

SCIENTIFIC ARTICLE

Organic fertilization and alternative products in the control of powdery mildew

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Abstract

Rose is a plant of high nutritional requirement, susceptible to powdery mildew disease caused by fungus *Oidium leucoconium*, which causes leaf fall and losses in flower production. The objective of this study was to evaluate powdery mildew severity in rose cultivar ‘Grand Gala’ in response to organic fertilization and the application of alternative products to disease control. The first experiment was set in a factorial arrangement, with 5 alternative products: spraying with water as a control (PA), lime sulfur (CS), neem oil (ON), mixture of sodium bicarbonate and canola oil (BC) and coffee pyroligneous acid (APC) and 2 organic fertilizers: chicken manure (EA) and biofertilizer based on banana stalk (B). Disease severity was assessed at 0, 15, 30 and 45 days after the treatments. In the second experiment, asymptomatic leaves or with different powdery mildew severity levels were sprayed only once with the same alternative products mentioned above. Severity was assessed at 0, 7 and 14 days. The organic fertilizations did not influence the reduction in powdery mildew severity in rose. At 45 days, APC yielded a greater reduction in disease severity (81.6%), followed by treatments based on BC, ON and CS. Greater reduction in disease severity in experiment 2 occurred in the treatments of BC and CS, followed by APC. Therefore, it is possible to conclude that APC and the BC have the potential to control rose powdery mildew in an organic cultivation system.

Keywords: *Rosa* sp. *Oidium leucoconium*, severity, sodium bicarbonate, coffee pyroligneous acid.

Resumo

Aduba o org nica e produtos alternativos no controle do  id o da roseira

A roseira   uma planta de elevada exig ncia nutricional e suscet vel ao  id o, doena que causa queda de folhas e perdas na produ o de flores. Objetivou-se com esse trabalho avaliar a severidade de  id o em roseira cultivar ‘Grand Gala’ em resposta   aduba o org nica e a aplica o de produtos alternativos para o controle da doena. O primeiro experimento foi instalado em arranjo fatorial, sendo 5 produtos alternativos:  gua pot vel como testemunha- (AP), calda sulfoc lcica (CS);  leo de nem (ON), mistura de bicarbonato de s dio mais  leo de canola (BC),  cido pirolenhoso de caf  (APC) e 2 aduba es org nicas: esterco de aves (EA) e biofertilizante   base de engao de bananeira (B). As avalia es da severidade da doena foram realizadas aos 0, 15, 30 e 45 dias ap s os tratamentos. No segundo experimento, folhas assintom ticas ou com diferentes severidades de  id o foram pulverizadas apenas uma vez com os mesmos produtos alternativos mencionados anteriormente. A avalia o da severidade foi feita aos 0, 7 e 14 dias. As aduba es org nicas n o influenciaram na redu o da severidade do  id o da roseira. Aos 45 dias, APC proporcionou maior redu o na severidade da doena (81,6%), seguido pelos tratamentos   base BC (61%), ON (58,96%) e CS (60,3%). Maior redu o da severidade da doena no experimento 2 ocorreu nos tratamentos com BC e CS, seguida pelo APC. Portanto, pode-se concluir que o APC e BC possuem potencial no controle do  id o da roseira em sistema de cultivo org nico.

Palavras-chave: *Rosa* sp. *Oidium leucoconium*, severidade, bicarbonato de s dio,  cido pirolenhoso de caf .

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Received Nov 05, 2019 | Accepted Feb 14, 2020 | Available online Mar 09, 2020

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<https://doi.org/10.1590/2447-536X.v26i1.2109>

Area Editor: M rkilla Zunete Beckmann-Cavalcante

Introduction

Rose (*Rosa* spp.) is one of the main ornamental plants and its economic and cultural potential has been explored for many years through its use in floriculture and landscaping, in the constitution of cosmetics and medicines, besides gastronomy (Domínguez-Serrano et al., 2016; Prata et al., 2017). Rose is the main cut flower produced in the world. However, it is a species of high nutritional demand, susceptible to various diseases such as mildew (*Peronospora sparsa* Berk.), gray mold (*Botrytis cinerea* Pers. Fr.) and mainly powdery mildew (*Oidium luecoconium*) (Wallr. Ex Fr. Lev.) (Almeida et al., 2014; Youren et al., 2015), which causes damage to the tissues of stems, leaves and petals (Horst, 1992). Radiation, temperature, air circulation in the environment, and relative humidity of air are the climatic conditions that most influence the spread and severity of this pathogen (Alexandre et al., 2016). Powdery mildew shows a close relationship with environmental conditions at any time of the year, but the complete pathogen cycle occurs under temperature conditions around 21° C and high relative humidity (Domínguez-Serrano et al., 2016).

Powdery mildew control in commercial rose cultivation occurs as in other conventional agricultural crops, where synthetic fungicides are commonly used to protect leaves at the onset of early lesions (Ribeiro et al., 2015). However, the use of these products has been continuous and abusive, which has led to the selection of resistant pathogens and various environmental and health problems, both for the worker in the field and for the consumer. As a result, society has been aware and demanding products free of pesticides, opting for products from organic agriculture.

In order to reduce such problems, a wide range of alternative and less aggressive products have been used in agriculture. However, few of these products have proven to be efficient for crops of economic interest, especially in the floriculture sector, causing producers themselves to conduct these tests, subject to errors and success.

Research with other crops like coffee shows that addition to irrigation, mineral nutrition is also a tool for maintaining plant health (Barbosa Junior, et al., 2019).

Research on the influence of fertilization on the diseases progress of rose is incipient. In rose-growing, organic fertilization has been increasingly used, either alone or in conjunction with synthetic fertilizers. In cultivation organic, biofertilizers such as poultry and cattle manure are commonly used (Almeida et al., 2014, Ribeiro et al., 2015).

Due to the agronomic importance of rose, the economic damage caused by powdery mildew and the environmental problems caused by the application of synthetic pesticides, it is necessary to conduct research for quality production and control of this pathogen in the crop. There is also a great demand from flower producers for research involving the phytosanitary and nutritional management of crops of economic importance, such as rose. Thus, due to the scarcity of information in these areas in the literature and the existing demand among producers, this study aimed to evaluate the severity of powdery mildew in 'Grand Gala' rose in response to the use of organic fertilization and alternative products.

Material and methods

The experiment was conducted from November 2016 to October 2017 in a region with an altitude of 1030 m, with typical tropical climate, warm and semi-humid, with a short rainy season (November to March) and another dry and long season (April to October). According to the Koppen classification, the climate is considered Aw, that is, warm tropical with summer rains and annual average temperatures around 24 °C and average annual rainfall between 1100 mm.

Grafted 40 cm 'Grand Gala' rose seedlings were used, planted at a spacing of 1.2 m between rows and 15 cm between plants. The plants were grown in a protected environment with 100-micron transparent agricultural film and black shading screen with 50% reduction in light incidence, with 6 meters wide and 18 meters long, ceiling height measuring 3.2 meters. Soil sample was collected to determine its composition with medium texture and medium organic matter content (Table 1).

Table 1. Soil analysis of the experimental area (0-20 cm depth).

Soil attributes	Results
pH in water	5.4
P Melich (mg dcm ⁻³)	1.24
Remaining P (mg L ⁻¹)	37.55
K (mg dcm ⁻³)	112
Ca (cmolc dcm ⁻³)	3.70
Mg (cmolc dcm ⁻³)	1.30
Al (cmolc dcm ⁻³)	0.10
H + Al (cmolc dcm ⁻³)	2.90
SB (cmolc dcm ⁻³)	5.29
t (cmolc dcm ⁻³)	5.39
m (%)	2
T (cmolc dcm ⁻³)	8.18
V (%)	65
Org. Mat. (dag Kg ⁻¹)	3.39
Org. Carbon (dag kg ⁻¹)	1.96
Coarse sand (dag kg ⁻¹)	9.60
Fine sand (dag kg ⁻¹)	42.10
Silt (dag kg ⁻¹)	28
Clay (dag kg ⁻¹)	20

Source: Soil Analysis Laboratory - Institute of Agricultural Sciences - Montes Claros - Universidade Federal de Minas Gerais.

Before planting, the soil was prepared with scarification and liming to raise base saturation to 70% (Almeida et al., 2014). At planting, 10 g of magnesium thermophosphate per plant and 10 L of cattle manure per linear meter were used. Irrigation was performed daily by dripping and weed control was performed manually. No chemical pesticides were used during the experimental period and, before the treatments were applied, all plants were sprayed weekly with lime sulfur and sodium bicarbonate alternately and received 20 g of poultry manure every 15 days.

Experiment 1 – Study of organic fertilization and spraying with sodium bicarbonate, oil and plant extract products in the control of rose powdery mildew

The experiment was set up five months after planting the roses in a 5x2 factorial arrangement, with 5 products

for the control of powdery mildew and 2 types of fertilization, totaling ten treatments, with four replications and ten plants per plot in a randomized block design. Alternative products applied for the control of powdery mildew were: spraying with water as a control (PA), lime sulfur (5 mL L⁻¹) (CS), neem oil (1 mL L⁻¹) (ON), mixture of sodium bicarbonate and canola oil (10 grams of sodium bicarbonate + 10 mL of oil) (BC) and coffee pyroligneous acid (100 mL L⁻¹) (APC). For fertilization, chicken manure (EA) and biofertilizer based on banana stalk (B) were used. The biofertilizer was produced with banana bunch stems, manure and additives to accelerate decomposition with the following physicochemical characteristics: pH 6.97, 3.1% MO, 0.5% N, 1% P, 1% K, 0.5% Ca, 0.5% Mg, 1% S, 0.1% B, 0.05% Cu, 0.05% Mn, 0.05% Fe and 0.05% Zn

Table 2. Analytical parameters of the chemical composition of pyroligneous acid obtained in the coffee roasting process used in powdery mildew control.

Analytical Parameter	Results	Units
Humic acid	<1.00	% m/v
Fulvic acid	1.50	% m/v
Organic matter	0.83	% m/v
Electric conductivity	257.6	uS.cm ⁻¹
Total phenols	99.60	mg C ₆ H ₅ OH L ⁻¹
pH	5.53	-
Total nitrogen	2550	mg.L ⁻¹
K ₂ O	0.70	mg.L ⁻¹
P ₂ O ₅	57.52	mg.L ⁻¹
Mg	0.326	mg.L ⁻¹
Ca	1.80	mg.L ⁻¹
Zn	0.202	mg.L ⁻¹
Fe	0.015	mg.L ⁻¹
Cu	<0.003	mg.L ⁻¹
TOC	13350	mg.L ⁻¹

Source: Environmental Chemistry Laboratory - Institute of Chemistry - São Paulo - Universidade de São Paulo.

Spraying occurred weekly for 50 days, and the products were diluted in 4 liters of water and applied with manual costal sprayer. Each plant received an average of 0.05 L of solution, enough for complete watering. Fertilization was carried out biweekly, with 50 g of chicken manure per plant or 50 mL of biofertilizer applied to the soil according to the treatments.

The evaluation of severity of rose powdery mildew was performed at 0, 15, 30 and 45 days after the treatments. Therefore, the last three leaflets of a complete and composite leaf were selected in the middle third of the plant in a total of 12 leaflets per treatment and the lesions were photographed (Figure 1)



Figure 1. Rosebush with powdery mildew infection on all leaves. Source: Authors, 2017.

The images were made with a digital camera with a resolution of 13 megapixels. The leaflets were placed on white paper to obtain the photographs and the photos were taken in an oblique position, at a distance that allowed the recognition of the entire leaf area. The leaves evaluated were not extracted from the plant. From the photographs

of the plant leaflets, the Image J software was used to estimate the total area of the leaf limb and the white one corresponded to the powdery mildew lesion. Thus, from the white area, the percentage of disease severity after the different treatments in each evaluation period was obtained (Figure 2).

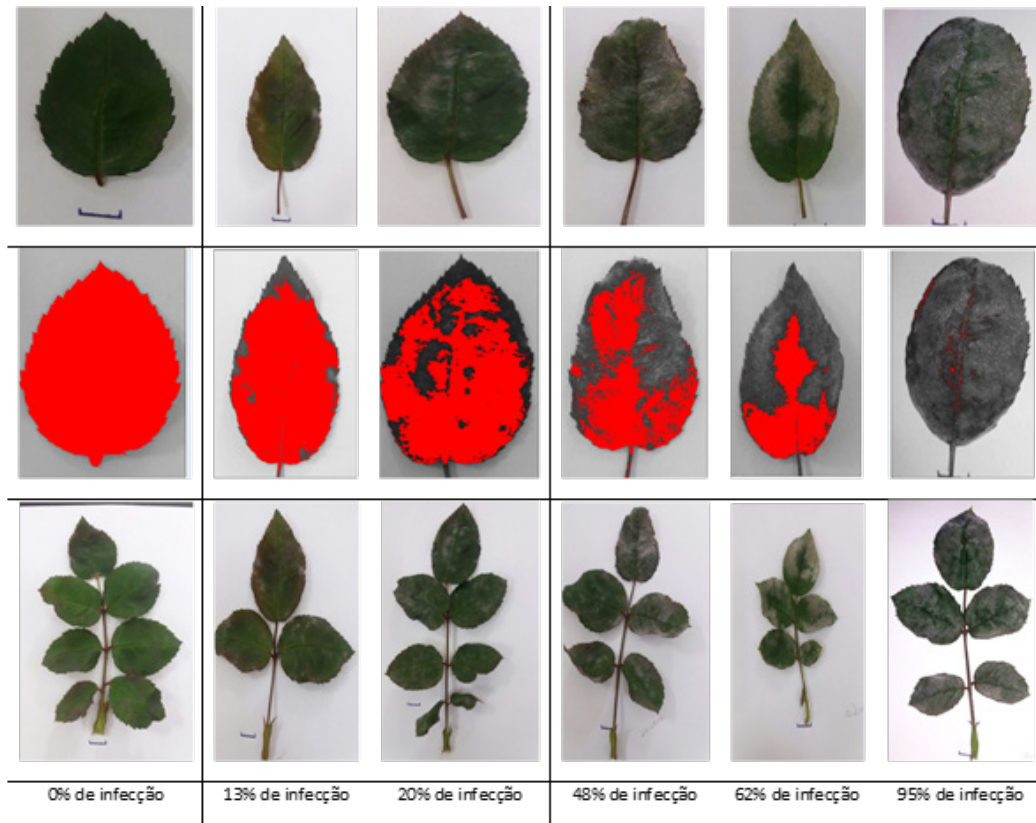


Figure 2. Rose leaves affected by powdery mildew, to understand the conditions observed in the field regarding the levels of infection. Source: Authors, 2017.

Experiment 2 – Alternative products in the management of rose powdery mildew

In order to clarify whether the powdery mildew infection came from spores already present in the plant or from new inoculum sources, experiment 2 was set one month after the completion of experiment 1, using other plants grown in a greenhouse. Through this test, it would be possible to understand the behavior of fungal infection in plants. The plastic cover of the leaves was performed to verify the reduction or increase of the severity of the disease in the leaves while covered and then exposed. Thus, it could lead to inferences about the occurrence or not of new infections. The plastic covering of the leaves was performed in order to verify the reduction or increase in the severity of the disease in the leaves while covered and then exposed. Thus, it could lead to inferences about the occurrence or not of new infections. The experimental design was completely randomized, with eleven treatments and four replications. Treatments consisted of: T1- asymptomatic plastic-coated leaf with initial severity of 0%; T2- plastic-coated leaf with symptoms of powdery mildew,

with initial severity of 29.77%; T3- plastic-coated leaf with symptoms of powdery mildew, with initial severity of 55%; T4- plastic-sprayed leaf with lime sulfur, initial severity of 34.26% and T5- plastic-coated leaf sprayed with lime sulfur, initial severity of 56.86%; T6- plastic-coated leaf sprayed with neem oil, initial severity of 34.76% and T7- plastic-coated leaf sprayed with neem oil, with initial severity of 83.03%; T8- plastic-coated leaf sprayed with sodium bicarbonate solution and canola oil, with initial severity of 24.43% and T9- leaf sprayed with sodium bicarbonate solution and canola oil, with initial severity of 56.73%; T10- plastic-coated leaf sprayed with coffee pyroligneous acid, with initial severity of 32.80%; T11- plastic-coated leaf sprayed with coffee pyroligneous acid, with initial severity of 48.33%. The leaves of all treatments, after spraying, were covered with clear plastic for 7 days. After this period, the plastic was permanently removed and the leaves were immediately evaluated. The treatments consisted of a single spray, where the products were diluted in water, using the same concentrations of experiment 1.

In this study, the severity of rose powdery mildew was evaluated at 0, 7 and 14 days after the treatments. Thus, the complete and composite leaves that received the treatments were photographed. The images were made with a digital camera, with a resolution of 13 megapixels. To obtain the photographs, the leaves were placed on white paper with a reference line in length, the photos were taken in an oblique position, at a distance that allowed the recognition of the entire leaf area. The photographs that were initially colored were transformed to grayscale (8 bits) and then submitted to the computer software Image J, in which a spatial measurement was calibrated using the reference line present in all photos and the object to be measured was determined, in order to estimate the total leaf limb area and the white area corresponding to the powdery mildew lesion. Thus, from the white area, the percentage of disease severity was obtained after the different treatments and evaluation periods.

Statistical analysis

For the statistical analysis, generalized linear models (GLM) were constructed (Crawley, 2013), with the aid of the R statistical software, version 3.2.4 (R Development Core Team, 2016). In experiment 1, it was evaluated whether the percentage of the area affected by the fungus - severity (response variable) varies as a function of the control products, fertilization methods and their interaction (explanatory variables). In experiment 2, it was verified whether the different treatments affected the percentage of the area affected by the fungus. In both experiments,

the binomial error distribution with Logit function and Quasibinomial overdispersion were used, with the significance of the complete models tested and the non-significant terms removed from the model (Crawley, 2013). Subsequently, residual analysis of the minimum models was performed to verify their adequacy. Values of $p < 0.05$ were considered statistically significant.

Results and Discussion

Experiment 1

The results of this research show that it is possible to control powdery mildew with products alternative to conventional chemical pesticides and thus reduce the environmental impacts and the unhealthiness caused by them in rose cultivation. Not all products tested were sufficiently efficient and the fertilizations studied did not differ statistically in the control of powdery mildew. It was also observed that there was no interaction between fertilization and the application of products with potential fungicidal action in mildew severity in any of the evaluated periods. In the first evaluation, there were no significant differences among treatments of sprayed fungicide products in disease severity but, in the other evaluation periods, there was a statistical difference among treatments (Table 3).

Coffee pyroligneous acid yielded the greatest reduction in powdery mildew severity, followed by treatments using sodium bicarbonate, neem extract and lime sulfur (Figure 3).

Table 3. Control of *Oidium leucoconium* in roses treated with different products and evaluated for disease severity at 15, 30 and 45 days after spraying.

Treatments	Severity (%)			
	0 day ^{n.s}	15 days	30 days	45 days
Control (Water)	62.47 ± 5.87	54.56 ± 3.83 b	62.58 ± 7.86 c	63.09 ± 3.35 c
Lime sulfur	73.05 ± 5.17	51.72 ± 1.70 b	40.08 ± 7.76 b	28.97 ± 5.01 b
Neem oil	65.40 ± 6.70	42.21 ± 5.78ab	38.13 ± 4.85 b	26.84 ± 5.94 b
Sodium bicarbonate + canola oil	65.62 ± 6.98	48.21 ± 6.71 b	24.76 ± 4.08 ab	25.56 ± 4.75 b
Coffee pyroligneous acid	64.54 ± 4.33	33.03 ± 5.69 a	21.08 ± 3.68 a	11.0 ± 1.33 a

*Means followed by the same letter in the column do not differ statistically by contrast analysis at 5% probability.

^{n.s} Not significant.

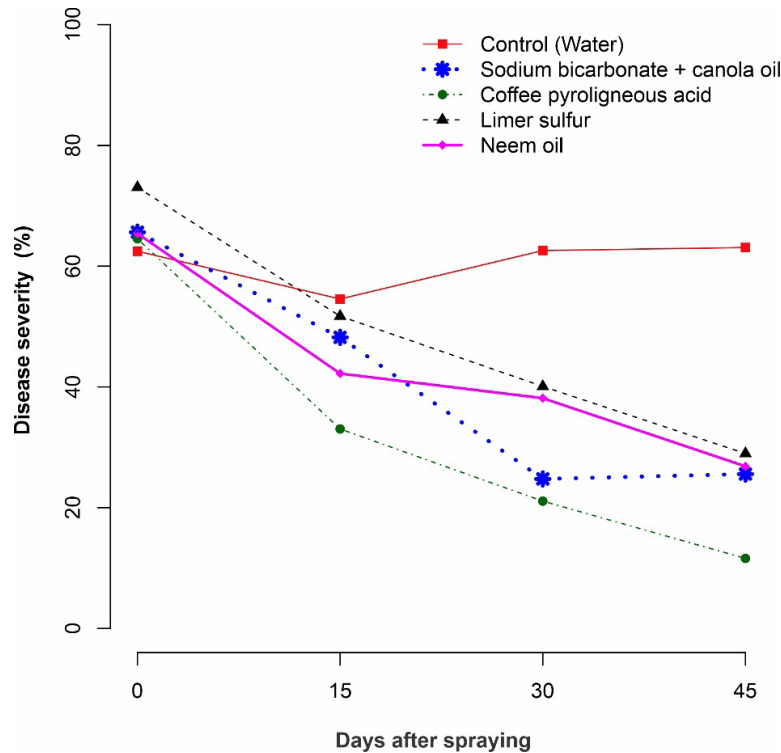


Figure 3. Severity of *Oidium leucoconium* in roses treated with different products and evaluated at 15, 30 and 45 days after spraying.

When setting the experiment, the occurrence of powdery mildew was around 62% on leaves and homogeneously in plants, which can be explained due to the absence of significant differences among treatments in the first evaluation. At 15 days after treatment application (second evaluation), the greatest reduction in disease severity occurred with the application of coffee pyroligneous acid (39.46%), followed by neem oil (22.63%), compared with the water control (Table 3).

The application of fungicide products in plants yielded reductions in disease severity over the evaluation period, with the largest reductions observed with the application of coffee pyroligneous acid, reducing disease severity by 81.6% at 45 days, while in the other treatments, there was no significant difference and the reduction ranged from 54 to 59.5%. Thus, it can be inferred that coffee pyroligneous acid was the most efficient product to control the fungus, since it presented the greatest fungicidal action, followed by neem oil, sodium bicarbonate and lime sulfur, which had similar effects.

Coffee pyroligneous acid has in its chemical composition compounds such as copper, zinc, phenols, fulvic acid, humic acid and potassium oxide (Table 2), which may have interfered with fungal growth. Coffee pyroligneous acid compounds may have acted as pH modifiers, favoring antagonists capable of inhibiting the pathogenic fungus (Souza et al., 2018). Nutrients such as copper and zinc lead to plant protection, which may have influenced the rose response to the pathogen, since they may act as enzyme activators (Özkay et al., 2014). In the literature, phenolics compounds are described with fungicidal action in plants (Cruz-Silva et al., 2016, Gomes et al., 2018).

Phenolic compounds present in plant tissues have inhibitory effects on fungal growth (Varigi et al., 2017; Gomes et al., 2018). Phenolic compounds are chemicals called secondary metabolites, which can interfere with microbial cell membrane integrity or inhibit spore germination. Thus, they are essential for plant growth and reproduction and as protective agents, being secreted as a defense mechanism (Vicente and Boscaiu, 2018). Other studies have confirmed the efficiency of pyroligneous acid in inhibiting bacteria (Mmjieje and Hornung, 2015; Zhang et al., 2019) and fungus as *Rhizoctonia solani* (Hossain et al., 2015), *Colletotrichum gloeosporioides* (Ribeiro et al., 2016) and *Botryodiplodia theobromae* (Theapparath et al., 2015).

The compounds that constitute coffee pyroligneous acid that was applied to control *O. leucoconium* in rose probably acted in different mechanisms, which yielded higher efficiency than the other products tested in rose cultivation. The literature results with the isolated use of these compounds found in coffee pyroligneous acid corroborate the results of this study, demonstrating that these products have a high potential for fungicidal use. Andrade and Mata (2018) demonstrated that copper phosphite is effective to control *in vitro* *Rhizoctonia solani*, *Fusarium oxysporum*, *Botrytis cinerea*, *Lasiodiplodia theobromae*, *Sclerotinia sclerotium* and *Colletotrichum gloeosporioides*. According to Silva et al. (2016), zinc sulfate at a concentration of 2 g L⁻¹ controlled 56% of *Oidium* spp. in eucalyptus minicuttings, demonstrating the antifungal efficiency of this nutrient. In this case, zinc may act nutritionally on the plant or directly on the pathogen and can cause biochemical changes in fungal cells, being capable of disrupting cells integrity

and preventing pathogen growth (Santos et al., 2019). According to Canellas et al. (2015), products containing humic and fulvic acids may act as physiological regulators, contributing to plant tolerance to phytosanitary problems.

Despite not expressing itself as the best product in reducing severity, lime sulfur yielded satisfactory results; thus, it should be the subject of further studies in order to explore its potential. Results from other studies confirm the efficiency of lime sulfur as a fungicide in the control of *Stemphylium solani in vitro* (Domingues et al., 2017) and angular leaf spot in common bean crop (Carvalho et al., 2010). According to Ming et al. (2012), the reduction in the rate of fungal leaf diseases in sweet passion fruit crop can be explained by the fact that lime sulfur contains sulfur, which acts as a phytoprotective agent, in addition to the fungistatic action. The application of lime sulfur in this study led to a reduction in severity, compared to the control, without, however, highlighting in disease control, which also occurred in the study by Mazaro et al. (2013), in which there was no significant reduction in the area below the disease progress curve with the application of the syrup, but there was a reduction in mycosphaerella severity in strawberry.

The use of sodium bicarbonate has been reported in the control of fungus in several crops, such as pear (Lai et al., 2015), citrus (Fallanaj et al., 2016), rose (Horst et al., 1992) and grape (Quin et al., 2015). According to Bhalerao et al. (2019), sodium bicarbonate at a concentration of 1%

controlled 87.92% of *Alternaria solani*, 65.44% of *Rhizopus stolonifer*, 88.06% of *Aspergillus niger* and 84.83% of *Colletotrichum gloeosporioides*. Sodium bicarbonate compounds may act directly on the pathogen and/or induce plant defense responses (Lyon et al., 1995). The product has as advantages the low risk of environmental contamination (Franco and Bettiol, 2002) low cost and easy access. According to Janisiewicz and Conway (2010), the effect of bicarbonate is basically fungistatic and fungal spores are not inactivated, only their germination is delayed. The authors further state that twinned spores appear to be more easily inactivated by the presence of these substances than non-germinated spores. Sodium bicarbonate inhibited 100% growth of *C. gloeosporioides* (Ferreira et al., 2015) and, according to Tatagiba et al. (2002), it showed as a promising product in the control of powdery mildew, presenting potential use in disease management in papaya crop.

In this study, neem oil showed efficiency in reducing powdery mildew severity (Figure 1). In the literature, there are several studies on neem oil that confirm its fungicidal action (Nahak and Sahu, 2015).

Experiment 2

Significant differences were observed among treatments in the two evaluation periods studied (Table 4), and the greatest reduction in disease severity occurred at 14 days after treatments (Figure 2) in leaves sprayed with sodium bicarbonate and lime sulfur (Table 4).

Table 4. Percentage of powdery mildew severity in roses with different initial severity levels in leaves sprayed with different products and evaluation of disease progression at 7 and 14 days after treatments.

Treatments	Severity (%)		
	0 day	7 days	14 days
T1 Asymptomatic leaf with plastic	0.00 f	0.00 d	0.00 d
T2 Symptom leaf + water with plastic	29.77 ± 4.70 de	11.37 ± 1.11 c	10.30 ± 2.10 c
T3 Symptom leaf with plastic	55.00 ± 2.67 bc	23.67 ± 4.39 b	17.07 ± 6.39 abc
T4 Lime sulfur	34.26 ± 7.51 cde	28.43 ± 5.87 b	8.37 ± 0.71 c
T5 Lime sulfur	56.86 ± 16.54 b	47.43 ± 7.77 a	14.10 ± 0.64 abc
T6 Neem oil	34.76 ± 4.49 cde	23.80 ± 2.02 b	14.93 ± 5.52 abc
T7 Neem oil	83.03 ± 9.62 a	47.43 ± 11.03 a	21.90 ± 7.65 ab
T8 Sodium bicarbonate	24.43 ± 5.57e	5.16 ± 2.02 c	11.47 ± 1.49 bc
T9 Sodium bicarbonate	56.73 ± 3.39 b	34.73 ± 1.27 ab	8.47 ± 0.81 c
T10 APC	32.80 ± 5.53 e	36.30 ± 2.71 ab	26.60 ± 8.09 a
T11 APC	48.33 ± 2.29 bcd	48.13 ± 10.19 a	13.53 ± 3.30 b

*Means followed by the same letter in the column do not differ statistically by contrast analysis at 5% probability.

At seven days after spraying, lower disease severity was observed in all treatments, except for the control with asymptomatic leaves, which showed no powdery mildew symptoms during the 14 days of the experiment. However, spraying the leaf with initial severity of 29.7% of powdery mildew (control 2) with water followed by plastic covering yielded a reduction of 18.4% and 19.5% in disease severity at 7 and 14 days, respectively. In control 3, with symptoms, the reduction in severity was lower compared to control 2. The use of plastic protection may have changed conditions on the leaf surface, which provided reduction in the severity of control 3, even if it did not received any type of spray.

Therefore, it is inferred that there were no new infections, with the progressive behavior of severity reduction until 14 days. In the control with symptoms, without spraying, the reduction in severity was lower, compared to control 2. This greater reduction in the control 2 can be explained by the removal of mycelium and conidia during the water spraying process, which may have eliminated the inoculum source and prevented new infections due to the use of the plastic cover. On the other hand, covering the leaves with a plastic bag possibly increased the temperature and relative humidity of the leaf phylloplane, causing lower disease progression.

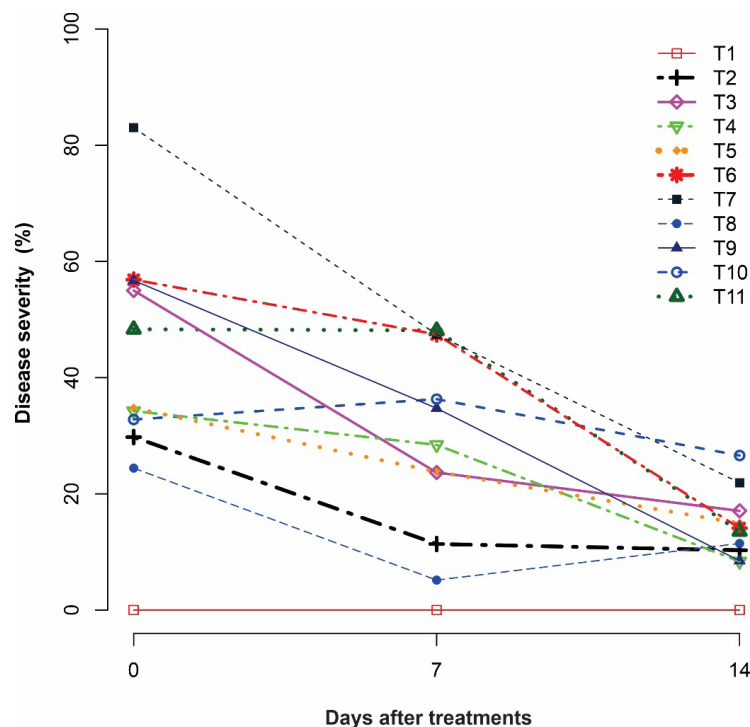


Figure 4. Severity of *Oidium leucoconium* in roses treated with different products and evaluated at 7 and 14 days after spraying.

Except for the treatments with coffee pyroligneous acid and leaves with initial severity of 24.43% with sodium bicarbonate, when there is a comparison of the spraying of the less severe leaves (0 days) with those after 7 days of application of the different treatments, it was observed that leaves with lower initial severity consequently yielded greater reductions in disease severity (Figure 2). Treatments with sodium bicarbonate (leaves with initial severity of 56.73%) and lime sulfur (initial severity of 34.26%) caused the largest reductions in disease severity, followed by coffee pyroligneous acid (initial severity of 48.33%). Therefore, the earlier disease control measures are adopted, the more effective it is to prevent its progress or reduce its severity. In this experiment with plastic cover, the treatment of sodium bicarbonate and lime sulfur had better results, compared to experiment 1. Lime sulfur is a protective fungicide requiring new applications every 7 or 14 days. It can be inferred that the use of plastic

allowed greater fungicidal action of lime sulfur and sodium bicarbonate or the synergistic interaction of the product and other factors (Figure 2).

Neem oil initially showed high efficiency in the control of fungal growth. In the long term, coffee pyroligneous acid was the most efficient, leading to continuous reductions and, in the short term, its effect was variable, but even when applied to plants with high fungal infestation, it was efficient in reducing disease severity (Figure 2). The effect of coffee pyroligneous acid (APC) on the reduction in disease severity at 15 days (experiment 1) was 48.8% and, at 14 days (experiment 2), 74%, demonstrating greater control efficiency after 2 applications of the product. Thus, it can be observed that, in both experiment 1 and experiment 2, APC has great potential for use in the control of rose powdery mildew. In the literature, several studies have demonstrated the potential of pyroligneous acid for fungicidal use (Ribeiro et al., 2016; Souza et al., 2018).

The results found in this study show that sodium bicarbonate, lime sulfur, acid and vegetable oil based products can be used for the management of rose powdery mildew and are a low cost option without environmental and human health damage. Organic fertilization, even without significant differences, due to the short evaluation period, is an important tool for the nutritional management of rose under organic cultivation conditions. The study paves the way for several others related to the management of rose powdery mildew, such as evaluating dosages and *in vitro* study, as well as elaboration of diagrammatic and descriptive scales of this pathogen in rose, which are important tools for disease monitoring and control decision making.

Conclusions

Alternative sodium bicarbonate + canola oil (10 g + 10 mL L⁻¹), lime sulfur (5 mL L⁻¹), coffee pyroligneous acid (100 mL L⁻¹) and neem oil based products (1 mL L⁻¹) reduce powdery mildew severity in rose. Coffee pyroligneous acid has high fungicidal potential, demonstrating greater control efficiency after 2 product applications. Fertilization did not influence disease severity reduction.

Author Contribution

S.M.B.R. ⁰⁰⁰⁰⁻⁰⁰⁰³⁻¹⁹⁰⁶⁻⁶⁷²³: Preparation, implementation, data collection, evaluation and scientific writing; **E.F.A.A.** ⁰⁰⁰⁰⁻⁰⁰⁰²⁻⁰⁸⁰⁰⁻⁸³⁷⁹: Research orientation and scientific writing; **F.D.S.R.** ⁰⁰⁰⁰⁻⁰⁰⁰²⁻²⁵⁰⁶⁻³⁴⁴¹: Research co-orientation and scientific writing; **M.D.F.G.F.** ⁰⁰⁰⁰⁻⁰⁰⁰¹⁻⁷⁴⁹⁶⁻⁵⁵⁵⁹: Statistical analysis of sample data and intellectual contributions to scientific research; **E.B.D.S.** ⁰⁰⁰⁰⁻⁰⁰⁰³⁻²⁷⁶¹⁻⁴⁹¹⁰: Implementation, data collection and evaluation.

Acknowledgements

The authors would like to thank FAPEMIG and CNPq, for funding the research and the scholarships. The authors are also thankful to the company Café Janaúba for supplying the coffee pyroligneous.

References

ALEXANDRE, M.A.V.; TOFOLI, J.G.; ALMEIDA, I.M.G.; OLIVEIRA, C.M.G. Doenças das plantas ornamentais. In: AMORIN, L.; REZENDE, J.A.M.; BERGAMIN FILHO, A. CAMARGO, L.E.A. **Manual de Fitopatologia**: Ouro Fino: Editora Agronômica Ceres, 2016, v.2. p.603-624.

ALMEIDA, E.F.A.; PIVETTA, K.F.L.; PAIVA, P.D.O.; ICHINOSE, J.G.S.; GIMENES, R.; REIS, S. N. CARVALHO, L.M.; RIBEIRO, M.N.O. Rosa. In: PAIVA, P.D.O.; ALMEIDA, E.F.A. **Produção de flores de corte**: Lavras: Editora da UFPA, 2014, v.2. p. 607-708.

ANDRADE, D.A.; MATA, R.G. Eficácia de fungicidas químicos para el control *in vitro* de diferentes fitopatógenos em condiciones controladas. **Arnaldoa**, v.25, n.2, p.489-498, 2018. DOI: <http://doi.org/10.22497/arnaldoa.252.25209>

BARBOSA JÚNIOR, M.P.; POZZA, E.A.; SANTOS NETO, H.; SILVA, M.L.O.; POZZA, A.A.A.; GUIMARÃES, R.J.; SOUZA, P.E. Brown eye spot in coffee subjected to different drip irrigation and fertilization management. **Australasian Plant Pathology**, v.48, p.245-252, 2019. DOI: <https://doi.org/10.1007/s13313-019-0623-y>

BHALERAO, J.B.; CHAVAN, R.A.; DHARBALE, B.B.; SWAMI, C.S.; KARDILE, P.B.; KENDRE, A.H. Studies on *in-vitro* efficacy of chemicals against major fungi associated with post-harvest rot of tomato. **Journal of Pharmacognosy and Phytochemistry**, v.8, n.2, p.1159-1163, 2019.

CARVALHO, W.P.; WANDERLEY, A.; OLIVEIRA, C.M. Controle de mancha-angular utilizando-se caldas fertiprotetoras em cultivo orgânico de feijoeiro irrigado. **Pesquisa Agropecuária Tropical**, v.40, n.4, p.476-482, 2010.

CANELLAS, L.P.; OLIVARES, F.L.; AGUIAR, N.O.; JONES, D.L.; NEBBIOSOC, A.; MAZZEI, P.; PICCOLO, A. Humic and fulvic acids as biostimulants in horticulture. **Scientia Horticulturae**, v.196, p.15-27, 2015. DOI: [10.1016/j.scienta.2015.09.013](https://doi.org/10.1016/j.scienta.2015.09.013)

CRAWLEY, M. J. **The R book**: Chichester: John Wiley & Sons Ltd, 2013. 975p.

CRUZ-SILVA, S.C.B.; MATIAS, R.; BONO, J.A.M.; SANTOS, K.S.; LUDWIG, J. Antifungal potential of extracts and fractions of *Randia nitida* leaves on soybean pathogens and their phytochemistry. **Revista Caatinga**, v.29, n.3, p.594-602, 2016. DOI: <http://dx.doi.org/10.1590/1983-21252016v29n309rc>

DOMINGUES, D.; RODRIGUES C.; BAMBOLIM, A.; QUEIROZ, D.G.; PERES, W.M. Sensibilidade de *Stemphylium solani* a extratos vegetais e caldas e controle da doença no tomateiro em estufa. **Revista de Ciências Agrárias**, v.40, n.1, p.114-123, 2017. DOI: <http://dx.doi.org/10.19084/RCA15129>

DOMÍNGUEZ-SERRANO, D.; GARCÍA-VELASCO, R.; MORA-HERRERA, M.E.; SALGADO-SICLAN, M.L.; GONZÁLEZ-DÍAZ, J.G. La cenicilla del rosal (*Podospaera pannosa*). **Agrociencia**, v.50, n.7, p.901-917, 2016.

FALLANAJ, F.; IPPOLITO, A.; LIGORIO, A.; GARGANESE, F.; ZAVANELLA, C.; SANZAN, S.M. Electrolyzed sodium bicarbonate inhibits *Penicillium digitatum* and induces defence responses against green mould in citrus fruit. **Postharvest Biology and Technology**, v.115, p.18-29, 2016. DOI: [10.1016/j.postharvbio.2015.12.009](https://doi.org/10.1016/j.postharvbio.2015.12.009)

- FERREIRA, E. M. S.; MALTA, C. M.; COELHO, C. M.; SANZIO, R. Substâncias GRAS no controle do crescimento de *Colletotrichum gloeosporioides* e *Fusarium guttiforme* in vitro. **Journal of Bioenergy and Food Science**, v.2, n.4, p.183-188, 2015. DOI: 10.18067/jbfs.v2i4.67
- FRANCO, D.A.D.S.; BETTIOL, W. Efeito de produtos alternativos para o controle do bolor verde (*Penicillium digitatum*) em pós-colheita de citros. **Revista Brasileira de Fruticultura**, v.24, n.2, p.569-572, 2002. DOI: 10.1590/S0100-29452002000200059
- GOMES, E.M.C.; FIRMINO, A.V.; PENA, R.C.M.; ALMEIDA, S.S. M.S. Efeito inibitório in vitro de extratos de *Cinnamomum zeylanicum* Blume no controle de *Cylindrocladium candelabrum*. **Ciência Florestal**, v.28, n.4, p.1559-1567, 2018. DOI: <http://dx.doi.org/10.5902/1980509835103>.
- HORST, R.K.; KAWAMOTO, S.O.; PORTER, L.L. Effect of sodium bicarbonate and oils on the control of powdery mildew and black spots in roses. **Plant Disease**, v.76, n.3, p.247-251, 1992.
- HOSSAIN, M.M.; SCOTT, I.M.; MCGARVEY, B.D.; CONN, K.; FERRANTE, L.; BERRUTI, F.; BRIENS, C. Insecticidal and anti-microbial activity of bio-oil derived from fast pyrolysis of lignin, cellulose and hemicellulose. **Journal of Pest Science**, v. 88, n.1, p.171-179, 2015.
- JANISIEWICZ, J.W.; CONWAY, W.S. Combining biological control with physical and chemical treatments to control fruit decay after harvest. **Stewart Postharvest Review**, v.6, n.1, p.1-3, 2010. DOI: 10.2212/spr.2010.1.3
- LAI, T.; BAI, X.; WANG, Y.; ZHOU, J.; SHI, N.; ZHOU, T. Inhibitory effect of exogenous sodium bicarbonate on development and pathogenicity of postharvest disease *Penicillium expansum*. **Scientia Horticulturae**, n.187, p.108-114. DOI: 10.1016/j.scienta.2015.03.010
- LYON, G.D.; REGLINSKI, T.; NEWTON, A.C. Novel disease control compounds: the potential to immunize plants against infection. **Plant Pathology**, v.44, n.3, p.407-427, 1995. DOI: <https://doi.org/10.1111/j.1365-3059.1995.tb01664.x>
- MAZARO, S.M.; MANGNABOSCO, M.C.; CITADIN, I.; PAULUS, D.; GOUVEA, A. Produção e qualidade de morangueiros sob diferentes concentrações de calda bordalesa, sulfocálcica e biofertilizante supermagro. **Semina: Ciências Agrárias**, v.1, n.34, p.3285-3294, 2013. DOI: 10.5433/1679-0359.2013v34n6Supl1p3285
- MING, L.C.; MAIA-ALMEIDA, C.I.; MARQUES, M.O.M.; CONCEIÇÃO, D.M.; YUHARA, T.; LEONEL, S.; SILVA, J. Eficiência da calda bordalesa e sulfocálcica em diferentes concentrações e idade de planta no controle de doenças foliares de maracujá-doce em cultivo orgânico. **Journal of biotechnology and biodiversity**, v.3, n.2, p.30-35, 2012.
- MMJIEJE, J.; HORNUNG, A. The potential application of pyrolygneous acid in the UK agricultural industry. **Journal of Crop Improvement**, v.29, n.15, p.228-246, 2015. DOI: <https://doi.org/10.1080/15427528.2014.995328>
- NAHAK, G.; SAHU, R.K. Biopesticidal effect of leaf extract of neem (*Azadirachta indica* A. Juss) on growth parameters and diseases of tomato. **Journal of Applied and Natural Science**, v.7, n.1, p.482-488, 2015. DOI: 10.31018/jans.v7i1.636
- ÖZKAY, F.; KIRAN, S.; TAŞ, I.; KUŞVURAN, S. Effects of copper, zinc, lead and cadmium applied with irrigation water on some eggplant plant growth parameters and soil properties. **Turkish Journal of Agricultural and Natural Sciences**, v.1, n.3, p.377-383, 2014.
- PRATA, G.G.B.; SOUZA, K.O.; LOPES, M.M.A.; OLIVEIRA, L.S.; ARAGAO, F.A.S.; ALVES, R.E.; SILVA, S.M. Nutritional characterization, bioactive compounds and antioxidant activity of Brazilian roses (*Rosa* spp). **Journal of Agricultural Science & Technology**, v.19, n.4, 2017.
- QUIN, X.; XIAO, H.; XUE, C.; YU, Z.; YANG, R.; CAI, Z.; SI, L. Biocontrol of gray mold in grapes with the yeast *Hanseniaspora uvarum* alone and in combination with salicylic acid or sodium bicarbonate. **Postharvest Biology and Technology**, v.100, p.160-167, 2015. DOI: 10.1016/j.postharvbio.2014.09.010
- RIBEIRO, M.N.O.; ALMEIDA, E.F.A.; LESSA, M.A. RIBEIRO JÚNIOR, P.M.; BARBOSA, S.S.; FIGUEIREDO, J.R.M.; REIS, S.N. Effects of plant conduction systems and organic fertilizer management on disease incidence and severity in 'Osiana' and 'Carola' rose. **Ornamental Horticulture**, v.21, n.1, p.85-92, 2015. DOI: 10.14295/rbho.v21i1.778
- RIBEIRO, J.G.; SERRA, I.M.R.S.; ARAÚJO, M.U.P. Use of natural products to control anthracnose caused by *Colletotrichum gloeosporioides* in papaya. **Summa Phytopathologica**, v.42, n.2, p.160-164, 2016. DOI: <http://dx.doi.org/10.1590/0100-5405/2023>.
- SANTOS, R.A.A.; D'ADDAZIO, V.; SILVA, J.V.G.; FALQUETO, A.R.; SILVA, M.B.; SCHMILDT, E.R.; FERNANDES, A.A. Antifungal activity of copper, zinc and potassium compounds on mycelial growth and conidial germination of *Fusarium solani* f. sp. *piperis*. **Microbiology Research Journal International**, v.29, n.6, p.1-11, 2019. DOI: <https://doi.org/10.9734/mrji/2019/v29i630179>
- SILVA, A.C.; RESENDE, M.L.V.; SOUZA, P.E.; PÔSSA, K.F.; SILVA JÚNIOR, M.B. Extrato vegetal, fosfito e sulfato de zinco no controle do oídio em eucalipto. **Revista Ciência Agrônômica**, v.47, n.1, p.93-100, 2016.

- SOUZA, J.L.S.; GUIMARÃES, V.B.S.; CAMPOS, A. D.; LUND, R.G. Antimicrobial potential of pyroligneous extracts – a systematic review and technological prospecting. **Biotechnology and Industrial Microbiology**, v.49, n.1, p.128-139, 2018.
- TATAGIBA, J.S.; LIBERATO, J.R.; ZAMBOLIM, L.; COSTA, H.; VENTURA, J.A. Controle químico do oídio do mamoeiro. **Fitopatologia Brasileira**, v.27, p.219-222. 2002. DOI: <http://dx.doi.org/10.1590/S0100-41582002000200017>
- THEAPPARAT, Y.; CHANDUMPAL, A.; LEELASUPHAKUL, W.; LAEMSAK, N. Pyroligneous acids from carbonization of wood and bamboo: their components and antifungal activity. **Journal of Tropical Forest Science**, v.27, n.4, p.517–526, 2015.
- VAGIRI, M.; JOHANSSON, E.; RUMPUNENA, K. Phenolic compounds in black currant leaves - an interaction between the plant and foliar diseases? **Journal of plants interactions**, v.12, n.1, p.193-199, 2017. DOI: <https://doi.org/10.1080/17429145.2017.1316524>
- VICENTE, O.; BOSCAIU, M. Flavonoids: antioxidant compounds for plant defence... and for a healthy human diet. **Notulae Botanicae Horti Agrobotanici Cluj-Napoca**, v.46, n.1, p.14-21, 2018. DOI: 10.15835/nbha46110992
- YOUREN, F.; JINGYANG, X.; BAOSHENG, L.; PENGHUA, B. Mini-review of major diseases of *Rosa chinensis* Jacq in China. **Plant Diseases and Pests**, v.6, n.3, p.10-13, 2015.
- ZHANG, C.; LUO, S.; XU, F.; BU, Q.; QIU, L. Chemical characteristics and antimicrobial performance of wood vinegar produced from pyrolysis of polyploidy mulberry branches. **Journal of Biobased Materials and Bioenergy**, v.13, n.6, p.812-819, 2019. DOI: <https://doi.org/10.1166/jbmb.2019.1923>