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Essential Oils with Potential as Insecticidal Agents: A Review

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Abstract

Botanical pesticides/insecticides have a proven track record and long use as simple extractives for pest control reviewed, with an emphasis on natural products that have received regulatory approval. Public concern over use of synthetic insecticides is growing. So botanicals are now replacement by synthetics, the new environmental movement has provided a favourable environment for the rebirth of botanical insecticides. Essential oil products are natural compounds with insecticidal properties and their use in crop protection is as old as agricultural practice. essential oils may provide potential alternatives to currently used insect-control agents, however, essential oils have negative side effects, such as toxicity to humans and animals, environmental contamination, and toxicity to non-target insects have become apparent and interest in less hazardous alternatives of pest control is therefore being renewed. Plant species with known insecticidal actions are being promoted and research is being conducted to find new sources of botanical insecticides.

Keywords

Natural Products, Essential Oil, Insecticides

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1. Introduction

Natural products/Botanical pesticides are naturally occurring chemicals extracted from plants. Natural pesticidal products are available as an alternative to synthetic chemical formulations but they are not necessarily less toxic to humans. Some of the most deadly, fast acting toxins and potent carcinogens occur naturally [1, 2]. Natural products or eco-friendly pesticides are an excellent alternative to synthetic pesticides as a means to reduce negative impacts to human health and the environment. The move toward green chemistry processes and the continuing need for developing new crop protection tools with novel modes of action makes discovery and commercialization of natural products as green pesticides, an attractive and profitable pursuit that is commanding attention. The concept of "Green Pesticides" refers to all types of nature-oriented and beneficial pest control materials that can contribute to reduce the pest population and increase food production. Green pesticides are safe, eco-friendly and are more compatible with the environmental components than synthetic pesticides [3]. Now, the encouragement of use of products from natural resources and even the extremely biodegradable synthetic and semi synthetic products in pest management has been considered to constitute the umbrella of green pesticides [4-6]. Biological activities of essential oils depends upon its chemical composition which, in turn, varies with plant parts used for extraction, extraction method, plant phenological stage, harvesting season, plant age, soil nature and

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environmental conditions [7, 8]. Insecticides based on essential oils and its constituents have been proved effective against many stored-grain insect pests. These have been formulated and applied variously as repellant [9-11], antifeedants [12], growth inhibitors [13, 14], oviposition inhibitors [11, 15] and ovicides [16].

Storage of food grains started with the beginning of agriculture as a safe guard against poor harvests and famine. Simultaneously, several insect species started damaging stored grains both quantitatively and qualitatively and constitute major problem in storing food grains. This damage amounts to 10%-40% in countries lacking modern storage technologies [17]. In India, this damage at a farm level is approximate10% of total production [18]. Among important stored product insect pests, red flour beetle, *Tribolium castaneum* Herbst (Coleoptera: Tenebrionidae) is a cosmopolitan, polyphagous and major secondary pest of processed or damaged grains [19]. This pest has been reported to attack the germ part of the grain. Their presence in stored foods directly affects both quantity and quality of commodity [20]. Rice weevil, *Sitophilus oryzae* L. (Coleloptera: Curculionidae) is also major cosmopolitan pest affecting stored rice. Both larval and adult stages devour kernel, causing weight losses and deterioration of quality and facilitating development of micro-organisms in stored cereals [21, 22]. Attacked seed has a lower germination and also is unlikely to meet stringent industry standards on milling quality. A number of insecticides have been developed for successful control of this pest but use of chemicals against insect pests of stored grains has become ineffective due to the development of resistance in them [23-25]. Ecological variations in the resistance status of different insect pests to diverse insecticides have been observed by various researchers [26-28]. Insecticide resistance and consequent losses of food arising from failure of chemicals in pest control have caused economic losses of several billion dollars worldwide each year [29]. It also increased risk of ozone depletion, neurotoxic, carcinogenic, teratogenic and mutagenic effects in non-targets and cross- and multi-resistance in insects [30-33]. This increased public awareness regarding human safety and environmental damage due to insecticides also diverted attention towards the useof plant products in stored-grain insect pest management. Amongst plant derived chemicals, essential oils have come into play since last two to three decades. Essential oils are natural complex secondary metabolites characterized by strong odour, volatility and have generally lower density than water [34]. Due to their volatility, essential oils are environmentally non persistent [35, 36]. Essential oils are 'generally recognized as safe' by United States Food and Drug Administration (FDA). Recent researches have reported insecticidal nature of several essential oils [37-43].

2. A Brief History

Plants are composed of chemical substances of which some are not directly beneficial for the growth and development of the organism. These secondary compounds have usually been regarded as a part of the plants' defence against plant-feeding insects and other herbivores [44]. The insecticidal and a caricidal property of a number of plants have been discovered long ago, and some of the plants can compete with synthetic means of control [45, 46]. The pesticidal properties of many plants have been known for a long time and natural pesticides based on plant extracts such as rotenone, nicotine and pyrethrum have been commonly used in pest control during the earlier half of this century. However, after the Second World War, they lost their importance with the introduction of the synthetic organic chemicals. The organic chemicals were concentrated products with a high knock-down effect on pest organisms. The chemicals could be produced in large quantities relatively cheaply and they rapidly substituted most other pesticides in the 1950s [47]. As is well known the use of persistent organochlorines like DDT and of the acute toxic organo-phosphorous compounds has led to hazardous effects on environment and human beings. In response efforts were made to strengthen the integrated pest management approach where chemical control, if at all necessary, should be combined with other methods like crop sanitation, resistant varieties and biological control. In addition, attention was directed towards the development of alternative chemicals. One example is the isolation and identification of pyrethrins from the Pyrethrum plant, *Chrysanthemum cinerariifolium,* which made it possible to synthesize the pyrethroids. These broad-spectrum insecticides with both reduced persistence and toxicity (in relation to organochlorines and organophosphorous compounds) spread over the world in the seventies [47]. To the disadvantages of pesticide contamination of the environment and human health risks other aspects can be added. Misuse of non-selective chemicals can wipe out the natural enemies and induce problems with development of resistance. About 450 pest species of insects and mites have now developed resistance to one or more major synthetic pesticides [48]. The yearly consumption of pesticides in developing countries was estimated at 600 000 tons in 1988 with a drastic increase of 184% during 1980-1884 in Africa alone [49]. Because pyrethroids and other newly developed pesticides are expensive many of the harmful but cheaper ones such as DDT are still used today. The success of the pyrethroids has shown the pest control potential of plant derived substances and has revitalized the interest in plants which contain chemical compounds with pesticidal properties. Jacobson [50, 51], who identified the pyrethrins, reviewed the literature on insecticides from plants, covering more than 3000 plant species during the period from 1941-1971. More detailed information on chemical structure, isolation and properties of major botanical insecticides such as pyrethroids, rotenoids and tobacco alkaloids are given by [52]. More recently, Grainge and Ahmed [53] have compiled a global data base which is divided in three sections: 1. a list of 2 400 potential pest-control plant species together with a description of the plant and its pest-control ingredients, the mode of action and the organisms which are controlled. 2. Pests (including nematodes, fungi and bacteria) and plants that control them. 3. Poisonous plants and plants controlling human and animal pests. Also, a list of 41 plant species with broad-spectrum pest-control properties which deserve special attention with regard to large scale use in developing countries [47]. Botanicals were used before other kinds of pesticides. In the beginning it was noted that some plants protect themselves better than others. Since 4000 thousands of years ago had been the use the neem tree (*Azadirachtaindica* Juss.; Meliaceae) as pesticides [54]. In the 18th century, some publications dealt with plant-based formulations to control insect pests [55]. The neem tree, *Azadirachtaindica,* is so far the most promising example of plants currently used for pest control. This holy tree in India, from where it originates, now has a global distribution throughout the tropics. It is used for many purposes such as shade tree, poles for construction, medicine, tooth sticks and as a source of insecticide [56]. Many studied was carried out on the pesticidal properties of the neem tree [57-59]. At the end of the 19th century, methods including the use of toxic plants [60, 61]. Integration of empirical and scientific observations led to the development of plant extracts. The first botanicals and allelochemicals to be used as pesticides came from easily available products. Pest insects were targeted more than pathogens because they could be easily identified [62-65]. The development of botanicals used as pesticides resulted from the observation of the traditional uses of plants and extracts for cattle and crop protection, followed by checking the efficiency of these practices and identification of the active molecules. A systematic screening of families of plants collected during prospecting campaigns followed by biological tests in order to discover the active molecules. Before the Second World War, four main groups of compounds were in fact commonly used: nicotine and alkaloids, rotenone and rotenoids, pyrethrum and pyrethrins, and vegetable oils. This situation continued until the 1960s [66]. At present there are four major types of botanical products used for insect control (pyrethrum, rotenone, neem, and essential oils), along with three others in limited use (ryania, nicotine, and sabadilla). Additional plant extracts and oils (e. g. garlic oil, Capsicum oleoresin). Functional of botanical pesticides varied from product to another and from sources to others. Commercial development of pesticides based on plant has been greatly facilitated by exemption from registration for certain products commonly used in processed foods [67]. This opportunity has spurred the development of botanical insecticides, acracides, fungicides, bactericides, nematicides and herbicides for agricultural and industrial applications and for the consumer market as described by [68-70]. A summary of how neem products are used as bio-pesticides, the mode of action, effects on pests and natural enemies is also produced by [71]. Although the active ingredients in the neem, such as the azadirachtin, are known, it has not been possible to synthesize these complex compounds. Stable formulations of purified extracts are commercialized (Margosan-O and others) and distributed in several countries. Recently in India, during the runup to the signing of the GATT accords, this product has caused debate about the question of patent and the right for farmers to use homemade products from their own neem trees. In general, plants with pesticidal properties can be exploited in three ways. Firstly, by using parts of plants whole, in powder or as crude extracts in water or other solvents, secondly, as purified extracts, like rotenone and Margosan-O and finally as a key to synthesize a chemical compound which then could be produced industrially. Today there is considerable interest among biochemists and botanists to screen plants for secondary chemical compounds, which could be used for developing medicals and pesticides, particularly in the tropical rain forests where plant species are numerous but threatened with extinction [72]. However, it is an expensive and difficult process to isolate and identify the active ingredients and further to produce them in formulations which can be commercialized. Further natural pesticides are not uniform products but rather consist of different active ingredients which often vary in concentration from sample to sample. This makes toxicological tests difficult and costly to run [73]. Therefore one can expect that the interest of the chemical industry in developing new bio-pesticides is rather limited. There is an urgent need to build up reliable food production systems in developing countries, not the least in Africa, where people regularly are faced with harsh environmental constraints of drought and pest outbreaks, a constant lack of agricultural inputs and limited financial means. [47]. Now, efforts have already been made to support the development and use of natural pesticides. In a policy document about bio-pesticides in developing countries. Outline prospects and research priorities. This document contributes with a useful background of the exploitation of plant-derived pesticides [47, 74].

3. Essential Oil as a Tool for Insect Pest Control

In the past few years, several studies have focused on the potential use of essential oil applications in biological control of different insect pests. The essential oils may be more rapidly degraded in the environment than synthetic compounds, and some have increased specificity that favours beneficial in-sects [75]. Their action against stored product insects has been extensively studied [76]. Moreover, these natural derivatives are considered to be an alternative means of controlling harmful larvae of Lepidoptera. Recent research has demonstrated their larvicidal and antifeeding effects [77-79], their capacity to delay development and adult emergence and cause egg mortality [80], their deterrent effects on oviposition [81], and their arrestant and repellent action [82]. Despite these most promising properties, problems related to their volatility, poor water solubility, and aptitude for oxidation have to be resolved before they are used as an alternative pest control system [83]. Pesticides are usually formulated as both conventional liquid (aqueous and non-aqueous solutions or dispersions) and solid (wettable powders and water-dispersible granules) systems or as controlled-release systems [84]. The choice of formulation is influenced by several factors, such as the physical, chemical, and biological properties of the pesticide; the mode of application; the crop to be treated; and agricultural practices. Economic considerations also have to be taken into account particularly when repeat field applications are necessary to maintain pest control. Controlled-release formulations allowing smaller quantities of pesticide to be used more effectively over a given time interval seem to be the best choice to meet these multiple demands of efficacy, suitability to mode of application, and minimization of environmental damage [85]. Moretti et al. [86] studied the effects of some essential oils on*Limantriadispar* (Lepi-doptera: Lymantridae, gypsy moth) larvae, one of the most serious pests of cork oak forests. The results showed that the tested oils (*Thymus herba-barona* Loisel, *Rosmarinus officinalis* L, *Myrtus communis* L, *Eucalyptus globules* Labill, *Salvia officinalis* L, *Helichrysum italicum* sub microphyllum G Don) possess interesting larvicidal effects that make them suitable for application in integrated control strategies. The microencapsulation process gave high encapsulation yields (over 98%) with both essential oils, which have different chemical compositions. The micro-capsules had toxic effects at a concentration similar to that usually employed for localized treatments with microgranular synthetic pesticides. Toxicity appeared to be maximized when the microparticles adhered to the typical hair structures of several defoliator families. These formulations seem to be able to protect the core material against environ-mental agents and could be considered for use in controlled drug release systems. The natural active principles they contain could provide an alternative system in insect pest control.

Chemicalcompounds from the roots of vetiver grass possessrepellent properties useful against ants, cockroach, bedbugs, headlices flied and moth [87, 88]. Vetiver oil and many of its constituents are also repellent and toxic totermites [89-92]. In addition, wood treated with nootkatone a compound and feeding deterrent against Formosan Subteranean termites. They are environmentally less harmful than synthetic pesticidesand acting in many insects in different ways. The roots of some cultivars of vetiver plant and ecotypes possess essential oil that has been utilized as fragrant material since ancient times. The plant also contains active ingredients used in traditional medicine and as botanical pesticide. Sujatha [93] reported the insecticidal activity of the root extract of *Vetiveria zizanioides*(L.). Batish et al. [94] reported that Eucalyptus essential oil possesses a wide spectrum of biological activity including anti-microbial, fungicidal, insecticidal/insect repellent, herbicidal, acaricidal and nematicidal.

Essential oils of lemon grass (*Cymbopogon flexuosus*), eulcalyptus (*Eulcalyptus globules*), rosemary (*Rosmarinus officinalis*), vetiver (*Vetiveria zizanioides*), clove (*Eugenia caryophyllus*) and thyme (*Thymus vulgaris*) are known for their pest control properties. While peppermint (*Mentha piperita*) repels ants, flies, lice and moths. Spearmint (*Menthaspicata*) and basil (*Ocimum basilicum*) are also effective in warding off flies. Moreover, essential oils of *Artemesia vulgaris*, *Melaleuca leucodendron*, *Pelargonium roseum*, *Lavandula angustifolia*, *Mentha piperita* and *Juniperus virginiana* are also effective against various insects [95]. However, volatile oil constituents of *Mentha* species are highly effective against *Callosobruchus maculates* and *Tribolium castanum*, the common stored grain pests [96].

Essential oils derived from eucalyptus and lemongrass has also been foundeffective as animal repellents, antifeedants, insecticides, miticides and antimicrobial products [97]. Essential oil from *Cinnamomumzeylanicum*, *Cymbopogoncitratus*, *Lavandulaangustifolia*syn. *L. officinalis*, *Tanacetumvulgare*, *Rabdosiamelissoides,* *Acoruscalamus*, *Eugenia caryophyllata*, *Ocimum* spp., *Gaultheriaprocumbens*, *Cuminumcymium*, *Buniumpersicum*, *Trachyspermumammi*, *Foeniculumvulgare*, *Abelmoschusmoschatus*, *Cedrus* spp. and *Piper* spp. are also known for their varied pest control properties [97]. Citronella (*Cymbopogon winterianus*) essential oil has been used as an insect repellent and an animal repellent. The larvicidal activity of citronella oilhas been mainly attributed to its major monoterpenic constituent citronellal [97]. Vetiver (*Vetiveria zizanioides*) root essential oil is known to protect clothes and other valuable materials from insect attack when placed in closets, drawers, and chests. Catnip(*Nepeta cateria*) essential oil is highly effective for repelling mosquitoes, bees and other flying insects. The most active constituent in catnip has been identified as nepetalactone. It repels mosquitoes ten times more than DEET. It is particularly effective against *Aedes aegypti* mosquito, a vector for yellow fever virus. Oil of *Trachyspermum* sp. is also larvicidal against *A. Aegypti* and southern house mosquito, *Culexquinque fasciatus* [97]. The essential oils of *Zingiber officinale* rhizomes (*Zingiberaceae*) and *Piper cubebaberries* (*Piperaceae*) were exhibited insecticidal and anti-feeding activities against *T. Castaneum* and *S. oryzae* .[98].

Plant essential oils are complex mixture of mainly terpenoids, particularly Monoterpenes (C10) and sesquiterpenes (C15), and a variety of aromatic phenols, oxides, ethers, alcohols, esters, aldehydes and ketones that determine the characteristic aroma and odour of the donor plant. Presence of volatile monoterpenes or essential oils in theplants provides an important defence strategy to the plants, particularly against herbivorous insect pests and pathogenic fungi [99]. These volatile terpenoids also play a vital role in plant–plant interactions and serve as attractants for pollinators [100]. They act as signalling molecules and depict evolutionary relationship with their functional roles [101]. Aromatic plants and their essential oils have been used since antiquity in flavour and fragrances, as condiment or spice, in medicines, as antimicrobial/insecticidal agents, and to repel in sector protect stored products [101-103]. These constitute effective alternatives to synthetic pesticides without producing adverse effects on the environment [102, 104]. However, the attempts to characterize their pest control activity under in vitro conditions started in 1900s [101]. Moreover, the interest in essential oils has regained momentum during the last decade, primarily due to their fumigant and contact insecticidal activities and the less stringent regulatory approval mechanisms for their exploration due to long history of use [105]. Of late, the essential oils are being tried as potential candidates for weed [106-108], and pest and disease management [104, 109, 110]. It is primarily because essential oils are easily extractable, eco-friendly being biodegradable and get easily catabolized in the environment [111], do not persist in soil and water [104, 105, 112], possess low or no toxicity against vertebrates-fishes, birds and mammals [113] and play animportant role in plant protection against pests [102-104].

Essential oil used as insect/pest repellent and as a pesticidal agent [114]. Additionally, the presence of essential oil also provides defence advantage to *Eucalytpus* leaves against herbivory and attack by harmful insects [115]. In general, the plant secondary metabolites including phenolics, tannins and even monoterpenes are considered to have co-evolved with herbivory [116-118]. The pesticidal activity of eucalyptus oils has been due to the components such as 1,8-cineole, citronellal, citronellol, citronellyl acetate, p-cymene, eucamalol, limonene, linalool, α-pinene, ϒ-terpinene, α-terpineol, alloocimene, and aromadendrene[119-126]. The various components of eucalyptus essential oil actsynergistically (and not additively) to bring the overall pesticidal activity [122]. Among the various components of eucalyptus oil, 1,8-cineole is the most important one and, in fact, a characteristic compound of the genus Eucalyptus, and is largely responsible for a variety of its pesticidal properties [123]. Eucalyptus oil can directly act as a natural insect repellent to provide protection against mosquitoes and other harmful arthropods or serves antifeedant activity against herbivores. Yang et al. [127] reported that essential oils from *E. globules* and its major monoterpene 1,8-cineole showed toxicity against human head lice, *Pediculus humanuscapitis*. The pediculicidal activity of essential oil and its major component 1,8-cineole was more than that of commercially used pediculides-delta-phenothrinor pyrethrum [127]. Of late, Ceferino et al. [128] demonstrated the fumigant toxicity/repellent activity of essential oil from *E. cinerea*, *E. viminalis* and *E. saligna*, against permethrin-resistant human-head lice. So, essential oils could be used for the development of new products for control of human head lice [128].

Eucalyptus oil has also been used as an antifeedant, particularly against biting insects [129- 133]. Trigg [129, 130] reported that eucalyptus based products used on humans as insect repellent canprotect from biting insects. Later, Fradin and Day [134]reported that eucalyptus oil can prevent mosquito bite. Lucia et al. [135]demonstrated that essential oil from *E. globulusis* toxic to *Aedes aegypti* larvae. Seyoum et al. [136] reported that burning of leaves of *E. citriodora* provides a cost-effective method of household protection against mosquitoes in Africa. Of late, CDC (Center for Disease Control and Prevention, USA) recommended the use oflemon eucalyptus oil (with p-menthane-3,8-diol, PMD, as active ingredient) for protection against West Nile virus that causes neurological disease or even death and is spread by mosquitoes[137].

Essential oils and their components can be effectively used to dispel ticks and mites, both parasitic and free-living [138, 139]. Eucalyptus oils rich in cineole have been shown to be effective against varroa mite, *Varroa jacobsoni*- an important parasite of honey bee [140], *Tetranychus urticae* and *Phytoseiulus persimilis* [141] and *Dermatophagoides pteronyssinus*[139]. Based on their study, Choi et al. [141] concluded that eucalyptus essential oils could be used as a natural acaricide for the control of *T. urticae*. Chagas et al. [142]evaluated the biocidal activity of essential oils from Eucalyptus citriodora, *E.*

globulus and *E. staigeriana* against the tick- *Boophilus microplus* and concluded that eucalyptus oils couldbe used as an ecologically and environmentally safer acaricide. Gardulf et al. [143]demonstrated the Citriodiol1, a Eucalyptus essential oil based commercially available product, significantly reduced the number of tick bites in humans and concluded that it could be used to reduce tick-borne infections. Sweet basil (*Ocimum basilicum*) was reported by [144] for its potential as a pesticide. Basil essential oils which are repellent, toxic or growth inhibitory to many insects [53]. Another species; *O. Suave* and O. *canum,* which have been used traditionally against pests. O. suave herb was often placed around windows and doors to keep the mosquitoes away. The principle compound of the essential oils from basil plant was eugenol which was shown to have a strong repellent effect on mosquitoes [145]. Also, linalool is another terpenoid found in basil which responsible for the toxic effect to the bruchid *Zabrotessub fasciatus* and other storage pests [146]. Extracts from *O. suave* have shown promising results in bioassays on maize weevils, *Sitophilus zeamais*. The plant was going to be in focus for future evaluation of botanical pesticides in stored grain at the village level [147].

Recent studies demonstrated the wide range of insect taxa that are affected by essential oils. Kanat and Alma [148] found insecticidal effects of essential oils from *Pinus brutia*, *Laurus nobilis*, *Liquidambar orientalis*, *Juniperus communis* subsp nana Willd, *Cupressussem pervirens*, *Lavandula stoechas*, *Lavandula angustifolia*, *Eucalyptus camaldulensis* and *Thymus vulgaris* against the larvae ofpine processionary moth, *Thaumetopoea pityocampa* Schiff. Ben Jemba et al. [149] found that *Laurus nobilis* essential oil was toxic activities against *Rhyzopertha dominica* and *Tribolium castaneum*.

The Insecticidal action of *Lavandula hybrida*, *Rosmarinus officinalis* and *Eucalyptus globulus* oils and of their 16 major constituents on *Acanthoscelides obtectus* adults was evaluated by Papachristos et al. [150]. All essential oils and monoterpenoids except linalyl and terpinyl acetate were active against both male and female *A. obtectus* adults, with LC50 values ranging from 0.8 to 47.1 mg litre^{-1} air depending on the insect's sex and the structure of the monoterpenoid. Among the monoterpenoids tested, terpinen-4-ol, 1,8-cineol, verbenone and camphor were the most active against *A. obtectus* adults. Ketones were generally more active than alcohols and both were more active than hydrocarbon.

4. Conclusion and Recommendations

There is a common interest in natural crop protection among many researchers and agricultural extensionists in most countries. Some plants are more frequently occurring in the studies than others, such as neem and neem related plants, tephrosia and species of the Euphorbiaceae family. There is a lack of a systematic approach to the problems related with the utilization of plant-derived pesticides. Many studies are carried out in isolation with little back-ground information about the plants and what has been done elsewhere. The documentation is so far scarce. This together with the problems of health risks and environmental pollution, owing to misuse of chemicals, provide good arguments for carrying out studies on natural pesticides. Support to these activities is therefore strongly recommended with particular reference to pest problems in vegetables, stored products and tree plantations. The aim should be to develop reliable pest control methods which are attractive and safe for farmers to use. we recommended to compile information on plants with potential pest control properties, to identify crops and target pests, and to concentrate on some promising plants, including different aspects, to establish work groups focusing on one or a few plants with a key-person as a coordinator and advisor, to carry out comparative studies with emphasis on the mechanisms, to publish and to organize a workshop where new findings are presented and control methods are critically analyzed in relation to the feedback from farmers.

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