Review Article

Fungi associated with major agricultural and forage crops in integrated systems of Brazilian tropical regions

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ABSTRACT

Integrated production systems were developed to preserve productive resources and maintain the profitability of agribusiness. However, the use of seeds of low physiological and sanitary quality and the implantation of agricultural and forage crops in production fields of low sanitary quality may favor the dissemination and proliferation of phytopathogens such as fungi. Therefore, using the scientific literature, this work aimed to identify the fungi associated with the main agricultural and forage crops that cause damage to the integrated production systems of Brazilian tropical regions and their control measures. This work was based on a literature review in the Scielo, Scopus and Google Scholar databases, with data obtained between 1999 and 2019. The keywords employed were “fungus”, “tropical grass”; “agricultural crops”; “ICLS” (Integrated Crop-Livestock); and “ICLF” (Crop-Livestock-Forest) and their respective terms in Portuguese, under different combinations. For the inclusion criteria, publications (papers, books, theses, dissertations, and scientific communiqués) from 1999 to 2019 which fit the study aim were selected, both in the Portuguese and English languages. The publications that did not meet the criteria of this study and were repeated in databases were considered as exclusion criteria. The main fungi associated with forage and agricultural crops and soils of integrated systems of Brazilian tropical regions are *Bipolaris* sp., *Curvularia* sp., *Exserohilum* syn. *Helminthosporium* sp., *Phoma* sp., *Fusarium* sp., *Macrophomina* sp., *Pythium* sp., *Rhizoctonia* sp. and *Sclerotium* sp. The main methods of fungal control are the use of quality seeds, crop rotation, resistant cultivars, and chemical seed treatment.

Keywords: Crop rotation, fungicides, resistant cultivars, sustainable agriculture, tropical grass

1. INTRODUCTION

Agribusiness is worldwide in importance, providing nutrients and contributing significantly to the world economy. Due to the widespread essentiality of agribusiness, there is a need to keep the systems that compose it increasingly productive while preserving the land and reducing the need to open new areas. In order to achieve this purpose, sustainable cultivation models have been created and perfected, such as Integrated Crop-Livestock (ICLS) and Crop-Livestock-Forest (ICLF) systems. These systems aim at the maximum use of the land without degradation, improvement in the physical-chemical quality of the soil, in the zootechnical indexes of the animal component and income diversification [1, 2, 3, 4, 5, 6, 7].

Both of the above-mentioned integrated systems (ICLS and ICLF), if poorly managed, might suffer from pest and disease attacks. In addition, the implantation of low sanitary quality crops in production fields, culminating in the use of seeds with low physiological and sanitary quality may favor the dissemination and proliferation of pests and phytopathogens in productive areas, reducing the yield of agricultural and forage crops and, consequently, affecting animal performance [8, 9, 10].

Among the phytopathogens that can affect productive areas, fungi and nematodes are the ones that cause most concern as they can decimate crops when in high incidence, being difficult to eradicate from the production system [10].

In order to adopt fungal control measures, aiming at the maximum yield of integrated systems in Brazilian tropical regions, it is necessary to know the fungal incidence in the production fields of the main crops used in these systems, considering that the cultivation of forages belonging to the genera *Brachiaria* syn. *Urochloa* and *Panicum,* as well as agricultural crops such as soybean, maize, sorghum, and millet, are predominant in integrated production systems [11, 12, 13, 14, 15, 16, 17, 18].

Based on this, this study aimed to identify the fungi associated with the main agricultural and forage crops that damage the integrated production systems of Brazilian tropical regions, as well as their control measures.

2. METHODOLOGY

This work was based on a literature review in the Scielo, Scopus and Google Scholar databases, with data between 1999 and 2019.

The keywords employed were “fungus”, “tropical grass”; “agricultural crops”; “ICLS”; and “ICLF”; and their respective terms in Portuguese “fungos”, “capins tropicais”; “culturas agrícolas”; “iLP”; and “iLPF”, under different combinations.

For inclusion criteria, publications (papers, books, theses, dissertations, and scientific communiqués) from 1999 to 2019 which fit the study aim were selected, both in the Portuguese and English languages. Publications prior to 1999, that did not meet the criteria of this study (analyzed by titles and abstract) and were repeated in the databases were considered as exclusion criteria.

After reading the titles of articles and other publications, we selected 100 publications that met the initially proposed criteria, which were read in full.

3. RESULTS AND DISCUSSION

Fungi are phytopathogenic agents at higher rates of association with seeds, presenting longevity in the productive system through the production of resistance structures [19, 20]. They are among the main causes of diseases in forage plants, causing losses in the yield and quality of the green mass produced, besides reducing the quality (germination and vigor) of the seeds [8, 9, 21, 22, 23, 24, 25, 26].

Among the fungi present in soils used in integrated systems, and the fungi associated with *Brachiaria* syn. *Urochloa* sp., *Panicum* sp. and main agricultural crops, there are phytopathogenic taxa belonging to the genera *Bipolaris* sp., *Curvularia* sp., *Exserohilum* syn. *Helminthosporium* sp., *Phoma* sp., *Fusarium* sp., *Macrophomina* sp., *Pythium* sp., *Rhizoctonia* sp., and *Sclerotium* sp.. There are also secondary fungi such as *Alternaria* sp., *Aspergillus* sp., *Cladosporium* sp., *Epicoccum* sp., *Nigrospora* sp., *Penicillium* sp., and *Trichoderma* sp. [8, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36].

Bipolaris sp.

Bipolarys sp. is a pathogenic fungus with a 100% seed transmission rate to the seedlings. It is the main fungus that attacks *Panicum* sp., causing leaf spot disease. However, this fungus can be associated with the integument and interior of the seeds and with crop residues of susceptible crops, such as tropical grasses, maize, wheat, rice, and coffee. In addition, it is favored by temperatures between 22 and 30 °C [24, 25, 37, 38, 39, 40, 41, 42, 43, 44, 45].

The disease and its symptoms are similar in susceptible cultures, being manifested as brown spots and coalescence of the lesions in episodes of severe infestation. These symptoms can be observed 50 days after the sowing of susceptible crops in infected areas and/or using contaminated seeds [37, 38, 46]. In addition to the symptoms of contamination by phytopathogens in tropical plants, it causes disturbances in animals and humans, such as allergies, pulmonary and cutaneous infections [47].

Listing as alternatives to control the disease, the use of resistant cultivars and fungicides is commonly employed. The application of pyraclostrobin associated with epoxyconazole or tebuconazole alone has been promising for the reduction of the disease intensity in *P. maximum* seed production fields, increasing the speed of germination. In addition, cultural control, such as crop rotation, is an effective measure for disease control, since it reduces the initial inoculum [37, 38, 48].

Furthermore, the fungal control can be performed by means of seed treatment with fungicides, aiming to reduce the incidence of fungi in the seeds and in the soil, especially in the initial stages of development of the susceptible plants, besides avoiding the introduction or re-inoculation of phytopathogens [49, 50].

***Curvularia* sp.**

Curvularia sp. is a pathogenic fungus found in several regions of the world that has an important incidence in forage plants of the *P. maximum* species, causing the leaf spot disease [24, 25, 51]. Furthermore, it can cause rotting, reduction of germination up to seed unfeasibility (associating to the integument and endosperm), and death of seedlings in susceptible species, such as tropical grasses and maize, reproducing asexually by ascomycetes [28, 37, 39, 52, 53, 54, 55].

In addition to the diseases that it causes in susceptible plants, the fungus can cause allergic conditions, endocarditis, pheochycosis, mycetoma, onychomycosis, keratitis, brain abscesses, urinary and pulmonary infections, and infectious wounds in animals and humans [56, 57, 58, 59, 60, 61].

For the *Curvularia* sp. control it is possible to employ a seed treatment with the thiram or thiram-associated carboxin fungicides, which also have efficiency in the control of other fungi, such as *Alternaria* sp., *Gerlachia* sp. and *Dreschlera* sp.; as well as the fungicides fludioxonil combined with metalaxyl-M, colorless fludioxonil comminuted with metalaxyl-M, and thiram alone, which also have fungus control efficiency on *Penicillium* sp., *Alternaria* sp., *Drechslera* sp., and so forth. In addition, the association of thiram and thiabendazole fungicides in seed treatment may promote a greater emergence of seedlings [28, 62, 63].

***Exserohilum* syn. *Helminthosporium* sp.**

Such as the fungus *Curvularia* sp., the fungus *Exserohilum* syn. *Helminthosporium* sp. causes rotting, seed unfeasibility and death of seedlings, as well as leaf and stem spot diseases. The manifested symptoms are necrotic and elliptic lesions with intense sporulation of the pathogen [9, 37, 64].

It survives in crop remains (saprophytic form) and in the soil, forming resistance structures and associating to seeds (integument and endosperm) and hosts, such as tropical grasses, sorghum and maize (causing helminthosporiosis). In addition, the fungus is favored by temperatures between 18 and 27 °C and high moisture. The main control method is through genetic resistance and crop rotation with resistant cultures [39, 41, 42, 43, 44, 64].

***Phoma* sp.**

The pathogenic fungus *Phoma* sp. affects several crops from many continents, such as soybean and coffee. In the European region, the main etiological agent in soybean is *Phoma pinodella* (=*Phoma sojicola*). The causal agent in Brazil is the fungus *Phyllosticta sojicola* [35, 65, 66, 67].

Furthermore, this fungus also focuses on forages of the genus *P. maximum.* The symptoms depend on the severity of the incidence, beginning four or five days after the inoculation, causing leaf spot with elongated, necrotic and irregular characteristics, rotting, seed unfeasibility and death of seedlings. By possessing fast and aggressive growth, it can even kill infected seeds before germination [25, 37, 51, 68]. The fungus belongs to the group of mitosporic fungi and is a Coelomycete, presenting cylindrical, hyaline and small non-septate conidia [69].

An efficient alternative to control this fungus is the treatment of seeds with thiram fungicides, thiram associated to carboxin, fludioxonil combined with metalaxyl-M, colorless fludioxonil comminuted with metalaxyl-M, and thiram alone [28, 62, 63].

***Fusarium* sp.**

Fungi of the genus *Fusarium* sp. cause damage to agricultural production systems composed of several agricultural crops, tropical grasses, and animals. This occurs due to the incidence of fusariosis and production of mycotoxin. The symptom of fusariosis in plants is dependent on the phytopathogen species and on the interspecific relation between host-phytopathogen. Mycotoxins can cause symptoms such as false heat, abortion, stillbirths, infertility, problems in the digestive system, bleeding, anemia due to the destruction of the bone marrow, vomiting, necrosis of the epidermis and death of the animals [70, 71, 72].

The *F. solani* species causes red root rot in the soybean crop, a symptom of which is the rotting of the root system; *F. moniliforme* causes the fusarium rot disease in crops of cotton, rice, maize, sorghum, and tropical grasses, in addition to the potential for intoxication of animals due to the production of mycotoxins (zearalenone, fumonisins, and vomitoxins or deoxynivalenol). *F. graminearum, F. equiseti,* and *F. tricintum* also produce mycotoxins in maize, sorghum, soybean, wheat, and oat crops, as well as *F. pallidoroseum,* which can break the stem and lead to the tipping of the cotton, beans and soybean plants [70, 73].

Furthermore, tropical grass seeds susceptible to phytopathogens may increase the inoculum potential in the area and act as a reservoir for future dissemination in crops that will succeed in the area, such as pine, cotton, wheat, rice, bean, soybean, maize, sugarcane, and so forth. The incidence level can be influenced by ideal climatic conditions of high temperature and soil moisture [24, 25, 34].

An effective measure for the control of these phytopathogens is the chemical treatment of seeds with fungicides. Among the available options in the commercialization, as previously mentioned for the control of *Curvularia* sp. and *Phoma* sp, the use of thiram or carboxin associated with thiram is highlighted, besides the fungicides fludioxonil combined with metalaxyl-M, colorless fludioxonil comminuted with metalaxyl-M, and thiram alone. In the absence of resistant cultivars, well-drained and fertilized soils and healthy and certified seeds can be employed [28, 34, 62, 63].

***Macrophomina* sp.**

The genus *Macrophomina* sp. inhabits the soils and manages to multiply in vegetal remains by means of its propagation structures produced by the mycelium (microsclerocios). These structures are resistant to adverse conditions for long periods in the soil. The ideal conditions for phytopathogens to develop are high temperatures and moisture. Moreover, after the insertion into the production area, it attacks roots, stems, leaves, and fruits of susceptible crops, such as sunflower, cotton, sorghum, maize, soybean, and bean, among others. The main species, *M. phaseolina,* triggers symptoms corresponding to grayish lesions that may evolve to rot and tissue destruction. On the other hand, this tissue disruption causes chlorosis, wilt, drought, and death of susceptible plants [34, 74].

The broad spectrum of susceptible species and the absence of resistant cultivars hinder the control through crop rotation, although the performing of this practice with forage grasses is recommended. Also, it is always recommended to use healthy and certified seeds [34].

It is observed that soybean plants produce the phytoalexin gliceolin when infected by *M. phaseolina,* a compound that has the potential to restrict the development of the mentioned fungus through the rapid biosynthesis of glycerol by the plant during fungal infection. This feature may promote genetic improvement programs in the search for resistant plants to *M. phaseolina*. As a palliative measure to reduce the incidence of these phytopathogens, it is possible to use cultivars with higher tolerance to drought and/or high temperatures [75, 76].

***Pythium* sp.**

This pathogen is an inhabitant of the soil which can infect seeds and seedlings. It can be associated with plant remains (saprophytes) or susceptible plants, such as soybean, sorghum, cotton, bean, maize, wheat and tropical grasses. The fungus presents resistance structures (oospores) that allow its survival in adverse conditions [73, 77].

The most frequent species are *P. graminicola* and *P. debaryanum*, but *P. ultimum* causes the most impact. Due, the lesions develop rapidly causing chlorosis, growth reduction, wilt, root rot and tipping of the plant in ideal conditions of development (high moisture and mild temperature) [73, 77].

Furthermore, it also causes economic losses to the agricultural production system since it contributes to the onset of sudden death (root rot and plant tipping) of the Marandu grass (*B.* syn. *Urochloa brizantha* cv. Marandu), along with *Rhizoctonia* sp., *Fusarium* sp. and water stress [37, 78].

***Rhizoctonia* sp.**

The fungus Rhizoctonia is a saprophytic fungus, being able to exert parasitism on several crops and animals. It presents a high gene flow, genetic diversity, sexual reproduction and dispersion of clones with high adaptability, as well as producing resistance structures (sclerotia) which remain in the soil for long periods [73, 79, 80].

The *R. solani* species can cause leaf burning, collection rot and death in tropical grasses, soybean and maize; in soybean, it causes plant tipping and root rot, which may reduce the vigor and germination rate of the seeds, as well as toxins that inhibit plant growth. In cotton, the fungus causes the tipping of the plants [73, 79, 80, 81].

The methods that have effectiveness in controlling the fungi living in the soil, such as *Pythium* sp. and *Rhizoctonia* sp., are based on the chemical treatment of seeds, rotation of crops with resistant species (grasses) and elimination of crop residues. With regard to the biological control, isolates of the fungus *Trichoderma* spp. have effectiveness in the control of *R. solani* [34, 82, 83].

***Sclerotium* sp.**

The main species, *Sclerotium rolfsii*, lives in the soil and affects crops of soybean, bean, potato, and tomato, among others. It causes the rotting of roots and colon, wilt and tipping of infected plants. The symptoms are manifested in the region of the lap of the plant and correspond to dark spots that originate the cortical rot. This rot can be identified by the formation of a white mycelium and brown-colored resistance structures (sclerocytes). The destruction of tissues occurs under these structures and, with that, wilt, drought and death of the plants. The ideal development conditions occur in regions of tropical climate, with temperatures within 25 and 35 °C and soil moisture in 70% of the field capacity [34, 73, 84].

As a control method, the need to use healthy and certified seeds, the elimination of crop residues and crop rotation with maize and cotton (resistant plants) are highlighted, as well as the efficiency of the fungicide tebuconazole in the colony growth and in the germination of sclerotia of *S. rolfsi* with regard to the chemical control [34, 85, 86].

In general, for the fungal control, it is always necessary to employ seeds with high physiological and sanitary quality, as well as crop rotation, resistant cultivars and chemical treatment of seeds with fungicides. Seed treatment has a low cost and can improve seed germination and seedling development. However, for effective seed treatment and fungal control, effective fungicides are necessary [34, 49, 87, 88].

Occurrence regions and economic impacts: Brazil as case study

In Brazil, *Bipolaris* sp. is more frequent in the Southern region, although with severity ranging from low to average. However, *Exserohilum* syn. *Helminthosporium* sp. can reduce up to 50% of the production, primarily in the second harvest of sorghum, in the Brazilian states of São Paulo, Pernambuco, and Distrito Federal, and of maize and tropical grasses in the Brazilian states of São Paulo and Minas Gerais, respectively [89, 90, 91]. At world level, *Exserohilum* syn. *Helminthosporium* sp. can also be found in the Dominican Republic [92].

The fungus *Curvularia* sp. in tropical grasses can be found in the Brazilian states of Mato Grosso, Minas Gerais, and São Paulo, as well as in maize crops in the states of Mato Grosso, Mato Grosso do Sul and Pernambuco [91]. The worldwide distribution of this fungus occurs in tropical and subtropical regions [93]. *Phoma* sp. occurs both in the European region and in Brazil [35, 65, 66, 67]. Reported in Honduras, Costa Rica, Panama, and Colombia in the 1960s, *Fusarium* sp., has primarily reached the Northeast region of Brazil [94].

The occurrence of *Macrophomina* sp. associated with soybean crops can be found in the Center-West region of Brazil, besides the states of Paraná, Rio Grande do Sul, São Paulo, Minas Gerais, and Maranhão. The association with cotton is reported in São Paulo, Paraíba, Pernambuco, Minas Gerais, and Paraná. The association with bean crops might occur in the entire Brazilian territory, except for the states of Amazonas, Roraima, Amapá, Rondônia, and Acre. The association with maize might occur in the South, Southeast and Central-West regions, besides the states of Pernambuco and Bahia. The association with sunflower is verified in Mato Grosso, São Paulo, and Paraná. The association with sorghum is reported in the Brazilian Northeast region and in the state of Rio Grande do Sul [91]. It can also be verified causing damage in Venezuelan crops [92].

The presence of *Rhizoctonia* sp. associated with tropical grasses can be verified in the Brazilian states of Pará and Mato Grosso; in the soybean crop it presents a wide distribution throughout the Brazilian territory, except in the states of Goiás, Espírito Santo, and Rio de Janeiro; as for cotton crops, it only occurs in the state of Paraná [91]. There are also incidence and damage reports of *Rhizoctonia* sp. and *Pythium* sp. in the state of Florida, in the United States of America [92]. Furthermore, the fungus *Rhizoctonia* sp. might cause economic impacts through the reduction of the initial plant population, generating the need for resowing, which costs 6.44% of the total production cost [81]. The occurrence of *Sclerotium* sp. has increased in the last few years, and it has been isolated from several locations in the Mid-North region of Brazil [34].

Generally, the severe incidence of fungi might lead to the increase in the production costs through the need for resowing due to damage in the initial stand of the crops [81]; and through the need for the application of chemical (via seed and leaves) and biological treatments. Furthermore, it negatively affects the crop yield since it causes a reduction in the production of green mass and in the photosynthetic ability, with a reflection of these effects in the production and quality of the grains. The percentages of cost increase and yield reduction in the crops are variable and dependent on the level of incidence by the phytopathogens, interspecific interaction between pathogen and host, disease severity and abiotic conditions [95, 96, 97, 98, 99, 100].

Briefly, based on the scientific findings presented in this paper, the following table was generated (Table 1).

Table 1. Most occurring regions, susceptible crops, damages and control of the fungi discussed in this paper.

Fungi	Regions	Susceptible crops	Damages	Controls
Bipolaris sp.	Regions with a temperatures between 22 and 30 °C; Brazil	Tropical grasses, maize, wheat, rice and coffee	In plants: brown spots and coalescence of the lesions; In animals and humans: allergies, pulmonary and cutaneous infections	Resistant cultivars; Fungicides tebuconazole; pyraclostrobin with epoxyconazole
***Curvularia* sp.**	Found in several regions of the world; tropical and subtropical regions; Brazil	Tropical grasses and maize	In plants: leaf spot disease; In animals and humans: allergic conditions, urinary and pulmonary infections, among others	Fungicides thiram; thiram with carboxin; fludioxonil with metalaxyl-M and thiabendazole.
***Exserohilum* sp.**	Regions with a temperatures between 18 and 27 °C and high moisture; Brazil and Dominican Republic	Tropical grasses, sorghum and maize	In plants: leaf and stem spot diseases, rotting, seed unfeasibility and death of seedlings	Genetic resistance; crop rotation
***Phoma* sp.**	Brazil and European region	Soybean and coffee	In plants: leaf spot, rotting, seed unfeasibility and death of seedlings	Fungicides thiram; thiram with carboxin and fludioxonil with metalaxyl-M
***Fusarium* sp.**	Regions with high temperature and soil moisture; Honduras, Costa Rica, Panama, Colombia and Brazil	Pine, cotton, wheat, rice, bean, soybean, maize, sugarcane, sorghum, and tropical grasses	In plants: red root rot and fusarium rot disease; In animals: intoxication due mycotoxins	Resistant cultivars; healthy and certified seeds; Fungicides thiram; carboxin with thiram and fludioxonil with metalaxyl-M
***Macrophomina* sp.**	Regions with high temperatures and moisture; Brazil and Venezuela	Sunflower, cotton, sorghum, maize, soybean and bean	In plants: rot and tissue destruction of roots, stems, leaves, and fruits	Cultivars with higher tolerance to drought and/or high temperatures
***Pythium* sp.**	Regions with high moisture and mild temperature; Brazil and United States of America	Soybean, sorghum, cotton, bean, maize, wheat and tropical grasses	In plants: chlorosis, growth reduction, wilt, root rot and tipping	Chemical treatment of seeds; rotation of crops; elimination of crop residues; biological control with Trichoderma spp.
***Rhizoctonia* sp.**	Brazil and United States of America	Tropical grasses, soybean, maize, and cotton	In plants: leaf burning, rot, tipping, inhibit growth and death	Chemical treatment of seeds; rotation of crops; elimination of crop residues; biological control with Trichoderma spp.
***Sclerotium* sp.**	Regions with temperatures within 25 and 35 °C; Brazil	Soybean, bean, potato, and tomato	In plants: cortical rot, wilt, drought and death	Healthy and certified seeds; elimination of crop residues; crop rotation; fungicide tebuconazole

4. CONCLUSION

The main fungi associated with forage and agricultural crops and soils of integrated systems in Brazilian tropical regions are *Bipolaris* sp., *Curvularia* sp., *Exserohilum* syn. *Helminthosporium* sp., *Phoma* sp., *Fusarium* sp., *Macrophomina* sp., *Pythium* sp., *Rhizoctonia* sp. and *Sclerotium* sp.

The main methods of fungal control involve the employment of high-quality seeds, crop rotation, resistant cultivars and chemical seed treatment.

COMPETING INTERESTS

We declare that no competing interests exist.

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