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PRINCIPAL COMPONENTS OF THE INTENSITY OF SQUAMOUS ROT ON PRICKLY PEAR PLANTATIONS IN THE SEMIARID REGION OF THE STATE OF PARAÍBA, BRAZIL[1]

ANNE EVELYNE FRANCO DE SOUZA[2], LUCIANA CORDEIRO DO NASCIMENTO[3], BRENO OLIVEIRA DE SOUZA[3]*

ABSTRACT – The aim of the present study was to identify fungal pathogens associated with prickly pear rot and the main components of squamous rot on plantations in the semiarid region of the state of Paraíba, Brazil. Pathogens were identified morphologically. The determination of the main components of squamous rot intensity was based on the incidence and severity of the disease. Fifteen genera of fungi were associated with rot, including *Scytalidium* sp., which was found on all plantations. The analyses indicated that relative humidity and rainfall favored the intensity of rot more than temperature. At least three pathogens were found to be associated with a high incidence of rot in prickly pear species in the semiarid region of the state of Paraíba, Brazil, but *Scytalidium* sp. was the most widely distributed. Moreover, the disease caused by this fungus intensifies and progresses under conditions of high humidity at moderate temperatures.

Keywords: *Opuntia ficus-indica*. Progress of plant diseases. Epidemiology.

COMPONENTES PRINCIPAIS DE INTENSIDADE DA PODRIDÃO ESCAMOSA EM PALMA FORRAGEIRA ‘GIGANTE’ NO SEMIÁRIDO PARAIBANO

RESUMO - Objetivou-se identificar os patógenos fúngicos associados às podridões de palma ‘Gigante’ e os componentes principais de intensidade da Podridão Escamosa em plantios no semiárido paraibano. Os patógenos foram identificados morfologicamente e os componentes principais de intensidade foram obtidos a partir da incidência e severidade da doença. Foram identificados quinze gêneros de patógenos fúngicos associados às podridões, dentre eles, *Scytalidium* sp., que estava em todos os plantios. A podridão escamosa progrediu significativamente e a associação entre clima e doença indicou que a umidade relativa do ar e a precipitação pluviométrica favoreceram mais a intensidade da doença nos plantios, do que a temperatura. Pelo menos três patógenos estão associados às podridões em palma ‘Gigante’ no semiárido paraibano com elevada incidência, mas a podridão escamosa (*Scytalidium* sp.) é a mais distribuída, pois se intensifica e progride devido a umidade elevada do ar em temperatura moderada.

Palavras-chave: *Opuntia ficus-indica.* Progresso de doenças de plantas. Epidemiologia.

*Corresponding author
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[2]Department of Veterinary Science, Universidade Federal da Paraíba, Areia, PB, Brazil; anne@cca.ufpb.br.
[3]Program of Postgraduate in Agronomy, Universidade Federal da Paraíba, Areia, PB, Brazil; luciana.cordeiro@cca.ufpb.br, breno.oliveiras@yahoo.com.br.

INTRODUCTION

The prickly pear species *Opuntia ficus-indica* (L.) Mill. and *Nopalea cochenillifera* (L.) Salm-Dyck. have been grown in dry tropical areas of Africa, Europe and the Americas since the 17th century. These species are considered important crops in arid and semiarid regions of tropical countries (BONFIM et al, 2013). In South America, prickly pears in Peru, Chile, Bolivia, Argentina and Brazil are grown for diverse purposes, such as feeding ruminant species. These cacti serve as a food and moisture source for animals during long drought periods and constitute an important crop, especially in family farming activities in semiarid regions (LOPES et al, 2012).

It is estimated that Brazil has approximately 550 thousand hectares of cactus plantations, concentrated mainly in the northeastern states of Paraíba, Pernambuco and Alagoas, with a mean production of 29,604 plants per hectare in two years of cultivation (SILVA et al., 2015). The most widely grown strains of prickly pear in northeastern Brazil are the rounded, IPA-20 clone and giant types (LOPES et al, 2012). The giant prickly pear is resistant to the climatic adversities of a semiarid environment. However, its yield is compromised due to the occurrence of pathogens, especially those of a fungal nature, which attack the large, moisture-rich cladodes, root system and fruit in the pre-harvest and post-harvest phases, causing rot (SOUZA et al., 2010; BONFIM et al., 2013).

The rotting of cladodes, roots and joints reduces productivity and limits cultivation (LOPES et al, 2012). The most prevalent rot-forming fungus is *Scytalidium lignicola* Pesante (SOUZA et al., 2010). However, cactus diseases have been little studied and information is limited to symptoms, the pathogenicity of causal agents, surveys of the damage caused and chemical control measures (SANTOS et al., 2006; SOUZA et al., 2010; LOPES et al, 2012; BONFIM et al., 2013). Thus, knowledge regarding the period of pathogen infection is of considerable importance to the definition of the best rot control strategy.

Epidemiological studies involving an analysis of spatiotemporal dynamics are fundamental to the control of plant diseases (BERGAMIN-FILHO; AMORIM, 1996). However, many crops adapted to tropical climates, such as the prickly pear (BONFIM, et al., 2013), have not been characterized with regard to the period of greatest susceptibility to pathogens. Thus, the recommendations of chemical control are limited to the cultivation period and the use of healthy cladodes or seeds as well as the removal and destruction of infected cladodes and the spraying of fungicides every 15 to 20 days in the period considered most favorable to rot (SANTOS et al, 2006). However, this control calendar fails to consider efficient plant protection and is responsible for the high incidence of rot found in semiarid regions of Brazil.

The determination of the most favorable period for infection is essential to the proper management of rot and can lead to reductions in both production costs and risks to the environment. Therefore, the aim of the present study was to contribute to the development of more efficient rot management strategies for the giant strain of the prickly pear through the morphological identification of fungal pathogens associated with squamous rot and the principal components of rot intensity on plantations located in the semiarid region of the state of Paraíba in northeastern Brazil.

MATERIAL AND METHODS

Cladodes of the giant prickly pear with squamous rot were collected from rural properties in 38 municipalities in the semiarid region of the state of Paraíba, Brazil: São José de Piranhas, Conceição, Diamante, Itaporanga, Imaculada, Maturéia, Teixeira, Desterro, Catolé do Rocha, Santa Luzia, Junco do Seridó, Juazeirinho, Cubati, São Vicente do Seridó, Pedra Lavrada, Nova Palmeira, Picuí, Taperoá, Ouro Velho, Monteiro, Cabaceiras, Gurjão, Boqueirão, Caturité, Barra de Santana, Boa Vista, Queimadas, Campina Grande, Cuité, Soledade, Barra de Santa Rosa, Remígio, Algodão de Jandaíra, Cacimba de Dentro, Gado Bravo, Aroeiras, Umbuzeiro and Natuba. Ten cladodes with symptoms of rot and signs of pathogens (SANTOS et al., 2006; SOUZA et al., 2010) were collected from each location and sent to the Phytopathology Laboratory of the Center for Agrarian Sciences of the Federal University of Paraíba for the isolation, morphological identification and pathogenicity test of the associated fungi. For such, visual inspections were performed to assess the symptoms on the plant as well as the signs and structures of the pathogens (BARNETT; HUNTER, 1972; ROSSMAN et al., 1994; SOUZA et al., 2010).

Two sets of variables were used for the epidemiological assessments, i.e. those related to climate and disease. With regard to climate, relative humidity, rainfall and temperature values were obtained from the meteorological station on Pedra Rica Farm in the state of Paraíba. For the evaluation of the disease, ten plants were randomly selected and rot intensity was evaluated based on the incidence and severity between January and December 2009 on Pedra Rica Farm in the municipality of Barra de Santana, Paraíba. The incidence on cladodes (SOUZA et al., 2010) was determined using the McKinney index (1923). The area of cladode damaged by the pathogen was used for the creation of a disease intensity scale based on the degree of severity caused by the progression of the disease (CAMPBELL; MADDEN, 1990). Disease intensity on all cladodes was determined on a monthly basis. For this, photographs were taken and the images were transferred to a microcomputer with a resolution of 300 dpi (Figure 1) for subsequent analysis using the Quant® software program.

Based on severity, the disease progression rate and area under the disease progression curve (CAMPBELL; MADDEN, 1990) were calculated as follows: disease progression rate (r) = (1/t)*ln(X/x0), in which t = time elapsed between first and last evaluation in days, ln = natural logarithm, X_1 = disease severity at last evaluation (%) and X_0 = disease severity at first evaluation (%); area under the curve = Σ(yi + yi+1)/2 * (ti+1 – ti), in which n = number of evaluations, y = disease severity (%) and t = time in days. The area under the disease progression curve was analyzed in an entirely random design. The Scott-Knott test with 5% probability was used in the comparison of means with the aid of the SISVAR® software program. Multivariate analysis was performed between the two sets of variables, in which the principal components of the disease (PC1 and PC2) were estimated (JOLLIFFE, 2002). Canonical correlation analysis (SILVA et al., 2015) was performed between the principal components of rot estimated in the multivariate analysis (PC1 and PC2). All statistical tests were conducted using the Statistical Analysis System (SAS).

RESULTS AND DISCUSSION

Fifteen genera of fungal pathogens were associated with rot of the giant prickly pear: *Lasiodiplodia* spp., *Fusarium* spp. *Alternaria* sp., *Aspergillus* spp., *Cladosporium* sp., *Colletotrichum* sp., *Curvularia* sp., *Exserohilum* sp. *Macrophomina* sp. *Nigrospora* sp., *Pestalotia* sp., *Rhizopus stolonifer*, *Rhizoctonia* sp., *Sphaceloma* sp. and *Scytalidium* sp. However, only *S. lignicola* was found on all plantations sampled and is associated with squamous rot. Bonfim et al. (2013) found other rot-causing fungi on *O. ficus-indica*. Incidence rates of 100, 55.20 and 47.30% were found for *Scytalidium* sp., *Lasiodiplodia* spp. and *Fusarium* spp., respectively (SOUZA et al., 2010).

The etiology of squamous rot was attributed to *S. lignicola* based on the identification of morphological macrostructures and microstructures (LOPES et al., 2012). *S. lignicola* is an anamorph of *Botryosphaeria* spp. that has high genetic variability (CROUS et al., 2006) and has been associated with other agricultural crops, causing spots on vanilla leaves, stems and fruit (*Vanilla planifolia*) (VERZIGNASSI et al., 2007), spots on citrus fruits (*Citrus* sp.) (OREN et al., 2001) and black rot on the roots of cassava plants (*Manihot esculenta*) (SERRA et al., 2009). However, a more detailed identification, such as phylogenetic analysis, is needed to confirm this etiology for the giant prickly pear. Some studies report this pathogen as a producer of the enzymes β-glucosidase and cellulase (DESAI et al., 1983), which explains the capacity of the fungus to act as a pathogen in other crops of economic importance as well as the prickly pear.

Squamous rot was more incident in the last month of the evaluation (December), with an incidence rate of 75% (SOUZA et al., 2010). The disease is characterized by the development of well-defined symptoms with undulating spots similar to scales the progress to dry rot, beginning mainly at the base and reaching the entire area of the cladodes (SANTOS et al., 2006; LOPES et al., 2012). Based on severity (%), different degrees of squamous rot intensity were determined: I_1 10%; I_2 11% to 25%; I_3 26 to 50%, I_4 51 to 75% and I_5 > 75% (Figure 1).

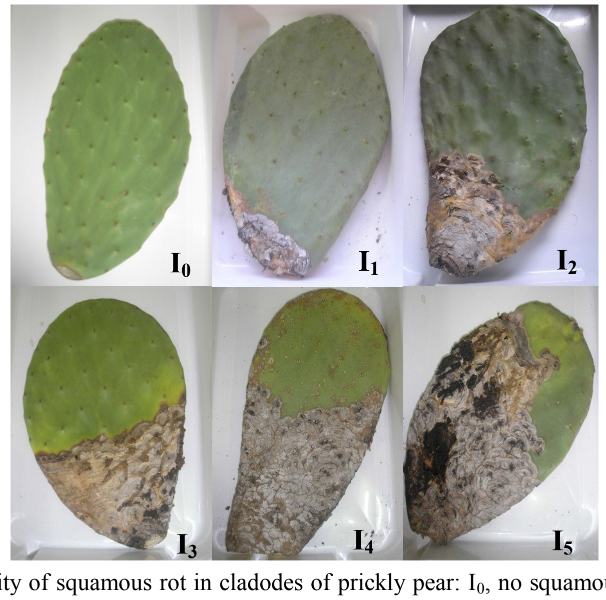

Figure 1. Degrees of intensity of squamous rot in cladodes of prickly pear: I_0, no squamous rot; I_1, 10% squamous rot; I_2, 11 to 25% squamous rot; I_3 26 to 50% squamous rot; I_4, 51-75% squamous rot; I_5, over 75% squamous rot. Barra de Santana, PB, 2009.

Squamous rot on the giant prickly pear progressed significantly on the plantations: 10.59a, 12.20a, 13.60a, 18.52a, 26.84a, 20.13a, 50.54a, 80.54b, 93.31b and 107.92c (Figure 2). These findings underscore the need for effective control measures throughout the year rather than only in the rainy season, which is considered more favorable to the disease (SANTOS et al., 2006).

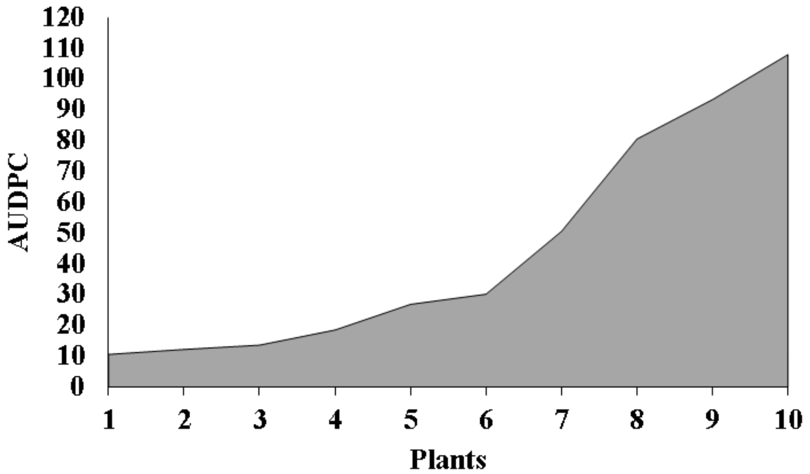

Figure 2. Area under disease of progression curve of squamous rot on prickly pear in the semiarid region of Paraíba. AUDPC = area under disease progression curve.

The incidence and progression of the disease increased with an increase in rainfall and humidity on the plantations. Thus, disease intensity was favored by climate variables (Figure 3) and was analyzed with disease variables. Taken together, these variables reveal greater disease intensity during more humid months on days with moderate temperatures.

Wild and farmed populations of the prickly pear in arid and semiarid regions of Mexico demonstrate considerable variability with regard to resistance and susceptibility to pathogens due to abiotic factors that affect development and productivity in the region (CANTWELL, 1995). Despite the irregular distribution throughout the year in the semiarid region of the state of Paraíba, Brazil, weekly climate factors on the plantations were decisive with regard to the infection, survival and maintenance of the pathogenicity of *Scytalidium* sp., favoring the intensity of squamous rot throughout the year of evaluation.

Generally, no fluctuations occurred with regard to temperature (minimum: 17.5°C; mean: 26.5°C; maximum: 29°C) or relative humidity (75%). Rainfall was 192.5 mm, relative humidity was 73.9% and temperature was 25.7°C in April 2009, whereas rainfall dropped to 176.3 mm, with relative humidity at 76.5% and temperature at 25.3°C in May of the same year (Figure 3). In the studied semiarid region, considerable precipitation can occur on some days in the rainy season as well as a large number of several days without rain in the same season. Rain can be abundant, but is irregular and poorly distributed. Consulting the scientific literature on the climate in regions with scarce rainfall throughout the world, northeastern Brazil is not uniformly semiarid and is not classified by universal standards. In the *agreste* (transition region between the humid coastal region and the semiarid interior), mean annual precipitation was 713 mm over a 25-year period. In the semi-arid *caatinga* biome in the state of Alagoas, mean rainfall was 719 mm over a 25-year period. In the *agreste* of the states of Rio Grande do Norte and Piauí, mean precipitation was 1000 mm over a 22-year period. In the semiarid Seridó region in the state of Rio Grande do Norte, an annual mean of 600 mm was recorded over a 22-year period. An annual mean of 750 mm was recorded over 20 years of observations in the semi-arid region of the state of Paraíba (DUQUE, 2004). The climate variables on the plantations analyzed lead one to suspect that precipitation recorded over long spans of time could mask or confound the interpretation of local climate in the short period of time evaluated on the plantations in the present study.

Epidemics are generally favored by higher or lower temperatures than the optimum temperature range for the plant. Such temperatures decrease the level of resistance, making plants susceptible to disease, whereas pathogens remain vigorous and stronger than the hosts. Moreover, prolonged or frequent high moisture in the form of dew, rain or relative air humidity is a predominant factor in the development of most epidemics, as it facilitates the reproduction and dissemination of the majority of pathogens (CHALFOUN; LIMA, 2006). Thus, studies on climate behavior and its influence on diseases among agricultural crops can make important contributions to the prediction and consequent control of the intensity of diseases, such as squamous rot among prickly pears in the semiarid region of the state of Paraíba, Brazil.

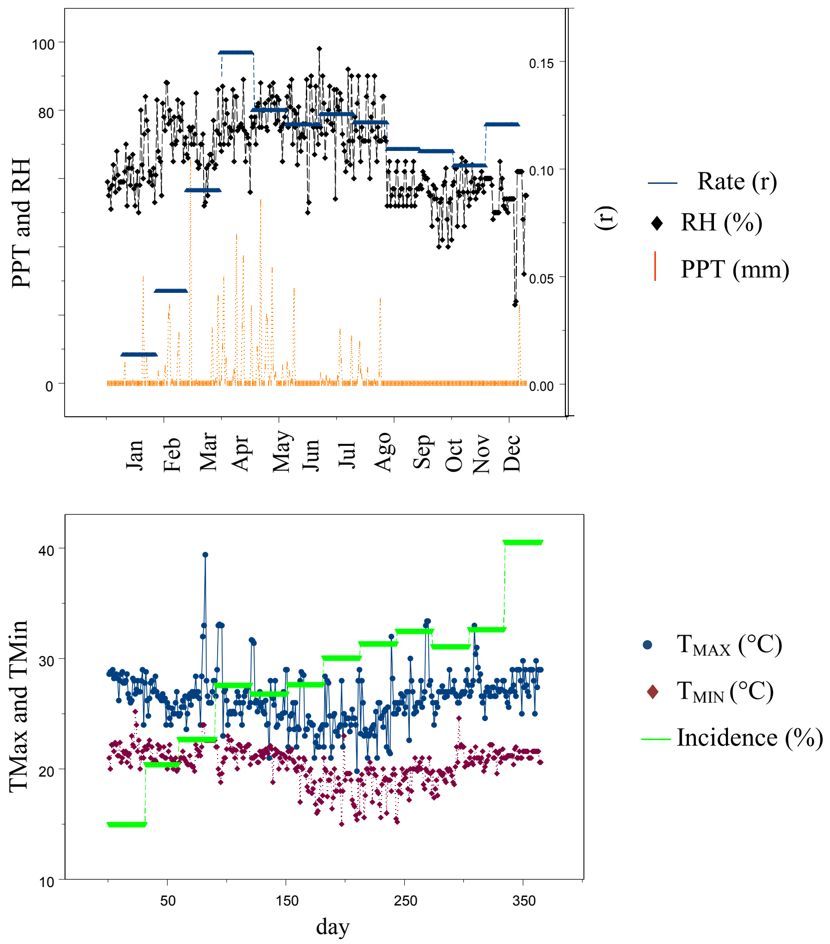

Figure 3. Incidence and progression of squamous rot on prickly pear in the semiarid region of Paraíba. Barra de Santana, 2009. (r) = Rate of disease progress. PPT = Pluviometric preciptation; RH = Relative humidity of air; T_{max} = Maximum temperature; T_{min} = Minimum temperature. Source: SONDA/CPTEC/INMET of Meteorological Cariri Station, PB.

The main components of disease intensity (MP1 and MP2) revealed a strong, significant association between the climate and disease variables analyzed (Table 1). PC2 demonstrated that the disease progression rate was more influenced by climate conditions on the plantations (0.530395). The strongest associations were with relative humidity and rainfall (0.475957 and 0.442589, respectively in PC2). The association with temperature was negative (-0.500814). Together with the disease variables, the climate variables enhanced the intensity of squamous rot throughout the evaluations. According to MP1, this association accounted for 45.66% of the stimulation of the disease, whereas MP2 demonstrated that 83.81% of this association intensified squamous rot under the plantation conditions evaluated. As MP1 was estimated, but did not meet the minimum criteria for multivariate analysis established by Jolliffe (2002), PC2 was considered (Table 1).

Table 1. Main components of intensity of squamous rot on prickly pear in semiarid region of Paraíba.

Variables	Main component of disease	
	MP1	MP2
Disease		
Incidence	0.585783	0.127203
Severity	0.575107	0.171070
Rate of disease progress (r)	0.315385	0.530395
Climate		
Temperature	-0.075124	-0.500814
Pluviometric preciptation (PPT)	0.268976	0.442589
Relative humidity (RH)	0.385553	0.475957
AV (%)	45.66	83.81**

**Significant at 1% probability according to the chi-squared test. AV = accumulated variance. MP1 = main component 1. MP2 = main component 2.

A canonical correlation was found between the climate and disease variables analyzed. The incidence, severity and progression of the disease were positively correlated with rainfall (1.1893) and relative humidity (1.9173), with significant retention index and accumulated variance values. The correlation with temperature was negative (-0.7059) (Table 2). Thus, under the conditions of the present study, relative humidity and rainfall, although poorly distributed throughout the year evaluated, exerted a greater influence on the intensity of squamous rot than temperature and are therefore the determinants of the increase in the intensity of this disease on the evaluated plantations.

Table 2. Canonical correlation between squamous rot and climate in semiarid of Paraíba.

Variables	**Canonical correlation**	
	[1]1°	[2]2°
Disease		
Incidence	0.0539	1.7223
Severity	-1.0929	0.9215
Rate of progress disease (r)	0.0599	1.1700
Climate		
Temperature	1.1609	-0.7059
Pluviometric preciptation (PPT)	-0.7275	1.1893
Relative humidity (RH)	1.9173	0.6445
R (%)	67	94.5*
AV (%)	98.93	90.16**

*Significant at 5% probability and **Significant at 1% probability according to the chi-squared test. R = Retention Index. AV = accumulated variance. [1]First canonical pair ; [2]Second canonical pair.

CONCLUSIONS

At least three pathogens were found to be associated with the high incidence of squamous rot on the giant prickly pear in the semiarid region of the state of Paraíba, Brazil, but *Scytalidium* sp. was the most widely distributed. The disease caused by this fungus intensifies and progresses due to high humidity at moderate temperatures.

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