Natural products from plants: an environmentally friendly tool to control of *Macrophomina phaseolina* (Tassi) Goid. (Botryosphaeriaceae)

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Macrophomina phaseolina (Tassi) Goid. causes the disease charcoal rot on a broad range of plants in many areas of the world. The fungus is responsible for economic losses in various crops. To face this burden, several alternatives of treatment have been used for control of the disease caused by *M. phaseolina* in plants, mainly by using chemical products that usually can affect human health and cause environmental damage. However, due to the side effects of chemicals, several scientists around world have been made several efforts as an attempt to develop new bioalternative techniques to control charcoal rot, thus trying to avoid the traditional chemical control. This review summarizes plant alternative compounds to chemicals, and cites sixty two plants with antifungal properties against *M. phaseolina*. The activities described in this review show that there are many plant extracts, essential oils and pure compounds that should undergo further studies to better understand whether they may be used, in the future, as a field biopesticide.

Keywords: Biopesticides; essential oil; plant extract; phytopathogenic fungi; bioactive compounds; botanical pesticides

1. Introduction

The fungi take an important part in the microorganism world. They might have benefit to sciences, industries and technology. Nevertheless, filamentous fungi appear to be a potential harm for humans, animals and crops. In fact, many of them are phytopathogenic and/or mycotoxigenic.

Plant pathogens are responsible for yield loss in many economically important crops and trees. Crop protection technologies which include herbicides, insecticides, fungicides as well as biotechnology products, help to control thousands of weed species, harmful insects and numerous plant diseases that affect crops. Without these important technologies of crop protection and pest control, the world food production would decline, substantial crop damage would take place, many fruits and vegetables would be in short supply, and the price of agro-food products would rise.

During the second half of the twentieth century, one of the major concerns in agriculture was focused on pollution originated by the extensive use of highly toxic agrochemicals such as pesticides [1,2]. Since the 1970s several studies have shown that, besides the harmful effects at the public health level, the use of pesticides have led to the emergence of phytopathogen resistance caused by the systematic use of a product [3]. As the presence of pathogens in crops of global economic importance is persistent, both industry and academy have increased their efforts in finding solutions to that problem.

However, pesticides have been linked with deleterious effects on environment and human health. Children exposed to pesticides have increased rates of leukemia and brain cancer (astrocytomas) [4], and pregnant women with exposure have higher miscarriage rates [5]. Pesticides may also damage the lungs and nervous system and cause cardiovascular congenital malformations [6, 7]. In nature, pesticides can easily contaminate the air, ground and water when they run off from fields; as a result, plant and animal life may be threatened.

Recently, there has been an increasing interest in phytopathogens control strategies with natural substances released by plants, namely allelochemicals (allelopathic compounds), rather than with chemical compounds [8, 9]. Thus, there are reasons to develop alternatives to conventional pesticides, alternatives that are of low environmental risk and present a lower risk of the development of pesticide resistance in the pathogen; a characteristic that will enhance durability of agriculture and environment.

Due to the ineffectiveness of chemical controls, natural products including plant extracts (PEs) and essential oils (EOs) present many advantages in terms of sustainability, mode of action and toxicity within an integrated management strategy for the disease [10], where biological control arises as an alternative challenge. Moreover, interest in secondary metabolites from PEs and EOs, as potential antimicrobial agents for use in crop protection, has increased during recent decades [11, 12.

Macrophomina phaseolina (Tassi) Goid. causes the disease charcoal rot on a broad range of plants in many areas of the world [13]. The fungus has a wide geographical distribution, and is especially found in tropical and subtropical countries with arid to semi-arid climates in Africa, Asia, Europe, and North and South America [14, 15, 16].

The lack of a known teleomorph has stalled its taxonomy over the years [17, 18]; however, a thorough phylogenetic study of 113 members of the family Botryosphaeriaceae using ribosomal DNA sequences was able to separate the genera *Macrophomina* and *Tiarosporella* [18]. *M. phaseolina* is very widespread across the world and poses a threat to crop production [19]. It is one of the most destructive plant pathogens in the tropics and subtropics, causing disease in a wide range of host plants [20], with the most common diseases being charcoal rot, damping-off [21], dry rot, wilt, leaf blight and ashy stem blight. In addition, *M. phaseolina* from different crops are cross-pathogenic [22]. The fungus is known to cause stalk rot or charcoal rot disease in more than 500 plant species worldwide in arid and water-deficient regions of the world [23], including grass species such as *Avena sativa*, *Sorghum bicolor* and *Zea mays*, legumes such as *Arachis hypogaea*, *Cicer arietinum*, *Glycine max*, *Medicago sativa*, *Phaseolus* spp. and *Vigna unguiculata*, and many other species of agricultural importance and of woody plants [24, 25]. It can survive for up to 15 years in the soil as a saprophyte [26, 27]. It survives in the soil mainly as microsclerotia that germinate repeatedly during the crop-growing season [28]. It is seedborne [29], found both on the seed coat and cotyledons [20], and causes charcoal rot by infecting the roots. Infected seeds produce infected seedlings that can transmit the pathogen into the fruit via the peduncle and so infect the seeds within the fruit, and augment the inoculum potential in the soil.

2. Methods

An extensive review of the literature was undertaken in different national and international scientific sources, such as Centre for Reviews and Dissemination (http://www.crd.york.ac.uk/CRDWeb/), The Cochrane Library (http://www.thecochranelibrary.com), PubMed (http://www.ncbi.nlm.nih.gov/pubmed/), Science Direct (http://www.sciencedirect.com/), Scopus (http://www.scopus.com/), Lilacs (http://lilacs.bvsalud.org/), Scielo (http://www.scielo.org/php/index.php), Web of Knowledge (http://apps.webofknowledge.com), EMBASE and Scholar Google (http://scholar.google.com.br/). Combinations of the following terms were used to search: "*Macrophomina phaseolinaa*" OR "antifungal activity" OR "antimicrobial activity" OR "antiphytophatogenic activity". Manuscript selection was based on inclusion criteria: articles published in English, Spanish and Portuguese.

3. Taxonomy and Nomenclature

The taxonomic status of *M. phaseolina* (Figure 1) has been revised several times over the past 100 years. The genus *Macrophomina* was first established by Petrak (1923) with the description of *M. philippinensis* from the dried specimens of *Sesamum orientale* collected by G. M. Reyes in Philippines in 1921. However, the pycnidial state (microsclerotial state of the fungus was originally named *Macrophoma phaseolina* by Tassi (1901) and *Macrophoma phaseoli* by Maublanc (1905). Halsted (1890) described the sclerotial state (microsclerotial state) as *Rhizoctonia bataticola* (Taub.) Butler on sweet potato (*Ipomoea batatas*). Finally, Ashby (1927) critically examined and compared the type specimens of the fungus from beans with other related genera and established the binomial species *Macrophomina phaseoli* (Maubl.) (Ashby, 1927). Later, Goidanich (1947) changed the binomial *Macrophomina phaseoli* to *Macrophomina phaseolina* (Tassi.) Goid., since the original specimen of *Macrophomina* was collected by Tassi in 1901. Hence, the two names, that is, *Macrophomina phaseoli* (Maubl.) Ashby and *Macrophomina phaseolina* (Tassi.) Goid. became widely accepted in the literature. Additional synonyms for *Macrophomina phaseolina* exist in the literature including *Sclerotium bataticola* (Taubenh, 1913), *Macrophoma cajani* P. Syd. and Butler (Sydow and Butler, 1916, Farr and Rossman 2010), *Macrophoma chorchori* (Sawada, 1916), *Macrophoma sesame* (Sewada, 1922) and *Tiarosporella phaseolina* (Tassi; Aa, 1981). An unconfirmed report (Mihail 1992) of a teleomorph of *M. phaseolina* naming it as *Orbilia obscura* (Ghosh et al. 1964) is also available. Currently, *M. phaseolina* (Tassi.) Goid. 1947 is officially recognized as the correct taxonomic name (CMI description of pathogenic fungi and bacteria no. 275) with the sclerotial phase known as *Rhizoctonia bataticola* [30]. *Macrophomina* is a monotypic genus, composed of only one species, "*phaseolina*". Despite the teleomorph being unknown in this pathogen, *M. phaseolina* is a member of the family Botryosphaeriaceae [18].

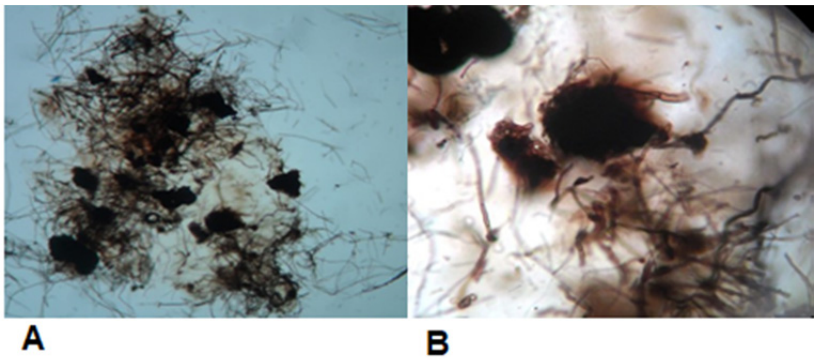

Figure 1

4. Secondary metabolites as a tool for the control of *M. phaseolina*

The secondary metabolites in plants can be divided into different categories according to their biosynthetic principles [31, 32]. A simple classification includes three main groups (Figure 2) [32].

5. Plant extract

Science ancient times, mankind has used plants to treat common diseases an some of these traditional medicines are still included as part of the habitual treatments of various maladies [33]. The activity of plant extracts may therefore make possible in the actually the design of less expensive alternatives on different sciences as agrobiotechnology, to be used by friendly by environment, to generate a change on using chemical compounds [34].

Initial screenings of plants for possible antifungal activities usually begin with crude aqueous or alcohol extractions, followed by various organic fractionation methods. The choice of extraction procedure depends on the nature of the source material and the compounds to be isolated. Since most of the identified components from plants active against microorganisms are aromatic or saturated organic compounds, they are most often obtained through initial ethanol or methanol extraction [21].

Indeed, plants constitute a powerful source of bioactive molecules usually synthesized in response to stress conditions and produce antibacterial, antiviral and antifungal effects [35, 36]. These secondary plant metabolites are often active against a small number of specific target microorganism species [37]. Furthermore, they are biodegradable to nontoxic products, not phytotoxic and are generally regarded as safe to mammals (GRAS) by the United States Food and Drug Administration [38]. Therefore, it becomes evident that these substances have enormous potential to improve the future agrochemical technology [37].

In Table 1, a compilation of the antifungical activity of plant extracts and/or isolated compounds shows properties against *M. phaseolina*. These extracts are alternatives that can be analyzed by agrobiotechnology to be efficient as antifungal on crop diseases and can be environmentally friendly with less secondary effects by health human. Research laboratories worldwide have found literally thousands of phytochemicals, which have in *in vitro* inhibitory effects on *M. phaseolina* in differents crops. Therefore, plant extracts in the form of decoction, infusion or tincture represent an important bioalternative by the population for treatment of diseases caused by *M. phaseolina* on different crops.

6. Essential oil

Essential oils, also known as essences, volatile oils, etheric oils, or aetheroleum, are natural products formed by several volatile compounds [39, 40]. According to the International Standard Organization on Essential Oils (ISO 9235: 2013) and the European Pharmacopoeia [41] an essential oil is defined as the product obtained from plant raw material by hydrodistillation, steam distillation or dry distillation or by a suitable mechanical process (for *Citrus* fruits). Cold pressing without heat is usually used for *Citrus* fruit oils because their constituents are thermosensitive and unstable, converting into artifacts under heat and pressure. Moreover, essential oils are frequently associated with gums and resins that are separated by the distillation process [40].

The definition of an essential oil excludes other aromatic/volatile products obtained by different extractive techniques like extraction with solvents (concretes, absolutes), supercritical fluid extraction, and microwave-assisted extraction.

In nature, essential oils play very important roles in plant defense and signaling processes. For example, essential oils are involved in plant defense against microorganisms, insects, and herbivores, attraction of pollinating insects and fruit-dispersing animals, water regulation and allelopathic interactions [42; 43; 44]. In addition, they are valuable natural

products used as raw materials in many fields, such as pharmaceutical, agronomic, food, sanitary, cosmetic, and perfume industries.

In Table 2 are compiled the essential oils of different plants and the isolated compounds that were evaluated against the fungus *M. phaseolina*. Different studies have demonstrated the effectiveness of essential oils or their active compounds on a range of plant pathogenic bacteria and fungi responsible for preand postharvest diseases. Also, because of the increasing demand for effective, safe, natural products, quantitative data on plant oils and extracts and the resurgence of interest in natural control of plant infectious bacterial and fungal pathogens are required and could lead to a new antimicrobial agent, which could support the use of the plant to treat various infective diseases. Nonetheless, plant essential oils have several important benefits; they are superior for disease control, effective at very low dosages of even less than one gallon per acre, excellent in spreading and sticking properties on leaf surfaces and at low cost and have little or no toxicity to man and animals and have much lower level of risk to the environment than with current synthetic pesticides.

7. Concluding remarks

The need for increasing agricultural productivity and quality has led to an excessive use of chemical fertilizer, creating serious environmental pollution. The use of biopesticides is an alternative for sustaining high production with low ecological Impact. This review records several results about the use of extract plants, pure compounds isolated from plants and essential oil that support their use in the treatment of phytopathogenic disease caused by *M. phaseolina.* In the reviewed literatures for the present study, 29 genus belonging to 22 plant families were investigated for antifungal activities against plant pathogenic fungi. Of these, Fabaceae (7 species), Asteraceae (5 species) and Lamiaceae (3 species) were the predominant families used by researchers.

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Table 1 Antifungal activity of plant extracts and/or pure compounds against *Macrophomina phaseolina*.

Family/Species	Common name	Local	Extract/Compounds/Plant organ	Assay *In vitro*	References
Acanthaceae					
Adhatoda vasica	Uninformed	Bangladesh	Methanol 80% extract/ Leaf	9 % radial mycelial growth inhibition Nystatin = 71%	Begum et al. 2007
Justicia adhatoda L. (Syn.: *Adhatoda zeylanica* Medik.[a])	Uninformed	Pakistan	Ethanolic extract (EE)/ Leaves	Food poison technique; 300g/L; Inhibition of 25.09%	Aslam et al. 2010
Apocynaceae					
Catharenthus roseus	Uninformed	Bangladesh	Methanol 80% extract/ Leaf	0 % radial mycelial growth inhibition Nystatin = 71%	Begum et al. 2007
Araceae					
Acorus calamus	Uninformed	Bangladesh	Methanol 80% extract/ Rhizome	100 % radial mycelial growth inhibition Nystatin = 71%	Begum et al. 2007
Asteraceae					
Cirsium arvense	Uninformed	Pakistan	Methanol extract (ME)/Leaf, Stem, Root and Inflorescence	ME Leaf 1% = ME Stem 1% = 6 ME Root 1%= 11 ME Inflorescence 1% = 2 ME Leaf 2% = 16 ME Stem 2% = 12 ME Root 2% = 16 ME Inflorescence 2% = 12 ME Leaf 3% = 29 ME Stem 3% = 22 ME Root 3% = 29 ME Inflorescence 3% = 12 ME Leaf 4% = 45 ME Stem 4% = 36 ME Root 4% = 32 ME Inflorescence 4% = 24 ME Leaf 5% = 74 ME Stem 5% = 57 ME Root 5% = 39 ME Inflorescence 5% = 30-	Banaras et al. 2017

Eupatorium odoratum	Uninformed	Bangladesh	Methanol 80% extract/ Leaf	74 % radial mycelial growth inhibition Nystatin = 71%	Begum et al. 2007
Eupatorium triplinerve	Uninformed	Bangladesh	Methanol 80% extract/ Aerial part	24 % radial mycelial growth inhibition Nystatin = 71%	Begum et al. 2007
Mikania cordata	Uninformed	Bangladesh	Methanol 80% extract/ Whole plant	15 % radial mycelial growth inhibition Nystatin = 71%	Begum et al. 2007
Family/Species	**Common name**	**Local**	**Extract/Compounds/Plant organ**	**Assay *In vitro***	**References**
Wedelia chinensis	Uninformed	Bangladesh	Methanol 80% extract/ Whole plant	0 % radial mycelial growth inhibition Nystatin = 71%	Begum et al. 2007
Avicenniaceae					
Avicennia alba	Uninformed	Bangladesh	Methanol 80% extract/Leaf	34 % radial mycelial growth inhibition Nystatin = 71%	Begum et al. 2007
Avicennia marina	Uninformed	Bangladesh	Methanol 80% extract/Leaf	29 % radial mycelial growth inhibition Nystatin = 71%	Begum et al. 2007
Avicennia officinalis	Uninformed	Bangladesh	Methanol 80% extract/ Leaf	36 % radial mycelial growth inhibition Nystatin = 71%	Begum et al. 2007
Brassicaceae					
Isatis tinctoria	Ban-Lan-Gen		Ethanolic extract (EE); 2-[Cyano(3-indolyl)methylene]-3-indolone (compound 1); Epiglucoisatisin (compound 2); 3´-Hydroxyepiglucoisatisin (compound 3); Sulfoglucobrassicin (compound 4); Isatan A (compound 5); Isatan B (compound 6)	Agar tube dilution method; 400µg/mL; EE = 61.0 compound 1 = 59.2% compound 2 = 79.5% compound 3 = 81.3% compound 4 = 56.7% compound 5 = 40.6% compound 6 = 30.9% Benlate = 100%[Δ]	Ahmad & Fatima 2008
				Disc diffusion method	Al-Askar, Rashad & Abdulkhair 2014
Burseraceae					
Boswellia serrata Roxb. ex Colebr.	Uninformed	India	Gum	Poisoned food Technique; 1% = 129 5% = 115 10% = 139 Control = 132	Badar et al. 2012
Capparaceae					
Capparis decidua	Uninformed	Pakistan	Ethanolic extract (EE)/ Leaves	Food poison technique; 300g/L; No inhibition in radial growth	Aslam et al. 2010
Clusiaceae					
Garcinia cowa	Uninformed	Bangladesh	Methanol 80% extract/ Leaf	18 % radial mycelial growth inhibition Nystatin = 71%	Begum et al. 2007
Combretaceae					
Anogeissus latifolia	Uninformed	Bangladesh	Methanol 80% extract/ Leaf	6 % radial mycelial growth inhibition Nystatin = 71%	Begum et al. 2007
Family/Species	**Common name**	**Local**	**Extract/Compounds/Plant organ**	**Assay *In vitro***	**References**
Terminalia chebula	Uninformed	Bangladesh	Methanol 80% extract/ Leaf	0 % radial mycelial growth inhibition Nystatin = 71%	Begum et al. 2007
Euphorbiaceae					
Sapium indicum	Uninformed	Bangladesh	Methanol 80% extract/Brark	21 % radial mycelial growth inhibition Nystatin = 71%	Begum et al. 2007
Dioscoreaceae					
Dioscoria aculeate	Uninformed	Bangladesh	Methanol 80% extract/Aerial part	0 % radial mycelial growth inhibition Nystatin = 71%	Begum et al. 2007
Fabaceae					
Acacia nilotica (L.) Delile (Syn. *Acacia arabica* (Lam.) Willd.[•])	Uninformed	India	Gum	Poisoned food Technique; 1% = 130	Badar et al. 2012

Acacia chundra (Rottler) Willd.	Uninformed	India	Gum	5% = 131 10% = 136 Control = 132 Poisoned food technique; 1% = 132 5% = 134 10% = 139 Control=132	Badar et al. 2012
Aeschynomene americana	Uninformed	Bangladesh	Methanol 80% extract/ Aerial part	7 % radial mycelial growth inhibition Nystatin = 71%	Begum et al. 2007
Butea monosperma (Lam.) Taub.	Uninformed	India	Gum	Poisoned food Technique; 1% = 128 5% = 137 10% = 140 Control = 132	Badar et al. 2012
Dalbergia sisoo	Uninformed	Bangladesh	Methanol 80% extract/ Leaf	29 % radial mycelial growth inhibition Nystatin = 71%	Begum et al. 2007
Samanea saman	Uninformed	Bangladesh	Methanol 80% extract/ Leaf	31 % radial mycelial growth inhibition Nystatin = 71%	Begum et al. 2007
Sarca indica	Uninformed	Bangladesh	Methanol 80% extract/ Bark	29 % radial mycelial growth inhibition Nystatin = 71%	Begum et al. 2007
Lamiaceae *Hyptis suaveolens*	Uninformed	Bangladesh	Methanol 80% extract/ Leaf	47 % radial mycelial growth inhibition Nystatin = 71%	Begum et al. 2007
Lauraceae *Litsea glutinosa*	Uninformed	Bangladesh	Methanol 80% extract/ Leaf	0 % radial mycelial growth inhibition Nystatin = 71%	Begum et al. 2007

Family/Species	**Common name**	**Local**	**Extract/Compounds/Plant organ**	**Assay *In vitro***	**References**
Lythraceae *Lawsonia inermis*	Uninformed	Bangladesh	Methanol 80% extract/ Leaf	18 % radial mycelial growth inhibition Nystatin = 71%	Begum et al. 2007
Magnoliaceae *Michelia champaca*	Uninformed	Bangladesh	Methanol 80% extract/ Leaf	0 % radial mycelial growth inhibition Nystatin = 71%	Begum et al. 2007
Melastomataceae *Melastoma malabathricum*	Uninformed	Bangladesh	Methanol 80% extract/ Leaf	0 % radial mycelial growth inhibition Nystatin = 71%	Begum et al. 2007
Meliaceae *Azadirachta indica*	Uninformed	Pakistan	Ethanolic extract (EE)/ Leaves	Food poison technique; 300g/L; No inhibition in radial mycelial growth	Aslam et al. 2010
	Uninformed	India	Gum	Poisoned food Technique; 1% = 127 5% = 134 10% = 138 Control = 122-	Badar et al. 2012
Phyllanthaceae *Phyllanthus emblica*	Uninformed	Bangladesh	Methanol 80% extract/ Leaf	18 % radial mycelial growth inhibition Nystatin = 71%	Begum et al. 2007
Piperaceae *Piper betel*	Uninformed	Bangladesh	Methanol 80% extract/ Leaf	49 % radial mycelial growth inhibition Nystatin = 71%	Begum et al. 2007
Poaceae *Cymbopogon flexuosus*	Uninformed	Bangladesh	Methanol 80% extract/ Leaf	20 % radial mycelial growth inhibition Nystatin = 71%	Begum et al. 2007
Cymbopogon osmastonii	Uninformed	Bangladesh	Methanol 80% extract/ Leaf	17 % radial mycelial	Begum et al. 2007

				growth inhibition Nystatin = 71%	
Oryza sativa L. var. Basmati-385	Rice	Pakistan	Whole plant/ Aqueous extract (AE); Methanol extract (ME); n-Hexane extract (HE)	AE 1% = -21 AE 3% = -52 AE 5% = -41 ME 1% = -04 ME 3% = -01 ME 5% = -05 HE 1% = -45 HE 3% = -60 HE 5% = -45	Bajwa et al. 2008

Family/Species	**Common name**	**Local**	**Extract/Compounds/Plant organ**	**Assay *In vitro***	**References**
Oryza sativa L. var. Basmati-386	Rice	Pakistan	Whole plant/ Aqueous extract (AE); Methanol extract (ME); n-Hexane extract (HE)	AE 1% = -44 AE 3% = -21 AE 5% = -36 ME 1% = -01 ME 3% = -03 ME 5% = -04 HE 1% = -24 HE 3% = -49 HE 5% = -51	Bajwa et al. 2008
Oryza sativa L. var. Basmati Super	Rice	Pakistan	Whole plant/ Aqueous extract (AE); Methanol extract (ME); n-Hexane extract (HE)	AE 1% = -42 AE 3% = -41 AE 5% = -42 ME 1% = -01 ME 3% = -01 ME 5% = -05 HE 1% = -38 HE 3% = -18 HE 5% = -50	Bajwa et al. 2008
Rubiaceae					
Hedyotis corymbosa	Uninformed	Bangladesh	Methanol 80% extract/ Whole plant	12 % radial mycelial growth inhibition Nystatin = 71%	Begum et al. 2007
Paederia foetida	Uninformed	Bangladesh	Methanol 80% extract/ Whole plant	17 % radial mycelial growth inhibition Nystatin = 71%	Begum et al. 2007
Rutaceae					
Citrus aurantifolia L.	Uninformed	India	Leaves/ Aqueous extract (AE)	Poisoned food technique 5% = 28 10% = 18 15% = 11 20% = 3 Carbendazim (0.1%) = 9	Balamurugan 2014
Citrus grandis	Uninformed	Bangladesh	Methanol 80% extract/ Leaf	7 % radial mycelial growth inhibition Nystatin = 71%	Begum et al. 2007
Micromelum minutum	Uninformed	Bangladesh	Methanol 80% extract/ Leaf	42 % radial mycelial growth inhibition Nystatin = 71%	Begum et al. 2007
Salvadoraceae					
Salvadora oleoides Decne.	Uninformed	Pakistan	Ethanolic extract (EE)/ Leaves	Food poison technique; 300g/L; Inhibition of 17.92%	Aslam et al. 2010
Sapindaceae					
Dodonaea viscosa	Uninformed	Pakistan	Ethanolic extract (EE)/ Leaves	Food poison technique; 300g/L; Inhibition of 52.06%	Aslam et al. 2010

Family/Species	**Common name**	**Local**	**Extract/Compounds/Plant organ**	**Assay *In vitro***	**References**
Solanaceae					
Datura metel	Uninformed	Bangladesh	Methanol 80% extract/ Leaf	53 % radial mycelial growth inhibition Nystatin = 71%	Begum et al. 2007
Solanum filicifolium	Uninformed	Bangladesh	Methanol 80% extract/ Leaf	14 % radial mycelial growth inhibition Nystatin = 71%	Begum et al. 2007
Verbenaceae					
Clerodendrum viscosum	Uninformed	Bangladesh	Methanol 80% extract/ Leaf	39 % radial mycelial growth inhibition	Begum et al. 2007

Lantana camara	Uninformed	Bangladesh	Methanol 80% extract/ Leaf	Nystatin = 71% 0 % radial mycelial growth inhibition	Begum et al. 2007
Lippa javanica	Uninformed	Bangladesh	Methanol 80% extract/ Leaf	Nystatin = 71% 19 % radial mycelial growth inhibition	Begum et al. 2007
Vitaceae				Nystatin = 71%	
Cissus repens	Uninformed	Bangladesh	Methanol 80% extract/ Aerial part	26 % radial mycelial growth inhibition Nystatin = 71%	Begum et al. 2007
Zingiberaceae					
Hedychium thyrsiforme	Uninformed	Bangladesh	Methanol 80% extract/ Leaf	35 % radial mycelial growth inhibition Nystatin = 71%	Begum et al. 2007
Zingiber zerumbet	Uninformed	Bangladesh	Methanol 80% extract/ Aerial part	35 % radial mycelial growth inhibition Nystatin = 71%	Begum et al. 2007

Δ = Standard drugs;. ♣ = Plant name used by authors;

Table 2 Antifungal activity of essential oil and/or pure compounds against *Macrophomina phaseolina*.

Family/Species	**Common name**	**Local**	**Plant organ/Major active component**	**Assay (*In vitro*)**	**References**
Asteraceae *Artemisia nilagirica* vern. Kunja		India	Aerial parts/α-thujone (36.35%), β-thujone (9.37%), germacrene D (6.32%), 4-terpineol (6.31%), β-caryophyllene (5.43%), camphene (5.47%),	Poisoned food technique ED50 = 93.23 mg L^{-1} Bavistin = <20 mg L^{-1}	Sati et al. 2013
Eupatorium triplinerve		Bangladesh	Aerial parts/ 2-tert-butyl-1,4-methoxbenzene (74.27%) and b-selinene (8.59%)	Minimum inhibitory concentration (MIC) assays EO 100 ppm = 85 EO 250 ppm = 88 EO 500 ppm = 89 EO 750 ppm = 90 Nystatin 1000ppm = 92 Nystatin 100 ppm = 71 (Percent radial growth inhibition)	Begum Bhuiyan, Taznin 2010
Apiaceae *Carum carvi* L.	Caraway	Bangladesh	Seed/ Thymol (48.20%), o-cymene (19.29%), γ-terpinen (17.61%), trimethylene dichloride (8.81%), β- pinene (3.08%), 2-(1-cyclohexenyl) cyclohexanone (0.68%), β- phellandrene (0.67%), 3-carene (0.57%), α-thujene (0.55%) and linalool (0.54%)	100 = 100% 250 = 100% 500 = 100% 750 = 100% Nystatin 100 ppm = 71% (Percent radial mycelial growth inhibition)	Begum et al. 2008
Ferulago angulata (Schlecht.) Boiss. "Chavir" or "Chavil"	"Chavir" or "Chavil"	Iran	Seed/ (Z)-β-ocimene (19.93%), α-pinene (15.50%), p-cymene (7.67%), sabinene (7.49%) and β-phellandrene (5.50%)	Disc diffusion 3th day: 100 (μL L^{-1}) = 41.93±5.03; 200 (μL L^{-1}) = 49.31±5.85; 400 (μL L^{-1}) = 73.04±4.99; 800 (μL L^{-1}) = 76.94±4.75 6th day: 100 (μL L^{-1}) = 30.64±6.65; 200 (μL L^{-1}) = 39.17±4.38; 400 (μL L^{-1}) = 47.42±5.63; 800 (μL L^{-1}) = 63.33±3.51 Agar dilution 3th day / 6th day	Moghaddam et al. 2018

				100 (µL L^{-1}) = 75.21±3.36 200 (µL L^{-1}) = 75.69±4.31 400 (µL L^{-1}) = 88.26±1.47 800 (µL L^{-1}) = 88.68±2.98	100 (µL L^{-1}) = 67.22±1.43 200 (µL L^{-1}) = 70.83±4.66 400 (µL L^{-1}) = 72.78±4.67 800 (µL L^{-1}) = 75.28±2.47	
Geraniaceae *Geranium viscosissimum*	Geranium		Geraniol, Citronellol, Tannins including gallic acid*	Fungal radial growth 1% = 48.3 2% = 56.3 4% = 95.5▲		Abdel-Kader, El-Mougy & Lashin 2011
Labiatae *Thymus vulgaris*	Thyme		thymol, carvacrol, geraniol, thymol methyl ether, α -pinene*	Fungal radial growth 1% = 43.3 2% = 53.3 4% = 97.5▲		Abdel-Kader, El-Mougy & Lashin 2011
Lamiaceae *Mentha piperita*	Peppermint		Menthol, menthone, menthyl acetate, viridiflorol, ledol*	Fungal radial growth 1% = 37.7 2% = 56.4 4% = 85.5▲		Abdel-Kader, El-Mougy & Lashin 2011
Nepeta leucophylla *Nepeta clarkei* Umbelliferae						

Family/Species	**Common name**	**Local**	**Plant organ/Major active component**	**Assay (*In vitro*)**	**References**
Dianthus caryophyllus	Carnation		Eugenol, α-pinene, myrcene*	Fungal radial growth 1% = 72.2 2% = 100 4% = 100▲	Abdel-Kader, El-Mougy & Lashin 2011
Carum carvi	Caraway		Carvone, limonene, carveol, pinen, thujone*	Fungal radial growth 1% = 38.8 2% = 42.2 4% = 52.2▲	Abdel-Kader, El-Mougy & Lashin 2011
Zingiberaceae *Curcuma leucorhiza* Roxb	Uninformed	India	Rhizome oil: Germacrone (19.7%) and curdione (19.1%) Leaf oil: Curdione (19.5%), germacrone (9.6%), 1,8-cineole (7.4%), and camphor (7.2%)	Disc-diffusion assay Ineffective (no inhibition zone observed)	Devi et al. 2012

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