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REVIEW

# Application of fungicides in the vegetative stage of soybean [*Glycine max* (L.) Merrill]: Mini-review

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**Abstract:** The significant growth of soybean cultivation [*Glycine max* (L.) Merrill], and the expansion of agriculture throughout Brazil, which occurred during the period of evidence of the industrial policy of import substitution, placed the product as an ideal crop to supply the global demand was growing. Several diseases have already been reported in soybeans, but the incidence and severity depend on some factors, such as climate, cultivars, pathogen inoculum potential, soil structure and fertility, and plant vigor, among others. The disease scenario in soybean crops in Brazil has been changing every year, with an increase in the severity of some diseases, both in the aerial part and those caused by soil-dwelling fungi. The use of resistant cultivars can be adopted and is the most efficient way to control diseases. However, even with adequate management, it is necessary to apply fungicides. For more efficient disease management, it is important to know the effectiveness of the main fungicides used in the crop, in terms of their ability to reduce the progress of the disease in the field; selecting the most efficient fungicides for management. The results of the study demonstrated that fungicides positioned in different application programs reduce the incidence of fungal diseases and improve productivity.
**Keywords:** Fungicides; Soybean cultivation; Fungal diseases; Fungal resistance.

## 1. Introduction

In Brazil, the production of soybeans [*Glycine max* (L.) Merrill] is of paramount importance as it is the main oilseed crop in Brazilian agribusiness (Horikoshi et al., 2021). The relevant growth of soybean cultivation in the country and its expansion of agriculture throughout Brazil occurred during the period of evidence of the industrial policy of import substitution, where the product was inserted as an ideal crop to meet the world demand, which was in full growth. The expansion of soybean cultivation was considered pioneering, making the 1970s a period of great development, especially for the Central-West region (Sarzi et al., 2019; Pozebon et al., 2020; Martins et al., 2023).

According to data from the National Supply Company - CONAB (06/2023), soybean production in Brazil in the 2022/2023 harvest was 154,566.3 million tons (Embrapa, 2023), which places the country as the largest producer of this crop in the world. In particular, the state of Goiás produced around 17,734.9 million tons in this harvest with a planted area of 4,547.4 million hectares.

Thus, in addition to being one of the main global commodities, the soybean complex, made up of soybeans and their derivatives such as oil and bran, has great economic importance for the Brazilian market with the increase in domestic consumption and revenue from exports, as an importing country China (Oliveira; Schneider, 2016; Barbosa et al., 2019). Of the total soybeans produced in the country, 60.7% are for the foreign market and 30.3% are used in the domestic market (Embrapa, 2023).

During soybean cultivation in the vegetative phase, fungicides are applied, many of which are available on the agricultural market, and this chemical class is one of the main ways to control fungal diseases in this crop (Godoy, 2017). Fungicides can be classified into several aspects: in terms of mobility and/or positioning on the plant (topical/immobile, mesostemic, locosystemic, and systemic), in terms of the moment of application and the subphases of the infectious process involved (preventive, curative and eradicative), regarding the absorption of the fungicide by the spores (contact and/or residual/protective), regarding the mechanism, or mode of action, or biochemical mode of action (Reis; Bresolin, 2007).

According to Junqueira et al. (2021) and Moraes et al. (2023), fungicides belonging to the triazole and strobilurin chemical groups are the most used in soybean cultivation. In Brazil, there are 303 registered commercial products for fungal disease control in soybean, of which 50% belong to the triazole group and 25% belong to the strobilurins group, which can be formulated alone or in combination, presenting stable solutions.

Triazoles act by inhibiting the synthesis of ergosterol, a lipid present in the fungal membrane (Villani et al., 2016), which performs a function similar to that of phytosterols (Yang et al., 2015). Another widely used fungicide chemical group in soybeans is carboxamides, which comprise 5% of registered fungicides in Brazil.

Between the end of the vegetative phase and the beginning of the reproductive phase, fungicides are applied, although several researchers are against this application during this period due to problems in the positioning of the first pod and flower abortion. According to Junqueira et al. (2021) and Hanke et al. (2022), fungicides are mainly used from the beginning of the reproductive period, when symptoms become more visible. This period is critical for productivity. Still in this study, the researchers mention that several producers and companies raised doubts about the possible effect of applying fungicides in the soybean flowering phase. Fungicides applied during soybean flowering may result in a reduction in pod establishment due to increased flower abortion. This may be a consequence of the fungicidal effects on pollen tube germination, a fundamental process to ensure fertilization.

In this sense, the use of fungicides during the vegetative period must be evaluated as a beneficial option, thus avoiding possible losses in productivity due to the abortion of flowers, due to the use of this class of pesticide in the reproductive period.

In this study, a systematic review was carried out on the benefits of using fungicides during the growing season in soybean [*Glycine max* (L.) Merrill].

## 2. Material and Methods

### *2.1. Systematic review*

In this study, a systematic literature review (SLR) was adopted. The systematic literature review methodology is presented in this section. We adopted Scopus, the largest database of peer-reviewed literature with a holistic coverage of academic articles, as the database for searching the literature (http://elsevier.com/Elsevier.com, 2024). To define the scope of the study, we identified three clusters of keywords. We searched the articles by using the following portfolio: soy and fungicide keywords; soy and fungicide for soybeans and fungicide in the vegetative phase of soybeans keywords; and soy, chemical fungicide, and biological fungicide keywords to ensure that the terms used in this study better-identified articles (i.e., the scope could not be too broad to search the literature).

Specifically, we used the “advanced search” on Scopus to search for the following keywords: First, we used soy OR soybean OR “fungicide for soybeans” OR “chemical and biological fungicide for soybeans” OR “fungicide application of soybean vegetative phase” OR “soybean production in Brazil” OR “diseases in soybean crops” OR “use of fungicides in Brazil” OR “physiology of soybean fungicides” OR “future of fungicides” as terms to search for articles related to fungicide soybeans.

In this process, we chose “Article” as the document type, “English, Portuguese, and Spanish” as the language of the articles, and “Peer Reviewed Journal” as the article type for searching.

Initially, the search result yielded 800 relevant articles in the database. We then used the following criteria to select articles for inclusion: articles focusing on fungicides for soybeans, fungicide application in the vegetative phase, soybean production in Brazil, synthetic fungicides, and biological fungicides. Articles that did not focus on soybean fungicides were excluded.

After reviewing the title and abstract when searching for the articles, we found 170 potential articles for review. Then, adopting the same criteria, we reviewed the full text and finally identified 60 articles to include in the study. The final article search was conducted in April 2024. In the following sections, the descriptive analysis and thematic analysis are presented to evaluate the literature according to the publication information and key themes.

## 3. Literature review

### *3.1. Soybean cultivation*

Soy [*Glycine max* (L.) Merrill] is an oilseed legume known worldwide for its use in human and animal food and with value in the national and international market (Oliveira et al., 2017). It is the main oilseed cultivated worldwide and the most important source of protein in animal feed, it is also used in human food. This crop is currently grown in several regions of Brazil with different cultivars adapted to each Brazilian scenario, where it presents variability in terms of its productive performance, which leads to selection for breeding programs in other environments, productive and with desired characteristics (Matei et al., 2018).

Soybeans are characterized as a short-day plant, that is, they are C3 vegetables in the photosynthesis pathway, where they must have a period of exposure to photosynthetically active radiation – the period called critical, when nighttime periods are longer than daytime, which favors the flowering of this plant. culture. However, the response to soybean photoperiod is quantitative and not absolute, as flowering will occur even in non-ideal conditions. Floral induction promotes the transformation of vegetative meristems into reproductive ones, and the differentiation of buds into floral primordia, which is decisive for soybean productivity (Floss, 2004; Lin et al., 2021; Staniak et al., 2023).

It was in Northeast Asia that the origin and domestication of soybeans took place, mainly in China and adjacent regions, and with navigation it spread throughout the West (Chung; Singh, 2008). Several experiments were conducted over the years to complete the domestication work of this crop for new environments, thus, there was a diversification in cultivars for different regions. From that point on, cultivars with different production rates were created, strengthening agricultural development in several regions, including in Brazil for human and animal food and intensifying commercial transactions between people and different nations (Wang et al., 2016; Umburanas et al., 2022).

In Brazil, the first reports of soybean cultivation date back to 1882 in the state of Bahia, introduced by Gustavo D'Ultra without success, being taken to São Paulo and cultivated by Daffert in 1892 at the Agronomic Institute of Campinas. From 1908 onwards, Japanese immigrants achieved better results and in 1914 soybeans were introduced in Rio Grande do Sul (Freitas, 2011). The implementation of soybean breeding programs in Brazil made it possible to advance the crop to low latitude regions, through the development of more adapted cultivars through the incorporation of genes that delay flowering even under inductive photoperiod conditions, giving the characteristic of long juvenile period (Priolli et al., 2002; Faxo et al., 2015; Santos et al., 2016).

Thus, it is stated that soybeans were introduced in Brazil with good technological status, with improved varieties, production systems, and adequate machinery, but with production imported from temperate regions, such as the United States (US). The expansion of soybeans to the Cerrado Domain was an achievement of pasture and production institutions in Brazil, such as soil correction, creation of adapted cultivars, crop management, and phytosanitary control suitable for the development of this crop. In lands previously characterized for extensive livestock farming, production, and productivity grow, becoming the main crop in the Center-West of the country with adapted cultivars, showing satisfactory increases and production profitability above the national average (Galindo et al., 2018; Costa et al., 2019).

### *3.2. Soy production in Brazil*

In Brazil, soybean production is today of great importance as it is the main crop included in Brazilian agribusiness. The significant growth of soybean cultivation in the country and the expansion of agriculture throughout Brazil, which occurred during the period of the industrial import substitution policy, made the product an ideal crop to meet the growing global demand. The expansion of soybean cultivation was considered pioneering, making the 1970s a period of great development, especially for the Central-West region (Toloi et al., 2021; Martins et al., 2023; Ferreira et al., 2023).

According to data from the *Companhia Nacional de Abastecimento* – CONAB (06/2023), soybean production in Brazil in the 2022/2023 harvest was 154,566.3 million tons (Embrapa, 2023), which places the country as the largest producer in the world. Goiás produced 17,734.9 million tons in the same harvest with a planted area of 4,547.4 million hectares.

Thus, in addition to constituting one of the main global commodities, the soybean complex, composed of soybeans in grains and their derivatives such as oil and bran, has great economic importance for the Brazilian market with the increase in domestic consumption and revenue from exports (Oliveira et al., 2017; Colussi et al., 2022). Of the total soybeans produced in the country, 60.7% are for the foreign market and 30.3% are used in the domestic market (Branco et al., 2021; Embrapa, 2023; Toloi et al., 2023).

Scientific advances in soil management technologies, with acidity correction techniques; The seed inoculation process for biological nitrogen fixation, and balanced fertilization with macronutrients and micronutrients allowed the crop to express its potential in the different soil and climate conditions of the Brazilian territory (Freitas, 2011; Raut et al., 2020). Another major factor that contributed to the expansion of soybeans in Brazil was the implementation of integrated pest management, controlling the main insects that cause economic damage to this crop. In this sense, it is worth highlighting the beginning of the use of fungicides from the 90s to control the main diseases. These two technologies have gained importance since the implementation of the crop through seed treatment (Oliveira et al, 2017; Freitas, 2011; Haider et al., 2021).

### *3.3. Diseases in soybean crops*

Diseases that affect soybean cultivation have intensified in recent years with the increase in the sown area, the wide sowing window, the expansion of the crop to new regions, and the entry of new pathogens into the country. Approximately 40 diseases caused by fungi, bacteria, viruses, and nematodes have already been identified in Brazil (Barros, 2008, Embrapa, 2014). The importance of each disease varies from year to year, between regions, between properties in the same region, and even between plots of the same property, depending on the cultivar used, the sowing time, the level of technology used, and mainly the conditions of climate in each harvest (Rahman et al., 2020; Abbas et al., 2020).

According to Embrapa Soybean Disease Identification Manual (2014), Roese et al. (2020), and Roth et al. (2020), diseases caused by fungi are known as: Anthracnose (*Colletotrichum truncatum*); Stem canker (*Diaporthe aspalathi* and *D. caulivora*); Cercospora leaf blight and purple spot (*Cercospora kikuchii*); Rust (*Phakopsora pachyrhizi* and *P. meibomiae*); Target spot and Corynespora root rot (*Corynespora cassiicola*); Ascochyta leaf spot (*Ascochyta longae*); Myrothecium leaf spot (*Myrothecium roridum*); Frog's eye spot (*Cercospora sojina*); Brown spot (*Septoria glycines*); Honeydew or late blight (*Rhizoctonia solani* AG1); Downy mildew (*Peronospora manshurica*); Overturning and death in Rhizoctonia tree (*Rhizoctonia solani*); Sclerotium damping off and wilting (*Sclerotium rolfsii*); Powdery mildew (*Microsphaera diffusa*); White mold (Sclerotinia sclerotiorum); Root charcoal rot (*Macrophomina phaseolina*); Brown stem rot (*Cadophora gregata*; Rosellinia root rot (*Rosellinia necatrix*); Stem and pod dryness (*Phomopsis* spp.); Phytophthora root rot (*Phytophthora soyae*); Red root rot (*Fusarium brasiliense*, *F. tucumaniae*, *F. crassistipitatum*). , those caused by viruses: Calic mosaic (Alfalfa Mosaic Virus - AMV), Bean mottle (Bean Pod Mottle Virus - BPMV), Common soybean mosaic (Soybean Mosaic Virus - SMV), Stem necrosis (Cowpea Mild Mottle Virus - CPMMV ), Bud blight (Tobacco Streak Virus - TSV) and also diseases caused by nematodes: Cyst nematode (*Heterodera glycines*), Root-knot nematodes (*Meloidogyne incognita* and *M. javanica*), Wound nematode (*Pratylenchus brachyurus*), Reniforme nematode (*Rotylenchulus reniformis*).

As already seen, Brazil is one of the main agricultural producers in the world, with around 20% of exports being represented by agricultural products in this context, among the factors that influence losses in agriculture, the occurrence of diseases caused by fungi, and fungicides are one of the solutions for controlling and combating these diseases.

Diseases can affect all phases of the plant cycle and can cause productivity losses ranging from 10% to 20%, although this compromise can reach 100% of production when there is no adequate management (Godoy, 2021) .

However, the occurrence of these diseases can be reduced with prophylaxin measures in the treatment of seeds with fungicides, thus protecting against fungi present in the soil during emergence; use of crop rotation, to reduce the population of pathogens that survive from one harvest to another in crop residues; and the elimination of soil compaction, to promote good root development and reduce water accumulation during rainy periods (Panth et al., 2020).

Asadabadi et al. (2021) and Moraes & Sumita (2022) describe that the most efficient forms of control, for most diseases in soybean crops, include correct crop management, crop rotation or succession (cultural control); use of resistant cultivars (genetic control); sanitary void; control with chemical or biological formulated fungicides; use of pathogen-free seeds; efficient seed treatments, and adequate population and spacing.

It is also observed that many diseases can occur in soybean crops (Ferreira et al., 1979; Sinclair, 1982; Embrapa, 2011), and rust and white mold are the diseases that have been causing high costs for their control with fungicides, in addition to losses in soybean production and quality. The disease is caused by the fungus *Phakopsora pachyrhizi* Syd. & P. Syd manifests itself in an irregular form, called Asian Rust. Its symptom is small dots less than a millimeter in diameter, and reddish-brown, on the upper part of the leaf (Meira et al., 2020). In more severe situations of infection, these spots can increase, forming large brown spots, and causing yellowing and even leaf fall (Henning et al., 1997). White mold caused by *Sclerotinia sclerotiorum* (Lib.) de Bary is difficult to control, since the pathogen forms sclerotia (survival structures), which can remain viable for several years, requiring integrated management, as, there are no cultivars resistant to this fungal pathology (Braga et al., 2020; Ferreira, 2023; Hossain et al., 2023).

There are also other soybean diseases, such as anthracnose, caused by *Colletotrichum dematium* var.

*truncata*, which is considered an end-of-cycle disease, which affects the initial phase of pod formation and is favored by high levels of rainfall and high temperatures, especially in the final stages of the crop cycle (Galli et al., 2007; Song et al., 2020). The fungus affects the plant at any stage of development and can cause a complete drop of pods or total deterioration of seeds in delayed harvest (Moraes; Sumita, 2022; Kazartsev et al., 2023).

Target spot is another disease that also affects leaves caused by the fungus *Corynespora cassiicola*. According to Almeida et al. (2005) and Rondon & Lawrence (2021), the lesions of this disease begin with small brown spots, with a yellowish halo, later evolving into large circular spots of light brown to dark brown color, reaching up to two centimeters in diameter. Generally, these spots have darker spots in the center of the circumference, in the shape of a target. Some soybean cultivars have more tolerance or more susceptibility and may suffer severe defoliation, the stem and pods become well infected, even in the roots, producing sporulation.

Furthermore, there are other diseases that, in conditions favorable to their development, have been controlled in the aerial part by the use of fungicides, such as end-of-cycle diseases, target spots, already evident, and powdery mildew. Efficient disease control depends on correct management, including chemical control, when necessary, at the right time, and in an appropriate manner (Xiao et al., 2020; Gikas et al., 2022).

### *3.4. The use of fungicides in Brazil*

The fungicide class of pesticide is widely used to combat fungi that attack agriculture every year, in its various crops. Any chemical compound used for this purpose is called a fungicide. Soybean productivity is influenced by several biotic and abiotic factors, which makes management and cultural treatments essential tools for the success of the crop (Cavalcante et al., 2020; Vielba-Fernández et al., 2020).

The role of fungicides in protecting crops against diseases is indisputable, and currently, due to production characteristics, it is impossible to produce numerous crops without the use of these products, from the treatment of propagation organs to products in post-harvest (Spadotto; Bettiol, 1997; Cota, 2018; Hu; Chen, 2021; Corkley et al., 2022).

In 2008, Brazil overtook the United States and became the world's largest pesticide market. In 2010, the consumption of pesticides in Brazil increased by 190% in the year and fungicides accounted for 14% of this market (Furlong et al., 2020; Santos et al., 2020). According to FAO (2008), fungicide consumption reached a potential area of approximately 800 thousand hectares. The numbers indicate the widespread use of active ingredients such as fungicides in vegetable planting areas in Brazil, which may be 8 to 16 times greater in this production than that used in soybean cultivation (Takahashi; Melhem, 2014; Acari et al., 2021).

With the emergence of Asian rust (*Phakopsora pachyrhizi*) in 2001, new products were registered. The use of fungicides has been intensified as it is the only tool that prevents reductions in productivity in the presence of rust. Other diseases also controlled by fungicides include target spot (*Corynespora cassiicola*), anthracnose (*Colletotrichum truncatum*), white mold (Sclerotinia sclerotiorum) and honeydew (*Rhizoctonia solani* AG1) (Giongo, 2022). Among the main modes of action used to control diseases in soybean crops, methyl benzimidazole carbamate (MBC), demethylation inhibitors (IDM), external quinone inhibitors (IQe) and succinate dehydrogenase inhibitors (ISDH) stand out.). Despite the great contribution, intensive use may result in the selection of less sensitive or resistant fungal isolates (Vieira, 2018; Reis et al., 2021; Bastos et al., 2021).

### *3.5. Fungicide management and physiological processes and soybean productivity*

The use of resistant cultivars can be adopted and is the most efficient way to control the disease. Furthermore, the occurrence of diseases in soybeans and their greater severity depend on factors such as climate, cultivars, pathogen inoculum potential, soil structure and fertility, and plant vigor, among others (Ito, 2013; Chang et al., 2020). When implementing soybean cultivation, it is important to acquire good quality, certified seeds and preferably with genetic resistance to pathogens, according to their availability. Paying attention to the soil is another very important factor. It is recommended to carry out analysis and correction of acidity, according to the result, so that the soybean plant uses fertilization more efficiently. Thus, adequate liming and fertilization and adequate levels of potassium can provide greater vigor to plants and, when attacked by pathogens, they can manifest their resistance and suffer less, with less severity of the disease (Alsajri et al., 2020; Agrofit, 2022; Goettel et al., 2022; Jaques et al., 2022).

Crop rotation, including green manure, can reduce the potential for inoculum of pathogens in the soil, in addition to improving soil structure, reducing compaction, enriching microbiological diversity, increasing organisms beneficial to the crop, providing greater protection against pathogens (Ito, 2013).

However, even resistant cultivars can become susceptible when sown at times that favor the disease (Grigolli, 2014), making it necessary to apply fungicides. According to Ribeiro et al. (2017), the attack of phytopathogens and their dissemination when exposed to ideal conditions for their development is very rapid, which is reflected in the decrease in genetic and productive potential, and consequently in the drop in productivity.

Leaf diseases cause losses ranging between 15 and 20% of production, but some diseases can cause losses of almost 100% (Juhász et al., 2013). One of the main challenges for soybean cultivation is the phytosanitary management of diseases (Fonseca; Araújo, 2015). Fungicides, in addition to being applied in isolation, have commonly been associated with other compounds, which have shown satisfactory results, increasing the effectiveness in the management of diseases of the most varied crops, especially in the management of soybean cultivation, the combination of fungicide with substances that have an additive and synergistic effect, when used in association (Meneghetti et al., 2010; Ioris Junior, 2019).

To reduce the resistance of pathogens to the active ingredients of fungicides, taking into account the possibility of vulnerability (Reis, 2005; Ribeiro et al., 2019; Toda et al., 2021), other strategies must be employed in disease management. There has been an attempt to make new associations and the use of new methodologies, such as the use of alternative control, and the search for mechanisms that can reduce environmental and health impacts, among which we can mention the induction of resistance (Jacinto, 2019; Beckie et al., 2021).

For more efficient disease management, it is important to know the effectiveness of the main fungicides used in the crop, in terms of their ability to reduce the progress of the disease in the field; selecting the most efficient fungicides in management with the rotation of molecules. Thus, reducing the multiplication of pathogen inoculum in the area, as well as the incidence of fungal populations that are not very sensitive to the main fungicides registered for the crop; thus, preserving the efficiency of the fungicide molecule for a longer period (Meyer et al., 2018; Kang et al., 2022).

Resistance induction is described in the literature as a stimulated defense on a systemic basis, which involves the activation of existing defense mechanisms in plants, either by biotic factors or abiotic factors in effective control against pathogens, be they bacteria, viruses, nematodes and fungi (Zanata; Wordell Filho, 2022; Yin et al., 2023).

### *3.6. Fungicide management in the vegetative phase*

Currently, it is common to use a basic model for fungicide applications, in which the economic factor often stands out to the detriment of technical, climatic, and scientific aspects. However, productivity losses due to diseases have worsened in recent harvests, indicating the need to improve management techniques, including chemical control (Fernandes et al., 2020; Bandara et al., 2020).

According to Barbosa et al. (2014) and Duffeck et al. (2020), fungicide treatments and sowing time are determining factors in the severity of the disease and its interference with crop productivity. Characters related to vegetative development are more dependent on variations in the plant population.

Corroborating this, Fernandes et al. (2020) point out that the practice of applying fungicides in advance, in the vegetative stage of soybeans, has grown. Typically, this application is done with plants at the V3 or V4 stage, together with the post-emergence herbicide application. Fungicide applications at this stage greatly favor the deposition of fungicidal molecules in adequate quantities throughout the plant, including the 'future bottom' (Fernandes et al., 2020).

According to Souza (2021), there is a correlation between the consequences of the disease known as Asian soybean rust and the pressing need to anticipate fungicide applications for the vegetative stage of soybeans to increase control in the lower canopy of the crop. However, according to the authors, it is not known about the real importance of the lower canopy in the productive components of the crop and whether the criterion for starting fungicide applications in the vegetative stage is the most appropriate in the management of soybean rust.

Zanatta & Wordell Filho (2022), in their work that aimed to test different fungicide application intervals on the severity of Asian rust disease in an experiment in Rio Grande do Sul, Brazil, resulted in no significant difference between treatments for the variable grain yield and that the severity of the disease only differed between the R5.3 and R5.6 stages. Although it was not possible to verify a difference in yield between the treatments, probably due to the dry climate that affected the period during which the experiment was conducted, a decrease in the severity of the disease could be verified with the increase in the number of fungicide applications, due to the data statistics. This highlights the importance of using fungicides.

In work carried out by Zambiazzi et al. (2018), increasing gains were observed as the management strategy used a greater number of applications during the crop cycle with an average gain of 170 $kg.ha^{-1}$ per application, however, such gains were continuous up to five applications. Secon et al. (2019), observed productivity gains with up to five fungicide applications, with the cultivar TMG 7262 RR, showing higher productivity than the cultivar without the Asian rust resistance gene.

For more efficient disease management, it is important to know the effectiveness of the main fungicides used in the crop, in terms of their ability to reduce the progress of the disease in the field; selecting the most efficient fungicides in management with the rotation of molecules. Thus, reducing the multiplication of pathogen inoculum in the area, as well as the incidence of fungal populations that are not very sensitive to the main fungicides registered for the crop; thus, preserving the efficiency of the fungicide molecule for a longer period (Meyer et al., 2018; Toda et al., 2021; Lockhart et al., 2023).

The main fungicides used are from the groups of triazoles, strobilurins, triazolinthione, and carboxamides, which are formulated individually or not, as is the case of the fungicide trifloxystrobin + prothioconazole, widely used in soybean cultivation. Multisite fungicides, such as copper oxychloride, chlorothalonil, and mancozeb, play an important role in anti-resistance management for site-specific fungicides, as they affect different metabolic points of the fungus and present a low risk of resistance. The use of multisite fungicides increases efficiency in controlling Asian rust (Matsuzaki et al., 2020; Schoffel et al., 2023).

In a study coordinated by Nanuci (2020), the objective was to research new tools that help in the management of resistance to *P. pachyrhizi* along with other diseases through chemical control with the addition of multisite fungicides in mixtures and isolation. The author demonstrated in his results that the use of multisite fungicides in mixtures or alternately to control fungal diseases in soybean crops is efficient, ensuring the productive capacity of the evaluated cultivars.

According to Kajihara et al. (2021) in their study, the use of fungicides in application programs provided profitability for soybean crops, even greater when there were conditions more favorable to the disease, especially in later cultivation seasons due to the greater presence of the inoculum.

In the study coordinated by Godoy et al. (2023), which aimed to evaluate the efficiency of fungicides at the end of the cycle, an application was carried out 50 days after sowing with Fox Xpro 0.5 L/ha$^{-1}$ (bixafen + prothioconazole + trifloxystrobin 62.5 + 87.5 + 75 g a.i./ha$^{-1}$) + Áureo 0.25% *v/v* in all treatments, except in the absolute control (T1). The results demonstrated that even in the initial sowings, several experiments had an incidence of other diseases such as target spot, Asian rust, white mold, and powdery mildew, all of which must be considered in the disease management program to avoid reduced productivity.

Thus, the authors describe that fungicides with known efficiency must be used within rational management, always prioritizing rotation with different modes of action and adapting management to the sowing time, cultivar, property size and application logistics, climatic conditions, and the incidence of diseases in the region and on the property (Godoy et al., 2023).

According to the study by Borghelot (2023), which aimed to evaluate the progression of target spot in an area with *C. cassiicola* inoculation against two soybean cultivars and the number of applications of systemic fungicides associated with multisite and their effects on crop yield. The results demonstrated that target spot management must be planned, even if there are currently no cultivars with an immunity resistance phenotype, partial resistance is an important component to be taken into consideration when choosing the cultivar for planting. Furthermore, other variables affect the management of the disease, such as the climatic conditions of the harvest, the presence of the pathogen in the region, and the active ingredients of the fungicides, among other variables. It is essential to use more than one method of controlling the disease, avoiding the evolution of resistance to fungicidal molecules that are still effective and available on the market (El-Baky et al., 2021; Verma et al., 2022).

Abrantes (2023) highlighted that among the main modes of action of fungicides used to control diseases in soybean crops in Brazil, the most notable are Methyl Benzimidazole Carbamate (MBC, benzimidazoles), Demethylation Inhibitors (DMI, triazoles), Quinone Oxidase Inhibitors (QoI, strobilurins) and, more recently, the new generation of Succinate Dehydrogenase Inhibitor (SDHI, carboxamides) molecules (Meyer; Godoy, 2014). Approximately 70 fungicides from these chemical groups are registered for the control of this disease, separately or in mixtures.

According to Bonafin (2023) in a study on the control of Asian rust in soybeans, with and without v0 application, using chemical and biological fungicides, where according to the authors, zero application of fungicide aims to protect the plant in the vegetative stages, facilitating deposition of this before closing the canopy. The results of the study demonstrated that fungicides positioned in different application programs both with and without application in V0 reduce the development of Asian soybean rust and also defoliation. The use of chemical fungicides associated with biological fungicides applied protectively guarantees the reduction of selection pressure on the fungus *P. pachyrhizi*. The T4 treatment (without V0 and first application at V8) ensures better control of Asian rust compared to T2 (without V0 and first application at V6), indicating that with the late onset of the disease, the first application can be made from V8, optimizing the positioning of applications. Treatments using fungicides ensure the greater thousand-grain weight and number of pods and grains per plant.

Therefore, the use of biological fungicides associated with chemicals demonstrated better results, so biofungicides can be an important tool in combating foliar diseases, which cause a decrease in productivity. Preventive applications of fungicides have resulted in lower productivity losses (Oliveira, 2017; Ons et al., 2022), in addition to a longer control period, a longer interval between applications, and better fungicide performance (Vitti et al., 2004; Pacholak et al., 2022).

## 4. Conclusion

The use of fungicides in agriculture is currently one of the promising alternatives, as in addition to combating different fungal groups, it is also capable of preventing the selection of resistant strains of these microorganisms from occurring, making the use of biologicals another tool in disease control.

Fungicides with known efficiency must be used within rational management, always prioritizing rotation with different modes of action and adapting management to the sowing time, characteristics of the soybean cultivar, extension of the rural property, application logistics, climatic conditions, and the incidence of diseases in the microregion and macroregions.

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## 6. References

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## Ethics

Not applicable.