Chapter 6

Chemical Control of Eucalyptus Rust: Brazilian Experiences

Marcus Vinicius Masson, Willian Bucker Moraes and Edson Luiz Furtado

Additional information is available at the end of the chapter

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1. Introduction

Eucalyptus (*Eucalyptus* spp.) naturally occurs in Australia, Indonesia and neighboring islands such as Flores, Alor and Wetar. The genus *Eucalyptus* belongs to the Myrtaceae family, with around 600 species and sub-species, and shows high plasticity and worldwide dispersion, growing satisfactorily under different edaphoclimatic conditions and surpassing those of the regions of origin. Less than 1 % of these 600 species have been used for industrial purposes. In essence, the use of eucalyptus in the worldwide industry is based on two species, mainly: *E. globulus, E. grandis* and their hybrids with *E. urophylla*, and hybrids between *E. saligna* and *E. camaldulensis*, planted in large scale in Brazil. These Eucalyptus trees are used for the production of paper, cellulose, wood, coal, cluster, sawmill, furniture, oils for pharmaceutical industries, honey, windbreak, and in civil construction and ornamentation.

The importance of eucalypt plantation for Brazil can be assessed based on the participation of the forest sector in the economy's country. Initially supported by governmental tax incentives for reforestation and later by the National Programs for Steel Industry and Charcoal and for cellulose and paper production. Currently, the estimated area of eucalyptus crops in Brazil is of 4.5 million hectares, occupying 66% of the Brazilian reforested area in 2010 [1].

Eucalyptus was considered a genus practically free of diseases until 1970's. However, the progress of reforestation areas to warmer and wetter regions, with the planting of more susceptible species and the repeated use of the same area for planting, created favorable conditions to the occurrence of diseases. Among the latter is rust disease caused by *Puccinia psidii* [2, 3]. Besides the eucalyptus, the pathogen infects other species of *Myrtaceae* [4]. Severe disease infection may cause deformation and necrosis in the shoot of the host reducing the volumetric growth [5-7].

Eucalyptus rust caused by *Puccinia psidii* Winter is currently a very common and severe disease affecting crops of eucalyptus, which is highly susceptible to the disease when it is younger than two years old [8]. Native of South America, rust was first reported in Brazil in 1929 [9] and formally described in 1944 [10]. Nowadays, it is one of the most important diseases of *Eucalyptus* in the country. It affects both seedlings in the nursery and young plants, up to two years old, in the field, reducing the culture productivity and sometimes leading the most susceptible species to death. It may also infect shoots after clear-cutting and clonal gardens and mini-gardens. The first considerable damages were caused in Espírito Santo in the 1970's to crops of *Eucalyptus grandis*, which were less than two years old and imported from South Africa (IPEF). In São Paulo State, the first cases of this disease were found in commercial crops of this same species in the 1990's. High infection rates were also detected for both nurseries and crops in the regions of Vale do Rio Doce, Minas Gerais, Espírito Santo and South of Bahia.

According to a survey carried out by Furtado & Marino (2003), *P. psidii* was found in 14 eucalyptus species and 23 native and exotic Myrtaceae species in Brazil. Besides eucalyptus, this pathogen infects other species of Myrtaceae such as guava, myrtle, Brazilian grape, strawberry guava, Surinam cherry and jambul trees. In these Myrtaceae hosts, besides meristematic vegetative tissues, the fungus infects flowers and growing fruits and may lead to significant losses [11]. Myrtaceae is considered as Eucalyptus rust's original host.

Puccinia psidii is a serious threat to eucalyptus crops in different parts of the world, especially in Australia, to where eucalyptus is native. Occurrences have also been reported in some South American countries such as: Argentina, Colombia, Ecuador, Paraguay, Uruguay and Venezuela; Central America, in the following countries: Cuba, Dominican Republic, Jamaica, Puerto Rico and Trinidad; and North America in South Florida [12]. *Puccinia psidii* incidences were also reported in Japan [13] and Hawaii [14], both for the species *Metrosideros polymorpha.*

There are reports of *Puccinia psidii* attacks to plant species endemic to Australia such as *Melaleuca quinquinervia*in Florida [15] and *Acmena smithii* in Brazil [16]. Recently, [17] found *Uredo rangelii* (morphologically different from *P. psidii*) parasitizing the species *Agonis flexuosa*, *Callistemon viminalis* and *Syncarpia glomulifera*.

Eucalyptus rust is no longer a disease that causes considerable damages only in rare occasions [11]. During the surveys of *Eucalyptus* plantations in Mozambique in May and July 2009, typical rust disease symptoms were observed on eucalyptus trees in several localities in Maputo Province, as well as in Niassa Province. Subsequently, the rust disease has also been found in KwaZulu-Natal in South Africa. These were disturbing findings given the importance of eucalyptus or guava rust fungus, *Puccinia psidii*. Thus far, *P. psidii* has been the only known rust fungus associated with *Eucalyptus* species, and it is one of the greatest threats to *Eucalyptus* forest plantation and to *Myrtaceae* in natural forest ecosystems. Urediniospores have been found and shown to be distinct from *P. psidii* [18].

Data related to damage are shown in Table 1. It considers 30 m^3/ha/year, seven years for harvesting, 20% of medium damage, and USA 700/ton of pulp. The losses of eucalyptus wood account for more than 2 million dollars per year in Brazil.

STATE	TOTAL AREA (hectares)	RISK AREA (%)	DISEASED AREA	PRODUCTION (*m3*)	DAMAGE (*m3*)	LOSSES (US$)
BAHIA	550.127	7	38.509	8.086.867	1.617.373	404.343
ESPÍRITO SANTO	207.687	10	20.769	4.361.427	872.285	218.071
MATO GROSSO DO SUL	208.819	5	10.441	2.192.600	438.520	109.629
SÃO PAULO	813.372	15	122.006	25.621.218	5.124.144	1.281.060
MINAS GERAIS	1.105.961	5	55.298	11.612.591	2.322.518	580.629
PARANÁ	123.070	7	8.615	1.809.129	361.826	90.456
SANTA CATARINA	74.008	7	5.181	1.087.918	217.584	54.395
RIO GRANDE DO SUL	222.245	5	11.112	2.333.573	466.715	116.678

Table 1. Damages and losses estimated for different Brazilian States, according to the risk area per state.

2. Symptomatology

This disease is characterized by production of urediniospores, pulverulent and yellow, in the affected tissues. When it infects highly susceptible varieties, it causes malformations, necroses, hypertrophy, minicankers and death of the growing portions of growth. Although the uredinia phase is the most common and the major form of dissemination of this disease, in warmer periods, teliospores can be produced. As it is a biotrophic pathogen, its growth and multiplication require live tissues of the host, making impossible to culture "in vitro" in routinely employed media. This fungus extracts nutrients by means of haustoria formed inside live cells of the host [19].

Symptoms of Myrtaceous rust on various hosts are shown in Figure 1.

The primary symptoms of this disease occur in the young tissues of developing leaves and stem. They start with chlorotic spots that transform into pustules or wounds, where they become exposed with the rupture matter of epidermis, pulverulent urediniospore of bright yellow coloration. These pustules may coalesce, covering the surface of eucalyptus shoots when the attack is intense. Consequently, the affected tissues die and become dry, obtaining a dark coloration as if they were burnt.

Depends on the environmental conditions, the plant may react to the infection and produce new shoots. With the development of leaves and stem, the yellow spores disappear; giving rise to salient, rough, brown lesions. In the leaves, these lesions are spread on both leaves surfaces and sometimes on the midrib. They are commonly delimited by a dark and purplish halo. In the branches, the verrucous characteristic of lesions becomes highly typical. As the attack occurs before the leaves complete their development, they frequently become distorted. Development of the disease can compromise highly susceptible plants, resulting in atrophy when severely affected. These plants may be outcompeted by adjacent ones that are less affected or healthy and continue to grow normally.

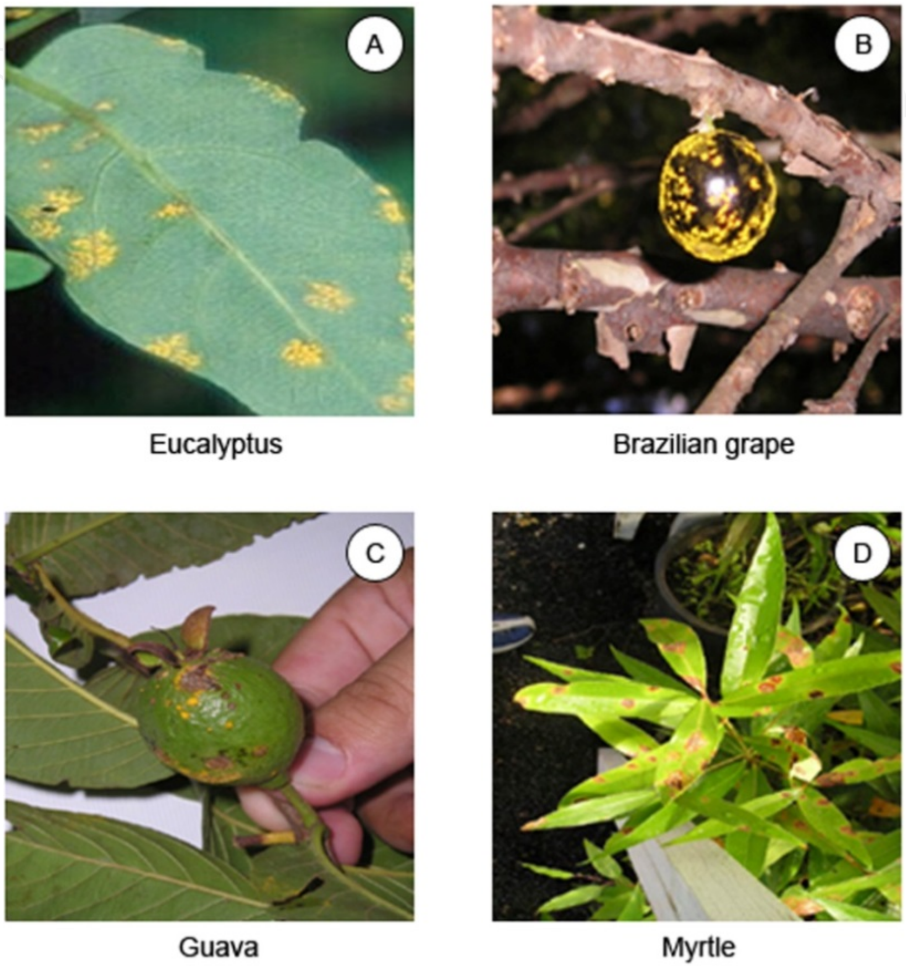

Figure 1. Some hosts of Myrtaceous rust. A: *Eucalyptus*; B: Brazilian grape (*Myrcia* sp.); C: Guava (*Psidium guajava*); D: Myrtle (*Syzygium jambos*).

3. Disease biology

Puccinia psidii produces two types of spores: urediniospores and teliospores.

Urediniospores, which are formed during the favorable phase to the fungus development, show a variable form predominantly globose, elliptical, pyriform and angular, measuring 14-20 x 18-27 micra. They are echinulate with hyaline episporium.

Teliospores are rare, and formed under conditions that are unfavorable to the pathogen. It is found frequently in the same injuries where urediniospores are formed. Teliospores are bicellular, of variable form, with predominance of elliptical and oblong-oval forms. Alternate hosts for this pathogen are unknown.

Spores are spread by the action of wind, rain, insects and birds. However, young developing tissues and favorable environmental conditions are needed for the infection to occur. The existence of young tissues is related to the phenology of the host, as were observed by Ferreira (1989), and the favorable environmental conditions consist in temperatures between 18 and 25ºC, and rather high relative humidity.

Such conditions are important for the development of this disease since they act on the pathogen, allowing the propagation and germination of its infective structures, as well as on the host phenology and consequently on the interaction pathogen against host [20].The most severe attacks occur in young crops, aged between 3–12 months, under favorable environmental conditions. Although there are no specific studies about the effect of the environment on the disease in eucalyptus, based on the reports of other crops, mild temperatures and high air relative humidity indexes are critical factors leading to even more severe attacks.

Rust affects young plants in the nursery and in the field. Temperatures within the range of 18-25 °C (optimal = 23ºC), prolonged periods of leaf wetness (nocturnal dew or drizzle for periods longer than 6 h per 5-7 consecutive days) are favorable to the infection. Mature organs, absence of wetness and temperatures above 30ºC and below 10ºC disfavor the infection [19-22].

Urediniospore directly penetrates epidermal cells, through the cuticle and the epidermis, forming the appresorium. The fungus colonization is intercellular, with the formation of intracellular haustoria. The latter are specialized structures to absorb nutrients inside the host cells. Depends on the use of fungicides in areas where the severity of rust disease is high, the pathogen may change phases since its number of healthy tissue is reduced, the telial phase being predominant in case of adversities.

In general, when the plants reach the phenological stage B [8] (at around 3-4 m height) they escape the disease, probably due to the decreased favorable conditions to the infection in young susceptible plant parts.

Climate analyses using mathematical models to predict rust disease are considered important tools to understand the disease in the field, pointing to epidemiological scenarios in regions where the climate consists of mild temperatures, with daily averages around 20ºC and, daily average relative air humidity of 90% or more.

4. Management of the fungus *P. psidii*

Rust can be controlled by applying fungicides, harvesting susceptible genetic materials in periods unfavorable to the disease (escape by period) and planting resistant materials. Planting *Eucalyptus* with rapid growth genotypes is another recommended measure. The use of genetic resistance is the most ideal control measure since it has the lowest cost, is easy to conduct, and reduces the impact of fungicides on the environment. Resistant *Eucalyptus* species, different origin of seed progenies or clones can be selected for commercial crops or to be used in breeding programs. In the breeding program, candidate lines can be selected from natural infections in the field, in areas where the disease is severe or by means of artificial inoculation of the pathogen into seedlings. Although the selection of resistant materials has been successful in forest companies, the resistance inheritance in the pathosystem *P. psidii* - *Eucalyptus*, is not well known, however, essential to determine crossing strategies in breeding programs.

The use of fungicides to control eucalyptus rust is in an important tool for integrated management. The chemical groups of Triazole and Strobilurin are mostly used for disease control and the first group presents better efficacy results. Depending on the severity of the disease, different chemical groups may be used in nursery and in the field. The disease severity should be verified based on numerical criteria, since subjective scales are normally adopted [6, 41]. The first five pairs of leaves (10 leaves) apical leaves of all juvenile branches of each plant should be analyzed, using a diagrammatic scale, in order to include all the parts susceptible to the infection by *P. psidii*. The severity of the rust disease is obtained as percentage of the injured leaf area [23].

The fungicide efficacy may be compromised if the assessment is performed wrongly or without epidemiological criteria, such as quantification of plant diseases.

For assessment of rust in the field, a diagrammatic scale (Figure 2) can be used.

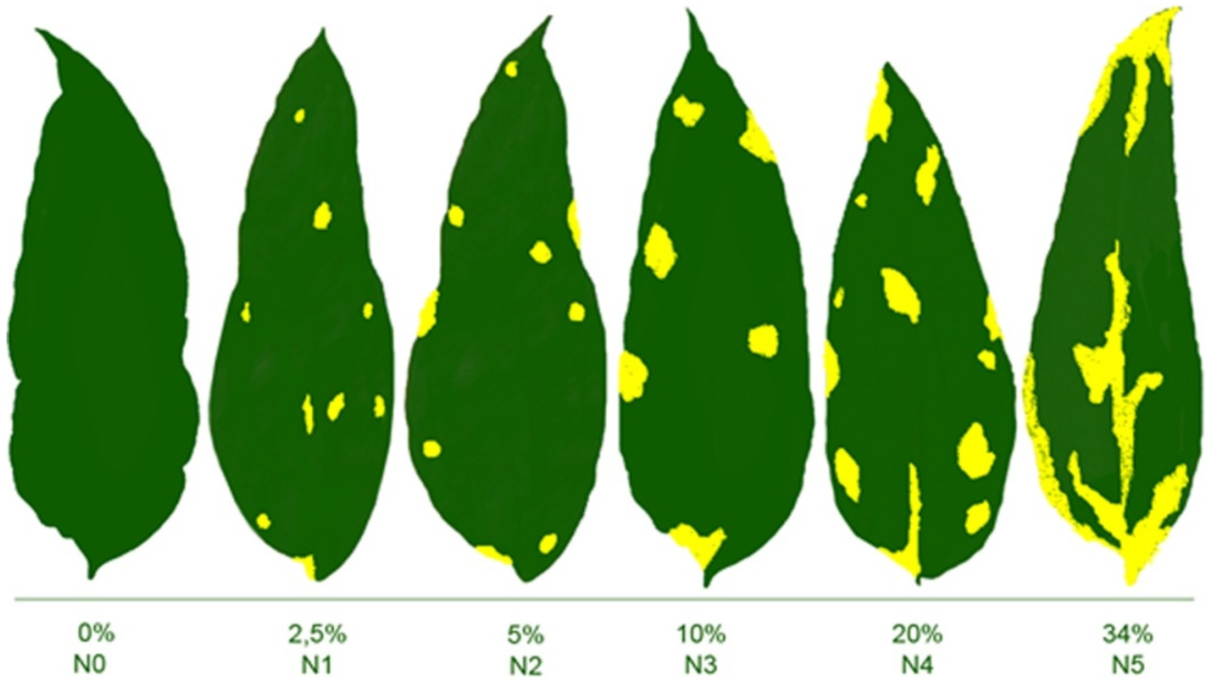

Figure 2. Diagrammatic scale for eucalyptus rust (percentage of Leaf Area with rust).

Correct quantification of diseases is one of the most important factors to be considered in the efficacy of the fungicide in experiments or crops, in the nursery or in the field, and thus shall be performed with extreme criteria. Incidence or severity can be estimated based on the rust intensity in the field. Data collected in the south of BahiaState, Brazil, to quantify rust disease of eucalyptus with two diagrammatic scales, %LAR (Leaf Area with Rust- Fig. 2) [23], and the field scale proposed by Takahashi (2002), modified by Zamprogno et al (2008), were used to obtain a mathematical model by linear regression between both, with: y = 7.2463x – 2.3399, R^2 of 0.703, where y is the percentage of injured leaf area (%LAR), and x, levels of field scale (Figure 3A). This work assessed 180 plants in 9 treatments, subdivided in 4 replicates of 5 plants each. This model is applied to data for assessment using a field scale modified by Zamprogno et al (2008). A total of 321 plants in different soil and climate regions in the South of Bahia State were assessed and data of incidence and severity of the disease were obtaining, transforming the field severity into %LAR. The use of linear regression resulted in the following model: y = 0.0776x + 0.0324, with R^2 of 0.7154, where y is the incidence (decimal number), and x is %LAR.

In studies of fungicide efficacy, [23] assessed the severity of rust disease after application of different fungicides in different levels. Upon 7 days after application of fungicide solutions, the authors obtained 74.23% of relative efficiency, and 92.01% in 15 days, for the level of solution 1.5 mL/L of fungicide tebuconazol + trifloxistrobine, using the "Percentage Rate of Fungicide Efficiency - %EF" [23].

The interpretation of the result obtained by Masson (2009) was: eucalyptus rust is caused by a high infection capability pathogen. When susceptible genetic materials were planted in the field, this disease spread very rapidly along with the direction of the planting line. The disease shows an aggregation pattern with low incidence values in the field, while the level of aggregation ascend with increased incidence over time.

Studies of fungicide efficacy are valuable in programs for eucalyptus crops in Brazil and in the world, not only due to the response obtained against the pathogen, but also due to the host's potential to recover tissues and morphological structures. In fact, in Brazil, the fungicides should be used in experimental character due to the policy of product recording under progress in the country (registration with the Agriculture Ministry, for use in the crop).

5. History of fungicide application to control eucalyptus rust

The use of fungicides in the forest sector is targeted especially to control rust started in seedling production in nurseries. For eucalyptus rust, weekly spraying with mancozeb or copper oxychloride in the levels of 160-200 g/100L water, or triadimenol in 75 mL/100L or triforine in 28 mL/100L were recommended [8]. In laboratory tests, the protective fungicides mancozeb and copper oxychloride protected susceptible leaves when applied up to ten days before inoculation, while the systemic fungicides triadimenol and triforine had the same effect. These materials were assimilated from 30 minutes after spraying and translocated from one leaf blade to the another on the opposite side of the stalk and to the blade immediately above, and also had a kick-back effect when applied up to six days after the inoculation [25-26].

According Ferreira (1989), when resistance measures were adopted, fungicides were rarely recommended under field conditions; this control measure could be used only in special situations such as the commercial planting of highly susceptible to rust, which associated with other management practices, would require one or a few applications to control the disease in a young crop or in shoots after clear cutting. To prevent fungus resistance, the author mentioned the use of protective fungicide separately or in a protective + systemic mixture, or the alternation of an application of protective fungicide with an application of systemic fungicide.

Until 1989, there had been no practice of fungicide application to control such a disease in the field. These data were documented by Krugner & Auer (2005), who indicated products made from triadimenol and azoxystrobin was used to control rust in nurseries as a curative material and clonal gardens and "exceptionally" in the field for materials of high commercial value. Considering epidemics that occurred in the southeast region, especially in Vale do Paraíba, São Paulo State, in 1991, the first rust outbreaks occurred, initially in Santa Branca Municipality. In 1992, Redenção da Serra and Jambeiro were attacked and finally, in 1996 and 1997, the whole region of Vale do Paraíba was affected, including 3-to-14-month-old crops of several genetic materials of *Eucalyptus grandis*, and the damages concerned a large number of farmers [28].

Some companies opted for chemical control in the field after tests and the publication of the results of a study related to the caused damages (Table 2). [6] Obtained 27.08% of damage to plants aged 19 months.

Region	**Guararema**		**São José**		**Taubaté**	
Farm	Rogemar	Rogemar	Varadouro	S. Pedro I	N.S.Ajuda	Gaspar
Plot	4	6	10	6	9	7
Procedence	Paraibuna	Paraibuna	Salto	Botucatu	Taubaté	Resende
Planting date	7/10/1996	12/23/1996	11/20/1996	8/1/1996	7/18/1996	6/28/1996
Age (years)	4.25	3.83	3.92	4.17	4.33	4.33
% plants with rust	76.15	71.60	79.59	85.19	66.67	71.88
% real production	67.23	74.90	74.18	81.08	67.48	76.69
% damage	32.77	25.10	25.82	18.92	32.52	23.31

Table 2. Percentage of damage caused by eucalyptus rust in Brazil [11].

Chemical control in the forest area remained restrict to nursery for a long time. The application of fungicide in the field can be a feasible method once the disease has reached the whole region of Vale do Paraíba and currently the whole south region of São Paulo State where majority. Preventive and curative activity tests were carried out using the fungicides: Triazoles (propiconazole, triadimenol, tebuconazole and cyproconazole) – FRAC Code 3; Anilides (Oxycarboxin) – FRAC Code 7, phthalonitrile (Chlorothalonil) – FRAC Code M5; Dithiocarbamate (mancozeb) – FRAC Code M3, and cuprous (copper oxychloride and cuprous oxide) – FRAC Code M1, in curative activity and preventive assays in Guararema Municipality, Sao Paulo State. The crops of susceptible genetic materials aged 7 months, with the disease established, and aged 4 months, without the disease, assessing the percentage of shoots with rust. Applications were performed in every 14 days, in a total of 6 applications. In the preventive test (Figure 3), fungicides made from Cyproconazole, Triadimenol and Tebuconazole showed the best results after the last application.

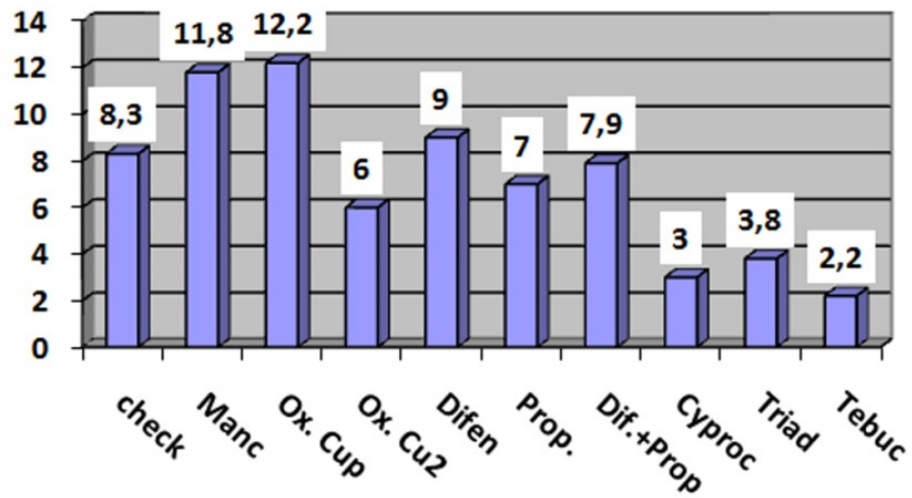

Figure 3. Preventive chemical control of eucalyptus rust. 1997. Vale do Paraiba-Brazil [4].

In the curative activity test (Figure 4), in which plants had more than 70% symptomatic shoots, all treatments showed efficacy, especially fungicides made from mancozeb (preventing the development of new lesions), difenoconazole, tebuconazole, propiconazole and triadimenol, which reduced the disease to less than 10% symptomatic shoots. The last two treatments remained close to zero [4].

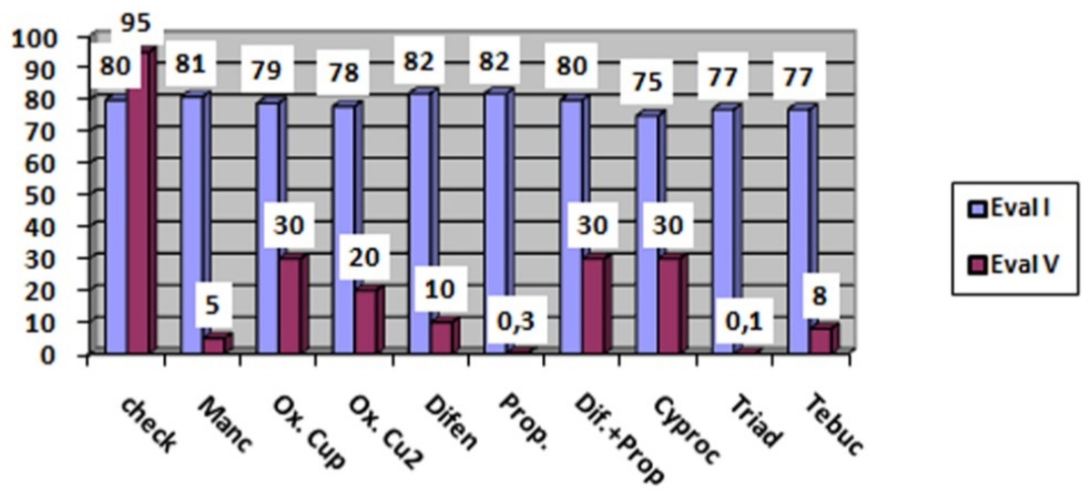

Figure 4. Healing chemical control of eucalyptus rust. 1997. Vale do Paraiba-Brazil [4].

Other field experiments were carried out in northeast region, on the north coast of Bahia State, in the commercial crop areas of Bahia Specialty Cellulose/Copener Florestal Ltda. Sprouting management was used in this assay, based on the larger quantity of young branches and leaf shoots of higher susceptibility to infection by *P. psidii*. The clonal material were used a susceptible hybrid of *Eucalyptus grandis* x *Eucalyptus urophylla* ("urograndis") [23]. To evaluate the efficiency and economic viability of fungicides to control eucalyptus rust, a test was set up in the field. The experimental design adopted for the test was randomized blocks, 3 x 3 (3 products and 3 doses) in factorial arrangement, with 0.5, 1.0 and 1.5 mL or g of commercial product per liter of solution. The treatments were: 1) control; 2) azoxystrobin (strobilurins); 3) tebuconazole (triazole); 4) tebuconazole + trifloxystrobin (triazole + strobilurins). Four replicates were used to assess plant disease severity based on the percentage of damaged leaf area. Higher fungicide levels led to a greater reduction in the disease in the plants in 7 and 15 days after the application. The fungicide tebuconazole + trifloxystrobin in 1.5 mL / L was most efficient against eucalyptus rust under field conditions. The fungicide tebuconazole was most economically viable at the three tested levels.

TREATMENT	7DAA1*	14DAA1	7DAA2	14 DAA2	7DAA3	14 DAA3	21DAA3
1.Control	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.Azoxistrobin+ Ciproconazole+ Tiametoxam (250)	44.3	73.3	83.8	83.0	84.5	73.6	62.8
3.Azoxistrobin+ Ciproconazole+ Tiametoxam (330)	49.2	75.9	85.7	86.8	88.4	84.9	72.7
4.Azoxistrobin+ Ciproconazole+ Tiametoxam (400)	49.2	82.3	87.8	87.7	89.5	95.3	81.7
5.Azoxistrobin+ Difenoconazole (300)	55.8	82.2	89.5	88.5	90.9	88.3	82.5
6.Azoxistrobin+ Difenoconazole (400)	77.0	81.0	89.5	96.4	94.5	93.8	91.7
7.Azoxistrobin+ Difenoconazole (500)	68.9	87.3	95.5	96.8	96.7	94.5	92.8
8.Azoxistrobin+ Difenoconazole (300)+mineral oil (600)	62.7	86.1	91.7	94.7	95.5	94.5	90.6
9.Azoxistrobin+ Difenoconazole (400)+mineral oil (600)	80.4	91.1	94.3	94.7	96.0	94.9	91.3
10.Azoxistrobin + Ciproconazole (300) + mineral oil (600)	73.8	81.0	87.4	94.7	95.5	93.8	89.1
11.Piraclostrobin+ Epoxiconazole(500)	67.3	79.7	85.7	85.9	85.0	71.8	63.3
12. Trifloxistrobin+ Tebuconazole(750)	62.4	83.5	87.8	90.3	95.0	85.9	82.5

Table 3. Relative efficiency of fungicides in controlling eucalyptus rust in the field. Itatinga-Sao Paulo State. DAA* - Days After Application (Furtado et al., n.p.).

In the Central-South region of São Paulo State, a field assay was carried out at Primavera Farm, located in Itatinga, São Paulo State, and the used species was *Eucalyptus grandis* under are growth induction and aged 6 months, from March 11 to May 06, 2011, with spacing between plants of 3 x 2 m. Applications occurred in 14-days of intervals. The assay was carried out in randomized blocks with 5 replicates and 12 treatments, and the plot size was 6x60 m. The application was applied by using a costal sprayer. Five sample plots were established and constituted of 6 plants each. The application volume was 200 L/ha for application with costal sprayer. The used equipment was manual costal of the Jacto's company, model PJH, "JA-2 Inox", under constant pressure of 40 lb.pol-2.

Year	Active	Rate (a.i.)	Where	Reference
1989	Mancozeb Cupric oxid Triadimenol Triforine	160-200 g/100L 160-200 g/100L 70 mL/100L 28 mL/100L	Nursery	[8]
2002	Mancozeb Cupricoxid Triadimenol Difenoconazole Propiconazole Cyproconazole Tebuconazole Difen. + propic.	160 g/100L 352 g/100L 100 mL/100L 100 mL/100L 125 mL/100L 50 mL/100L 125 mL/100L 80 mL/100L	Nursery and field	[4]
2002	Triadimenol	50 mL/100L	Nursery	[42]
2004	Triadimenol Azoxistrobin Mancozeb Cupper Oxicloreto	50 mL/100 L 20 mL/100L 160-200 g/100L 160-200 g/100L	Nursery	[19]
2005	Triadimenol Azoxistrobin	Not described	Nursery	[27]
2011	Azoxistrobin Tebuconazol Tebuconazol + Trifloxistrobin	500-1500 mL/ha 500-1500 mL/ha 500-1500 mL/ha	Field	[23]
2012	Azoxistrobin+ Ciproconazol+ Tiametoxam Azoxistrobin+ Difenoconazole Azoxistrobin + Ciproconazol Piraclostrobin+ Epoxiconazol Trifloxistrobin + Tebuconazol	250 – 400 mL/ha 300 – 500 mL/ha 300 – 450 mL/ha 500 mL/ha 750 mL/ha	Field	Furtado et al. (n.p.)

Table 4. Chronology of the use of fungicides to control eucalyptus rust in Brazil.

The results of the relative efficiency of treatments (Table 3) showed the evidence that the most efficient treatments, in 3 applications, were: azoxistrobin + ciproconazol + tiametoxam

(400 mL/ha), azoxistrobin + difenoconazole (300 to 500 mL/ha, with or without adjuvant), the fungicide azoxistrobin + ciproconazole and the fungicide trifloxistrobin + tebuconazole (750 mL/ha).

The chronology of the use of fungicides to control eucalyptus rust in Brazil is shown in Table 4.

6. Perspectives of fungicide application to control eucalyptus rust

Chemical control of eucalyptus rust is a very useful tool for the management since it may allow the use of clones that are highly productive but susceptible to the disease both under crop conditions and in nurseries [29]. However, the use of fungicides to control this pathogen in eucalyptus is only technically recommended for emergency cases due to the limited number of registered products for this crop.

FSC (Forest Stewardship Council) promotes the management of forests all around the world, in an environmentally responsible, social and economically viable manner, by establishing the Principles and Criteria of Forest Management, renown and respected worldwide. In 2007, a list of prohibited agrochemicals was published, making unviable the control of some pests and diseases affecting *Eucalyptus*. Based on that list, a project was developed to derogate the rule for some products, allowing the control of such eucalyptus pests and diseases. To achieve a more careful assessment that could satisfy the countries interested in the forest sector, a new group of experts from FSC International Commission for Chemicals was formed in order to increase the process transparency and elaborate new criteria for prohibiting the use of pesticides in forests.

Based on these criteria, several studies were developed for the control of eucalyptus rust, considering the criteria elaborated for FSC and the standards in Brazil, resulting in the Prioritization of the Registration of chemical products, given the economic importance of the culture, the increase in areas affected by this disease and in economic losses, the absence of registered products for the culture, and the presence of registered products for other plants cultivated in Brazil, with similar problems.

7. Fungicide application methods to control eucalyptus rust

Rust can cause damages up to 44%, on average, to the production of São Paulo State [30]. Rust can be controlled by means of fungicide application, harvesting of susceptible materials in periods unfavorable to this disease (escape by period) and planting of resistant materials. The use of fungicides to control eucalyptus rust has shown satisfactory control levels, reducing the disease intensity in the field and consequently damages and losses [6, 23, 31, 32-35].

Application technology is the great importance plant disease to control programs. The current concepts of pesticide application have four points that must be considered essential for the successful preservation of harvests and reduction in attacks by pests and pathogens: appropriate period, coverage, level and safety [36]. The influence of biological, meteorological and agronomical factors, not always predictable, must be also considered [37].

Among with the most frequently used application methods, aerial, by tractor and costal, manual or motorized, questions were raised to answer what would be the most efficient application method for the application of agrochemicals in order to have protection against eucalyptus rust. Aerial and terrestrial applications can be complementary, but not necessarily concurrent, due to their peculiarities from a technical and operational point of view, making essential to learn their major differentials to take the decision of adopting one or the other technology [38].

Aerial application has become an appeal to the forest sector, especially due to the shortage of manpower. The use of specialized professionals and complete regulation and supervision of agricultural aircraft activities made aerial application a safe and effective tool for pesticide application with lower risk of environmental contamination. In addition, it allows the treatment of large areas in the appropriate moment in a short period, preventing the increase in areas with and/or new incidences of eucalyptus rust in the field. It has very good application uniformity since the application is not interfered by the ground irregularities, which may occur in application using tractor [32].

The optimal environmental conditions for eucalyptus rust are temperatures around 18 to 25°C and relative humidity above 90%. Considering aerial spraying during rainy periods, the areas can be sprayed as soon as the rain stops, allowing control in the beginning of the epidemics and reducing damages (reduced productivity) and losses (reduced financial value). On the other hand, it will be very difficult to spray using tractors of the rain. The aerial application also does not cause damages to the forest floor due to soil "kneading" and compression. In addition, because of a low spraying volume, each drop tends to have higher product concentration [32].

The aerial application must respect the environmental parameters also adopted as reference by application by tractor, which include: temperature around 27 to 30°C and relative humidity of 55%; fungicides must never be applied when there is no wind, the minimum required is 3 km/h, and the application must be interrupted when the wind is superior to 15 Km/h; ideal drop spectra between 200 um and 250 um. The flight height must be 3 to 4 meters above the crop, considering the application range for fungicides around 18 meters and application velocity of 100 m/h, obtaining a treated area of 4.80 ha/minute [39]. It must be highlighted that everything depends on the crop conditions such as: disease intensity; time requirement of fungicide to be applied soon after infection event, also the distance from the runway. The spraying cost is directly related to the area size, i.e., the larger the area the lower the aerial spraying cost.

The success of any application method is directly associated with use of an effective product, properly adjusted equipment, and right application timing for control. Thus, continuous monitoring of crop areas is required because the interval between applications, the target to be reached, the climate conditions and the disease intensity in the field must be considered.

The study shown below aimed to compare different application methods (manual costal sprayer, tractor turbo atomizer and aerial application) in eucalyptus rust control, using the fungicide azoxystrobin (AZ) + cyproconazole (CCZ) in different levels [40]. The experiment was conducted in randomized blocks with seven treatments and five replicates, and each replicate consisted of 10 plants. The treatments and their respective levels were: control, costal sprayer (0.3 L/ha of AZ + CCZ + 0.6 L/ha of mineral oil), costal sprayer (0.45 L/ha of AZ + CCZ), Atomizer (0.3 L/ha of AZ + CCZ + 0.6 L/ha of mineral oil), Atomizer (0.45 L/ha of AZ + CCZ), aerial (0.3 L/ha AZ + CCZ + 0.6 L/ha of mineral oil), aerial (0.45 L/ha of AZ + CCZ). The spray volumes were 200 L/ha for the costal sprayer, 350 L/ha for the atomizer and 20 L/ha for aerial application (Figure 5). Natural epidemic conditions were used. Two applications were carried out in a range of 14 days. Evaluations were done within 7 days, in addition to the previous evaluations, 2 after the first application and more 4 evaluations after the second application. For the assessment of rust severity, a diagrammatic scale was used.

Results were analyzed and Relative Efficiency % (RE) and Area Under Disease Progress Curve (AUDPC) were calculated in 28 days after the second application (Figures 6 and 7).

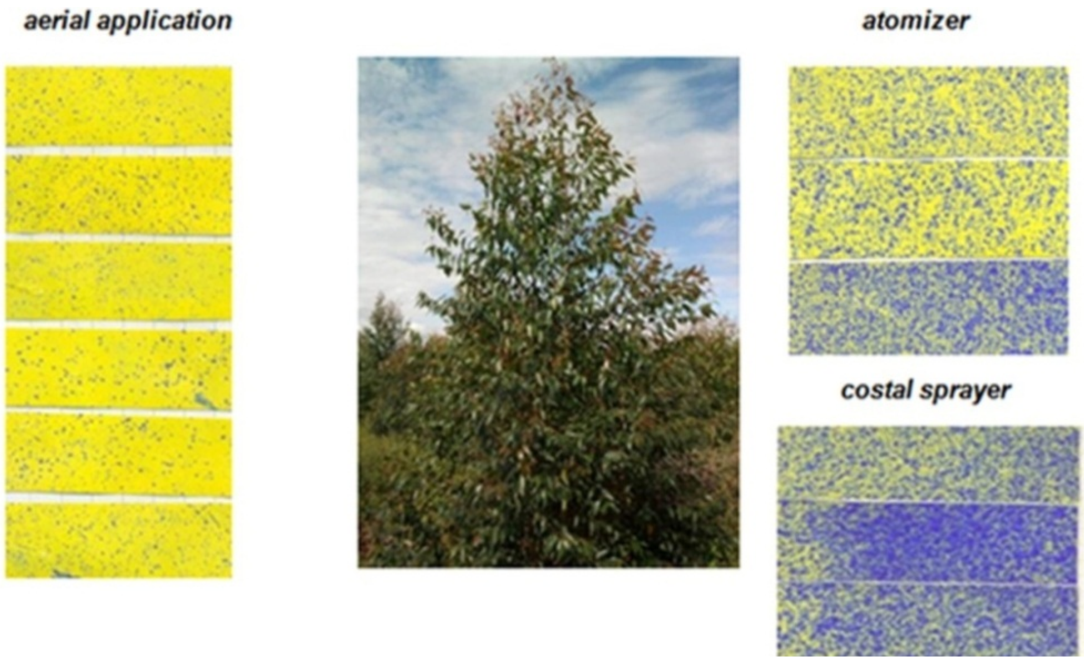

Figure 5. Application Coverage in aerial application, atomizer and costal sprayer [40].

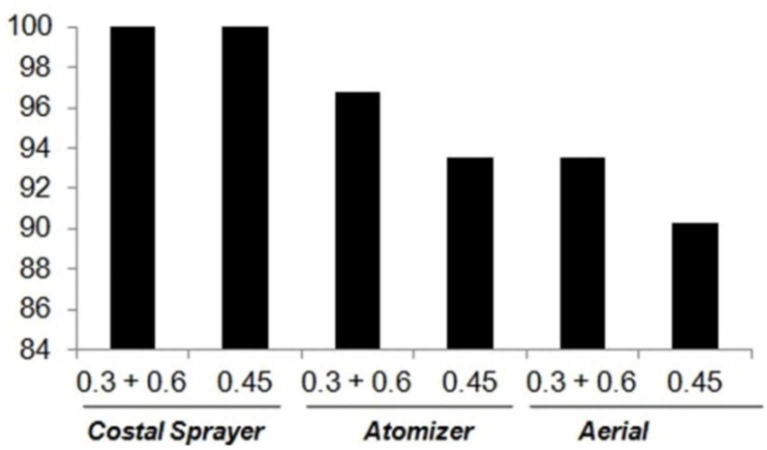

Figure 6. Relative Efficiency % (RE) of different treatments in eucalyptus rust control [40].

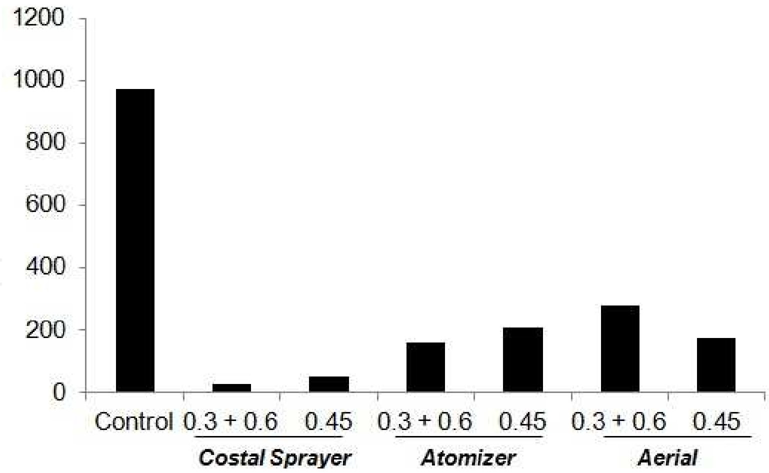

Figure 7. AUDPC (Area Under Disease Progress Curve) of different treatments in eucalyptus rust control [40].

All used application methods and levels were effective in controlling eucalyptus rust; ER was above 90% in 28 days after the second application, providing a reduction in the disease severity over time. No anomalies were observed regarding the effect of phytotoxicity.

The viability of eucalyptus rust control can be exemplified as follows:

A eucalyptus forest has a mean annual increase (MAI) of 30 m^3/ha/year. In 7 years, productivity will be 210 m^3/ha, considering 20% of damage = 42 m^3/ha and the price of R$ 76.00 m^3 of wood; the estimated loss will be R$ 3192.00/ha. An application for the control of the same area would require 0.45 L product=R$ 52.50/ha and aerial application cost of R$ 22.00/ha, with an estimated expense of R$ 74.50/ha which corresponds to 2.37% of the estimated loss for the same area [23].

8. Conclusions

The use of chemical control of eucalyptus rust, in the field, in Brazil is relatively recent. It has grown in importance in the last years since the number of epidemics is increasing, eucalyptus has becoming more like a agronomic crop and less of a forest tree, and due to restriction of genetic basis of breeding programs. Resistance sources have become scarcer and easily overcome by the diversity and the variability of pathogens, including eucalyptus rust. Therefore, chemical control has become a component of great importance in integrated management.

The materials for chemical control have been evolved rapidly, from older products such as cuprous and dithiocarbamates to strobilurins, and recently, the mixture of the latter with triazoles become common approach. This trend has been seen in other pathosystems such as rusts of wheat and soybean. There is still much to be done to find the phenological stage and the selection of areas of higher risk to start control, clonal mosaic composition with different resistance genes to prevent the pathogen proliferation, and rotation of different active principles to increase their lifetime, preventing the emergence of resistant isolates.

The chemical control of eucalyptus rust, as well as its application methods, is viable since it reduces damages and losses to eucalyptus crops. It may also allow the maintenance of clones that are highly productive but susceptible to the disease.

Perspectives in the scenario of integrated handling of plant diseases, within the context of epidemiology point, to studies of disease dynamics, geostatistical and climatic, by mathematical modeling. Fundamentally, additional tools such as using fungicides and genetic improvement, from studies of inheriting resistance and hybridization, are complementary and essential for the success of integrated crop handling.

Author details

Marcus Vinicius Masson, Willian Bucker Moraes and Edson Luiz Furtado
São Paulo State University, UNESP, College of Agronomic Science, FCA, Department of Plant Production, Plant-Health Protection Sector, Botucatu, Brazil

Marcus Vinicius Masson
Bahia Specialty Cellulose/Copener Florestal, Dr. José Thiago Correa St., Alagoinhas Velha, Alagoinhas, BA 48030-480, Brazil

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