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Alternatives and low-cost strategies to control of pathogens in bean seeds: a review

Alternativas e estratégias de baixo custo para o controle de patógenos em sementes de feijão: uma revisão

Alternativas y estrategias de bajo costo para el control de patógenos en semillas de frijol: una revisión

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Abstract

Seeds pathogens compromise the production of beans. Seed treatment is used to mitigate the pathogens' incidence and damage; however, the forms of control must be efficient and safe. Our main hypothesis is that synthetic chemicals are the most efficient treatment against bean seed pathogens. Thus, we discuss the controls of pathogens in bean seeds using different treatments and identify the technologies studied for these purposes. This review assessed papers that used different strategies to control the bean seed pathogen. There are treatment classifications in which synthetic chemicals are the most efficient to control these pathogens, but as a burden, they pose a risk to human health, animals, and the environment. However, alternative, and complementary solutions to control these microorganisms have been sought in physical, natural, and biological control. Of the studies evaluated, 35.29% used biological control, 17.65% used control with natural agents, 11.76% used physical control, and the others corresponded to 5.88% each. 72.22% are related to the control of fungal pathogens, 16.67% to the control of bacteria, and only 11.11% to the virus. 94.12% were effective, and only 5.88% were not successful in controlling. Overall, our findings expand our knowledge about the alternative treatments that are efficient against pathogens associated with bean seeds which could serve as an alternative tool for plant disease management and seed treatment.

Keywords: *Phaseolus vulgaris* L.; Seed disease; Management practices; Sanity.

Resumo
Patógenos de sementes comprometem a produção de feijão. O tratamento de sementes é usado para mitigar a incidência e os danos dos patógenos; entretanto, as formas de controle devem ser eficientes e seguras. Dessa forma, o objetivo deste trabalho é discutir os controles de patógenos em sementes de feijão utilizando diferentes tratamentos e identificamos as tecnologias estudadas para esses fins. Esta revisão avaliou artigos que utilizaram diferentes estratégias para controlar o patógeno de sementes de feijão. Existem classificações de tratamento, em que os produtos químicos sintéticos são os mais eficientes, mas, representam risco à saúde humana, aos animais e ao meio ambiente. No entanto, soluções alternativas e complementares para o controle desses microrganismos têm sido buscadas no controle físico, natural e biológico. Dos estudos avaliados, 35,29% utilizaram controle biológico, 17,65% utilizaram controle com agentes naturais, 11,76% utilizaram controle físico e os demais corresponderam a 5,88% cada. 72,22% estão relacionados ao controle de patógenos fúngicos, 16,67% ao controle de bactérias e apenas 11,11% ao vírus. 94,12% foram eficazes e apenas 5,88% não tiveram sucesso no controle. Os tratamentos alternativos que são eficientes contra patógenos associados a sementes de feijão que podem servir como uma ferramenta alternativa para o manejo de doenças de plantas e tratamento de sementes.
Palavras-chave: *Phaseolus vulgaris* L.; Doença de sementes; Práticas de manejo; Sanidade.

Resumen
Patógenos en semillas que comprometen la producción de frijol. El tratamiento de semillas se usa para mitigar la falla y el daño por patógenos; Sin embargo, las formas de control deben ser eficientes y seguras. De esta forma, el objetivo de este trabajo es luchar contra el control de patógenos en semillas de frijol utilizando diferentes tratamientos e identificamos cómo se utilizan las tecnologías para estos fines. Esta revisión evaluó artículos que utilizan diferentes estrategias para controlar el patógeno de la semilla de frijol. Existen clasificaciones de tratamientos, en los que los químicos sintéticos son los más eficientes, pero representan un riesgo para la salud, los animales y el medio ambiente. Sin embargo, se han utilizado soluciones alternativas y complementarias para el control de estos microorganismos en el control físico, natural y biológico. De los estudios de evaluación, el 35,29% utiliza control biológico, el 17,65% utiliza control natural, el 11,76% utiliza control físico y los demás corresponden al 5,88% cada uno. El 72,22% está relacionado con el control de patógenos fúngicos, el 16,67% con el control de bacterias y solo el 11,11% con el virus. El 94,12% fueron efectivos y solo el 5,88% no tuvieron éxito en el control. Tratamientos alternativos que son eficientes contra los patógenos asociados a la semilla de frijol que pueden servir como una herramienta alternativa para el manejo de enfermedades de las plantas y el tratamiento de semillas.
Palabras clave: *Phaseolus vulgaris* L.; Enfermedad de la semilla; Prácticas de manejo; Sanidad.

1. Introduction

Common beans (*Phaseolus vulgaris* L.) is among the top three crops for human consumption, after soybeans (*Glycine max* (L.) Merr.) and peanuts (*Arachis hypogea* L.) (Mayo-prieto et al. 2020). In addition, it is a Fabaceae of higher worldwide importance, especially in developing countries, as they are sources of protein, starch, and dietary fiber in the population's diet, making them beneficial to health (Meziadi et al. 2016; Los et al. 2018).

The bean is produced by small and large producers with different technological levels, seeking to meet the increasingly high consumer demand (Ishizuka et al. 2020). However, bean is considered a rustic plant, the producers use seeds with low technologies and low phytosanitary quality, that can be an agent of disease transmission and source of primary pathogen inoculum (Sabaté et al. 2018). So, these contaminated seeds cause direct problems such as rot, shrinkage, necrosis, and reduction of physiological potential around the world (Kumar; Gupta 2020; Naqvi; Rehman 2013).

Several microorganisms cause disease in a seedling such as fungus, bacteria, virus, or nematodes, it is a seed-borne pathogen (Yahaya; Yakasai 2022)..The fungal pathogens that affect seeds are divided into field and storage pathogens (Amza 2018). Most of these are common in storage and belong to the genera *Penicillium*, *Aspergillus*, and *Rhizopus* that deteriorate the seeds to the point of making them unfit for consumption and planting (Shamsi; Khatun 2016). On the other hand, field fungi, comprise the genera: *Alternaria*, *Colletotrichum*, *Cladosporium* Link, *Fusarium*, *Helminthosporium* Link, and *Aureobasidium* Viala & G. Boyer (as – Pullularia) that contaminate the seeds development on the mother plant or after their fruits have ripened (Christensen, Kaufmann 1965; Friesen et al. 2014). The diseases such as common bean mosaic virus (BCMV) are caused by virus and affect bean seeds, making them a source of disease dissemination (Elsharkawy; El-say 2015). The mainl example of diseases caused by bacteria on beans is the spot, caused by *Xanthomonas* spp. (Derrasse et al. 2018).

Several treatments can be used to prevent, control, and reduce the incidence of inoculum of pathogens in seeds such as management with synthetic chemicals, physical strategies, biological control using antagonists, resistance-inducing compounds, inorganic and organic natural products (Spadaro et al. 2017). However, the better practices are dependent on the species to be treated, the pathogens involved, and the technological levels of the producers (Wolf et al. 2008; Fang et al. 2021). Thus, the aim of the present review was to provide a brief overview of the management strategies on the control of pathogens in bean seeds using different treatments and identify the technologies that have been studied for these purposes, their efficiency, and perspectives. To collect these data, seventeen scientific articles published between the years 2018 to 2022 were accessed.

2. Methodology

The methodology used in the research is a narrative literature review like those performed by Almeida et al. (2021), Souza et al. (2022) e Samreen et al. (2021). The contents were observed in which the following search platforms were used: SciELO, ScienceDirect, Elsevier, PubMed, SpringerLink, Google Scholar, and CAPES Periodical. Only international literature was searched with the selection criteria established by the authors but within the theme and year of publication. The search terms used were related to the areas of seed pathology, seed technology, and phytopathology, such as: "Seed-borne in beans", "seed-borne", "seed treatment", "common bean seed treatment" and "bean seed pathogens". For the survey of the most current studies regarding the controls of pathogens in bean seeds, 17 scientific articles were accessed from 2018 to 2022.

3. Development

3.1 Main pathogens that affect bean seeds

Seed-borne pathogens that cause disease in bean plants include viruses, viroids, nematodes, bacteria, and fungi (Spadaro et al. 2017). Associated with seeds these pathogens causes damage directly such as wrinkling, discoloration, biochemical changes, and loss of germination and vigor, can be disseminated by seeds in three different ways: internally the seed, externally, or in a mixture (Gaur et al. 2020).

Colletotrichum lindemuthianum (Sacc. & Magnus) Briosi & Cavara, *Diaporthe phaseolorum* (Cooke & Ellis) Sacc., *Diaporthe phaseolorum* var. *soybean* (Lehman) Wehm., *Fusarium oxysporum* f.sp. *phaseoli* JB Kendr. & WC Snyder, *Macrophomina phaseolina* (Tassi) Goid., *Phytophthora phaseoli* Thaxt., *Rhizoctonia solani* JG Kühn, *Sclerotinia sclerotiorum* (Lib.) De Bary (Gaur et al. 2020) are the fungal group that causes diseases in bean seeds. For El-benawy et al. (2020), the most abundant fungal pathogens found in bean seeds are *Aspergillus niger* Tiegh, *A. flavus* Link, *A. ochraceus* G. Wilh., *Rhizopus stolonifer* (Ehrenb.) Vuill. and *Cladosporium* spp.

Seeds are also vectors for nematodes and viruses. Viruses cause low production yields and economic losses, and in these cases, control measures must be preventive (Kaur et al. 2020). For example, common bean mosaic virus (*Bean common mosaic virus*-BCMV) has the potential for vertical transmission through contaminated seeds. However, there is no efficient biological or natural control strategy against BCMV infection. (Mardani-Mehrabad et al. 2020). For Meziadi et al. (2017), the most efficient control for diseases of viral etiology is through certified plants and seeds, chemical control of the vector, and genetic resistance.

The losses caused by bacterial pathogens in seeds are also variable in environmental conditions and each location (Singh; Rathaur 2020). According to Singh and Rathaur (2020), the bacteria *Pseudomonas syringae* pv. *phaseolicola*, *Curtobacterium flaccumfaciens* pv. *flaccumfaciens*, *Xanthomonas axonopodis* pv. *phaseoli*, *X. fuscans* var. *fuscans* are bean seed-borne pathogens. In which common bean bacterial scab, caused by pathogens *Xanthomonas citri* pv. *fuscans* (Xcf) and *Xanthomonas phaseoli* pv. *phaseoli* (Xpp) causes damage to all aerial parts of plants, including seeds, so using seeds free of these pathogens is essential as a management tactic (Chen et al. 2021).

Concern about seed-borne bacteria is pertinent, as management strategies for these pathogens are limited due to the limited amount of chemical treatment. Alternatively, the solution to this problem has been sought in physical control, such as thermotherapy, biological control, and seed health tests. However, it is essential to emphasize that the effectiveness of these controls will depend on the location of these pathogens in the seed and on their ability to disseminate (Darrasse et al. 2018).

3.2 Methods used for the control of pathogens associated with bean seeds

There are many treatment classifications for seed sector, such as fungicides, insecticides, and biocontrol, but they can also be divided into natural chemicals and non-chemicals (Bisen et al. 2015). Seed treatment to protect against pests and diseases is a practice used for centuries, such as the salt used in the year 1600 to treat wheat seeds against rust (Hitaj et al. 2020). Later, in 1920, it evolved into organic mercury to control seed-borne pathogens, and in 1930, dithiocarbamates and organotin fungicides began to be used (Oerke 2006; Goggi 2011).

However, according to Hitaj et al. (2020), the low amount of published data regarding seed treatment makes it difficult for researchers and farmers to compare the benefits and costs, evaluate economic aspects and yields, and adverse effects on the environment.

3.2.1 Synthetic chemicals

Diseased bean seeds treated with fungicides arethe most effective way to control pathogens that affect the crop in the early stages, and its importance has become notorious in commercial plantations (Cardillo et al. 2019). There are three directions for treating seeds with fungicides; the first is to control soil-transmitted fungal pathogens; the second refers to the control of fungal pathogens that are on the surface of the seed and the third to the control of those that are inside the seed (Mcmullen; Lamey 2000). However, it is important to note that fungicides do not control bacterial or viral pathogens, nor do they control all fungi (Mcmullen and Lamey, 2000).

For seed treatment with synthetic chemicals, products belonging to the chemical groups of triazole, carboxin, acylalaninate, dicarboximide, benzimidazole, and strobilurins, as well as the products: carboxin + thiram, fludioxonil + metalaxyl-M, fluazinam+thiophanate- methyl, carbendazim, fludioxonil, diazinon, captan, thiophanate-methyl, diazinon + captan + thiophanate-methyl (DCT) and metalaxyl-M + fludioxonil + azoxystrobin (MFA) (Gillard et al. 2012; Udayashankar et al. 2012; Gillard; Ranatunga 2013; Oliveira et al. 2016).

Neseri and Hemmati (2017) recommend that bean seeds are treated with fungicide before planting to reduce epidemics caused by *Fusarium* and *Rhizoctonia* root rots. However, sterilization of the seed surface – which results in the death of external microorganisms – can promote the growth of endogenous fungi (El-benawy et al. 2020). Synthetic fungicides can act at a single site of action or at multiple sites (multisite) (Baibakova et al. 2019; Yang et al. 2019). Fungicides from the strobiluraria group inhibit mitochondrial respiration by binding to the Qo site of cytochrome binding ATP production (Bartlett et al. 2002, Balba, 2007). Benzimidazoles achieve β-tubulin assembly, mitosis, and cell division (Oliver, Hewitt 2014), as does carbendazim which prevents microtube formation (Baibakova et al. 2019). Phenylamides inhibit RNA synthesis (Oliver, Hewitt, 2014) On the other hand, triazoles inhibit demethylation (sterol C-14 14α of 24-methylenedihydrolanosterol) (Ma, Michailides, 2005).

3.2.2 Physical treatment

Physical treatments can be divided into mechanical, thermal, ultrasonic, and radiation (Spadaro et al. 2017). The mechanical treatment uses brushing and classification; in thermal, hot water and aerated steam or hot air are used; the ultrasonic and radiation use microwaves and UV-C light (Spadaro et al. 2017). The most used are hot water, hot air, and electrons (Mancini et al. 2013), which are essential alternative controls in controlling fungal seed diseases (Matic et al. 2014). In thermal control, such as hot water, what makes it possible to control the pathogen is its exposure to high temperatures (Kalembra et al. 2021).

There is also non-thermal plasma, which presents itself as a promising and safe tool for controlling seed-borne pathogens (Pérez-Pizá et al. 2018). Low-temperature or cold plasma are partially ionized gases, usually coming from low-current electrical discharges in which kinetic energy is stored in electrons (Pérez-Pizá et al. 2018, Sera et al. 2021). By providing the formation of free radicals, ions, ultraviolet light, and other chemical species, these destroy microorganisms (Devi et al. 2017). Plasma treatments act against fungal pathogens by different modes of action: disruption and inhibition of hyphal growth, changes in cell wall surface, oxidative damage, DNA degradation, changes in enzymatic activity and decrease in pathogen activity (Avramadis et al. al. 2010, Šimončicová et al. 2018, Adhikari et al. 2020, Susmita et al. 2022). In bacteria, the mode of action is different, with membrane damage occurring in gram-negative, and in gram-positive, and increase of indices of reactive oxygen species (Han et al. 2016, Adhikari et al. 2020). Toyokawa et al. (2017) observed that roller carrier plasma acts against *Xanthomonas campestris* pv. *grasslands* degrading or oxidizing DNA and destroying lipopolysaccharides. However, it is essential to know that these methods have their advantages (it improves germination performance, initial seedling growth, adaptability to biotic and abiotic stress, dormancy breaking and enzymatic activity) and disadvantages (compromise seed quality, high exposure times, high energy demand, dose standardization and lack of studies in large agricultural areas), considering treatment time, temperature, and energy dose (Selcuk et al. 2008, Taheri et al. 2020, Adhikari et al. 2020, Guragain et al., 2021, Mildaziene et al. 2022, Than et al., 2022, Tanakaran, Matra, 2022).

Several authors have shown that non-thermal plasmas are able to control seed-transmitted pathogens, such as *Aspergillus parasiticus* Speare, *Penicillium* sp. in bean (Rüntzel et al. 2019), in addition to pathogens from chickpea, lentil, soybean (Selcuk et al. 2008; Pérez-Pizá et al. 2018, Taheri et al. 2020, Pérez-Pizá et al. 2021), peanut (Devi et al. 2017), Scots Pine (Swiecimska et al., 2020), onion (Kopacki et al. 2017), rice (Jo et al. 2014) and pepper (Ahmad et al. 2022). Non-thermal plasma, when applied to Fabaceae seeds under low stress, is beneficial for seed germination and seedling growth (Será et al. 2021, Yan et al. 2022), as the results found by Pérez-Pizá et al. (2019) in which it improved the germination of soybean seeds.

Microwave radiation for bean seed treatment to control *Xanthomonas phaseoli* pv. *phaseoli* (Friesen et al. 2014) and *C. lindemuthianum* (Friesen et al. 2014) were evaluated, but in both studies, even affecting less than 10% of seed germination, the method proved to be inefficient in controlling pathogens, not justifying the costs for large-scale treatment.

3.2.3 Natural control agents

During evolution, beans have acquired structural and biochemical defense mechanisms to protect themselves from phytopathogens (Andrade et al. 2020), such as antimicrobial peptides (AMPs) that function as a biochemical defense of plants against pathogen attacks (Campos et al. 2018). The AMPs can be found in roots, leaves, stems, and seeds (Nawrot et al. 2014). However, the presence of these toxic molecules in some organs may be low, such as those found by Andrade et al. (2020), in which using protein extracts from seeds of 19 bean genotypes did not inhibit the *in vitro* growth *Colletotrichum lindemuthianum* pathogens. (Sacc. & Magnus) Briosi & Cavara and *Fusarium solani* (Mart.) Sacc. Therefore, seed treatment methods are the most viable option since they are safer and cheaper to control diseases (Pushpavathi et al. 2017).

It is known that chemical control, especially the use of systemic fungicides, is the most used to control seed and plant diseases (Oerke 2006; Udayashankar et al. 2012; Gillard; Ranatunga 2013), but natural control methods or alternatives are also crucial in the control of these diseases, especially in terms of gaining space in the face of changes in public perceptions about the negative impacts of synthetic chemicals such as resistance gain, environmental damage and high cost (El-gali 2018; Silva et al. 2019; Almeida et al. 2021). From these disadvantages, antimicrobial characteristics have been sought in plants with intensified increase (Pushpavathi et al. 2017). Since some plants have bioactive substances and are sources of resistance inducers (Elsharkawy; El-sawy 2015; Zaker 2016; Hasan; Islam 2020), for the use of these active ingredients, several types of extraction can be used, such as aqueous, dry extract and oil extraction (Spadaro et al. 2017).

These substances biosynthesized in plant secondary metabolism with antimicrobial or elicitor effects can be divided into classes, the main ones being: phenolics, terpenoids, essential oils, alkaloids, lectins, polypeptides, and polyacetylenes (Zaker 2016; Cowan 1999). Phenolics are involved in cell wall membrane disruption and substrate deprivation; terpenoids and essential oils in the membrane rupture, whereas the alkaloids intercalate in the cell wall and/or DNA. Also, according to Cowan (1999), terpenoids are characteristic of plant odors and quinones and tannins for pigmentation. Simple phenolic compounds such as flavones, flavonoid glycosides, coumarins and anthraquinones act inhibiting proteins present in cells. In addition, promote cell lysis of the cytoplasmic membrane of phytopathogenic fungi (Jiménez-Reyes et al. 2019). As well, it enables the resistance conferred due to the presence of elicitor agents, and treating seeds with these elicitors can result in plant defense responses at the beginning of their development (Spadaro et al. 2017). Furthermore, many researchers support using natural products as biofungicides for seed treatment, such as extracts of *Agapanthus caulescens* Spreng., *Allium sativum* L., *Carica papaya* L., and *Syzygium cordatum* Hochst.ex Kraus (Masangwa et al. 2017), *Peganum harmala* L., *Urtica dioica* L. and *Helichrysum stoechas* DC (El-gali 2018) and *Azadirachta indica* A. Juss (Arefin et al. 2019). Essential oils of *Thymus vulgaris* L. (Chrapacienė et al. 2022), *Tithonia diversifolia* (Hemsl.) A. Gray (Dongmo et al. 2021) and *Melaleuca rhaphiophylla* Schauer (Zimmermann et al. 2022).

3.3 Biocontrol agents

Microorganisms used as biological control management strategies provide a safe option for the environment and are potentially stable compared to control with synthetic chemicals (Sabaté et al. 2020). Fungi of the *Trichoderma* genus are important antagonists since they can survive in different unfavorable conditions, have rapid colonization, compete for space, nutrients and modify the rhizosphere (El-benawy et al. 2020). Carvalho et al. (2014) concluded that *Trichoderma harzianum* (CEN287) reduced the incidence of *F. oxysporum* f.sp. *phaseoli* JB Kendr. & WC Snyder in “BRSValente” bean seeds, and promoting better plant growth.

There are also bacteria of the genus *Bacillus* spp., which are used because they have plant growth-promoting activities, agents for biological control, and production of bioactive compounds (Torres et al. 2017; Babalola 2010). *Bacillus amyloliquefaciens* PGPBacCA1 was tested as a seed treatment and controlled *Aspergillus* spp., *Penicillium* spp., and *Fusarium* spp. in white bean cultivar; and *Rhizopus* spp., *Aspergillus* spp., *Penicillium* spp., *Fusarium* spp. and *Rhizoctonia* spp were controlled in black bean cultivars (Torres et al. 2017). *B. subtilis* strain GBO3 was used in the field, and showed a reduction in bean root rot caused by *F. solani* f.sp. *phaseoli* WC Snyder & HN Hansen, *F. oxysporum* sensu Smith & Swingle and *R. solani* JG Kühn. However, the number of diseases that biocontrol organisms can control is still scarce, evident in the few products used (Fernandes et al. 2021).

Biocontrol agents can act against plant pathogens in directly and indirectly forms (Ferreira, Musumeci, 2021). The direct mode of action against the pathogens are competition for nutrients, spaces and oxygen, secretion of antimicrobials, enzyme-mediated lytic mechanism, hyperparasitism and produce antimicrobial metabolites such as those with antibiotic properties (Ashwini, Srividya, 2014, Zohora et al. 2016, Köhl et al. 2019, Ferreira, Musumeci, 2021). Indirectly, they promote plant strengthening and resistance induction, enabling the production of secondary metabolites (Ferreira, Musumeci, 2021).

3.4 Control technologies

According to Nzungize et al. (2012), in Latin America and on the African continent, the coating of bean seeds with synthetic chemicals to control seed-borne pathogens is one of the safest and most economically viable. The presence of many farmers with low purchasing power and low technological level, who do not have the resources to pay for these technologies and do not have instructions for their handling, results in their contamination and the environment. For Kalantari et al. (2018), there is a need to explore different mixtures of rhizobacteria with synergistic interaction, seeking a more sustainable bean production. Nevertheless, El-koly et al. (2021) reported that using chemical fungicides in the treatment of bean seeds was more efficient than biological ones.

Faced with the divergence of perceptions - based on results from particular studies - and the plurality of bean seed treatment, this study consulted 17 scientific articles about bean seed treatment, which forms of control were used, which pathogens were used and evaluated and whether they were efficient. Of the studies consulted, 35.29% used biological control to treate the diseases seeds against pathogens; 17.65% used natural agents control, 11.76% used the physical control, and other studies correspond 5.88%. They evaluated one or more forms of control or also two forms simultaneously. They are chemical, physical, and natural; chemical and biological; physical + chemical; natural + biological and chemical + biological. Among the etiological agents, 72.22% of the studies consulted are related to the control of fungal pathogens, 16.67% to bacteria control, and only 11.11% to virus control (Table 1).

Biological control and plant extracts are increasingly prominent in managing plant diseases and can target the pathogen directly or indirectly (El-Mohamedy et al. 2013; Marquez et al. 2021). According to Kalantari et al. (2018), the seeds,treated with *Bacillus subtilis* and *Rhizobium leguminosearum* reduces the incidence of root rot caused by *Fusarium solani* f. sp. *phaseoli* WC Snyder & HN Hansen, as well as increasing the vegetative and productive yield of beans. Sabaté et al. (2020) demonstrated that seeds inoculated with *Bacillus* sp. strain P12 showed a reduction of approximately 40% in the incidence of *Macrophomina phaseolina* (Tassi) Goid, as well as an increase in beneficial microorganisms in the soil and it was more efficient than the fungicide used (Maxim®Evolution).

Table 1 - List of studies that used different strategies to manage pathogens in *Phaseolus vulgaris* L. seeds.

Form of Control	**Treatment**	**Type of pathogen**	**Evaluated Pathogens**	**Is it effective in controlling the pathogen?**	**Reference**
Biological	*Bacillus* spp. B19, P12 e *B. amyloliquefaciens* B14	Bacterium	*Sclerotinia sclerotiorum* Lib. from Bary, *Cladosporium* sp., *Fusarium* sp., *Rhizopus* sp.	Yes	Sabaté et al. (2018).
Biological	*Bacillus amylolicefaciens* ALB629	Bacterium	*Rhizoctonia solani* JG Kühn	Yes	Martins et al. (2018).
Natural	*Helichrysum stoechas* DC.	Fungus	*Sclerotinia sclerotiorum* (Lib.) from Bary	Yes	El-Gali (2018).
Biological	*Bacillus subtilis*, *Rhizobium leguminosearum*	Fungus	*Fusarium solani* f.sp. *phaseoli* WC Snyder & HN Hansen	Yes	Kalantari et al. (2018).
Natural	essential oil of *Cinnamomum zeylanicum* Garcin ex Blume	Fungus	*Aspergillus* spp. and *Penicillium* spp.	Yes	Valentini et al. (2019).
Natural	Ulvan	Fungus	*Fusarium oxysporum* f.sp.	No	Borba et al. (2019).

			phaseoli WC Snyder & HN Hansen		
Biological Chemical Natural	*Trichoderma harzianum* Rifai Iprodione 20% + tebuconazole 10% and extract of cloves, thymus and garlic.	Fungus	*Colletotrichum lindemuthianum* (Sacc. & Magnus) Briosi & Cavara and *Colletotrichum dematium* (Pers.) Grove.	Yes	Sewedy et al. (2019).
Biological	*Pseudomonas putida F1*	Virus	Common mosaic (BCMV)	Yes	Elsharkawy; El-Sawy (2019).
Physicist	Cold plasma	Fungus	*Aspergillus parasiticus* Speare and *Penicillium* sp.	Yes	Runtzel et al. (2019).
Biological	*Bacilo* sp. strain P12	Fungus	*Macrophomina phaseolina* (Tassi) Goid	Yes	Sabaté et al. (2020)
Biological	*Trichoderma atroviride* P. Karst	Fungus	*Macrophomina phaseolina* (Tassi) Goid and *Rhizoctonia solani* JG Kühn	Yes	El-Benawy et al. (2020).
Physicist + Chemical	Gamma rays + salicylic acid	Virus	Common bean mosaic (BCMV)	Yes	Mardani-mehrabad et al. (2020).
Chemical, Physicist and natural.	Benomyl, garlic clove extract and heat treatment.	Fungus	*Alternaria, Aspergillus, Curvularia, Drechslera, Fusarium, Mucor, Penicillium* and *Rhizopus.*	Yes	Hussain et al. (2020).
Natural+ Biological	Mycorrhizal lemongrass essential oil	Fungus	*Fusarium solani* f. sp. *phaseoli* (Fsp) WC Snyder & HN Hansen	Yes	Eke et al. (2020).
Chemical + Biological	Methyl thiophanate, fludyoxonyl, *Trichoderma asperellum* Samuels, Lieckf. & Nirenberg and *Trichoderma* sp. strain 1306	Fungus	*Fusarium oxysporum f.sp. phaseoli* JB Kendr. & WC Snyder	Yes	Ishizuka et al. (2020).
Physicist	High pressure carbon dioxide	Bacterium and Fungus	*Escherichia coli* AW1.7, *Salmonella Typhimurium* ATCC13311, *Salmonella Senftenberg* ATCC43845, *Salmonella Bareilly* FUA1934, *Salmonella Enteritidis* FUA1946, *Salmonella Thompson* FUA1955, *Aspergillus niger* FUA 5001, *Penicillium roqueforti* FUA 5004	Yes	Fang et al. (2021).
Chemical and Biological	Carboxin + thiram, fludioxonil + metalaxyl-M, tebuconazole, (tolclophos-methyl + thiram, *Bacillus subtilis, Trichoderma asperellum* and *Trichoderma harzianum*	Fungus	*Fusarium solani* (Mart.) Sacc., *Rhizoctonia solani* JG Kühn, *Pythium ultimum* Trow and *Sclerotium rolfsi* Sacc.	Yes	El-koly et al. (2021).

Source: From the authors.

The efficiency of different treatments in controlling these seed pathogens, 94.12% of the studies were efficient in the seed disease control, and only 5.88% were not efficient. The study conducted by Borba et al. (2019) corresponded to the unsuccessful percentages, which stated that even though Ulvana provided an emergence increase of 61%, it did not control *F. solani* f.sp. *phaseoli* (Fsp) WC Snyder & HN Hansen in bean seeds. However, Eke et al. (2020) demonstrated that mycorrhizal lemongrass essential oil efficiently controls these pathogens.

As for Ishizuka et al. (2020), the combination of methyl ethiophanate with *Trichoderma* sp. reduces the incidence of *F. oxysporum* f.sp. *phaseoli* (Fsp) WC Snyder & HN Hansen. According to Sewedy et al. (2019), *Trichoderma harzianum*, Iprodione 20% + Tebuconazole 10%, and clove, thyme, and garlic extracts decreased the growth of *Colletotrichum lindemuthianum* (Sacc. & Magnus) Briosi & Cavara and *Colletotrichum dematium* (Pers.) Grove. Hussain et al. (2020), evaluating bean seed microflora and its treatment in three types of control: Benomyl, garlic clove extract, and heat treatment (50 °C for 15min), observed that all of them were efficient in controlling *Alternaria* sp., *Aspergillus* sp., *Curvularia* sp. *Drechslera* sp., *Fusarium* sp., *Mucor* sp., *Penicillium* sp., and *Rhizopus* sp., Benomyl treatment was more efficient.

According to El-Gali (2018), the use of extracts and powders of *Helichrysum stoechas* DC. are effective and inexpensive to control *Sclerotinia sclerotiorum* (Lib.), De Bary, in the seed, the presence of high content of phenols, flavonoids, glycosides, tannins, terpenoids, and resins in the leaves may be related to this success. Valentini et al. (2019) state that the essential oil of *Cinnamomum zeylanicum* Garcin ex Blume was efficient in controlling *Aspergillus* spp. and *Penicillium* spp.

Regarding physical control, the study carried out by Fang et al. (2021) showed that high-pressure carbon dioxide treatments can be used to reduce or eliminate bacterial and fungal contaminants. Mardani-Mehrabad et al. (2020) stated that the exogenous application of salicylic acid, associated or not, with low concentrations of gamma-ray in the seeds (20 and 30Gy) reduces the infection transmitted by seeds with BCMV. However, Elsharkwy et al. (2019) found the treatment with a biological agent with *Pseudomonas putida* F1 another option against BCMV since this treatment allowed a lower incidence of the disease and better plant development due to the increase of genes and defense enzymes. Rüntzel et al. (2019), exposing bean seeds to cold plasma for 10 to 30 minutes, found an efficient control of *Aspergillus parasiticus* Speare and *Penicillium* sp.

Among the results found in the present study, it was demonstrated that most studies focus on biological and natural control, but it is worth mentioning that when observing both the aforementioned controls, the use of seeds treated with synthetic chemicals as a control treatment was observed, such as studies by Sabaté et al. (2018), Martins et al. (2018), Sabaté et al. (2020), Valentini et al. (2019), Borba et al. (2019) and Eke et al. (2020) and Elsharkawy; El-Sawy (2019). Thus, it can be deduced that as synthetic chemicals already have their efficiency proven through their patents and registrations, new tools for alternative controls of these pathogens are important to being sought to provide an alternative tool to producers.

Therefore, the scientific perception becomes evident, which is also focused on using sustainable and low-cost technologies, enabling agriculture that is less aggressive to the environment and guarantees better food security. It is pertinent to emphasize that these alternative treatments are essential for organic agriculture and that their use is promising (Spadaro et al. 2017; Pushpavathi et al. 2017; Pérez-Pizá et al. 2019; Almeida et al. 2021), as there are few options to reduce seed-borne pathogens (Wolf et al. 2008).

4. Conclusion

In this study, we assessed the different strategies to management of bean seeds pathogens. Our analysis revealed that the use of synthetic chemicals is the most efficient strategy to manage plant disease caused by seed-borne pathogens, as shown in several studies. The mechanisms of action are inhibition of cell respiration, mitosis, cell division, RNA synthesis and demethylation. However, due to changes in society's perceptions of their impacts on the environment and human health, it was noticed that several researches consulted is focused on the use of alternative treatments, which the most studied are those about biocontrol and with natural agents, as well as a growing increase in the use of non-thermal plasma for the control of pathogens transmitted by seeds. These alternative treatments proved to be efficient in controlling pathogens associated with bean seeds, mainly against fungal agents. Thus, the set of changes caused by alternative strategies such as protein inhibition, cell lysis, and resistance conferred reflected in incidence and severity reductions of plant diseases. The Biocontrol and natural agents are alternative managements that can be considered tools for the control of seed diseases.

Considering the importance of seed-borne pathogens in bean plant, a better understanding of alternative management practices is of paramount importance to develop strategies that decrease production losses and focus on the concept of global health. Therefore, further studies are needed to explore more efficient natural agents, their form of application and action on specific pathogens transmitted by seeds.

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