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Review Paper

BOTANICAL EXTRACTS: A STEP TOWARDS ECO-FRIENDLY PEST MANAGEMENT STRATEGY

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ABSTRACT

Indiscriminate use of synthetic pesticides has posed different types of environmental, toxicological and other health-related problems. Recently, attention has been paid towards the exploitation of botanicals as plant protection agents and their use in integrated pest management. The characterization of potential bioactive compounds thus becomes a primary step in developing botanicals for pest management. As a result, ethnobotanical research on plants, standardisation of extraction processes, and botanicals must be properly designed after thorough evaluation in order to develop and fully exploit the uses of an effective and profitable botanical. Elicitation of a defence response in host plants by botanicals acting as inducers is a fascinating field and offers new prospects for using these substances in crop protection. This has prompted intensive research on the development of botanical agents in pest management. Thus, this review incorporates the relevant information on the potential use of botanicals in pest control.

Keywords: Botanicals, Eco-friendly, Extracts, Management

Food security and availability are major concerns around the globe with the ever-growing world population. Therefore, in the current scenario, the prospect of managing the agricultural system in an eco-friendly and profitable manner is a profound target of interest in order to meet the global food demand as a consequence of exponential population growth. Additionally, the development of sustainable agriculture contributes to its major role in the pest management system and is efficient only when tagged with natural plant products(Kumar *et al.,* 2021). In this quest for sustainability, environmentally friendly botanical preparations are needed to fulfil the current food demand worldwide (Abbey *et al.,* 2019). By just tapping into the recent global trends, one may come across that the present status of food consumption is more inclined towards the utilization of naturally derived products as a protection agent in order to rescue one from the exposure to acute poisoning by pesticides. Botanicals are popularly used in organic farming, where, at premium prices, organic foods are affordable, consumable, and also establish a foundation in the lucrative market where consumers potentially agree to pay as per convenience (Copping *et al.,* 2020).

The issue, allied with significant crop damage due to pests, has become a major constraint worldwide (Kaur *et al.,* 2021). Plant pests have the potential to cause a loss of 20–40% of global production, either directly or indirectly (Dimetry 2012). With the commercialization of synthetic chemicals and the development of resistant cultivars, pests were significantly lowered, and the production quantity of the crop observed a rise. Despite such management practices, pests still cause significant economic damage every year (Goel and Aggarwal 2007). As the usage of pesticides has increased in recent times, pesticidal resistance has emerged as a new constraint (Abirami*et al.,*2013). Besides having a direct negative effect on human and animal health, their excessive use is also associated with acute pesticide poisoning, changes in the natural ecological balance through the reduction of beneficial and non-target organisms, disturbance of aquatic and bird life leads to genetic defects in their subsequent progeny and detrimental to soil health, water and air quality (Chaubey*et al.,* 2017). This amalgamated with the growing demand for low-usage and less toxic crop protection agents by farmers, which further gave impetus to the search for new molecules with novel modes of action. Botanical extracts are candidates in the quest to provide solutions to these grand challenges. An array of questions arose revolving around this relatively neoteric term: "What are botanicals? How are they obtained? Has it been used earlier? " After an in-depth survey of the literature, it became evident that it is not a new concept after all. Since the onset of cultivation practices, plant-derived botanicals have been used as protectants before the rapid commercialization of pesticides (Sarda *et al.,*2020). Additionally, they are environmentally friendly, safe for humans with a narrow

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target range with a specific mode of action, non-toxic to the off-targeted organisms, and safer in nature for better human and environmental health (Cheng *et al.,* 2008).

Bioactive compounds collectively refer to all the biochemical metabolites present in plants that are responsible for the anti-microbial qualities that can be used in pest management (Kumar *et al.,* 2013). Research on botanical products for agricultural use, which had been neglected for a long time, has been encouraged in recent times with the increasing general public interest in organic products and crop protection by eco-friendly pest management strategies (Chhabra *et al.,* 2023). Therefore, botanicals will play an important role in shaping the future agricultural pest management approach with the increase in research and development, which has been lagging for a long time (Choudhury *et al.,* 2018).

Historical background

The earlier mentions of their application date back to 4000 years ago, as documented in Vrikshayurveda (Dodia*et al.,* 2008). Their mention for use is also seen in ancient Roman, Greek, Chinese, and hieroglyphic texts. Aromatic and medicinal plants were used in the form of extracts or decoctions against some ectoparasites and heleminths. Extensive use of plant extracts in post-handling and storage stages for protection against different pests has also been observed (Grzywacz*et al.,* 2014). In 1758, the use of essential oils from various plants was reported in Persia to control scabies from *Sarcoptesscabiei*. Further, botanicals were developed through the extraction of the bioactive compounds responsible for their efficacy against microbes. Nicotine, extracted from *Nicotiana tabacum* i.e., tobacco plants, and rotenone, extracted from *Derris elliptica* plants, were the first pesticides discovered and marketed heavily in the USA in 1945, but their use was later decreased due to their toxicity to non-target species (nicotine) and shorter shelf lives (pyrethrum). These were later replaced by cheaper and easiertohandle chemically synthesized pesticides such as carbamates, organochlorides, and organophosphates (Satish *et al.,* 2007). The indiscriminate use of chemical pesticides continued from that point, leading to negative effects like contamination of water bodies, soil and non-target organisms, as well as acute pesticide poisoning. They can also be termed "biopesticides". Since ancient times, approximately 2400 medicinal and aromatic plant species have been widely acknowledged for anti-microbial activities.

Phytochemical composition of botanical extracts and their action

Secondary metabolites are the biologically active forms of compounds that are present in plants and are attributed to various antimicrobial plant properties (Simmonds 2003). Crude plant extracts are able to activate defense mechanisms in host plants (Romanazzi*et al.,* 2012). The secondary metabolites found in botanicals cause toxicity to the cell walls, membranes, and organelles of targeted pests (Nagamma*et al.,* 2019). These metabolites inhibit spore germination, mycelial development, germ tube elongation, delayed sporulation, and reduced protein synthesis. These compounds might induce structural modifications of the fungal hyphae and inhibit aflatoxin and fumonisin production by some fungi (Doltsinis*et al.,* 2006).

Essential oils are volatile secondary metabolites, lipophilic complexes in nature with a strong odour and lower density (Bakkali*et al.,* 2008). These oily liquids are obtained from plants through fermentation, enfleurage and steam distillation (Burt 2004). They are produced by specialized gland cells that further interfere with the basic physiological, biochemical, metabolic, and behavioural functions. Essential oils and their derivatives have long been considered an alternative means of control against many harmful insects. Essential oils are isolated from plant material by distillation, whereas other volatile isolates are obtained by solvent extraction. Essential oils are generally derived from flowers (rose, jasmine, carnation and lavender), leaves (mint, lemongrass, jamrosa), leaves and stems (geranium, patchouli, cinnamon), bark (cinnamon, cassia), wood (cedar, sandal, pine), roots (vetiver, valerian), seeds (fennel, coriander, caraway, dill, nutmeg), fruits (bergamot, orange, lemon, juniper), rhizomes (ginger, curcuma) and oleoresin exudations (balsam of Peru). It works by causing the rapid degradation of harmful insects in the environment with increased specificity (Kemabonta and Falodu 2013). Monoterpenes are toxic in nature leading to drastic damage to cell organelles, cell membranes, and processes like respiration and photosynthesis. They serve as short-duration signals like alarm pheromones (Wachira *et al.,* 2014). Through their scanning electron microscopic studies, Sharma and Tripathi (2006) reported that the essential oil extracted from *Citrus sinensis* causes thinning and disintegration of hyphae and the absence of conidiophores in *Aspergillus niger*. Kamel (2010) reported antifeedant and insecticidal properties in the seed oil of moringa against the fall armyworm, *Spodoptera frugiperda*. Aqueous extracts of ground moringa leaves controlled dipteran (Alao and Adebayo 2015) and coleopteran pests in fields and in storage conditions (Longe 2016). Essential oils from thyme, *Eupatorium cannabinum*, *Z. officinale* and *Ocimum* have been found to induce host resistance against *Botrytis cinerea* (grey mould) through the priming of defense responses in apple fruit (Banani *et* *al.,* 2018).

Alkaloids extracted from *Ricinus communis, Pergularia tomentosa, Arachis hypogaea* demonstrated anti-feeding and larvicidal properties (Tripathi *et al.,* 2008). Piperidine, an alkaloid obtained from pepper was demonstrated to control a number of diseases incited by *Rhizoctonia solani, Magnaportheoryzae, B. cinerea, P. infestans*and *B. graminis*(Singh *et al.,* 2008).

Phenols are a broad chemical class of secondary metabolites that work principally by disrupting the cellular membranes and causing leakage. It has antimicrobial properties and is used implicitly in enhancing disease resistance by direct or indirect factors and contributing to wound healing via cell wall lignification. Phytoalexins induced by the initial infection further protect the host from infestation. Phenols are known to provide disease-reducing effects, employing several modes of action like resistance-induction. Curcuminoids isolated from the rhizomes of *Curcuma longa* inhibited the mycelial growth of *C. coccodes, C. gloeosporioides, and C. acutatum*causing anthracnose (Khakimov*et al.,* 2020).

Flavonoids form one of the major classes of oxygen-containing (Dougoud*et al.,* 2019)heterocyclic natural products that are widespread in green plants in the form of water-soluble glycosides in the vacuoles of epidermal cells. It is present in many forms, like flavanols, flavons, catechins, proanthocyanidins, isoflavanoids, quercetin, kaempferols and their glycosides (Mahulikar and Chavan 2007). They check the growth of fungus by inhibiting the processes of cell division, cell wall formation, and protein synthesis by influencing its growth and developmental behaviour. Flavonoids such as quercetin and rutin reportedly also inhibit the development and increase the mortality rates of the tobacco armyworm (Mahulikar and Chavan 2007). *Dianthus caryophyllus* flavonoids have inhibitory activity against different *Fusarium oxysporum* strains (Khan and Nasreen 2010).

Acetaldehyde is a naturally occurring volatile compound produced mostly during fruit ripening. It is reported to exhibit inhibitory properties against postharvest pathogens, inhibiting their germination and growth. Barkai-Golan (2001) noted that acetaldehyde fumigated fruits showed reduced fungal decay and conidial germination. High acetaldehyde concentrations resulted in extensive fruit phytoxicity and stem browning. Mari *et al.,* (2016) also reported that for fumigation purposes in strawberries, to significantly reduce graymold and *Rhizopus* rot during storage. Not only fungal but also bacterial postharvest diseases caused by *E. carotovora* in *Capsicum annum* were reduced when acetaldehyde was applied in polythene containers. This volatile compound is also known to inhibit postharvest microorganisms such as *Monilinafructicola, Penicillium* spp. and various other species of yeast found on fruits and vegetables because the aldehyde vapours are found to be most lethal to fungal and bacterial pathogens (Choi *et al.,* 2008).

Hydroxycinnamic acid and its derivatives come under the class of polyphenols which are hydroxyl derivatives of cinnamic acid. They are characterised by their antimicrobial properties and are reported to inhibit *Fusarium* spp.

Latex is a natural polymer rich in enzymes like glucosidases, lipases, proteases and chitinases. It is made up of a complex emulsion of many secondary metabolites that coagulates upon contact with air (Almenar*et al.,* 2007). Barkai-Golan (2001) has demonstrated that latex is a natural fungicide which is considered very effective against various fruit diseases. It also exhibits inhibitory properties against *Trichoderma* spp. *Fusarium* spp. and *Botrytis cinerea*. The water-soluble latex part of papaya can digest many fungal conidia completely, alongside many important postharvest pathogens (Ngadze*et al.,* 2014).

Botanical pesticides in use

Nicotine: Nicotine represents nicotinoids a class of heterocyclic compound alkaloids extracted from tobacco plants (*Nicotiana tabacum*). It is effective against many types of insect pests, particularly aphids, caterpillars, and other soft-bodied insects (Debjani*et al.,* 2017). Nicotine is the active component of tobacco for smoking. It is a type of synaptic poison that mimics the pathway of the acetylcholine neurotransmitter. It has long been used as an insecticide and medicine. Nicotine is an extremely fast-acting nerve toxin. Nicotine interacts with acetylcholine receptors at the synaptic nerve ends of the central nervous system resulting in uncontrolled nerve firing such as twitching, convulsions, and even death. Nicotine does not act as an acetylcholinesterase inhibitor. Its action is selective in nature, affecting only certain types of insects, animals and mammals (Kumar *et al.,* 2021).

Rotenone: Rotenone is a natural insecticide with a broad spectrum of applicability extracted from *Derris, Lonchocarpus, Tephrosia* and *Mundulea* species. It was the most commonly used pesticide in 1990 and was relatively safe when used correctly. But its higher doses are toxic to animal life. Rotenone is a respiratory enzyme inhibitor that interferes with NAD+ and coenzyme Q. Its activity results in the respiratory system’s failure. Rotenone blocks the oxidation of substrates like pyruvate, glutamate and alpha-ketoglutarate and also blocks the oxidation of NADH to NAD. Rotenone inhibits the mitochondrial respiratory chain pathway between diphosphopyridine nucleotide and flavin (Gurjar*et al.,* 2012). Rotenone is also a powerful inhibitor of the electron transport chain operative on the mitochondrial membrane.

Sabadilla: Sabadilla is a compound obtained from the seeds of a tropical lily plant of South American origin known as *Schoenocaulon officinale* belonging to the family Liliaceae. It is also known as caustic barley. The insecticide is formulated by treating the aged sabadilla seeds with alkali, activating many insecticidal alkaloids. The alkaloids found present in sabadilla seeds are known as veratrine alkaloids, constituting 3–6% of the total composition of aged, ripe sabadilla seeds. Among all the alkaloids, cevadine and veratridine are the most active insecticidally. These alkaloids possess neurotoxic activity by slowing sodium channels and disturbing membrane depolarization (Gurjar*et al.,* 2012). They were used against grasshoppers, cattle lice, and house flies. Sabadilla is a highly toxic insecticide even though the original ground seeds have the lowest mammal toxicity. It acts by disrupting the nerve cell membranes, leading to reduced activity and in some cases, even paralysis and death (Dimetry 2012).

Ryania: Ryanodine is a poisonous diterpenoid alkaloid extracted from the stems of *Ryania speciosa* (Salicaceae) which is used as an insecticide. Ryanodine, constituting roughly 0.2% of the stem wood dry weight, is the most active alkaloid found in the stem. Ryanodine is a kind of stomach poison. It is slow in action and works most effectively in hot weather. It does not cause rapid paralysis or death but stops the insects from feeding on the crop immediately (Mahulikar and Chavan 2007).

Pyrethrum: Pyrethrum is the dried powder of *Chrysanthemum cinerariaefolium that contains* chemicals like pyrethrins. Pyrethrins are composed of six related insecticidal compounds naturally occurring in the flower, such as pyrethrin I, pyrethrin II, cinerin I, cinerin II, jamolin I, and jamolin II. Its only drawback is that it degrades rapidly and very easily. Pyrethrins are neurotoxic insecticides that cause blockage of sodium channels in nerve axons, leading to their shutdown followed by death, mostly in cases of extreme exposure. Sodium channels control the sodium ion flux and are essential for signal transmission from nerve cells. Pyrethrins induce toxins that penetrate the insects' cuticle and reach the nervous system, binding their molecules to the voltage-gated sodium channels in nerve axons along their length. Such binding obstructs the normal functioning of the channels, resulting in hyperexcitation and loss of nerve cell function (Chengala and Singh 2017). The commercial preparations are harmful to fish but considerably less toxic to mammals. Pyrethroids are much more pronounced than DDT, affecting both the peripheral and central nervous systems of the insects (Copping 2020).

Azadirachtin: Neem-based products contain the very complex triterpenoid azadirachtin which has been derived from extracts of neem trees belonging to the family Meliaceae and has played a vital role in conferring disease protection (Mahulikar and Chavan 2007). Neem-based biopesticides are used predominantly in two ways: as neem oil cakes or as neem extracts. Azadirachtin, the active ingredient responsible for the pesticidal properties in neem and is present in 25 different derivatives. It is extracted from the seed kernels of the tree and is a registered biopesticide with negligible effects on the environment. It is the active ingredient in many pesticides, including azaguard, azasol, azamax and bioneem. Studies showed that complete inhibition of the growth of *Penicillium digitatum* was reported with the use of crude extracts from *Capsicum frutescence* and*Cerberaodollam* (Yoon *et al.,* 2013). Treatment with neem-based pesticides may lead to crippled wings or even death in soft-bodied insects. In the treatment of adult insects with azadirachitin infertility is increased; mating and sexual communication are disrupted. It also acts as a repellent by preventing insects from initiating feeding activity and causing insects to stop feeding due to the presence of deterrent taste factors or due to secondary hormonal or physiological effects of the ingested deterrent substance (Carpinella*et al.,* 2003). Neem oil acts after forming one layer on the insect's body, blocking the air openings and suffocating the insect. Hassan*et al.,* (2008) have also observed the fungistatic effect of achook (neem product) against the mycelial growth of *Phytophthora drechsleri* (Phytophthora blight of pigeon pea) at a 24 g/ml concentration. Neem extracts can effectively be integrated into management strategies of plant pathogens like *Phytophthora infestans* with a view to avoiding the development of fungicide resistance (Rani *et al.,* 2015).

Limonene: It is a closely related material that is also an extract from orange and other citrus fruit peels. Citrus oil extracts have been combined with insecticidal soap for use as contact poisons against aphids and mites. Limonene and linalool are contact poisons.Both the compounds evaporate readily from treated surfaces and have no residual effect.

Bitter leaf (*Vernonia amygdalina*): Sesquiterpene lactones with insecticidal activities against coleopteran pests and with repellent activities against lepidopteran pests have been isolated from bitter leaf (Kamel 2010).

Moringa (*Moringa oleifera*): Lectins in moringa seeds have larvicidal activity against the *Aedes egypti*. Laboratory trials performed by Kamel (2010) on the fall armyworm indicate that moringa seed oil has antifeedant and insecticidal properties.

Chinaberry (*Melia azedarach*): Chinaberry contains limonoids, whose insecticidal and antifeedant properties have been demonstrated on coleopteran, dipteran, and lepidopteran pests in laboratory trials (Carpinella et al. 2003). Studies indicated that aqueous extracts of chinaberry may be used to control cabbage aphids on cabbage. Hassane et al. (2008) tested ethanol, ethyl acetate and water extracts leaf of *Melia azedarach* against two tomato fungal pathogens at different concentrations and found that both ethanol and ethyl acetate extracts completely suppressed the growth of *F. oxysporum* and *A. solani*.

Extraction procedures

Extraction is basically the process of separating medicinally active portions of plant tissues using selective solvents through standard procedures. These include classes of preparations known as decoctions, infusions, fluid extracts, tinctures, extracts, or powdered extracts. The types of volatile isolates that are obtained commercially from aromatic plants are essential oils, concretes, absolutes, pomades and resinoids. Distillation methods are good for powdered almonds, rose petals and rose blossoms, whereas solvent extraction is suitable for expensive, delicate, and thermally unstable materials like jasmine, tuberose, and hyacinth (Kavitha and Satish 2011). The extract obtained after standardisation can be used as a plant protection agent in the form of tinctures or extracts (Yoon *et al.,* 2013). The general techniques of medicinal plant extraction include maceration, counter-current extraction, decoction, digestion, distillation, maceration, fermentation, hot continuous extraction, infusion, supercritical fluid extraction and ultrasound extraction (sonication).

Systemic acquired resistance: the role of botanicals

Induced or acquired resistance is the phenomenon in which prior treatment changes the biochemistry or physiology of the plant in such a way that it can effectively resist infection by a wide range of pathogens. Generally, in plants, induced resistance or acquired resistance is addressed within the scope of plant pathology. It is a well-documented fact that treatment of plants with botanical extracts can lead to the induction of resistance to pest attack. Induced resistance is not the creation of resistance where there is none. Systemic acquired resistance (SAR) occurs when resistance-induced resistance spreads systemically to untreated parts and organs of plants far from the site of initial infection or treatment with botanical agents. The phenomenon of SAR can be compared to immunisation or vaccination in humans and animals, although the underlying mechanisms are entirely different. Botanical extracts have been reported to induce a defence response in the infected plants and effectively control a wide range of diseases (Chakraborty and Chakraborty 2010). Studies on different botanical extracts have demonstrated the protective nature of the compounds and their inhibitory potential to protect plants from various fungal diseases(Deenamo*et al.,* 2018). Inducers act potentially through a secondary messenger enhancing the host defence mechanisms by either increasing the peroxidase activity, by phenol accumulation, or through some antioxidant enzyme inhibition (Hassan *et al.,* 2007).

Early attempts were made to use methanol leaf extract of *Datura metel*, which was reported to effectively reduce bacterial leaf blight incidence through induced resistance (Kagale*et al.,* 2004). Ashraf and Javaid (2007) provided a fungal disease control in sunflower plants treated with aqueous neem extract through a series of metabolic changes including induction of antioxidant defensive enzymes, phenol biosynthesis enzymes, and phenol accumulation.

It is well established that the induction of SAR and the enhancement of disease resistance result from elevated endogenous tissue levels of salicylic acid (Shara and Stohs 2015). Leaf and fruit extracts of plants like *Azadirachita indica* and *Reynoutriasachalinensis* are used in plant treatment by increasing the enzymatic activity and biosynthesis of antimicrobial compounds (Paul and Sharma 2002). Spinach and rhubarb leaf extracts induce a string of defence responses and could protect cucumber plants against *Colletotrichum* spp. Leaf extracts of the plant *Reynoutriasachalinensis* protect cucumber and tobacco plants against diseases such as powdery mildew by increasing the activities of key enzymes like POX, PPO, PAL (Sundar *et al.,* 2001). Kagale*et al.,* (2011) have demonstrated that foliar application of the aqueous leaf extracts of *Zizyphus jujuba* followed by challenge inoculation with *Rhizoctonia* induces systemic resistance in rice, as evident from significantly increased accumulation of POX, PAL and phenolic substances. Similarly, in potato tubers inoculated with *Fusariumsambicinum*, an increase in phenolic acids due to induced biosynthesis was seen in the area affected by the rot (Walters *et al.,* 2002).

Post-harvest application of botanicals

Volatile organic compounds obtained from botanicals are an eco-chemical approach in postharvest disease control as they are bio-based products with clear environmental benefits due to their renewability and biodegradability. Botanical products can be utilised at the post-harvest stage as washing agents, botanical sanitizers, bio-based edible coatings, antimicrobial agents, cushioning materials during transport, preservatives and as control measures for storage diseases (Mohammadi *et al.,* 2014). These bio agents serve as crucial barriers for respiration, transpiration, restricting the growth of a wide range of micro-organisms, reducing shrivelling and resulting in enhanced shelf life. Volatile organic compounds are potentially employed as gaseous treatments to control postharvest decay. Detailed experiments have been conducted on the plant's produced secondary metabolites and their antimicrobial effects on post-harvest pathogens with encouraging results (Mari *et al.,* 2016). Essential oils have great inhibitory activity with the advantage of their bioactivity in the vapour phase, which makes them a suitable fumigant for stored food protection by inhibiting the postharvest fungi under *in vitro* conditions. Essential oils of *Mentha arvensis*, *Ocimum*and *Zingiber officinale* were found to exhibit fungitoxic activity against *Penicillium italicum* causing blue mould rot of oranges during storage, which in turn resulted in enhanced storage life (Tripathi and Dubey 2004). In 2008, essential oils of mint and tulsi were found to be effective fumigants in the control of fungi that cause post-harvest decay in stored peaches (Ziedan and Farrag 2008). Similarly, the essential oil extracted from the epicarp of *Citrus sinensis* exhibited absolute fungitoxicity against the 10 post-harvest pathogens (Sharma and Tripathi 2006). Razzaghi*et al.,* (2008) also showed inhibitory activity of essential oils of *Cymbopogon flexuosus* against dominant post-harvest fungal pathogens causing rotting in *Malus pumilo*fruits (Amiri *et al.,* 2008). (Dubey and Kishore 1998) reported that the essential oils extracted from the leaves of *Melaleuca Leucadendron*, *Ocimum*spp., and *Citrus medica* were able to protect several stored food commodities from bio-deterioration caused by *Aspergillus* species. The anti-bacterial sanitizers derived from fruits and vegetables are effective against a broad spectrum of micro-organisms, non-carcinogenic, non-mutagenic, non-toxic, and non-volatile (Bhagwat and Datar 2014).

Advantages of botanicals

Farmers are well adept at using plants to produce bioactive compounds due to the long-preserved traditional knowledge. They can also make the best use of the weeds and other medicinal plants in the vicinity (Karavaev *et al.,* 2002). The uses of botanicals are not limited only to agricultural practices. Many botanicals, especially the ones with citrol are used in daily households as insect repellents as well as plants with medicinal applications. Such plants are multi-potential in nature and their beneficiaries are far more numerous than any mentioned. They are environmentally renewable, inexhaustible, indigenously available, and easily accessible. Shorter shelf life and rapid degradation of botanicals might be more convenient in order to reduce the presence of harmful toxins in food and the environment (Magan and Aldred 2007). Since they are plant-derived in nature, they can be used at any time at any developmental stage with little damage to the quality of grains or crop plants. They are relatively cheaper and hence are referred to as suitable plant protecting agents in pest management strategies. Botanicals are quick to act on insect attack and subsequent feeding. They do not kill the insects but swiftly inhibit their feeding on the crop. Most of the biopesticides are stomach poisons, acting in the gut of the pest after feeding, significantly decreasing the death of non-target species. They are highly selective for insects and are far less aggressive than their synthetic counterparts with natural enemies. As with synthetic pesticides, resistance does not develop quickly in the case of botanicals.

Bio-pesticides are greatly favoured in integrated pest management (IPM) strategies due to their several desirable traits. Botanicals are selective in nature and do not for the most part, harm non-target species. They also produce little to no toxins and are thus, considered relatively safer. They are environmentally friendly, high efficacy, target specific and easily biodegradable in nature(Marin *et al.,* 2004).Ngadze (2014) reported that the leaf extracts of *A. sativum* and *C. papaya* can be used effectively for the control of late blight disease in potatoes. In India, Azadirachtin, Pyrethrum, and *Eucalyptus* leaf extract are the only three major botanicals registered and commercially used in the agricultural pest management system in that respective order for various purposes as per the Insecticide Act, 1968. The natural plant product Milsana extracted from *Reynoutriasacchalinensis* is the best natural fungicide known and has been reported to control powdery mildew of tomato, apple and begonia as well as downy mildew of grapevine and rust of bean (Chohan and Perveen 2015). In place of using botanicals as a single product and continuously using it, integrated pest management strategies propose using them at moderate levels and in rotations. They offer an alternative method for controlling and managing pollution caused by the indiscriminate use of synthetic pesticides (Nashwa and Abo-Elyousr, 2012). Thus, botanicals are suitable to be included in IPM programs. These demands have also risen with the increase in public interest in organic food and environmental safety. Nevertheless, the adoption of new botanicals in the world is majorly lagging behind in the global market and needs a boost in the research and development aspect to standardize more procedures and formulations and create better ones. Timorex Gold manufactured by Stockton group is the new generation of bio-fungicides based on a plant extract of *Melaleuca alternifolia* for the control of mildews, rust and blight diseases.

Disadvantages of Botanicals

Their formulation is based heavily on the availability of the raw material which cannot be the same all around the year due to seasonal changes and weather conditions. Therefore, there is no year-around availability. Most of them are deterrents and repellents rather than pesticides. Botanicals act swiftly to prevent insects from feeding often causing immediate paralysis, but they may not kill the insect for a long time. They also degrade rapidly under sunlight, UV light, air, or even moisture, which makes them less toxic environmentally, but may also need re-application time and again. They have short-term residual action with no established residue tolerance. There are no legal registrations or regulatory laws formed by the government establishing their manufacturing, distribution and use. Plant products are relatively safer than synthetic ones as they are less toxic but can still be harmful to non-target organisms like fishes, beneficial insects, mammals and pose a hazard to humans or the environment. They are not really a cheaper substitute for synthetic chemical pesticides, but sometimes they cost more than the chemical ones and results obtained in the laboratory and greenhouses fail to provide consistent disease control under field conditions. There is very little data on the standardisation of better solvent types and extraction procedures for extract distillation(Chengala and Singh 2017). In contrast to conventional synthetic pesticides, which are composed of a single active ingredient, plant-derived products are composed of complex chemical arrangements that work together in both behavioural and physiological processes. This makes registration of the formulated products in the state very expensive as the laws are made according to conventional single-ingredient pesticides. Thus, in the presence of more than one biologically active ingredient, which is the case in botanicals, the registration expense keeps on piling up, adding to the cost of formulation for the manufacturers (Mahulikar and Chavan 2007).

Conclusion and future prospects

Synthetic chemicals have been used predominately all around the world, combined with resistant varieties, for crop protection against pests and to harvest the maximum possible yield. This agricultural approach of synthetic plant protection techniques has led to grave health concerns over the years, such as toxicological problems, loss of soil fertility, disruption of the natural balance, loss of beneficial soil and other microbes. Concerns about the negative effects of chemicals have led to a growing consensus in favour of botanical alternatives. Botanicals do not accumulate any toxins in the environment; they are highly selective towards beneficial insects and low in toxicity levels. The concerns and risks associated with the use of synthetic chemicals have been well documented and should be put under serious regulation for better environmental and human health. Searching for novel classes with alternative modes of action and promoting the usage of those that are already well established is a concern too. Instead of using chemical fungicides and pesticides, farmers should use botanicals. But these sanctions should be put in place, and incentives for the use of botanicals should be given commercially by the government-authorized agencies at very cheap rates in comparison to chemicals to the farmers so that it is not viewed as an alternate niche market but as a new common method in the commercial marketplace. This way, we can make our environment and living world safer.

Concurrently, weaknesses in the biopesticide industry need to be addressed to promote wide adoption in practice. There is a serious lack of any regulations or policies targeted towards botanical formulations, their manufacturing, and their sale. There is a dearth of any safety regulations to assess the safety and toxicity levels of botanicals. Technological innovations should be promoted, allowing the development of more effective and safer products. Upcoming technologies like microencapsulation and nano-formulations, although expensive, should also be researched and promoted. Creating awareness about the advantages and merits of botanical pesticides, their working principles, application, target specificity, and how better harvesting and storage practises are needed Advancing our knowledge on the front of effectiveness, environmental conservation, and botanical regulation remains a big challenge, but addressing them will promote acceptance of botanical pesticides. With the current review, it will be fair to say that botanical preparations hold high potential in the years to come.

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