Apiaceae Family in Agriculture

Subjects: Horticulture

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Synthetic chemicals are used to protect crops and agricultural products, thereby producing high yields. However, intensive use of these synthetic chemicals significantly affects the environment and sustainable agriculture production. Moreover, direct or indirect exposure to these synthetic chemicals may cause acute or chronic toxicity in humans and animals. Due to their biodegradability, low toxicity, and being environmentally friendly, secondary metabolites derived from plant sources are being studied as a sustainable approach. Apiaceae family crops are a good source of bioactive phytochemicals. Many studies have found that Apiaceae extracts and essential oils possess various biocidal activities: antibacterial, antifungal, herbicidal, insecticidal or repellent, and larvicidal activities, among others. These various potent bioactivities make the Apiaceae an excellent alternative source for synthetic chemicals.

Keywords: Antibacterial ; antifungal ; biocides

1. Introduction

Apiaceae (formerly Umbelliferae) is one of the largest plant families in the order Apiales. Commonly known as parsley or carrot family, it consists of nearly 3780 species belonging to 434 genera distributed throughout many regions in the world [1]. The Apiaceae family includes some of the widely used vegetables and aromatic herbs such as carrot (*Daucus carota*), parsnip (*Pastinaca sativa*), celery (*Apium graveolens*), Gotu kola (*Centella asiatica*), parsley (*Petroselinum crispum*), coriander (*Coriandrum sativum*), dill (*Anethum graveolens*), fennel (*Foeniculum vulgare*), cumin (*Cuminum cyminum*), anise (*Pimpinella anisum*), caraway (*Carum carvi*), as well as poisonous species like water hemlock (*Cicuta maculata*), northern water hemlock (*Cicuta virosa*), poison hemlock (*Conium maculatum*), *Aethusa cynapium* (fool's parsley), and hemlock water-dropwort (*Oenanthe crocata*). Plants of the Apiaceae family are grown, not only as a nutritional source, but also as a source of flavour, fragrance, and medicine. Different parts, such as the root, leaf, leaf stalk, pseudo-bulb, and seed, serve these purposes. All parts of Apiaceae plants contain secretory glands that are important in storing essential oils (EOs), giving rise to the distinct flavour of each species [2][3][4]. Moreover, EO plays a vital role in plants: defence against bacteria, viruses, fungi, insects, and herbivores, and as an attractant to pollinators [5].

2. Phytochemicalsin Apiaceae Extracts

Several Apiaceae species are an excellent source of EOs, which contain more than 760 different chemical components [1][2]. The chemical composition varies with the plant part used for extraction, various extraction methods, phenological stages of the plant, harvesting season, plant age, soil nature, and environmental conditions. These variations in chemical composition have a direct effect on their biological activities [6][7]. Knowledge of these chemical constituents is vital to make use of this economically important plant family, not only for medicinal benefits, but also for environmental applications. Essential oils and their components, mainly monoterpenoids and sesquiterpenoids, show antimicrobial, repellent, chemosterilant, antifeeding, and other biocidal activities [8][9].

3. Potential Use of Apiaceae Extracts as Agrochemicals

Synthetic agrochemicals are used to manage weeds, pests, and phytopathogens, thus increasing productivity and food safety. However, long-time usage of these synthetic chemicals may lead to environmental contamination, accumulation of toxic residues and biomagnification through the food chain, development of insect resistance, and threats to humans and non-target organisms [10][11]. These synthetic chemicals produce acute or chronic toxicity in living beings, depending on physicochemical characteristics, concentration and exposure time, route of entry, toxicodynamics and toxicokinetics (absorption, distribution, half-life, metabolism, and elimination), a combination of various pesticides, and the components of their formulation [10]. Secondary metabolites, including EOs, from aromatic plants, drew much attention due to their low toxicity to animals and non-target insects, fast degradation in the environment, and local availability. Other than the many health benefits, the biocidal potential of Apiaceae has great importance in agriculture for use as a natural pesticide, herbicide or phytotoxin, and antimicrobial [12].

3.1. Insecticidal Activity for Crops and Stored Producs Protection

3.1.1. Insecticidal Activity to Protect Crops

Several Apiaceae genera are toxic to various insects [12]. *Tuta absoluta*, a major pest of tomato cropping, can be controlled by the EO of *Carum capticum* (Ajwain) [13]. Thymol, γ-terpinene, and ρ-cymene are the major components of *C. capticum* oil that showed AChE inhibition [13].

Ammi visnaga (toothpick-plant) seeds possess acaricidal activity against *Tetranychus urticae* Koch, which is a polyphagous species causing damage to numerous plants (around 1200 species), including major food crops and ornamental plants [14].

Cotton leafworm, *Spodoptera littoralis*, causes serious damage to important economic crops, such as maize, cotton, cereals, potatoes, tobacco, tomato, vegetables, and ornamental plants [15][16]. Apiaceae species, *C. carvi*, *F. vulgare*, *C. cyminum*, *C. caraway*, *C. sativum*, *D. carota* [16], *Helosciadium nodiflorum* (water celery) [17], and *Crithmum maritimum* [15] were demonstrated to possess toxicity against *S. littoralis* larvae. Benelli et al. [18] also suggest that cumin (*C. cyminum*) and anise (*P. anisum*) EOs can be used to protect crops from pests or to control insect vectors, as they have potential insecticidal activity against the peach-potato aphid (*Myzus persicae*) and the tobacco cutworm/cotton leafworm (*S. littoralis*), and insect vectors, such as the common housefly (*Musca domestica*). The crop pest *Spodoptera litura* is a threat to many crops and develops resistance to synthetic pesticides. This pest can be counteracted by sea fennel (*C. maritimum*) EOs [19].

3.1.2. Insecticidal Activity to Protect Stored Products

Several species of storage insect pests infest agricultural products and stored granaries, causing substantial weight losses (around 10%) and quality [6]. They may carry pathogens and contaminate food [20]. *Sitophilus oryzae* (rice weevil), *Sitophilus zeamais* (maize weevil), *Tyrophagus putrescentiae* (mould or cheese mite), *Tribolium confusum* (confused flour beetle), *Callosobruchus maculatus* (cowpea weevil), *Periplaneta americana* (American cockroach), *Tribolium castaneum* (red flour beetle) are some of the pests that affect stored cereals, grains, flour, and other dried products [20]. Research is focused on producing safe and low-risk natural compounds for pest control [21]. Several Apiaceae species were reported to carry insecticidal activities and have potential to protect stored grains from insect infestation.

Monoterpenes, such as (S)-(−)-linalool and (S)-(−)-menthone showed the most contact toxicity and fumigant activities, respectively, while α- pinene, menthone, citronellal, and linalool exhibited repellent activities against the rice weevil (*S. oryzae*) [22]. Cuminaldehyde and (S)-carvone showed strong repellent activities, fumigation toxicity, and AChE inhibition [23].

Apiaceae species were demonstrated to possess insecticidal and repellent activity. EOs from *F. vulgare*, *Petroselinum hortense*, *C. sativum*, and *P. anisum* showed stronger fumigant toxicity against the storage pest, red flour beetle (*T. castaneum*) than against the rice weevil (*S. oryzae*) [21]. *C. carvi* EO and two isolated main compounds, (R)-carvone and D-limonene, exhibited strong contact and fumigant toxicity against the maize weevil (*S. zeamais*) and the red flour beetle (*T. castaneum*) [24]. *A. graveolens* (dill), *C. cyminum* (cumin), and *P. crispum* (parsley) EOs were reported as having contact toxicity, fumigant, and repellent activities against the stored grain pest *S. zeamais*. Moreover, AChE inhibition was also reported with *P. crispum* and *C. cyminum* EOs [23]. *Trachyspermum ammi* EO also showed repellent and fumigant activity against the rice weevil (*S. oryzae*). In addition, *T. ammi* EO showed significant inhibition of AChE activity in rice weevils [6].

Insecticidal activity of EO derived from *A. graveolens* (dill) seeds was reported against *T. confusum* (confused flour beetle), *C. maculatus* (cowpea weevils), *M. domestica*, *P. americana* (American cockroach), and *T. castaneum* (red flour beetles)] [25].

Plodia interpunctella (Indian meal moth), *Sitotroga cerealella* (grain moth), and *T. putrescentiae* (mould or cheese mite) affecting stored products, such as grains, flours, feeds, dried nuts, and fruits, globally. *P. interpunctella* moth continuously produces a silken web on the food; *S. cerealella* larvae invade grains and complete the larval and pupal stages within the grains, thus decreasing grain weight and nutritional value; and *T. putrescentiae* mites disseminate toxic fungi and induce allergic reactions among workers engaged in agriculture and food industries. Camphor and linalool found in *C. sativum*

EO, extracted by steam distillation, exhibited acaricidal and insecticidal properties against *P. interpunctella*, *S. cerealella,* and *T. putrescentiae* [26].

3.2. Herbicidal/Phytotoxic Activity against Weeds

Many studies were undertaken to investigate the herbicidal potential of Apiaceae species against weeds. Enzymes such as α- amylase, catalase, and peroxidase enzymes play a key role in the physiological functions of the seeds and plants. Application of EOs increases oxidative stress in plant cells, which inhibits these enzymes and causes subsequent cell death. Moreover, the detrimental effect on the DNA and RNA of the cell results in decreased cell division, growth, and elongation [27].

Herbicidal effects of EOs derived from *C. sativum*, *C. carvi*, *F. vulgare*, and *P. anisum* were reported against various weeds [28]. *Eryngium triquetrum* EO and its major constituent falcarinol showed strong herbicidal activity against *Lepidium*, while *Smyrnium olusatrum* EO showed moderate herbicidal activity. Therefore, *E. triquetrum* and *S. olusatrum* EOs can be used in crop protection to inhibit photosynthesis in weeds [29].

Caraway (*C. carvi*) EO (oil in water emulsion) are rich in oxygenated monoterpenes and exhibited herbicidal activity against *Echinochloa crus-galli* (barnyard grass, a typical maize weed) [30]. *C. carvi* EO was found to inhibit the germination of seeds of common weeds, including *Amaranthus retroflexus*, *Centaurea salsotitialis*, *Raphanus raphanistrum*, *Rumex nepalensis*, *Sonchus oleraceus*, and *Sinapis arvensis* [31].

Fennel (*F. vulgare*) EO strongly inhibited the seed germination and seedling growth of grass weeds, *Phalaris minor*, *Avena ludoviciana*, broad-leaved weeds, *Rumex dentatus* and *Medicago denticulate*, and can, therefore, be used in the biological management of weeds in wheat (*Triticum aestivum*) crops [27]. Fennel (*F. vulgare*) EO was also reported for its phytotoxic activity against field bindweed (*Convolvulus arvensis*) with significant inhibition of germination and early growth in field bindweed seedlings [32].

3.3. Antimicrobial Activity against Phytopathogens

Plant pathogens, including fungi, bacteria, viruses, oomycetes, and nematodes, can cause diseases or damage to plants and result in significant crop yield and quality losses, of which fungi are the predominant pathogens, causing almost 30% of crop diseases during their cultivation or after harvest. Fungal disease symptoms on fruits, leaves, stems, and other plant parts include scabs, mouldy coatings, rust, smuts, powdery mildew, blotches, and rotted tissues. Plant diseases caused by phytopathogenic bacteria and fungi threaten human health and food security [33][34][35][36].

Various phytopathogenic bacteria, including *Xanthomonas* spp. (bacterial spots and blights), *Erwinia* spp. (soft rot, fire blight), *Pseudomonas* spp. (soft rot, bacterial canker), *Agrobacterium* spp. (crown gall), as well as *Ralstonia solanacearum* (bacterial wilt in banana), affect various agricultural plants [37].

Moreover, *Fusarium oxysporum* (vascular wilt of the banana tree), *Macrophomina phaseolina* (damping-off, seedling blight, and rot in peanuts, cabbage, pepper, chickpeas, soybeans, sweet potatoes, sesame, potatoes, sorghum, wheat, corn, etc.), *Alternaria alternata* (rot), *Penicillium digitatum* (green mould in citrus), and *Aspergillus flavus* (damping-off in peanut) are some of the fungi responsible for many diseases in various plants [36][38].

Apiaceae family plants were widely investigated for their potential biocidal activity against phytopathogens.

Apiaceae, such as Torilis anthriscus, Aegopodium podagraria, D. carota, Heracleum sphondyilium, Pimpinella saxifrage, P. sativa, Angelica silvestris, and F. vulgare exhibited antimicrobial activity against phytopathogenic bacteria Agrobacterium radiobacter pv tumefaciens, Erwinia carotowora, Pseudomonas fluorescens, and Pseudomonas glycinea [33]. The EO of C. maculatum (poison hemlock), a poisonous Apiaceae species, has antibacterial activity against Pseudomonas aeruginosa [39].

E. triquetrum EO exhibited strong antibacterial activities against potato blackleg disease, *Pectobacterium atrosepticum*, and the soil bacterium *Pseudomonas cichorii*, which is responsible for disease in lettuce, celery, and chrysanthemum, while *S. olusatrum* EO showed moderate antibacterial activity [29].

The Apiaceae Ferulago angulate exhibited toxicity in variable degrees against phytopathogenic bacteria (Erwinia amylovora, Xanthomonas oryzae, Pseudomonas syringae, Pectobacterium carotovorum, R. solanacearum, Bacillus thuringiensis), and fungi (A. alternata, Culvularia fallax, M. phaseolina, F. oxysporum, Cytospora sacchari, Colletotrichum tricbellum) [40].

A. alternata and *P. digitatum* are two postharvest pathogens in tomato fruits. Based on in vivo studies, *Carum copticum* and *F. vulgare* EOs have the potential to control postharvest decay in tomatoes caused by *A. alternata* and *P. digitatum* [41].

E. triquetrum and *S. olusatrum* EOs have potent antifungal and fumigant activity against *Fusarium graminearum* (cereal fusarium) and moderate activity against *Botrytis cinerea* (grey rot on tomatoes, strawberries). *S. olusatrum* EO showed strong antifungal activity against *F. graminearum* and *Zymoseptoria tritici*, which are responsible for the septoria blight [29].

A. graveolens (dill) seeds EO mainly consists of carvone, limonene, α-phellandrene, β-phellandrene and p-cymene and were proved to have antifungal (*Aspergillus niger*, *Aspergillus oryzae*, *A. flavus*, *A. alternata*) and antibacterial (*Escherichia coli*, *P. aeruginosa*, *Bacillus subtilis*, *Staphylococcus aureus*) activities [25].

Food poisoning is the most common cause of illness and death in both developed and developing countries. Most food poisoning diseases are caused by bacterial contamination. Pathogenic and food spoilage bacteria, such as *Salmonella typhi*, *E. coli*, *P. aeruginosa*, *S. aureus*, *Listeria monocytogenes*, and *Bacillus cereus* are the causal agents of foodborne diseases or food spoilage. Plant extracts are a good source of antimicrobial agents that can be used as food preservatives [42][43].

Apiaceae *C. cyminum* was reported to be effective against *S. aureus* [43]. Coriander (*C. sativum*) EO and its major compound linalool showed antibacterial activity against *Campylobacter jejuni* and *Campylobacter coli*, pathogens that cause foodborne diseases [44].

Coriander (*C. sativum*) was also reported to have strong antimicrobial activity against bacteria, *B. subtilis*, followed by *Stenotropomonas maltophilia*, and *Penicillium expansum* (fungi producing mycotoxin). Moreover, the strongest antibiofilm activity of coriander EO was also reported against *S. maltophilia* [45].

Carum nigrum (black caraway) seed EO has antibacterial activity against foodborne bacteria, *B. cereus* and *P. aeruginosa,* and antifungal activity against foodborne fungi, such as *P. purpurogenum*, *Acrophialophora fusispora*, *A. flavus*, and *A. niger* [46].

The antimicrobial activity of *T. ammi* (Ajwain) EO was demonstrated against various food spoilage and foodborne bacteria (*B. cereus*, *S. aureus*, *L. monocytogenes*, *Salmonella typhimurium*, *E. coli*) and fungi (*Penicillium citrinum*, *Penicillium chrysogenum*, *A. flavus*, *A. niger*, *Aspergillus parasiticus*) [47].

Moreover, certain fungi, including *Aspergillus* spp., *Fusarium* spp., and *Alternaria* spp., produce mycotoxins that can be harmful to human health due to hepatotoxic, nephrotoxic, and carcinogenic effects, or even cause death [34]. Mycotoxins are toxic secondary metabolites produced by certain fungal species in various agricultural and other food products, either in the field or during storage. Mycotoxin contamination in crops is potentially harmful to animals and human health. Aflatoxins B1, B2, G1, and G2 are the four major toxins generated in foods, of which the aflatoxin B1, secreted by *A. flavus*, *A. parasiticus* and *Aspergillus nomius*, is the most toxic and has potent teratogenic, mutagenic, hepatotoxic, and immune suppressive activities [48][49][50].

Apiaceae, *F. vulgare* EO extracted from flowers and roots, significantly inhibited the growth of *A. parasiticus* and the production of aflatoxins B1 and G1 [51]. Carvone and linalool compounds found in *C. carvi* and *C. sativum* seed EOs, respectively, showed an antifungal and aflatoxin-inhibition ability against *A. flavus*. Thus, they can be used as a preservative, particularly in post-harvest processing and the storage of agricultural products that are susceptible to aflatoxin contamination, such as cereals, dried fruits, and spices [50]. EOs of other Apiaceae plants, including *C. cyminum* [52], *C. carvi* [53][54], *C. sativum* [53], and *C. copticum* (*T. ammi*) were also reported to inhibit both growth and/or mycotoxin production.

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