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Enhancing The Health And Viability Of Forest Seeds: Understanding Pathogen Resistance And Reaction For Effective Preservation And Management

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Abstract:
Research on the health and viability tests of forest seeds is scarce and limited. It is of utmost importance to know more about the resistance and reaction of these seeds to pathogens, as they are easily vulnerable to disease-causing agents and have significant importance in forest plantations, both ecologically and economically. From such concepts, it becomes important to study pathogens observed in species, as they cause damage to plants such as burns, rots, molds, among others, leading to a reduction in the storage time of these seeds and losses at the field level through epidemics, as the identification of these antagonistic agents is more accurate and feasible through knowledge about environmental conditions, storage, and methods for managing these seeds. Through these concepts, this work aimed to conceptualize and present practical issues regarding the importance of preservation work and maintenance of the sanitary and physiological quality of seeds, as well as to expose some fungi associated with seeds according to some research, since seeds are natural goods that must be understood for their management and work to be executed in the best way.

Keywords*: forest pathology, seed treatment, seeds, phytosanitary*

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I. Introduction

There is a demand for seedlings of native species, which mostly propagate through seeds, which have been mainly used for the recovery of degraded areas, reconstitution of legal reserves on rural properties, or even for urban afforestation. However, the use of these species presents some limitations due to the lack of information on germination and vigor, as well as the sanitary quality of the seeds.

Knowledge about the sanitary characteristics of seeds is an important factor for obtaining forest seedlings, especially native ones, as well as for forming good quality seedlings and for the installation of any cultivation, since pathogens can be associated with them, causing damage both to the seeds, reducing the germinative power, and causing damping-off in pre- and post-emergence seedlings (Santos et al., 2001; Gallotti, 2003).

Among the pathogenic agents that can be associated with seeds are fungi, which represent the largest group, followed by bacteria and, to a lesser extent, viruses and nematodes (Machado, 2000). Neergaard (1979) describes the damage that can be caused by pathogenic agents associated with seeds, including pre-emergence death, root rot, seedling damping-off, necrotic spots on leaves and stems, deformations such as hypertrophies and underdevelopment, tissue discoloration, and latent infections.

Fungi attacking seeds of forest species have not received due attention over the years; consequently, there is ignorance about the mechanisms of transmission, method of penetration into the seed, modes of action, and damage caused by them (Homechin et al., 1986; Singh, 1997), as well as about the losses in physiological quality of seeds and also economic losses due to the presence of pathogens associated with seeds (Carneiro, 1987).

According to Carvalho & Nakagawa (2000), one of the ways that favor the survival and dissemination of pathogens is the aggregation of these agents in the seeds, since the seeds are propagules that present a greater potential for viability over time, compared to other vegetative propagation parts.

To obtain good quality seedlings, that is, to increase survival and good development of the seedling in the field, is associated with the sanitary quality of the seeds, since the presence of pathogens can reduce the germinative capacity of the seeds, causing great losses in seedling production due to a lack of knowledge about the association of pathogens in seeds (Soares, 2015). In this same context, obtaining good quality seedlings are factors that value prior knowledge of the health and quality of the chosen seed, since if they are infected, they are liable to spread and disseminate inocula in new areas (Carneiro, 1986). From works carried out by Lopes et al. (1991) & Castellani et al. (1996), it was observed that exposure of the seed to a complicated contamination can affect its physiological quality and even inhibit and cause degeneration in the germinative capacity of the seeds.

Due to the high potential for turnover and market of seeds as previously described, it becomes indispensable to have a greater acquisition of knowledge and information regarding the pathogenic and sanitary relations of seeds of various forest species that have not yet been studied. Therefore, the objective of the work was to present and discuss aspects related to the transmission of pathogens in forest seeds, list the main pathogens and diseases associated with forest seeds.

Storage fungi in seeds

Nowadays, producing and marketing seeds and seedlings means developing a set of procedures using appropriate technical standards according to the Federal Seed and Seedling Law (2003).

With this, storage becomes an essential task where seeds are kept as a means of security to be used later in new planting activities, however, during this process, various fungi can remain in the seeds causing deterioration or later affect the formation of the seedling.

It is fundamental to pay great attention to those newly harvested seeds, as they harbor storage fungi that have the capacity to survive in environments with low humidity, leading to a succession to field fungi and thus causing seed deterioration (Berjak, 1987; Soave & Wetzel, 1987; Carvalho & Nakagawa, 1988).

Fungi of the genus Aspergillus spp. and Penicillium spp., with high occurrence in forest species, cause seed rot during the storage and germination phases and are considered by the increase in their incidence in the post-harvest period of storage fungi (Christensen, 1973).

According to Berjak (1987), Soave, J. & Wetzel (1987), to ensure safety in seed stocks, it is necessary to have a long period of seed storage, in case of failed harvests, for example, and also for the conservation of germplasm.

The attack of pathogens on seeds is very frequent, since if not processed and stored correctly, the environment and the conditions of the place can make the seed susceptible to these agents. There are several problems caused by storage pathogens among them, rot, stains, cankers, and anthracnose (Peske et al., 2012).

One of the main diseases in forest nurseries is damping-off, which is caused by various soil-dwelling fungi, notably *Cilindrocladium* spp., *Fusarium* spp., *Phytophthora* spp., *Pythium* spp., and *Rhizoctonia solani*. The symptoms of the disease are verified in regions of the seedling's collar of soaked aspect, at the beginning, acquiring, later, dark color, product of the loss or alteration of tissues, thus causing the seedling to fall and die (Parisi et al.,2015).

The incidence of fungi in seeds can cause discolorations of the tegument, deformations, reduction of germination, diseases in seedlings, necrotic spots, and rot, thus reducing its germinative power and can cause problems in the formation of seedlings in the nursery, besides constituting primary foci of infection in the nursery and in the field (Camargo, 2007).

The use of healthy seeds in the face of a wide range of diseases in forest species is essential. Because, healthy seeds will originate also healthy seedlings, as well as, the increase of the survival rate of seedlings in the field. In this way, we can define that survival in the early stages influences the demography of populations, affecting the abundance, the distribution of adults, as well as, the composition and dynamics of the plant population.

Some fungal species have a critical lower limit of moisture that can be crucial for seed health, below such moisture the fungus ceases to act. The relative humidity of the environment determines the beginning of the infection process, where the seeds are in equilibrium with the relative humidity of the air, xerophytic fungi that attack such seeds can grow at a relative humidity of up to 70 %. A better condition for fungal infection is also the temperature, found between 28 – 35 °C as optimal for contamination.

The fungi *Aspergillus* sp. and *Penicillium* sp. are very frequent and are mainly associated with seed rot. These pathogens can settle in the internal tissues of the seeds, this contamination occurs at the moment of seed formation, and they survive inside the seeds until the moment when they have the ideal conditions for their development.

Various authors also describe the fungi *Aspergillus* sp. and *Penicillium* sp. as the cause of intoxication problems in humans and animals. These fungi can produce toxic substances such as mycotoxins, which come from the secondary metabolism of fungi, whose main characteristics are: a wide spectrum of toxicity, low molecular weight, and act at low concentrations (Bok et al., 2004).

The genera *Penicillium* and *Aspergillus* have the capacity to reduce the germinative power of the seed and cause the death of the embryo. In the lower degrees of seed moisture, close to the minimum limit for the growth of fungi, the attack is slow. However, as the degree of moisture of the seed rises, the loss of germination becomes more rapid, due to the rapid growth of the fungus (Angelini, 1986).

The fungi *Aspergillus* sp. *Penicillium* sp. attack various crops of economic importance, such as forest and agricultural species, of the same species and the same cultivar, subjected to similar storage conditions, since each seed and each lot have a history, determined by the conditions of production.

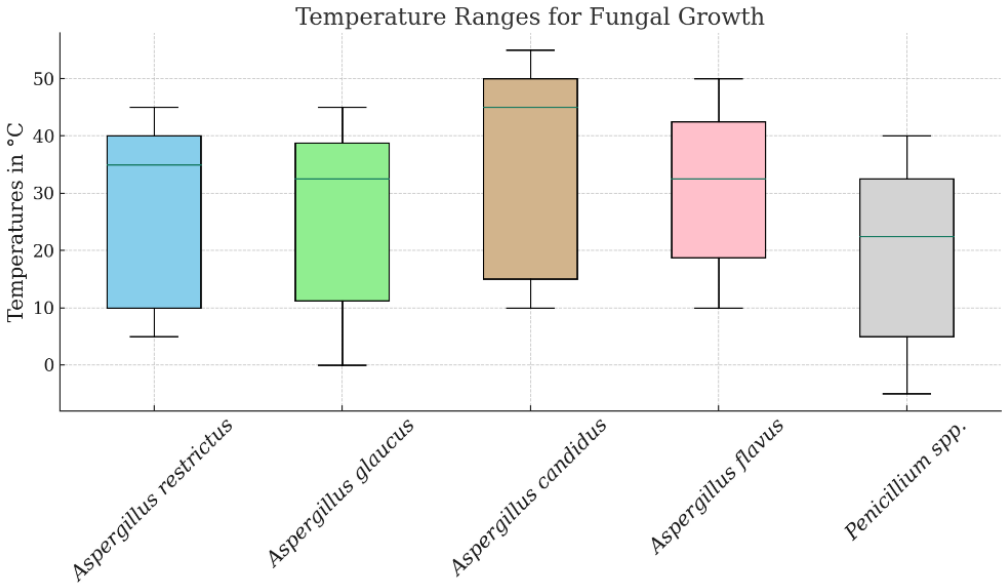
The most determining and most important factors in infection by storage fungi are: temperature, time, relative humidity of the environment, and moisture of the seed. Given this, some relationships between temperature and moisture of the species of *Aspergillus* sp. and *Penicillium* spp. are presented in "Table 1/Figure 1 and Table 2".

Table 1: Minimum, optimal, and maximum growth temperatures of fungi in seeds.

Fungi	**Temperaturas em ° C**					
	Minimum Range		**Ideal Range**		**Maximum Range**	
Aspergillus restrictus	5	10	10	35	40	45
Aspergillus glaucus	0	5	30	35	40	45
Aspergillus candidus	10	15	45	50	50	55
Aspergillus flavus	10	15	30	35	45	50
Penicillium spp.	-5	0	20	25	35	40

Source: Based in Souza (2004).

Figure 1 - Minimum, optimal, and maximum rangesgrowth temperatures of fungi in seeds.



Source: Based in Souza (2004).

Table 2: Relative Humidity Conditions for Fungal Growth

Storage Fungi 65–90% RH	*Aspergillus restrictus*
	Aspergillus glaucus
	Aspergillus candidus
	Aspergillus ochraceus
	Aspergillus flavus
Intermediate 85–90% RH	*Penicillium spp.*
	Fusarium spp.
	Yeasts
Field Fungi > 90,0% RH	*Alternaria spp.*
	Cladosporium spp.
	Helminthosporium spp.
	Helminthosporium spp.

Source: Based in Souza (2004).

Given the analysis of the tables, it can be considered that storage under ideal conditions is essential to avert the optimal conditions present in temperature and ambient humidity, both in the field and in storage. Some conditions provided by the environment make the seeds favorable to the growth of fungi, such as *Aspergillus* and *Penicillium* sp., which, as seen above, present similar growth characteristics. Such characteristics (temperature and humidity) are present in countries of tropical regions, like Brazil. The association of fungi with seeds shows an ever-growing concern, especially in tropical countries, which present diverse climatic conditions making a greater number of problems and adaptations appear unpredictable (Machado, 2000).

According to Lima Júnior (2010), periodic determinations of the moisture level between harvest and commercialization allow the identification of problems that may occur along the different processing phases and enable the adoption of appropriate measures for their solution. With this information, it is possible to properly manage the seeds using, if necessary, suitable practices that promote their conservation for longer periods, as is the case with orthodox seeds that require a low degree of moisture to maintain viability and which have a high moisture content at harvest, needing drying prior to storage.

Faiad et al. (1995), in a study in the Cerrado with seeds of native species, analyzed the fungi that presented an occurrence higher than 25%, which were: *Alternaria* sp., *Aspergillus* sp., *Cladosporium* sp., *Epicoccum* sp., *Fusarium* sp., *Penicillium* sp., *Pestalotia* sp., *Phoma* sp., *Phomopsis sojae*, *Rhizopus* sp., *Rhizoctonia solani*, and *Verticillium* sp. The most frequent fungi were from the genera *Penicillium* and *Aspergillus*. These results, according to the author, indicate that the seeds may not have been stored under good conditions. Other fungi considered saprophytes were also detected in this same work (Faiad et al., 1995), among them, *Alternaria* sp., *Chaetomium* sp., *Cladosporium* sp., *Nigrospora* sp., and *Rhizopus* sp. Some fungal species considered important pathogens for seedlings that cause damping-off, such as *Phomopsis* sp., *Fusarium* spp., *Sphaeropsis* sp., *Verticillium* sp., *Rhizoctonia* sp., and *Colletotrichum* sp. were detected in the studied species.

According to Lucca-Filho (1995), environmental conditions during the storage period and the characteristics of the seed lot, especially the physical state, water content, and initial inoculum, regulate the activity of storage fungi. Fungi can reduce seed germination, produce stunted young plants, necroses in the hypocotyl and roots (Chamberlain & Gray, 1974).

The importance of studying the best storage conditions is fundamental to avoid loss processes due to pathogenic contaminations to seeds, especially when environmental conditions are so favorable to their development.

Seed preparation for storage: Moisture control

The drying operation, suitable for each species and after extraction and cleaning, is an important condition for seeds with characteristics of tolerance to dehydration, to have their viability prolonged (Medeiros, 2001).

According to Albrecht (1993), the drying process requires control of seed moisture loss since above 45 to 60% humidity, the onset of germination is observed; above 18 to 20% humidity, seed heating is observed due to increased respiration rate and energy release; above 12 to 14% humidity, fungal development occurs; above 8 to 9% humidity, insect activity is reduced; from 5 to 7% humidity, storage with hermetic packaging is guaranteed for many years and below the critical level of 5 to 7% seed moisture (wet basis), continuing the drying process does not increase longevity. On the contrary, they can lose viability more quickly, especially if they are not fully mature.

From such conditions, it is understood that seeds that are tolerant to desiccation need to be harvested and treated at the right time, as soon as possible, processed and dried around 6% humidity so that the above phenomena do not occur.

Storage

Seed storage should start at physiological maturity, and the greatest challenge is to ensure that the seeds still present high quality after a certain period, prolonging their longevity by controlling the degree of moisture, temperature, and storage environment conditions (Crochemore 1993; Medeiros 2000).

It is seen that humidity and temperature are the main characteristics to increase the susceptibility to contamination during storage. The reduction in seed moisture content for some species (Araucaria, Acer, Citrus, etc.) causes loss of viability. In these cases, the seeds should be stored with a high moisture content at low temperatures to delay their deterioration.

According to Popinigis (1976), high moisture levels cause or favor an increase in seed temperature due to respiratory processes, increased susceptibility of the seed to thermal injuries during drying, increased activity of microorganisms, mainly fungi, and an increase in insect activity during storage (Table 3).

Table 3 - Consequences of increased seed moisture content during storage.

Seed moisture content	Consequence
Above 40-60%	The seeds germinate
Above 18-20%	Seed warming
Above 12-14%	Crescimento de fungos na semente
Above 8-9%	Fungal growth on seed

Source: Based in Popinigis (1976).

When there is a reduction in moisture content, fungal activity ceases. Therefore, processing methods for seed storage become necessary. For possible seed conservation in relation to moisture, the oven becomes indispensable. Species that go through the processing will be classified as to "longevity" and "desiccation".

Longevity, according to Ewart in 1908, divided them into three groups (Hong & Ellis, 2003): **Microbiotic**, those that tolerate storage up to three years, **mesobiotic**, which tolerate 3 - 15 years, and **macrobiotic**, which tolerate storage for more than 15 years.

The longevity of stored seeds is influenced mainly by the following factors (Hong & Ellis, 2003; Bonner, 2001): Initial seed quality; Seed moisture content; Time elapsed between harvest and storage; Phytosanitary and thermal treatments applied; Type of packaging; Storage temperature and relative humidity of storage.

According to Bonner (1989), the classification of seeds as to "desiccation" in storage is divided into:

• **Orthodox**: can be stored with less than 10% moisture content, maintaining or increasing longevity.

• Recalcitrant: do not tolerate desiccation to a moisture content lower than 25% to 50%, depending on the species, without losing viability (Bonner, 2001).

Many of the seeds considered tolerant to dehydration, such as those of *Mimosa scabrella*, can be stored for several months in room environment, in regions where the temperature is between 20 and 25°C. However, suitable places must be planned for greater maintenance of seed viability for long periods (Medeiros, 2001).

Conditions for storage

Some general principles for seed storage described by UFMS (2004) state that storage does not improve the quality of seeds, it only maintains them; The higher the temperature and humidity in storage, the greater the physiological activity of the seed and the faster its deterioration; Humidity is more important than temperature; Seed moisture is a function of relative humidity and to a lesser extent temperature; Dry cold is the best condition for storage of orthodox seeds; Immature and damaged seeds do not withstand storage well, while mature and undamaged seeds remain viable for longer; The storage potential varies with the species; It can also be added that: stored seeds always deteriorate over time (Kramer & Kozlowski, 1972).

The above conditions are suitable for orthodox seeds, while for recalcitrant seeds, they are not always applicable, and each species has its specific requirements. Orthodox seeds have a tegument impermeable to water, which facilitates the maintenance of low water contents during storage, after drying. Recalcitrant seeds, on the other hand, are characterized by not undergoing natural desiccation in the mother plant during the maturation process, being dispersed with high water contents that, if reduced to a critical level, will lead to rapid loss of viability and even death.

The process of seed deterioration in storage comprises a sequence of physiological and biochemical changes initiated right after the point of physiological maturity, which result in reduced vigor, culminating in the loss of germination capacity.

Storage aims primarily to reduce the speed and effects of deterioration in seeds, however, it is known that there is a vast diversity of species in relation to different tolerances to the storage potential of seeds, thus, a greater analysis of seeds for each species is needed before handling them.

Very little information is available regarding the conservation of seeds not tolerant to dehydration. Generally, for seeds with this physiological behavior, it is recommended to maintain the high initial moisture degree of the seeds and that these be taken to the nursery as soon as possible, aiming for planting and seedling production (Medeiros, 2001). Some species, such as *Araucaria angustifolia*, can be stored at a temperature of 5 °C or in a domestic refrigerator, for up to five months, when packaged in glass or plastic containers (Prange, 1964). According to Miglioranza et al. (1993), seeds of palm heart (*Euterpe edulis*) are capable of remaining viable for 56 days, when packaged in plastic bags containing carbonized and moistened rice straw and kept at room temperature.

Table 4: Reports of fungi associated with seeds of forest species from Brazil.

Pathogen	Forest Species
Alternaria tenuissima	*Senna occidentalis, Ligustrum lucidum, Handroanthus spp and Pinus*
Alternaria alternata	*Handroanthus sp., Pterogyne nitens*
Alternaria sp.	*Senna macranthera, Anadenanthera macrocarpa, Pterodon emarginatus, Rapanea ferruginea*
Alternaria spp.	*Apuleia leiocarpa , Cedrela fissilis , Cordia goeldiana , Enterolobium contortisiliquum , Pinus elliottii , Pinus taeda , Pseudobombax munguba , Handroanthus sp.p , Vochysia spp., Zygia*

	racemosa ou Zygia latifolia, Jacaranda caroba, Eucalyptus globulus, Schizolobium parahyba, Sesbania grandiflora
Aspergillus flavus	*Senna ocidenthalis, Pinus spp.*
Aspergillus fumigatus	*Pinus spp.*
Aspergillus niger	*Senna occidentalis, Ligustrum lucidum, Handroanthus spp and Pinus*
Aspergillus sydowi	*Senna ocidenthalis*
Aspergillus ustus	*Senna occidentalis, Ligustrum lucidum, Handroanthus spp, Pinus, Cedrela fissilis*
Aspergillus versicolor	*Handroanthus spp., Pinus*
Aspergillus wentii	*Senna occidentalis, Ligustrum lucidum*
Aspergillus sp.	*Acacia spp., Enterolobium contortisiliquum, Aspidosperma spp., Schinus spp., Cassia fistula, Cedrela odorata, Plathymenia reticulata, Anadenanthera colubrina, Prosopis juliflora, Handroanthus chrysotrichus, Bauhinia purpurea, Pterogyne nitens, Ceiba speciosa.*
Aspergillus spp	*Apuleia leiocarpa, Bagassa guianensis, Cedrela fissilis, Cordia goeldiana, Enterolobium contortisiliquum, Eucalyptus spp., Gmelina arborea, Jacaranda spp., Manilkara spp., Manilkara huberi, Mezilaurus itauba, Pinus elliottii, Pinus taeda, Handroanthus spp., Vochysia spp., Zygia spp., Pseudobombax munguba, Schizolobium parahyba.*
Botrytis sp.	*Acacia mearnsii*
Botryodiplodia sp	*Enterolobium contortisiliquum, Apuleia leiocarpa, Cedrela fissilis, Zygia spp., Pinus elliottii, Pinus taeda, Vochysia spp., Acacia mearnsii.*
Camarosporium sp.	*Handroanthus spp.*
Cephalosporium sp.	*Cordia goeldiana, Enterolobium contortisiliquum, Mezilaurus itauba, Pseudobombax munguba, Handroanthus spp.*
Chaetomium sp	*Handroanthus chrysotrichus, Cedrela fissilis, Schinus spp., Bowdichia virgilioides, Senna reticulata.*
Chaetomium spp.	*Cordia goeldiana, Enterolobium contortisiliquum, Zygia spp., Pinus taeda.*
Cladosporium oxysporium Berk	*Senna macranthera, Ligustrum lucidum, Cedrela odorata, Handroanthus chrysotrichus.*
Cladosporium spp.	*Cedrela fissilis, Enterolobium contortisiliquum, Zygia spp., Manilkara spp., Handroanthus spp., Anadenanthera colubrina, Senna reticulata, Bauhinia purpurea, Acacia mearnsii, Pterogyne nitens, Sesbania spp., Rapanea ferruginea.*
Colletotrichum sp	*Bauhinia purpurea, Rapanea ferruginea*
Curvularia lunata	*Handroanthus chrysotrichus*
Curvularia sp	*Cordia goeldiana, Enterolobium contortisiliquum, Eucalyptus spp., Jacaranda caroba, Manilkara spp., Manilkara huberi, Pinus elliottii, Pinus taeda, Pseudobombax munguba, Handroanthus spp., Vochysia spp., Apuleia leiocarpa, Cassia fistula, Plathymenia reticulata, Anadenanthera colubrina, Prosopis juliflora.*
Cylindrocladium sp.	*Acacia mearnsii*
Diplodia sp.	*Kielmeyera coriacea, Handroanthus chrysotrichus.*
Epicoccum purperescens	*Senna macranthera, Ligustrum lucidum, Handroanthus chrysotrichus.*
Epicoccum sp	*Acacia spp., Pinus elliottii, Pinus taeda, Handroanthus spp., Ceiba speciosa.*
Eupenicillium sp	*Senna macranthera.*
Eupenicillium ehrlichii	*Pinus*
Fusarium equisitii	*Ligustrum lucidum, Handroanthus chrysotrichus, Schinus spp., Anadenanthera colubrina, Senna reticulata.*
Fusarium moniliforme	*Handroanthus chrysotrichus, Pterogyne nitens.*
Fusarium oxysporum	*Aspidosperma polyneuron, Anadenanthera colubrina, Senna reticulata, Handroanthus chrysotrichus.*
Fusarium pallidoroseum	*Senna macranthera, Ligustrum lucidum, Cedrela odorata, Handroanthus chrysotrichus.*
Fusarium solani	*Senna spp.*
Fusarium spp.	*Enterolobium contortisiliquum, Prosopis juliflora, Cedrela odorata, Bauhinia purpurea, Handroanthus heptaphyllus, Acacia mearnsii, Rapanea ferruginea, Bagassa guianensis, Cedrela fissilis, Cordia goeldiana, Gmelina arborea, Jacaranda spp., Manilkara huberi, Mezilaurus itauba, Pinus elliottii, Pinus taeda, Pseudobombax munguba, Handroanthus spp., Apuleia leiocarpa, Eucalyptus spp., Manilkara spp.*
Gilmaniella sp.	*Pseudobombax munguba.*
Gliomastix sp.	*Jacaranda spp., Schinus spp..*
Libertella sp	*Pseudobombax munguba.*
Macrophoma sp.	*Apuleia leiocarpa, Cordia goeldiana, Gmelina arborea, Pinus elliottii, Pseudobombax munguba, Handroanthus spp..*
Monilia sp.	*Apuleia leiocarpa, Gmelina arborea, Pseudobombax munguba, Handroanthus spp., Vochysia spp., Plathymenia reticulata, Prosopis juliflora*
Monocillium sp.	*Cedrela fissilis, Manilkara spp., Manilkara huberi, Pseudobombax munguba, Handroanthus spp..*
Macrophomina sp.	*Rapanea ferruginea.*
Mucor sp.	*Ceiba speciosa.*
Nigrospora sp.	*Apuleia leiocarpa, Cordia goeldiana, Enterolobium contortisiliquum, Mezilaurus itauba, Pinus elliottii, Pinus taeda, Pseudobombax munguba, Handroanthus spp., Cordia spp., Jacaranda caroba, Sesbania spp.*
Oidiodendron sp	*Apuleia leiocarpa, Cordia goeldiana, Enterolobium contortisiliquum, Gmelina arborea, Pseudobombax munguba.*
Penicillium decumbens	*Fedegoso*
Penicillium donkii	*Senna occidentalis.*
Penicillium expansum	*Senna occidentalis, Ligustrum lucidum, Handroanthus chrysotrichus, Cedrela odorata, Pinus spp.*

Penicillium islandicum	*Ligustrum lucidum, Pinus spp.*
Penicillium raistrickii	*Pinus*
Penicillium rugulosum	*Senna occidentalis.*
Penicillium versicolor	*Senna occidentalis, Ligustrum lucidum*
Penicillium viridicatum	*Senna occidentalis.*
Penicillium sp.	*Enterolobium contortisiliquum, Acacia spp., Enterolobium contortisiliquum, Eucalyptus spp., Aspidosperma polyneuron, Kielmeyera coriacea, Plathymenia reticulata, Bauhinia purpurea, Acacia mearnsii, Pterogyne nitens, Ceiba speciosa.*
Penicillium spp.	*Apuleia leiocarpa, Bagassa guianensis, Cedrela fissilis, Cordia goeldiana, Eucalyptus spp., Zygia spp., Gmelina arborea, Jacaranda spp., Manilkara spp., Manilkara huberi, Mezilaurus itauba, Pinus elliottii, Pinus taeda, Pseudobombax munguba, Vochysia spp., Cedrela odorata, Schizolobium parahyba, Enterolobium contortisiliquum, Sesbania spp.*
Pestalotia sp.	*Cassia fistula, Cordia goeldiana, Zygia spp., Pinus elliottii, Pinus taeda, Anadenanthera colubrina, Prosopis juliflora, Cedrela odorata, Acacia mearnsii, Rapanea ferruginea.*
Pestalotiopsis guelpina	*Senna macranthera, Ligustrum lucidum, Cedrela odorata.*
Peyronellaea sp.	*Handroanthus spp.*
Phoma sp.	*Enterolobium contortisiliquum, Zygia spp., Jacaranda spp., Mezilaurus itauba, Pseudobombax munguba, Handroanthus impetiginosus, Pinus elliottii, Bowdichia spp., Handroanthus chrysotrichus.*
Pestalotiopsis guelpina	*Senna macranthera, Ligustrum lucidum, Cedrela fissilis.*
Peyronellaea sp.	*Handroanthus spp.*
Phoma sp.	*Enterolobium contortisiliquum, Zygia spp., Jacaranda spp., Mezilaurus itauba, Pseudobombax munguba, Handroanthus spp., Pinus elliottii, Bowdichia spp., Handroanthus chrysotrichus, Pterogyne nitens.*
Phomopsis sp.	*Enterolobium contortisiliquum, Acacia spp., Cedrela odorata, Eucalyptus spp., Handroanthus chrysotrichus.*
Pithomyces sp.	*Handroanthus spp.*
Pleospora sp.	*Vochysia spp..*
Rhizoctonia sp.	*Zygia spp., Cedrela odorata, Acacia mearnsii.*
Rhizopus sp.	*Aspidosperma polyneuron, Kielmeyera coriacea, Cassia fistula, Anadenanthera colubrina, Cedrela odorata, Bauhinia purpurea, Pterogyne nitens, Ceiba speciosa.*
Septoria sp.	*Cedrela fissilis*
Sphaeropsis sapinea	*Handroanthus spp.*
Stachybotrys sp.	*Handroanthus spp., Vochysia spp..*
Torula sp.	*Gmelina, paraju, P. elliottii, ipê*
Trichoderma sp	*Gmelina arborea, Manilkara spp., Pinus elliottii, Handroanthus spp..*
Trichoderma spp.	*Cordia goeldiana, Enterolobium contortisiliquum, Manilkara spp., Vochysia spp., Manilkara huberi, Mezilaurus itauba, Pinus elliottii, Pinus taeda, Vochysia spp., Schizolobium parahyba, Enterolobium contortisiliquum.*
Verticillium sp.	*Pinus elliottii, Pinus taeda, Enterolobium contortisiliquum, Eucalyptus spp.*

Source: Adapted from Santos et al. (2000); Larazotto et al. (2012); Martinelli-Seneme et al. (2006); Sales (1992); Parisi (2004); Santos et al. (2001); Nascimento et al. (2006); Cherobini, (2006); Lazarotto et al. (2010); Rego et al. (2009).

There are many species that share the same pathogen, even though these species are from different geographical, climatic, and edaphic conditions. Within natural forest species, the transmission of fungi through seeds is lacking in studies and research. Seeds are susceptible to attacks by pathogens, both in the field and during subsequent harvesting, drying, and processing operations (Carneiro, 1990). Fungi with potential to cause plant diseases from various genera, such as *Fusarium*, *Alternaria*, *Cylindrocladium*, among others, have been found in association with forest seeds, causing necrosis in the root system, lesions in seedling collars, damping-off, wilting, and death of seedlings, decreased germination capacity, and seed rot (Carneiro, 1986). For instance, pathogens commonly found such as *Pennicilium* spp. *Aspergilus* spp. have been found in species such as *Bauhinia variegata*, which is an exotic species of the Caesalpinaceae family, native to India, commonly known as "pata-de-vaca", and also in *Cedrela fissilis*, a species of the Meliaceae family widely distributed throughout the Southern and Southeastern regions of Brazil, in studies conducted by Larazotto et al. (2012) and Martinelli-Seneme et al. (2006).

The frequent occurrence of pathogens from the same genus in certain species indicates that there is no endemic barrier that separates different species' exposure to a specific pathogen. Pathogens occurring in seeds are non-specific, less evolved, and highly aggressive, attacking any part of the plant. Seeds attacked by fungi do not always show a decrease in their physiological quality due to such association. However, such pathogenic associations can favor the survival and even dissemination of the fungus. Considering this, Oliveira et al. (2003), comparing methods for disinfecting canafístula (*Peltophorum dubium*) seeds, detected mainly *Trichoderma* sp., *Penicillium* sp., *Aspergillus niger*, and *Fusarium* sp., and found that the percentage of infected seeds did not compromise germination.

The identification of fungi and pathogens is essential for seed use since most pathogens are transmitted through them. The use of healthy seeds is one of the key points for prevention and loss reduction. Just as rot and falls during seedling growth, symptoms commonly presented by *Rizhoctonia* spp., Cherobini (2006) states that

losses in germination due to seed rot were caused by fungi such as Aspergillus spp. and Penicillium spp. as more evident in forest crops. Fungi such as Fusarium and Alternaria can interfere with seedling quality and consequently reduce plant establishment in the field.

Tests for treatment of seed physiological quality

Among the main factors that affect seed quality, the association with microorganisms establishes an increasingly growing concern, especially in tropical countries, where the diversity in climatic conditions makes a greater number of problems related to health more predictable (Machado, 2002).

According to Barrocas et al. (2010), the methods used in detecting fungi in seeds are based on different aspects ranging from visual analysis of the sample and the impure fraction, as well as microscopic examination of the suspension from seed washing, embryo examination, roll of paper method, incubation in standardized culture media or semi-selective media, and incubation in filter paper substrate ("blotter-test") and, in most cases, confirmation by observation under a microscope.

From an ecological point of view, these agents can be grouped into field organisms, where phytopathogenic species predominate, and storage organisms, with a small number of species that deteriorate seeds. Some tests are commonly used to assess the physiological and sanitary quality of seeds, such as germination and vigor test, sanity test, and transmission test. These tests are developed under controlled laboratory conditions and are used for future comparison of different lots' behavior, since each seed can vary its expressions according to the genetic and sanitary inheritances of each one. According to Peske et al. (2003), growth and germination are defined as emergence and the development of essential embryo structures, manifesting their ability to give rise to a normal seedling under field conditions.

Some of the most common tests in seed treatment are described: sanity, transmission, and germination tests:

Sanity Tests: Sanity tests allow for a more thorough observation of problems that occur during seed harvesting and storage, enabling the establishment of methods for pathogen control. These tests can be conducted using the blotter-test method, where seeds, after being disinfested in a solution, typically sodium hypochlorite, are dispersed in transparent plastic boxes called "gerboxes" and then placed in an incubation chamber, where light and temperature are controlled (Brasil, 2017). The test can also be performed on potato dextrose agar (PDA) medium, where after seed disinfection and washing, they are dried on filter paper and then plated on potato dextrose agar (PDA) medium. Considering that PDA medium promotes excessive growth of surface contaminants, after an incubation period with light and temperature control, it is possible to analyze the contaminants in the medium along with the seeds (Brasil, 2017).

Transmission Test: For the transmission test, non-disinfested seeds are divided into repetitions, separated, and sown in styrofoam trays on a substrate, typically vermiculite, to verify whether there is seed-borne pathogen transmission. The seeds are then irrigated daily. The process ends with the verification, after a period of time (30-35 days) of the emergence of healthy seedlings and seedlings with disease symptoms. Seeds that do not germinate and symptomatic seedlings are subjected to a humid chamber and washed with sterilized water for pathogen identification (Brasil, 2017).

Germination Test: In order for the seed to express its maximum germination capacity, it needs to be provided with a series of optimal conditions. The ability to germinate and produce a normal seedling is assessed by the germination test, with the data obtained reflecting the seed lot quality, providing values for sowing, commercialization, and comparison with other seed lots (Figliolia et al., 1993). Each species requires specific conditions (such as variations in light, temperature, oxygen levels, substrate types) for germination, which are standardized so that they can be executed by different laboratories. For this test, the seeds are placed to germinate on a type of paper or substrate (roll of paper, blotter paper, sand, vermiculite), contained within a sterilized alcohol "gerbox". The paper/substrate containing the seeds is moistened repeatedly during the growth process. The boxes are placed in a BOD germination chamber with controlled temperature (e.g., 20, 25, and 30 °C) and photoperiod (e.g., 12h Light/12h Dark) (Brasil, 2017). Such conditions are specified in the Rules for Seed Analysis (Brasil, 2017), but in a very limited number compared to the diversity of species found in Brazil.

Seed Pathogen Control Treatments

The application of treatments becomes highly useful when treatments generally consist of a set of practices, both chemical and biological, essential for enhancing seed performance in the field.

Seed treatment, in a broad sense, involves the application of processes and substances that preserve or enhance seed performance, allowing for the maximum expression of the genetic potential of crops. This includes the application of pesticides (fungicides, insecticides, and nematicides), biological products (Trichoderma), inoculants (nitrogen-fixing Rhizobium bacteria), stimulants (hormones), micronutrients (Cu, Zn), etc., or submission to physical treatments (thermotherapy) (Menten & Moraes, 2010).

It is a set of technological tools of great importance in protecting crops worldwide, as it safeguards the beginning of cultivation from germination to early development (Buzzerio, 2010).

Pathogens, primarily fungi, can be located inside or outside the seeds, causing the following damages (Santos, 2002): rotting - before germination, as pathogens can become active as soon as they are sown; attacking seedlings and causing a reduction in their number; repeated sowing means additional expenses.

The efficiency of seed treatment for controlling pathogens (diseases) depends on the type and location of the pathogen, seed vigor, and the availability of suitable substances and processes (Menten & Moraes, 2010; Queiroga et al., 2012).

According to Santos (2000), seed processing employs methods that are essential for protecting seeds and seedlings against pathogens that cause diseases, preventing the onset of an epidemic (by reducing the amount of initial inoculum), and in the case of untreated substrate, providing protection to seeds and seedlings against pathogens that live and inhabit the soil.

The elimination of pathogens existing in seeds can be done through methods that expose the seeds to certain circumstances, with the aim of obtaining and growing a successful seedling in the field.

There are four types of seed treatments:

Chemical: Chemical treatment involves the application of fungicides, bactericides, insecticides, and nematicides. The product used for treatment must be effective against the target pathogen, exhibit low toxicity (to plants) and little toxicity to the environment and humans, as well as persistence, adhesion, coverage, non-corrosiveness, and non-explosiveness (Santos et al., 2011).

The efficiency of chemical seed treatment depends on local conditions, soil type, sowing depth, the species under study, among others, being influenced by genetic, physical, physiological, and seed health qualities. Only after the knowledge of these attributes, highlighting the health and physiological profile, should chemical treatment be recommended (Parisi et al., 2015).

Physical (thermotherapy): Seeds are subjected to heat (temperature-time binomial), being effective when the pathogen is more sensitive than the seed. It can be by immersion in hot water (49-52 °C / 15-30 min), exposure to hot air or dry heat (90-100 °C / 12 h), aerated steam (50-57 °C / 30 min), (Menten, 2010) and solar energy (40-54º) (Parisi et al., 2015). Considered a non-polluting and low-cost process, it is not commercially used due to lack of dissemination and lack of residual effect, i.e., it does not maintain action on seeds, especially against soil pathogens, requiring complementary seed treatment. However, this method can be an alternative for pathogen control and also for breaking dormancy in some forest species (Parisi et al., 2015).

Biological: Biological control agents (Trichoderma, Bacillus, etc.) are incorporated into seeds, acting through antagonism, hyperparasitism, and competition (Menten, 2010). Several fungi have the potential to be applied to seeds as biological agents, through immersion in a suspension of propagules (108 cells mL-1) for about 10 minutes. The great advantage of this method is that, besides being non-polluting, it can contribute to a more stable set of diseases. Since desirable organisms will be constantly added to the agroecosystem, altering its balance in favor of humans and with little impact on nature (Parisi et al., 2015).

Biochemical: It is the anaerobic fermentation of seeds for a certain period and is based on the sensitivity of seed pathogens to the chemicals released in fermentation. Under conditions of humidity and temperature, acids are generated, inactivating the pathogens present in the seeds. It is a procedure limited to a few cultivated species of little commercial value, also not presenting residual action and can be tested for forest species (Parisi et al., 2015).

II. Final considerations

The important role that seeds play in various activities, both natural and social, to satisfy our needs is well known. The study and prior knowledge of seed varieties, as well as storage and treatment characteristics, are essential for developing new research and discoveries about them because knowledge of the quality and origin of the seeds used is essential for obtaining quality seedlings in the field. Therefore, achieving success in forestry planting, especially commercially, requires essential and indispensable knowledge of the quality of the supplied seeds for success to be achieved.

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