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Plant extract as a strategy for the management of seed pathogens: a critical review

Extrato de plantas como estratégia para o manejo de patógenos fúngicos em sementes: uma revisão crítica

El extracto vegetal como estrategia para el manejo de patógenos de semillas: una revisión crítica

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Abstract
Seeds associated to fungal pathogens are efficient vehicles for disease dissemination in the field. Such pathogens affect the seed quality and longevity, causing a decrease or loss of germination, discoloration, necrosis, and decay, in addition to leading to the production of mycotoxins in some pathosystems. To control them several synthetic chemicals are used. Nevertheless, the use of synthetic chemicals poses a risk to human health and the environment. Therefore, there is a growing demand for the use of alternative methods for the treatment of seeds, such as plant extracts. This review evaluated the use and efficacy of plant extracts for the control of fungal pathogens associated to seeds. Some control methods are used in seed treatment, plant extracts stand out due to the secondary metabolic in their constitution, which inhibit pathogen growth. The literature review showed that 100% of the studies reported that plant extracts were efficient to control the different pathogens evaluated, 63% stated an increase in seed germination, 21% reported no change in germination, 5% mentioned negative interference, and 11% did not evaluate the use of plant extracts. The aqueous extracts were used as extractors in 72% of the studies. Plant extracts were reported as promising to replace synthetic fungicides in 33% of the studies; however, 67% did not compare their use. Nevertheless, efficient extraction methods are required, considering low persistence and volatilization of plant extracts in the field. Plant extracts are efficient to control fungal pathogens.
Keywords: Seed-borne fungi; Plant extracts; Secondary metabolites.

Resumo
Sementes associadas a patógenos fúngicos são veículos muito eficientes para a disseminação de doenças no campo, tais patógenos afetam a qualidade e longevidade das sementes causando diminuição ou perda da germinação, apodrecimento, necrose, produção de micotoxinas, descoloração e aborto das sementes. Para controlá-los vários produtos químicos sintéticos são utilizados. No entanto, causam riscos à saúde humana e ao meio ambiente. Sendo assim, é crescente a procura e utilização de outros métodos alternativos e que demonstram ser mais eficientes para o tratamento das sementes, um deles são os extratos vegetais. Dessa forma, esta revisão buscou avaliar o uso e

eficiência de extratos vegetais no controle de patógenos fúngicos associados as sementes. Entre as formas de controle utilizadas no tratamento das sementes os extratos vegetais se destacam, pois devido a presença de metabólicos secundários presentes nas plantas limitam o crescimento de organismos patogênicos. Entre as pesquisas analisadas 100% afirmaram que os extratos de plantas foram eficientes no controle dos patógenos, 63% proporcionaram aumento na germinação das sementes, 21% relataram que não houve mudança na germinação, 5 % relataram interferência negativa e 11% não avaliaram. Entre os extratores utilizados, 72% utilizam o aquoso, 33% afirmam ser promissor para substituição dos fungicidas sintéticos e 67% não analisaram. Porém, para sua utilização deve-se utilizar métodos de extração eficientes, assim como, deve está ciente das sua baixa persistência e volatilização em campo. Logo, os extratos de plantas são eficientes no controle de patógenos fúngicos.
Palavras-chave: Doenças de sementes; Extratos vegetais; Metabólitos secundários.

Resumen
Las semillas asociados con los hongos patógenos son vehículos muy eficientes para la diseminación de enfermedades en el campo, tales patógenos afectan la calidad y longevidad de las semillas. Para controlarlos se utilizan diversos productos químicos sintéticos. Sin embargo, plantean riesgos para la salud humana y el medio ambiente. Por lo tanto, está aumentando la búsqueda y el uso de otros métodos de tratamiento tratamiento alternativo, uno de ellos son los extractos de plantas. Por lo tanto, esta revisión buscó evaluar el uso y la eficiencia de extractos de plantas en el control de patógenos fúngicos asociados con semillas. Entre las formas de control utilizadas en el tratamiento de semillas destacan los extractos de plantas, debido a la presencia de metabolismo secundario presente en las plantas. Entre las encuestas analizadas, el 100% afirmó que los extractos de plantas fueron eficientes en el control de patógenos, el 63% proporcionó un aumento en la germinación de la semilla, el 21% informó que no hubo cambio en la germinación, el 5% informó interferencia negativa y el 11% no la evaluó. Entre los extractores utilizados, el 72% utiliza el acuoso, el 33% afirma ser prometedor para reemplazar fungicidas sintéticos y el 67% no lo analizó. Sin embargo, para su uso se deben utilizar métodos de extracción eficientes, además de ser consciente de su baja persistencia y volatilización en campo. Por lo tanto, los extractos de plantas son eficaces para controlar los patógenos fúngicos.
Palabras clave: Enfermedades de las semillas; Extractos vegetales; Metabolitos secundarios.

1. Introduction

Pathogens associated to seeds are efficient vehicles to disseminate diseases. This association also favors pathogen survival for a longer period, compromising seed quality and longevity and resulting in germination failure (Mancini et al., 2016; Chowdhury et al., 2015). Many fungi can attack different seed genera, such as *Alternaria* Nees, *Aspergillus* P. Micheli, *Cercospora* Fresen. ex Fuckel, *Cochliobolus* Drechsler (as – *Bipolaris*), *Curvularia* Boedijn, *Drechslera* S. Ito, *Fusarium* Link, *Penicillium*, *Pyricularia* Link, *Pythium* Nees, *Rhizoctonia* DC, and *Rhizopus* Ehrenb. (Pushpavathi et al., 2017). Some fungi start the infection process in the field, while others infect only under storage conditions (Amza, 2018), which generally determines the pathogen location in the seed, the type of infestation or infection, and consequently types of damage (Baker & Smith, 1966).

Pathogens in field crops usually transmit disease from seeds to seedlings and even to the adult plant (Gaur et al., 2020), causing different symptoms. Wheat pathogens are *Fusarium* spp., *Drechslera* spp., *Septoria* Sacc. spp. and some nematode species. Rice pathogens are *Pyricularia oryzae* Cavara, *Bipolaris oryzae* (Breda de Haan) Shoemaker (as – *Drechslera oryzae*) and corn pathogens are *Botryosphaeria* Ces. & De Not. spp. (as – *Diplodia* spp.), *Drechslera* spp., and *Fusarium* spp. (Neergaard, 1977). In forest species, seedling drops are the most common symptoms, caused by pathogens *Cylindrocladium* Morgan spp., *Fusarium* spp. and *Rhizoctonia solani* J.G. Kühn. (Parisi et al., 2019).

Chemical treatment is often used in pathogen control to mitigate damages to seed germination, preventing transmission to adult plants. Many classes of fungicides have their efficacy proven and registered, such as triazoles (DMI), phenylpyrroles (PP), phenylamides (PA), benzimidazoles (MBC), and strobilurins (QoI) (Zeun et al., 2013).

Several methods are suggested to reduce the use of synthetic products, such as physical, microbial treatment, and treatment with natural agents (Koch & Roberts, 2014). Regarding natural agents, plant extracts has been intensively studied, because they are environmentally friendly, easily decomposed, and non-toxic to humans (Choudhury et al. 2018; Ogungbemile et al., 2020). The use natural agents in seed treatment appears as an option for the control of fungal diseases (Ahad et al., 2018).

Many extracts have already been tested, such as *Momordica charantia* L. (Shokouhi and Seifi 2020), *Allium sativum* L. (Araújo et al., 2019; Pascuali, 2018), *Cinnamomum zeylanicum* Blume and *Ocimum basilicum* L. (Dourado et al., 2020), *Pyrus communis* L., *Mentha longfolia* (L.) Huds., *Calendula officinalis* L., and *Chenopodium album* L. (Dar et al., 2018). Therefore, studies have investigated the sanitary quality of seeds (Lima et al., 2020), showing that plant extract is a promising alternative for pathogen control associated with seeds, reducing costs and impacts to the environment (Silva et al., 2019).

Many studies have been conducted to investigate the use of synthetic chemical products for disease management in seeds (Sartori et al., 2020; Scott et al., 2020; Shcherbakova et al., 2021). Nevertheless, studies on plant extracts for disease management are still incipient and further investigations are needed to provide alternative tools to synthetic products that are ecologically viable. Therefore, we hypothesize that extract of some plant species can reduce incidence and severity of fungal diseases, reducing seed losses. This review assessed 18 scientific articles on this topic to validate plant extracts as efficient in disease management associated with seeds.

2. Methodology

The methodology used in the study was a literature review, in which the authors established selection criteria based on the theme and year of publication. The selected literatures were national and international, through search platforms: SciELO, ScienceDirect, Elsevier, PubMed, SpringerLink and CAPES Journal. Several search terms were used, but all referring to seed pathology, seed technology, and phytopathology such as: “Seed-borne diseases”, “plant extracts in seed treatment”, “fungal pathogens in seeds”, and “seed pathogen control”. The survey of studies that use plant extracts to control pathogens in seeds 18 scientific articles were accessed between the periods of 2015 to 2021.

3. Development

3.1 Main fungal pathogens causing seed diseases

Pathogens propagated by seeds cause significant losses in seed yield and quality, resulting in low germinability and even damage to seedlings (Sarika et al, 2019). Many fungi are pathogenic to seeds, both in the field and during storage (Siegel & Babuscio, 2011). In the field, these pathogens can settle in the seeds even before storage and their growth occurs when the relative humidity is high, around 90-95%, and the seed moisture content is between 20 and 25% (Santos et al., 2016). Therefore, storage conditions are crucial to ensure seed sanitary quality.

Most storage pathogens of seeds belong to the genus *Penicillium*, *Aspergillus*, and *Rhizopus*, which grow rapidly, deteriorating and making seeds unsuitable for consumption and planting (Shamsi & Khatun, 2016). Mota et al. (2017) analyzed 34 samples of *Phaseolus lunatus* L. and found the presence of 22 fungal genera in which *Aspergillus* spp., *Penicillium* spp., *Curvularia* sp. and *Monilinia* Honey sp. represented 63.76% of the colonies. Shamsi & Khatun (2016) studied nine varieties of *Cicer arietinum* during storage and reported the occurrence of *Alternaria alternata* (Fr.) Keissl., *Aspergillus flavus* Link, *A. niger* Tiegh, *A. fumigatus* Fresen., *A. nidulans* (Eidam) G. Winter, *Curvularia lunata* (Wakker) Boedijn, *Penicillium* sp., *Rhizopus stolonifer* and *Trichoderma virid*. Ibrahim et al. (2017) reported changes in the viability of wheat seeds during storage for 18 months, in which the longer storage period decreased storage fungi, namely *Alternaria triticina* Prasada & Prabhu, *Bipolaris sorokiniana* Shoemaker, *Fusarium* spp. However, there was an increase in storage fungi *Aspergillus* spp. and *Penicillium* spp. In addition, *Botrytis* P. Micheli is a necrotrophic genus and some species can behave as a pathogen, infecting plants and seeds (Elad et al., 2016), causing gray mold, an important seed-borne disease (Taheri et al., 2020).

Field fungi, belonging to the genera *Alternaria*, *Cladosporium* Link, *Fusarium*, *Helminthosporium* Link, and *Aureobasidium* Viala & G. Boyer (as – *Pullularia*), contaminate seeds developing on the mother plant or after seed maturation, as seed moisture contents are lower than the contents required by field fungi during storage (Christensen & Kaufmann, 1965).

Nayyar et al. (2018) evaluated *Fusarium* species associated with *Sesamum indicum* L. seeds and found that *Fusarium proliferatum* (Matsush.) Nirenberg was the most frequent and severe isolate. Soomro et al. (2020) reported that seeds transmit most diseases that affect *Brassica napus* L. and *Alternaria brassicicola* (Schwein.), *Alternaria alternata*, *Curvularia lunata*, and *Fusarium* spp. are the most important. Naqvi & Rehman (2013) reported that the fungi associated with sorghum seeds worldwide are *Alternaria alternata*, *Aspergillus flavus*, *A. fumigatus*, *A. niger*, *Cladosporium* spp., *Fusarium fujikuroi* Nirenberg (as – *Fusarium moniliforme*), *F. oxysporum* Schltdl, *F. pallidoroseum* (Cooke) Sacc., *Curvularia spicifera* (Bainier) Boedijn (as – *Drechslera tetramera*), *Nigrospora* Zimm. spp., *Phoma* Sacc. spp., and *Rhizopus* spp. Gaur et al., (2020) emphasize that fungi *Alternaria* spp., *Bipolaris* spp., *Curvularia* spp., and *Fusarium* spp. infect seeds of brassica, barley, rice, and sorghum, respectively, while fungi *Drechslera* spp., *Bipolaris* spp., and *Septoria* spp. (Gaur et al., 2020) occur in cereal seeds.

3.2 Fungal pathogen damage in seeds

Seeds can be pathogen vectors that contaminate disease-free areas (Baker & Smith, 1966; Bisen et al., 2014; Shade et al., 2017). Pathogens can occur on the seed surface or inside the tissues, characterized as endophytes (Barret et al., 2015). In leafy vegetables, contamination of a small number of seeds is enough to trigger high incidence of the disease in the production area and *Fusarium oxysporum* Schltdl and *Verticillium dahliae* Kleb are some of the most common pathogens (Koch et al., 2014).

Pathogens in seeds, acting externally and internally, can cause seed discoloration, shrinkage (Gaur et al., 2020), seed abortion, rot, necrosis, decrease or loss of germination capacity, damage to seedlings as well as diseases in the later stages of plant growth (Naqvi & Rehman, 2013). When they infect the seeds internally, fungi destroy the endosperm and embryo, compromising germination and development of seedlings (Michelle et al., 2010).

According to Hendrix and Campbell (1973), fungi of the *Pythium* Nees genus infect seeds and seedlings before emergence, resulting in damping-off in pre-emergence, while *Cercospora kikuchii* (Tak. Matsumoto & Tomoy.) M.W. Gardner causes seed discoloration (Alloatti et al., 2015). In soybean (*Glycine max* L.), *Pythium* Nees causes a purple spot (Upchurch & Ramirez 2010) and, when inside the embryonic tissues, it causes necrosis of cotyledons and vascular elements (Pathan et al., 1989). The fungi *Fusarium fujikuroi* (as – *Fusarium moniliforme*), *F. oxysporum* and *Penicillium* spp. also cause seed rot (Debnath et al., 2012).

Khare et al. (2017) report that pathogens *Pythium* spp., *Alternaria alternata*, *Fusarium* spp., *Macrophomina phaseolina* (Tassi) Goid. (as – *Rhizoctonia bataticola*), *R. solani* J.G. Kühn, *Athelia rolfsii* (Curzi) C.C. Tu & Kimbr. (as – *Sclerotium rolfsii*) and *Macrophomina phaseolina* cause seed rot of *Coriandrum sativum* L. Strains of genus *Curvularia* infect seeds internally and externally, causing pre- and post-emergence mortality. When *Curvularia lunata* occurs in *Dalbergia sissoo* Roxb seeds, it causes black or opaque discoloration affecting germination and viability of seeds and seedlings (Gupta et al., 2017).

Etaware (2019) studied morphological changes caused by fungi in seeds of *Colocynthis Citrullus* Linn. during storage and reported that *Lichtheimia corymbifera* (Cohn) Vuill. (as – *Absidia corymbifera*) and *Penicillium* spp. caused decomposition and mummification of melon seeds. *Cladosporium* spp. and *Aspergillus fumigatus* degraded the hilum and *A. flavus*, *Curvularia* spp. and *Cladosporium* spp. caused total discoloration of the integument of stored melon seeds. In wheat, different species of the *Fusarium* genus caused loss of grain yield, stand reduction, and seed rot (Laram et al., 2020). On the other hand, *Fusarium proliferatum* in sesame caused damping-off, reducing seedling growth and vigor (Nayyar et al., 2018).

Seed-associated pathogens can also produce mycotoxins that cause diseases in humans and animals, feeding on seeds directly or indirectly (Karaca et al., 2017). Most of these mycotoxins are potentially carcinogenic, teratogenic, tremorogenic, nephrotoxic, immunotoxic or hemorrhagic, and cause fungal contamination in oilseeds, resulting in the presence of mycotoxins in the extracted oil (Bhat et al., 2015). Fungi of the genera *Aspergillus*, *Fusarium* and *Penicillium* are mycotoxin producers (Bhat et al., 2010).

3.3 Forms of disease control

Treatments to protect seeds from pests and diseases have been used for centuries. For example, in the year 1600, wheat seeds were already treated with salt to help control wheat rust (Hitaj et al., 2020). Historically, synthetic fungicides were developed using compounds containing sulfur, copper, and mercury (Mancini et al., 2013). Mercury-based treatments are Phenyl Mercury Acetate (PMA), Methoxyethyl Mercury Chloride (MEMC), Ethyl Mercury Chloride (EMC), Mercury Chloride, and Mercuric Eoxide. Non-mercurial treatments are Thiram, Captan, Carbendazim, Metalaxyl, copper carbonate, copper sulfate, and cuprous oxide (Kunta et al., 2020).

In recent years, different control methods have been used for seed treatment. According to Spadaro et al. (2017), there are other treatments for pathogen control in seeds besides the use of synthetic chemicals. Physical treatments include mechanical, thermal, ultrasonic, and radiations and use inorganic natural products, such as copper, phosphate, sulfur bicarbonates, clay, and potassium. There are also treatments with antagonistic microorganisms, such as filamentous fungi, yeasts, and bacteria as biocontrol agents as well as the use of resistance-inducing compounds, such as elicitors and natural organic compounds, such as plant extracts and essential oils.

In physical treatments, the use of hot water, hot air, and electrons are more frequent. In biological treatments, biological control agents (BCAs) are used, which include fungi and bacteria (Mancini et al., 2013). Jiao et al. (2016) proved that radio frequency (RF) heating assisted by hot air has the potential to inhibit fungi and ensure biochemical and physiological quality of grain seeds. Carvalho et al. (2011) studied the effect of *Trichoderma harzianum* Rifai isolates as biocontrol of pathogens in bean seeds (*Phaseolus vulgares* L.) and proved that these isolates are efficient to reduce incidence of *Aspergillus*, *Cladosporium*, and *Sclerotinia sclerotiorum* (Lib.). Lima et al. (2016) evaluated the effect of plant extracts and essential oils in the control of *Alternaria alternata* and *A. dauci* in *Daucus carota* L. seeds and observed that garlic extract and orange essential oil showed potential to control both pathogens.

However, both synthetic and natural chemical methods must meet some requirements for an effective seed treatment. Treatments should be able to reduce the number or transmission rate of target pathogens to acceptable numbers without decreasing seed germination or vigor and storage capacity and be less toxic to humans, animals, and the environment (Koch & Roberts, 2014). Treatment efficacy depends on the internal infestation degree of the seed, the amount of inoculum in the lot, specificity, and the treatment phytotoxic potential (Du Toit, 2004).

3.4 Are plant extracts effective for the control of fungal pathogens in seeds?

In this review, we evaluated 18 articles on the use and efficacy of plant extracts for the control of fungal pathogens in seeds of cultivated plants. The literature survey showed that 100% of the articles reviewed report that plant extracts were effective to control pathogens. However, there is a difference in the efficacy level between each extract. In addition, 63% of the studies reported an increase of seed germination, 21% reported no change in germination, 5% reported negative interference, and 11% did not evaluate the effects of plant extracts on seed germination. Among the extractors used to prepare the extracts, 72% of the studies mentioned the use of aqueous extracts, 11% used ethanol, and 5.55% used citric, alcoholic, and citric acid + sodium benzoate + potassium sorbate and propylene glycol + water + sodium benzoate + potassium sorbate (Table 1).

Borges et al. (2018) state that plants have in general secondary metabolites responsible for the synthesis of several bioactive substances, which limit growth of other plants and protect against insects and pathogens, showing thus efficacy in disease management. Plant extracts contain large amounts of these bioactive substances, such as alkaloids, cyanogenic glycosides, glucosinolates, lipids, phenolics, terpenes, polyacetylenes, polythiens, tannins, phenols, resins, volatile and fixed oils that are stored in specific plant structures, such as in leaves, bark, seeds, fruits, and roots (Gupta et al. 2012; Borges et al. 2018).

The methods to extract these compounds must be effective, providing good extraction yield and efficacy (Gupta et al., 2012). Many solvents are used for the extraction of these compounds, such as water, methanol, ethanol, ethyl acetate, and others; however, the right solvent should be chosen for each extraction to have the best results (Ong et al., 2021). Raw water or alcohol are extractors usually used to select plants with possible antimicrobial activity (Yazdani et al., 2011).

According to Satish et al. (2007), aqueous extracts of *Acacia nilotica* L., *Achras zapota* L., *Datura stramonium* L., *Emblica officinalis* L., *Eucalyptus globules* L., *Lawsonia inermis* L., *Mimusops elengi* L., *Peltophorum pterocarpum* L., *Polyalthia longifólia* L., *Prosopis juliflora* L., *Punica granatum* L. and *Sygigium cumini* (L.) Skeels were effective to control *Aspergillus* sp. in sorghum, corn, and rice seeds. Aqueous extracts of *Moringa oleifera* Lam leaves in *Vigna uniguculata* L. seeds are efficient to control

Tabela 1: List of studies using plant extracts to control seed pathogens.

Plant extract	Extractor	Studied seed	Evaluated pathogens	Efficiency in pathogen control	Interference in seed germination	Promising for replacing fungicides	References
Aloe vera L., *Allium sativum* L., *Annona muricata* L., *Azadirachta indica* A.Juss, *Bidens pilosa* (L.) Griseb, *Camellia sinensis* (L.) Kuntze and *Chrysanthemum coccineum* Willd.	Aqueous	*Oryza sativa* L.	*Pyricularia grisea* Cooke ex Sacc	Yes	Positive	Not compare	Hubert et al., (2015).
Agapanthus caulescens Spreng., *Allium sativum* L., *Carica papaya* L. and *Syzygium cordatum* Hochst.ex Kraus	Aqueous	*Phaseolus vulgaris* L. and *Vigna unguiculata* (L.) Walp.	*Colletotrichum lindemuthianum* (Sacc. & Magnus) Briosi & Cavara and *Colletotrichum dematium* (Pers.) Grove	Yes	Positive	Yes	Masangwa et al., (2017).
Peganum harmala L., *Urtica dioica* L. and *Helichrysum stoechas* DC.	Aqueous	*Phaseolus vulgares* L.	*Sclerotinia sclerotiorum* (Lib.) De Bary	Yes	No effect	Not compare	El-Gali, (2018).
Cinnamomum verum J. Presl, *Coriandrum sativum* L. and *Syzygium aromaticum* (L.) Merr.	Aqueous	*Lactuca sativa* L.	*Cercospora longissima* Cooke & Ellis	Yes	Positive	Not compare	Carmello et at., (2018).
Allium sativum L., *Allamanda cathartica* L., *Tagetes* spp. and *Polygonum hydropiper* L.	Aqueous	*Corchorus capsularis* L. and *Corchorus olitorius* L.	*Colletotrichum corchori* Ikata & I. Tanaka, *Macrophomina phaseolina (*Tassi) Goid, *Fusarium* spp. and *Botryodiplodia theobromae* Pat.	Yes	Positive	Not compare	Ahad et al., (2018).

Pyrus communis L., *Mentha longifólia* Host, *Calendula officinalis* L., *Chenopodium álbum* Bosc. Ex Moq, *Cannabis sativa* L. and *Datura stramonium* L.	Aqueous	*Oryza sativa* L.	*Magnaporthe grisea* (TT Hebert)	Yes	Positive	Not compare	Dar et al., (2018).
Allium sativum L.	Aqueous	*Cucurbita moschata* Duch.	*Alternaria* sp., *Epicoccum* sp., *Fusarium* sp., *Nigrospora* sp., *Phoma* sp., *Rhizopus* sp., *Penicillium* sp. and *Aspergillus* sp.	Yes	No effect	Yes	Sousa et al., (2018).
Azadirachta indica A. Juss	Aqueous	*Raphanus sativus* L.	*Alternaria brassicae* (Berk.) Sacc.	Yes	Positive	Yes	Arefin et al., (2019).
Ateleia glazioviana Baill	Aqueous	*Lycopersicon esculentum* Mill	*Penicillium* sp.	Yes	Negative	Yes	Mauri et al., (2019).
Ocimum gratissimum L.	Aqueous	*Lycopersicon esculentum* Mill	*Penicillium* sp.	Yes	No effect	Yes	Mauri et al., (2019).
Bryophyllum pinnatum Kurz and *Petiveria alliacea* L.	Ethanol	*Vigna unguiculata* (L) Walp.	*Aspergillus flavus* Link, *Aspergillus parasiticus* Speare and *Aspergillus fumigatus* Fresen	Yes	Not rated	Not compare	Ogungbemile et al., (2020).
Cuminum cyminum Wall., *Zingiber officinale* Roscoe and *Citrullus colocynthis (*L.) Schrad	Alcoholic	*Hibiscus esculentus* L.	*Macrophomina phaseolina* (Tassi) Goid.	Yes	Positive	Not compare	Abdulhassan, et al., (2020).
Allium sativum L.	Uninformed	*Annona muricata* L.	*Lasiodiplodia theobromae* (Pat.)	Yes	Not rated	Yes	Santos et al., (2020).

			Griffon & Maubl and *Fusarium* sp.				
Aloe vera (L.) Burm.f. and *Morinda citrifolia* L.	Citric acid + sodium benzoate + potassium sorbate and propylene glycol + water + sodium benzoate + potassium sorbate	*Daucus carota* L.	*Alternaria alternata* (Fr.) Keissl and *Alternaria radicina* Meier, Drechsler & ED Eddy	Yes	Positive	Not compare	Górski et al., (2020).
Cinnamomum zeylanicum Blume and *Ocimum basilicum* L.	Aqueous	*Capsicum annum* L.	*Aspergillus* sp., *Curvularia lunata* (Wakker) Boedijn, *Rhizopus stolonifer* (Ehrenb.) Vuill, *Fusarium* sp. and *Phoma* sp.	Yes	Positive	Yes	Dourado et al., (2020).
Azadirachta indica A. Juss. and *Momordica charantia* L	Ethanol	*Moringa oleifera* Lam.	*Aspergillus* spp. and *Penicillium* spp.	Yes	Positive	Not compare	Lima et al., (2020).
Melia azedarach L., *Dendranthema grandiflora* Tzvelev and *Tagetes erecta* L.	Aqueous	*Carthamus tinctorius* L.	*Aspergillius* spp., *Fusarium* spp., *Nigrospora* spp., *Penicillium* spp., *Sclerotinia* spp. and *Rhizoctinia* spp.	Yes	Positive	Not compare	Menegaes et al., (2021).
Crassiphycus birdiae (E.Plastino & E.C.Oliveira) Gurgel	Aqueous	*Sesamum indicum* L.	*Aspergillus* sp., *Aspergillus* sp. and *Penicillium* sp.	Yes	Positive	Not compare	Silva et al., (2021).

Source: Authors.

Collectotrichum destructivum, although it depends on the concentration degree and exposure time of seeds (Akinbode & Ikotun, 2008). Righini et al. (2021) found that the aqueous extracts of *Anabaena minutissima*, *Ecklonia maxima* and *Jania adhaerens* were efficient to control *Rhizoctonia solani* in *Solanum lycopersicum*.

Plant extracts have a narrow range of specific action mode making them suitable for the control of specific pathogens. These plant extracts also have limited persistence in the field and a shorter shelf life than synthetic chemicals; nevertheless, they do not pose a residual threat and can be used in integrated pest management (IPM) (Zaker, 2016). However, plant extracts have many different molecules in their composition, which vary depending on the plant origin and the extraction process. For example, "Neem" extract can be found more than 50 different molecules. Azadicachtine is important in pest management and is one of its main constituents (Alabouvette et al., 2006). Similarly, quercetin, ß sitosterol, and polyphenolic flavonoids are fundamental in the management of fungal diseases (Kumari et al., 2020).

Degradation and volatilization of bioactive substances reduce efficacy of vegetable-based products under field conditions. However, an alternative to mitigate this disadvantage is to formulate bioactive vegetable products using biodegradable polymers, plasticizers, stabilizers, and antioxidants (Borges et al., 2018).

Despite the increased use of plant extracts as an alternative to synthetic chemical molecules, most studies did not compare the efficacy of extracts in replacement of fungicides (67%). However, 33% of the studies reported this comparison and stated that the extracts tested are promising to replace synthetic fungicides. Santos et al. (2020) used formaldehyde, mancozeb, and garlic extract in soursop seeds and found greater reduction in the incidence of *Lasioplodia theobromae* (Pat.) Griffon & Maubl. and *Fusarium* sp. with emphasis on garlic extract that controlled 100% of the fungus *Fusarium* sp. Sousa et al. (2018) treated pumpkin seeds with garlic extract Trichodel® and Captan® and verified that the extracts reduced the incidence level of *Alternaria* sp., *Epicoccum* sp., *Fusarium* sp., *Nigrospora* sp., *Phoma* sp. to less than 20%. Arefin et al. (2019) state that the integrated use of *Trichoderma harzianum* isolate, Iprodione, Rovral 50WP and *Azadirachta indica* leaf extract enables a better control of *Alternaria brassicae* in *Raphanus sativus* L. Mauri et al. (2019) treated the seeds with extract of *Ocimum gratissimum* and extract of *Ateleia glazioviana* Baill and observed the inhibition of only *Penicillium* sp. in cherry tomato seeds. However, the use of Captana inhibited the fungi *Rhizopus* sp. and *Penicillium* sp.

Thus, plant extracts show efficacy in the control of phytopathogenic fungi associated with seeds. However, more studies are needed to better understand the extraction methods, modes of action, maintenance, and chemical stability of these products, as well as their comparison with other control methods for various pathosystems, due to their specificity, to apply to other cultures and to use them on large scale.

4. Conclusion

Plant extracts are effective to control fungal pathogens in seeds, as reported in several studies. Plant extracts act directly or indirectly on pathogen growth in the seed due to their bioactive compounds. They have a narrow range of mode of action, making plant extracts suitable to control a specific pathogen. Thus, changes caused by the extracts are reflected in the severity reduction of pathogens in plant seeds; therefore, extracts can be considered a management tool for fungal pathogens that affect seeds. Additional studies are needed for a better understanding of these products to expand their use to other cultures and produce them on large scale.

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