urban sprawls. Future climate warming indicates an increase in the sensitivity of insect pests towards more invasiveness, damage and ecological realism (Francesco et al., 2014). The analysis of sex ratios and average weights of the alates suggests that intrinsic colony factors warm climate affecting timing of the maturation alates, dispersal and flight (Chouvenc et al., 2017). Global warming as a consequence of climate change, and due to intensifying international trade of wooden items, cereals, fibres and other materials is responsible for unconditional distribution/ spread of insects to into new areas (Bradshaw et al., 2016). Due to safety reasons new technology must be based on green biochemicals to minimize the risk of biodiversity loss and contamination of food chain and biomagnfication. It will significantly cutdown the use of highly toxic pesticides and will assist in long term management of field and house holds termies (Venkata., 2019).



Photograph 1: (a-f) showing plastering of green trees, termites inside mound, invaded tree, green biomass and digested soil.

Table 1: Various methods used in termite control.

Method/s	**Product used**	**Effect**	**Termite species controlled**	**References**
SYNTHETIC PESTICIDES	Fipronil	More toxic	*R. flavipes*	Hu et al., 2005
	Indoxacarb	Toxic	*R. flavipes*	Hu et al., 2005
	Imidacloprid foam	Latent mortility	*C.formosanus*	Osbrink et al., 2005

	Boron compounds & borate	90% mortility	*C.acinaciformis*	Petres & Fitzgerald.,2006
	Isoborneol	Repellent	*C.formosanus*	Blaske et al.,2003
PLANT NATURAL PRODUCTS	Flavanoids	Antifeedent	*C.formosanus*	Ohmura et al.,2000
	Sophora flavescens contain alkaloids	Antifedent & repellent	*C.formosanus*	Mao & Henderson., 2007
	Callitris glaucophylla	Repellent	*C.formosanus*	Watanabe et al.,2005
	Seeds of *withania somnifera,coroton tiglium & Hygrophilia auriculata*	Distrupt the activity of their gut	*Microtermes Obesi.*	Duke et al., 2010
	Leaf of *Rhazya stricta Decne, Lantana camara*	Antifedent	*Psammotermes hybostoma*	Yuan et al., 2012
	Azadirachta indica	100% mortality	*Macrotermes sp*	Duke et al., 2010
MICROBIAL CONTROL	*Incistermes Scwarzi*	Comulative mortality	Drywood termite	Calleri et al., 2010
	Isaria fumosorosea, Metarhizium anisopliae & Bacillus thuringiensis	100% Mortality	*C.formosanus*	Wright et al., 2012
	Metarhizium Anisopilae & Beauveria bassiana	Fungal infesction in nest	Subterranean termite	Hussain et al., 2017
	Saccharum officinarum bagasse & pennisetum purpureum.	70% mortality	*C.formosanus*	Guerrero et al., 2015
BIOLOGICAL CONTROL	*Metarhizium anisopliae c-4-B strain spores*	Cause rapid mortality	*C.formosanus Alates & workers*	Wright et al.,2005
	Beauveria bassiana & M.anisopliae semiochemicals & fungal metabolites (Siderophores)	Employed with bait	*C.formosanus*	Culliney & Grace.,2000
	Blind Snake	Termite eating snake	*C.formosanus* Alates & workers	Petrakova et al.,2015
POISON BAITS	Noviflumuron	77% mortality	*C.formosanus*	Eger et al.,2012
	2- Deoxy – Glactose	70% mortality	*C.formosanus*	Veilon et al., 2010
	Bistrifluron	83% mortality	*C.formosanus*	Evans et al., 2010

Table 2: showing different citrus plants with chemical composition of their essential oils.

S.N.	Name of plants	Essential Oils major components	Activity against termites	Source(references)
1.	*Citrus maxima*	Monoterpene,limonene,β-pinene, geranyl acetate, verbenone	Effective	Varkey et al.,2014
2.	*Citrus grandis*	citronellal and citronellol	More toxic	Tsai et al.,2017
3.	*Citrus aurantifolia*	Germacrene isomers, Pineen, Linalool dimmer, Bornane, Citral, Anethole, Anisole, Safrole, Demitol	satisfactory	Adokoh et al.,2019
4.	*Citrus aurantium*	limonene, β-myrcene, α-pinene	More effective	Teneva et al., 2019
5.	*Citrus sinensis*	d-limonene, linalool, geraniol, nerol	More effective	Geraci et al.,2017
6.	*Citrus microcarpa*	Limonene,	More effective	Othman et al.,2016
7.	*Citrus medica*	limonene, gamma-terpinene, monoterpene aldehydes, alpha- and beta-pinene, myrcene, sesquiterpenes	More effective	Gabriele et al.,2009
8.	*Citrus paradisi*	limonene, alpha-terpinene, alpha-pinene, Sesquiterpene	More effective	Njoroge et al., 2005
9.	*Citrus latifolia*	d-limonene,β-thujene, β-pinene, γ-terpinene	Moderates	Ruiz-Perez et al.,2016
10.	*Citrus limon*	geranial, limonene, γ-terpinene	Effective	Amorim et al., 2016
11.	*Citrus japonica*	Limonene,germacrene, hexane	More effective	Nouri et al.,2016
12.	*Citrus hystrix*	Sabinene	Good	Othman et al.,2016
13.	*Aegle marmelos*	limonene, α-phellandrene, β-ocimene, α-pinene, (E)-caryophyllene, β-elemene, germacrene	Repellent activity	Verma et al.,2014
14.	*Casimiroa edulis*	sesquiterpene hydrocarbons, germacrene D, (E)-caryophyllene	Antifeedant activity	Mille et al., 2009
15.	*Clausena anisata*	E-ocimenone, Z-ocimenone, gamma-terpinene, germacrene D	Moderate toxic	Yaouba et al., 2011
16.	*Pilocarpus microphyllus*	2-tridecanone, beta-caryophyllene, 2-pentadecanone, caryophyllene oxide, germacrene D.	Toxic	Taveira et al., 2003
17.	*Pilocarpus spicatus*	Limonene	Repellant activity	Nogueira et al., 2020
18.	*Boenninghausenia albiflora*	β-myrcene, (Z)-β-guaiene, (Z)-β-ocimene, β-caryophyllene, bicyclogermacrene, α-terpinyl acetate, geijerene and β-copaene-4α-ol	More toxic	Padalia et al., 2012
19.	*Dictamnus albus*	Dictagymnin, Feniculin,Estragole	Toxic	Baser et al., 1994
20.	*Agathosma betulina*	limonene, pulegone, α-pinene, β-pinene,p-cymene, linalool	Feeding deterrant	Moolla et al.,2008

Table 3: Showing essential oil components of plants from different family.

S.N.	Essential oil yielding Plants	Family	Major chemical composition	Activity	Source (References)
1.	*Citrus* species	Rutaceae	Limonene, β-thujene, β-pinene,γ-terpinene, myrcene, sesquiterpenes	Antimicrobial, Termiticidal, Antifungal	Gabriele et al., 2009
2.	*Ocimum basilicum*	Lamiaceae	linalool, linalyl acetate	Antimicrobial, Antibacterial	Rezzoug et al., 2019
3.	*Thymus algeriensis*	Lamiaceae	α-terpinyl acetate, neryl acetate, α-pinene	Antimicrobial	Rezzoug et al., 2019
4.	*Tanacetum walteri*	Asteraceae	Thymol, 1,8-cineole, umbellulone, α-bisabolol, camphor	Antimicrobial	Ghaderi et al., 2019
5.	*Helichrysum italicum*	Asteraceae	Sesquiterpenes, β-eudesmene, β-bisabolene	Antimicrobial	Oliva et al., 2020
7.	*Syzygium aromaticum*	Myrtaceae	Eugenol	Antifungal, Antibacterial, Antimicrobial	Pinto et al., 2009
8.	*Eugenia caryophyllata*	Myrtaceae	carvacrol, thymol, eugenol, cinnamaldehyde	Antimicrobial, Anticancer	Chaieb et al., 2007
9.	*Eucalyptus camaldulensis*	Myrtaceae	1,8-cineole, α-pinene, α-phellandrene, p-cymene.	Antiacetyl-cholinesterase, Antifungal	Gakuubi et al., 2017
10.	*Thuja occidentalis*	Cupressaceae	Alpha-pinene,4-carene α -cedrol, terpinolene, β -myrcene, β -pinene, sabinene, D-Limonene	Antimicrobial	Qureshi et al., 2016
11.	*Tagetes patula*	Asteraceae	caryophyllene oxide, p-caryophyllene, spathulenol	Biting Deterrent Activity	Ali et al.,2016
12.	*Mentha piperita*	Lamiaceae	menthol, menthofuran, menthyl acetate, menthone,1,8-cineole	Antimicrobial, Antioxidant	Marwa et al.,2017
13.	*Cinnamomum zeylanicum*	Lauraceae	cinnamaldehyde, linalool, β-caryophyllene, eucalyptol, eugenol	Antioxidant, Antimicrobial	Behbahani et al.,2020
14.	*Ricinus communis*	Euphorbiaceae	α-thujone,1,8-cineole, α-pinene, camphor, camphene	Antimicrobial, Antifungal	Zarai et al.,2012
15.	*Jatropha curcas*	Euphorbiaceae	neophytadiene, phytol, trans-pinane, 6,10,14-trimethyl-2-pentadecanone, citronellyl propanoate	Anti-inflammatory	Adeosun et al.,2017
16.	*Helianthus annuus*	Asteraceae	α-pinene,verbenone, terpinolene, α-terpineol	Antioxidant, Antimicrobial	Liu et al.,2020

Table 4: Termite eating animal species.

Termite eating animals	Common name	Scientific name	REFERENCE
Birds	Pileated woodpeckers	*Dryocopus pileatus*	Ruth de Jauregui
	Red-headed woodpecker	*Melanerpes erythrocephalus*	Ruth de Jauregui
	Toco toucan	*Ramphastos toco*	Ruth de Jauregui
	Yellow-rumped cacique	*Cacicus cela*	Ruth de Jauregui
	Marabou stork	*Leptoptilos crumeniferus*	Ruth de Jauregui
	Chickens	*Gallus domesticus*	Ruth de Jauregui
	Guinea fowl	*Numida meleagris*	Ruth de Jauregui
	Egyptian goose	*Alopochen aegyptiacus*	Ruth de Jauregui
	American robin	*Turdus migratorius*	Ruth de Jauregui
	Common yellow throat	*Geothlypis trichas*	Ruth de Jauregui
	Golden-crowned sparrow	*Zonotrichia atricapilla*	Ruth de Jauregui
	Bluebird	*Sialia mexicana*	Ruth de Jauregui
Reptiles	Blind snake	*Indotyphlops braminus*	Keri Gardner
	Naked-toed geckos	*Gymnodactylus amarali*	Keri Gardner
	Armadillo girdled lizard	*Ouroborus cataphractus*	Keri Gardner
	Frill -necked lizard	*Chlamydosaurus kingi*	Keri Gardner
	legless lizard	*Lialis burtonis*	Keri Gardner
Mammals	Humans	*Homo sapiens*	Keri Gardner
	Civets	*Viverricula indica*	Keri Gardner
	Mongooses	*Herpestes edwardsi*	Keri Gardner
	Bats	*Desmodus rotundus*	Keri Gardner
	Echidna	*Tachyglossus aculeatus*	Keri Gardner
Insects	Spiders	*Achaearanea tepidariorum*	Paul Parsons, 2017
	Back ground Beetles	*Carabidae spp.*	Paul Parsons, 2017
	Wasps	*Vespa* spp.	Paul Parsons, 2017
	Praying Mantis	*Mantis religiosa*	Paul Parsons, 2017
	Fire ants	*Solenopsis spp.*	Paul Parsons, 2017

Table 5: Pheromone control of termites.

S. N.	Product in use	Effects	Against	References
1.	Trans-8-dodecatrienol & Z, Z E-3,6,8-dodecatrien-1-ol	Evoke trailing	*R. virginicus, R. speratus & R.santonensis*	Raina et al.,2005
2.	Z- dodec-3 en-1-ol	Induces orientation & recruitment	*Macrotermes annandalei*	Peppuy et al.,2001
3.	E-1- nitropentadec-1-ene & E-E-alpha-farnesene	Used for trapping termites	*pror-hinotermes canalifrons*	Sobotnik et al.,2008
4.	norsesquiterpene alcohol (E)-2,6,10-trimethyl-5,9-undecadien-1-ol	Reflects Communication behavior	*Mastotermes darwiniensis, Porotermes adamsoni* and *Stolotermes victoriensis*	Sillam-Dusses et al, 2007
5.	Juvenogens	Disruption of the social structure and ultimately the death of the termite colony.	*Zootermopsis angusticollis, Kalotermes flavicollis, Cryptotermes declivis, Reticulitermes santonensis* and *R. flavipes*	Hrdy et al., 2004

CONCLUSION

Indian white termite is a serious polyphagous insect pest in Eastern Uttar Pradesh; it is one of the most economically important subterranean species found in this climate zone. In last seven decades synthetic pesticides have been massively used for insect control. From researches all these conventional control methods have been proved quite hazardous and harmful for the environment, soil microorganisms, invertebrate and vertebrates. Hence, environmentally safe control methods are used to lowerdown risks of poisoning of biological habitats and food chain. New alternates in form of various natural plant products such as essential oils, poison baits, deterrents, repellents, fumigants, insecticidal bio-organic chemicals, genetic and biological control methods should employ to control this white termite. In addition, ecologically safer biological control of termites is possible by using natural enemies of termites i.e. parasites, parasitoids, predators and pathogens can be used to reduce and control termite population in crop fields. Inhibition of reproductive behavior in termites is the safest method for termite control. Moreover, feeding inhibition in termite feeding behaviour could be achieved by using pheromones, poison baits and feeding deterrent bio-orgnic compounds. Both semiochemicals and fungal metabolites (siderophores), or synthetic analogues of insect hormones, are also suggested for termite control. Besides this, environmentally safe methods such as photoimmobilization of natural termiticides in soil, entomopathogenic fungus *metharhizium anisopliae* is used for behavioural and physiogical disruption of termite life cycle. CO_2 generating baits could be used to exposed field termites with natural termiticides. Noviflumuron eliminate foraging population of termites. Few cultural control practices such as repetitive ploughing clean agronomic practices, mixed crop systems, mist fumigation, mulching and use of soil baits are safer for both environment and non target organisms. Natural populations of termites can be controlled by using green pest management that will also help to control pests and reduces harmful use of pesticides.

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