REVIEW ARTICLE

BOTANICAL FUNGICIDES; CURRENT STATUS, FUNGICIDAL PROPERTIES AND CHALLENGES FOR WIDE SCALE ADOPTION: A REVIEW

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ABSTRACT

About 70-80% losses in agricultural production due to microbial disease is caused by fungal pathogens. There are around 8,000 fungal species that cause 100,000 diseases in plants. It is impossible to control such a large species of fungi with chemical fungicides alone. Even if it is made possible, it would bring negative impacts to the environment and human health. Thus, it is a high time to seek an alternative to chemical fungicides which should be eco-friendly. Botanical fungicides can be the viable and sustainable alternative in this regard. A number of researches have proved the fungicidal properties of phytochemicals. They are easily degradable; maintain soil properties and safe to the environment and human. In the present context, researchers are showing interest towards botanical fungicides. Nevertheless, their commercialization and wide-scale adoption have not yet achieved. Thus, this study aims to reveal the current status and fungicidal properties of various potential plants and, also to investigate challenges for its adoption in commercial scale through critical analysis of the related literatures. Lack of sufficient knowledge and extension facilities at the farmer's level and slow result as compared to chemical fungicides are the major reasons behind their poor adoption. Thus, it is a high time for the collaboration among researchers, policy makers, businessman and farmers for the exploration, legalization, proper marketing and wide-scale adoption of botanical fungicides. If the approaches like sustainable agriculture, organic farming and integrated pest management (IPM) need to be extended, focuses should be given towards botanical fungicides.

KEYWORDS

Botanical fungicides, Present scenario, Antifungal properties, Adoption, Challenges.

1. INTRODUCTION

Fungi are the most damaging agents in agriculture sector among all the other groups of microorganisms. Fungal pathogens have caused havoc for all populations including farmers, researchers, agri-entrepreneurs, policymakers and consumers (Fletcher et al., 2006). Losses suffered by crops due to microbial disease is 16%, out of which 70-80% losses were caused by fungi (Moore, 2020). Agrios reported that about 8000 fungal species can cause around 100, 000 diseases in plants (Agrios, 2005). A group researcher revealed that we consume only 6% of the total dry biomass produce due to such losses during production (Alexander et al., 2017). The use of chemical fungicides to control plant diseases has begun since 1882 with the introduction of sulfur fungicides (McCallan, 2012). Chemical fungicides are reported to have effective control over fungal pathogens. Nevertheless, their long-term use has resulted great harm to the environment.

They degrade soil properties, bring risk to human health and cause negative impact to non-target organisms. They are also reported enhancing resistant capacity in fungal pathogens (Dovas et al., 1976; Cooke et al., 2006; Hahn et al., 2014). Furthermore, their residues reach to the water sources through runoff and result adverse effects to the

aquatic ecosystem. Botanical fungicides, on the other hand can be the viable and sustainable alternative in this regard. Botanical fungicides are the plant extracts, essential oils, gums, resins, etc that have potential mode of action to control fungal pathogens. These phytochemicals have the ability to control fungal pathogens in vitro and in vivo (Copping and Duke, 2007; Jalili et al., 2010; Romanuzzi et al., 2012). Cowan reveals there are more than 250,000 higher plant species that possess bioactive compounds which can be applied as agrochemicals and pharmaceuticals (Cowan, 1999).

There is no exact record for the first use of botanical fungicides, nevertheless the use of organic fungicides has begun since 1934 (McCallan, 2012). Botanical fungicides are environmentally safer and eco-friendly. The best part of them is that they are persistent for short time and are easily degradable. They do not cause harm to the useful microorganisms of soil and hence, help to maintain soil property. They lack cross-resistance due to their different mode of action than that of synthetic fungicides (Vidhyasekaran, 2004). Botanical fungicides can be easily prepared by farmers themselves at home, or they can afford it due to its lower price as compared to chemical fungicides. The adoption rate of botanical fungicides is high for those farmers who use plant extracts as a medicine for human disease (Nuzhat and Vidysagar, 2013).

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Gnanamanickam revealed that botanical fungicides have minimum negative impacts on the physiological processes of plants (Gnanamanickam, 2002). Despite having such potential advantages, botanical fungicides are underestimated. Commercialization in the production of botanical fungicides has not yet achieved. A lot of works or researches have been carried out focusing on the potential ability of plant products as fungicides. Nevertheless, there are limited studies for the minute investigation of the prevalent challenges and their solutions related to botanical fungicides. This study aims to present the current status of botanical fungicides, to reveal the fungicidal properties of the selected plants, to investigate the challenges for the commercialization and adoption of such products and to provide effective and appropriate solutions and future research guidelines through critical analysis of the situation.

2. METHODOLOGY

Related information was gathered by using secondary data. This paper is the outcome of the review of nearly three dozen of literature that includes journal articles, books, reports from different agricultural institutes and websites. After thorough study their conclusion is summarized and critically evaluated. Data from FAOSTAT were assembled to generate a graph with the help of Microsoft Excel Software.

3. RESULT AND DISCUSSION

3.1 Present scenario of the use of botanical fungicides

At present, with growing attention towards Integrated Pest Management (IPM) and organic farming, the use of botanical fungicides is rapidly increasing. The progressive farmers are now become concerned about the negative impacts of synthetic fungicides and show interest towards the use of botanical fungicides. Researchers are exerting their efforts for the exploration of potential plants having fungicidal properties. They are conducting researches to develop effective and convenient extraction methods and to know the mode of action on target fungi. The rate of the use of synthetic fungicides in agriculture is slowly increasing in these recent years as compared to 2000s (figure 1). This reveals that the use of botanical fungicides is gaining its momentum.

Figure 1: Synthetic fungicides used in agriculture (2000-2018) (FAO, 2020)

3.2 Classes of Phytochemicals and their mode of action

3.2.1 Phenolic compounds

Phenolic compounds are characterized by having an aromatic ring attached with one or more hydroxyl groups and, acts as antioxidants. They have C3 side chain at a lower level of oxidation and those containing no oxygen as referred as essential oils which possess antifungal property. The site(s) and number of hydroxyl groups on the phenolic compounds are directly proportional to their relative toxicity to fungi (Geissman, 1963). A group researcher revealed that phenolic compounds have both defensive and antifungal properties. Phenolic compound with antifungal property mainly includes simple phenolic compounds, tannin, flavonoids, flavanols, coumarin and its derivatives and anthraquinones (Furiga et al., 2009). The common phytochemicals which lie in phenolic groups with antifungal properties are quercetin, psoralen and anisaldehyde (Table 1).

Table 2: Mode of action of phenolic compounds (Cowan, 1999)	
Subclass	Mode of action
Simple phenol	Substrate deprivation
Phenolic acids	Membrane disruption
Quinones	Bind to adhesins, complex with cell wall, inactivate enzymes
Flavonoids	Bind to adhesins
Tannins	Bind to protein, bind to adhesins, membrane disruption, enzyme inhibition, substrate deprivation and metal ions complexation

3.2.2 Terpenoids and essential oils

The fragrance of plants is carried in the essential oil fraction which are enriched in compounds based on an isoprene structure and are called terpenes (Cowan, 1999). The general chemical structure terpene is C₁₀H₁₆. When terpenes contain oxygen functional group, it is referred as terpenoids. Terpenoids occur as diterpenes (C₂₀), triterpenes (C₃₀), tetraterpenes (C₄₀), hemiterpenes (C₅) and sesquiterpenes (C₁₅). A group research reported that terpenoids are normally produced in vegetative tissues, flowers and occasionally, in roots (Dudareva et al., 2004). Terpenoids cause membrane disruption of fungi with help of the lipophilic compounds (Mendoza et al., 1997; Cichewicz and Thorpe, 1996). The common phytochemicals which lies in this class are Eugenol, Caryophyllene oxide, Cinnamaldehyde, Myristicin, Thymol, Elemicin, Menthone, Citronellal, Terpinolene (Table 1).

3.2.3 Alkaloids

Alkaloids are chemically diverse group of cyclic nitrogen compounds. They are extremely toxic when pH is changed. During in vitro antifungal assays of the ethanol extract of roots and rhizome of the plant *Veratrum taliense*, a study reported that the verazine- (veramilaline, stenophylline B, stenophylline B-3-O-b-D-glucopyranoside, veramiline-3-O-b-D-glucopyranoside) and jervera-trum-type (jervine, jervine-3-O-b-D-glucopyranoside) alkaloids exhibited strong antifungal activities against the phytopathogenic fungus *Phytophthora capsici* with MICs of 160, 120, 160, 80, 80 and 120 mg·L⁻¹, respectively (Zhou et al., 2003). They are antifungal due to the fact that they intercalate into cell wall and/or DNA (Burdick, 1971; Houghton et al., 1994). Phytochemical which lies in the class of alkaloids are Anonaine and Tropane (Table 1).

Phenolic compounds

Terpenoids

Alkaloids

Figure 2: Structures of the phytochemicals mentioned in the table 1

4. CHALLENGES IN THE COMMERCIAL PRODUCTION AND ADOPTION OF BOTANICAL FUNGICIDES

Researches regarding the potential use of botanical products as fungicide are increasing at an exponential rate. Nevertheless, adoption of botanical fungicides in the farmer's level is not so satisfactory. Lack of sufficient knowledge about botanical fungicides and extension facilities are the major reasons behind this problem. Unavailability of botanical fungicides in the market at required time and less effective as compared to chemical fungicides repel the farmers from their adoption. Botanical fungicides can be produced by farmers themselves. But they are inclined towards chemical fungicides as the production of botanical fungicides requires specific plants and consumes significant time and labor. Furthermore, strict legislation, less persistent or rapid degradation and variation in the composition of active ingredients with plants grown in different climatic conditions prevent the large scale adoption of botanical fungicides (Isman and Grieneisen, 2014). A group researcher reveals that the toxic effect of botanical fungicides normally disappears within 14-21 days (Khalid et al., 2002). For the production of botanical fungicides in commercial scale, it requires large biomass of selective plants (Isman, 2006). This problem of bulkiness during collection, production and application obstructs in their wide scale production and adoption (Anjorin and Salako, 2009). Plant products for the production of fungicides have limited market range. Less market demand of such products and increasing demand of food crops hinder the commercial production of botanical fungicides.

5. WAYS FORWARD

5.1 Farmer's level

Extension facilities regarding identification, methods of preparation and application of botanical fungicides need to be provided at farmer's level for the production in small scale. Subsidies should be provided to them to encourage the production and application of botanical fungicides. Awareness regarding importance of botanical fungicides over chemical fungicides should be spread. Concept of organic farming and sustainable agriculture can attract them towards such products so focus should be given towards such approaches.

5.2 For commercial production

None of the producers are willing to take risk in their production. Thus, market for the botanical fungicides should be made secured. It would be better if the prices are fixed by the government according to their quality. It is necessary to make easy legislation for their import and export. Taxes should be reduced in such products and can be increased in chemical fungicides. Loan with negligible interest needs to be made available to the producers by the government for large scale production.

5.3 For researchers

Exploration of potential plants having fungicidal properties should be done. Percentage of essential oil in such plants can be increased by applying tools of plant breeding. Improvement in the methods of extraction and processing should be done to maintain good quality. Specific climatic conditions should be identified for the site-specific production of plant species by conducting number of researches.

6. CONCLUSION

Fungal pathogens have caused havoc to the agriculture sector. Though chemical fungicides can effectively control fungal pathogens, their long-term use contaminates the environment and brings risk to the human health. Botanical fungicides can be the viable and sustainable alternative to synthetic fungicides. Botanical fungicides are easily degradable, maintain soil properties and do not bring risk to the human health and non-target microorganisms present in the soil. In these recent years, the

use of botanical fungicides is in increasing rate. Nevertheless, their production and adoption is not yet satisfactory. Lack of sufficient knowledge about the importance of botanical fungicides, timely unavailable in market, strict legislation for their mobilization and more inclination of the farmers towards cereal crops rather than the commercial production of potential plants having fungicidal properties are the major reasons behind this problem. For effective and sustainable control of fungal pathogens, the use of botanical fungicides is indispensable. Extension facilities should be provided at grass root level. Concept of organic farming and integrated pest management (IPM) need to be extended among the farmers. The good coordination among the researchers, policymakers, businessman and farmers for the exploration, legalization, marketing and adoption of botanical fungicides is necessary.

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APPENDIX

Table 1: Twenty five potential plants with their antifungal properties

S.N	Common name	Scientific name	Family	Plant part used	Targeted fungus	Phytochemical present (Boulogne, 2012)	Extraction method	Class of phytochemical
1.	Neem	<i>Azadirachta indica</i>	Meliaceae	Leaf Seed	<i>Aspergillus niger</i> , <i>Fusarium oxysporum</i> and <i>Trichoderma reesei</i> (Upasana et al., 2002)	Quercetin	Hydro distillation	Phenolic compound
2.	Eucalyptus	<i>Eucalyptus globules</i>	Myrtle	Leaf	<i>Pythium ultimum</i> and <i>rhizoctonia solani</i> (Katooli et al., 2011)	Eugenol	Steam distillation	Terpenoids
3.	Turmeric	<i>Curcuma longa</i>	Zingiberaceae	Rhizome	<i>Helminthosporium oryzae</i> (Harish et al., 2004)	Eugenol	Hydro distillation	Terpenoids
4.	Clove	<i>Syzygium aromaticum</i>	Myrtle	Flower bud	<i>Aspergillus niger</i> (Viuda-Martos, 2007)	Eugenol, Caryophyllene oxide and cinnamaldehyde	Steam distillation	Terpenoids
5.	Ginger	<i>Zingiber officinale</i>	Zingiberaceae	Rhizome	<i>Penicillium digitatum</i> (Al-samarrai et al., 2012) <i>Fusarium oxysporum</i> f.sp. <i>lycopersici</i> (Rawal and Adhikari, 2016)	Gingerols	Hydro distillation	Phenolic compounds
6.	Black pepper	<i>Piper nigrum</i>	Piperaceae	Seed	<i>Aspergillus niger</i> (Avasthi et al., 2010)	Eugenol, myristicin	Steam distillation	Terpenoids
7.	Mint	<i>Mentha sp.</i>	Lamiaceae	Shoot parts	<i>Alternaria alternata</i> (Feng and Zheng, 2007) <i>Botrytis cinerea</i> (Mermer- Dogu and Zobar, 2014)	Menthone, Thymol	Steam distillation	Terpenoids
8.	Sweet flag	<i>Acorus calamus</i>	Acoraceae	Leaf, rhizome and stem	<i>Microsporium gypseum</i> , <i>Trichophyton rubrum</i> and <i>Penicillium marneffei</i> (Phongpaichit et al., 2005).	Elemicin, menthone and eugenol	Steam distillation / Hydro distillation	Terpenoids
9.	Lemon grass	<i>Cymbopogon nardus</i>	Poaceae	Leaf	<i>Candida</i> sp. (Silva et al., 2008)	Citronellal, terpinolene	Steam distillation	Terpenoids
10.	Rosemary	<i>Rosmarinus officinalis</i>	Lamiaceae	Leaf	<i>Aspergillus flavus</i> (Moghtader et al., 2011)	Thymol and caryophyllene oxide	Steam distillation	Terpenoids
11.	Croton	<i>Croton chichenensis</i>	Euphorbiaceae	Root	<i>Fusarium oxysporum</i> , <i>Alternaria tagetica</i> , <i>Colletotrichum gloeosporioides</i> and <i>Rhizopus</i> sp. (Gamboa-Angulo et al., 2008)	Eugenol	Hydro distillation	Terpenoids
12.	Tobacco	<i>Nicotiana glauca</i>	Solanaceae	Leaf	<i>Penicillium digitatum</i> and <i>Rhizopus</i> sp. (Suleiman, 2011)	Eugenol	Steam distillation	Terpenoids
13.	Cumin	<i>Cuminum cyminum</i>	Apiaceae	Seed	<i>Fusarium oxysporum</i> f.sp. <i>tulipae</i> (Boyras, 2005)	Anisaldehyde	Hydro distillation	Phenolic compound
14.	Cinnamon	<i>Cinnamomum verum</i>	Lauraceae	Leaf and bark	<i>A. niger</i> , <i>A. flavus</i> and <i>Fusarium</i> sp. (Singh et al., 2007)	Cinnamaldehyde, caryophyllene oxide and eugenol	Steam distillation	Terpenoids
15.	Lavender	<i>Lavandula sp.</i>	Lamiaceae	Leaf	<i>Alternaria alternata</i> (Zaker and Mosallanejad, 2010)	Caryophyllene oxide and eugenol	Steam distillation	Terpenoids
16.	Datura	<i>Datura stramonium</i>	Solanaceae	Leaf	<i>Alternaria alternata</i> (Pande and Chauhan, 2011) <i>A. fumigatus</i> , <i>A. flavus</i> and <i>A. niger</i> (Dabur et al., 2005)	Tropane	Acid-base extraction	Alkaloids
17.	Coriander	<i>Coriandrum sativum</i>	Apiaceae	Leaf and stem	<i>P. oryzae</i> , <i>T. padwickii</i> , <i>B. oryzae</i> , <i>A. alternata</i> , <i>D. halodes</i> and <i>F. oxysporum</i> (Mandal and Mandal, 2015)	Myristicin, psoralen	Hydro distillation / steam distillation	Terpenoids Phenolic compound
18.	Ashok	<i>Polalthyalongifolia</i>	Annonaceae	Leaf	<i>Colletotrichum musae</i> (Bhutia et al., 2015)	Anonaine	Acid-base extraction	Alkaloids
19.	Boldo	<i>Peumus boldus</i>	Monimiaceae	Leaf	<i>A. niger</i> and <i>A. flavus</i> (Souza et al., 2005)	Eugenol	Steam distillation	Terpenoids
20.	Tulsi	<i>Ocimum gratissimum</i>	Lamiaceae	Leaf and flower	<i>Alternaria</i> sp. and <i>Rhizoctonia solani</i> (Faria et al., 2006)	Thymol and eugenol	Steam distillation	Terpenoids
21.	Common sage	<i>Salvia officinalis</i>	Lamiaceae	Shoot parts	<i>Verticillium dahlia</i> and <i>Penicillium aurantiogriseum</i> (Rus et al., 2015)	Thymol and Caryophyllene oxide	Steam distillation	Terpenoids

22	Maidenhair tree	<i>Ginkgo biloba</i>	Ginkgoaceae	Leaf	<i>Rhizoctonia solani</i> (Oh et al., 2014)	Thymol	Steam distillation	Terpenoids
23	Citrus	<i>Citrus sp.</i>	Rutaceae	Citrus peel	<i>Botrytis cinerea</i> (Jing et al., 2014)	Thymol	Hydro distillation	Terpenoids
24	Lantana	<i>Lantana camara</i>	Verbenaceae	Leaf, fruits, stem	<i>Colletotrichum falcatum</i> (Sreeramulu et al., 2017) <i>A. flavus</i> and <i>A. niger</i> (Fayaz et al., 2017)	Eugenol	Hydro distillation	Terpenoids
25	Bael	<i>Aegle marmelos</i>	Rutaceae	Leaf	<i>Phomopsis vexans</i> (Singh et al., 2012)	Essential oil	Steam distillation	Terpenoids