Revista Ciência Agronômica, v. 51, n. 3, e20186092, 2020
Centro de Ciências Agrárias - Universidade Federal do Ceará, Fortaleza, CE
www.ccarevista.ufc.br

Technical Article
ISSN 1806-6690

Effect of climate and geographical conditions on the occurrence of cashew gummosis in the northeast of Brazil[1]

Efeito das condições climáticas e geográficas na ocorrência da resinose do cajueiro no nordeste brasileiro

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ABSTRACT - Cashew gummosis is one of the main diseases of the cashew in the semi-arid region of the northeast and is characterised by a decline in the plants and a reduction in stand. *Lasiodiplodia theobromae*, the causal agent, is an endophytic fungus that eventually takes on pathogenic characteristics; however, the environmental conditions that cause this change in behaviour are still unknown. It is assumed that stress in the host caused by environmental changes stimulate pathogenicity. The aim of this study was to define the relationship between climate and geographical factors and the occurrence of gummosis. Rainfall data, maximum and minimum temperature, thermal amplitude, and the altitude of 14 micro-regions in the northeast were compared and classified into five frequencies of disease occurrence: 0 (no occurrence), 1 (rare occurrence), 2 (frequent occurrence), 3 (generalised occurrence) and 4 (generalised high-severity occurrence). The data were submitted to the Doornik-Hansen test for multivariate normality, and principal component analysis was carried out using the correlation matrix between the climate and geographical variables and occurrence of the disease. Areas of disease severity were correlated (Pearson's correlation). Only thermal amplitude, altitude and latitude were associated with the different areas of gummosis occurrence. The districts of Buíque, in the state of Pernambuco, and São Raimundo Nonato, Canto do Buriti and Pio IX, in Piauí, with the highest incidence of the disease, had the highest values for thermal amplitude, altitude and latitude. Whereas the districts of Pacajus and Beberibe had a lower occurrence of gummosis, with lower values for thermal amplitude, altitude and latitude.

Key words: *Anacardium occidentale*. *Lasiodiplodia theobromae*. Pathosystem. Gummosis.

RESUMO - A resinose é uma das principais doenças do cajueiro no semiárido nordestino e caracteriza-se pelo declínio das plantas e redução do estande. *Lasiodiplodia theobromae*, agente causal, é um fungo endofítico que, eventualmente, assume o caráter patogênico, entretanto, as condições de ambiente que provocam esta mudança de comportamento ainda são desconhecidas. Presume-se que estresses no hospedeiro provocados por mudanças ambientais estimulam a patogenicidade. Este trabalho teve como objetivo estabelecer relações entre fatores climáticos e geográficos com a ocorrência da resinose. Foram comparados os dados de precipitação pluviométrica, temperaturas máxima e mínima, amplitude térmica e altitude de 14 microrregiões nordestinas classificadas em cinco frequências de ocorrência da doença: 0 (sem ocorrência), 1 (ocorrência rara), 2 (ocorrência frequente) e 3 (ocorrência generalizada) 4 (ocorrência generaliza em alta severidade). Os dados foram submetidos à análise de normalidade multivariada pelo teste de Doornik e Hansen e a análise dos componentes principais foi realizada por meio da matriz de correlação das variáveis climáticas, geográficas e da ocorrência da doença. As áreas de severidade da doença foram correlacionadas (Correlação de Pearson). Somente, a amplitude térmica, altitude e latitude foram associadas às diferentes áreas de ocorrência da resinose. Os municípios Buíque, em Pernambuco, São Raimundo Nonato, Canto do Buriti e Pio IX, no Piauí, em que ocorre a maior incidência da doença apresentaram os maiores valores de amplitude térmica, altitude e latitude. Enquanto que, os municípios Pacajus e Beberibe tiverem menores ocorrências da resinose e apresentaram os menores valores de amplitude térmica, altitude e latitude.

Palavras-chave: *Anacardium occidentale*. *Lasiodiplodia theobromae*. Patossistema. Resinose.

DOI: 10.5935/1806-6690.20200051
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Received for publication 05/11/2019; approved on 03/03/2020
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INTRODUCTION

Gummosis, caused by the fungus *Lasiodiplodia theobromae* (family Botryosphaeriaceae), is seen as the principal disease of the cashew in the semi-arid region of the northeast (MOREIRA *et al*., 2013). The disease is characterised by swelling of the tissues of the trunk and woody branches, which eventually crack and exude a characteristic gum, taking on the appearance of a dark canker. The spread of the disease is not well understood despite the fungus having been isolated from seeds and vegetative propagules, suggesting that materials of plant propagation may act as a primary source of inoculum (CARDOSO *et al*., 2009). However, the hypothesis of pathogen transmission by asymptomatic seedlings is seen as the main form of dissemination, since the endophytic survival of *L. theobromae* in plant tissue has been proven (CARDOSO *et al*., 2009).

Studies show that the fungus, *L. theobromae*, displays wide cultural, morphological and pathogenic variations between isolates from different geographical regions (LIMA *et al*., 2013; 2014), characterising high genetic diversity (CILLIERS, 1993; COUTINHO *et al*., 2017). Species of family Botryosphaeriaceae are found associated with various substrates in nature, predominating in trees and wood as opportunistic pathogens, of low aggressiveness and characterised by an endophytic phase (CARDOSO *et al*., 2009; CILLIERS, 1993; MANAWASINGHE *et al*., 2016; MOHALI *et al*., 2005; SLIPPERS; WINGFIELD, 2007), with its class III endophytes, characterised by a cycle of a quiescent and passive phase followed by an active and pathogenic phase, behaving like a latent pathogen (MANAWASINGHE *et al*., 2016). The factors that promote the change from the endophytic to the pathogenic state are still unknown. It is therefore not understood whether the environment directly influences pathogenicity in the fungus, or indirectly, the fungus becoming pathogenic when the plant loses vigour due to changes in the environment (ÁLVAREZ-LOAYZA *et al*., 2011; CIPRIANO *et al*., 2015; MANAWASINGHE *et al*., 2016; SLIPPERS; ÚRBEZ-TORRES *et al*., 2012; WINGFIELD, 2007).

Differences in enzyme activity between cashew clones resistant or susceptible to gummosis have been found, suggesting that proteins associated with stress predispose the plants to infection by *L. theobromae* (GONDIM *et al*., 2014).

In the semi-arid region of the northeast, water stress is a recurrent phenomenon, affecting production and biochemical and physiological processes in the plant. Such changes may leave the plant predisposed or vulnerable to attack by less-specialised pathogens, such as *L. theobromae*. On the other hand, the soil and climate directly influence plant metabolism, and can serve as indicators of positive or negative interactions in infectious processes.

Based on this approach, preliminary work was carried out to identify the association of climate factors in various areas of occurrence of cashew gummosis (VIANA *et al*., 2016). The aim of this study was to consolidate these interactions, including new regions and expanding the scope of the earlier study, making it conclusive in aiding future ecophysiological studies of this important pathosystem for the northeast of Brazil.

MATERIAL AND METHODS

Fourteen cashew-producing microregions, distributed over the states of Ceará, Pernambuco, Bahia and Piauí with a history of varying severity and occurrence of gummosis (CARDOSO *et al*., 2004; CARDOSO *et al*., 2009; CYSNE *et al*., 2010; FREIRE, 1991; FREIRE *et al*., 2002) were analysed for climate variables (Table 1). Two distinct groups of variables were formed, one quantitative (Table 1) and the other qualitative (Table 2). The districts were divided into five zones of gummosis occurrence: 0 (no occurrence), 1 (rare occurrence, <10% of the orchards), 2 (frequent occurrence, 10 to 25% of the orchards), 3 (generalised occurrence, 25 to 50% of the orchards) and 4 (generalised occurrence >50%). The choice of locations to be analysed considered the existence of previous surveys in the cashew-producing regions (published or not), and the distribution of weather stations.

In applying the multivariate analysis, the data were submitted to the Doornik-Hansen test for multivariate normality (2008) ($p<0.05$). Principal component analysis was then carried out using the correlation matrix between the climate and geographical variables and level of occurrence of the disease. Prior to this analysis, the data for each variable were standardised, resulting in a mean value of zero and a variance equal to one, as recommended by Cardozo *et al*. (2014). The number of components retained in the analysis was determined considering a minimum cumulative percentage variance of 80% and eigenvalue greater than one. The statistical analysis was carried out using the R v3.4.2 software, developed by the University of Auckland. The areas of disease severity were correlated (Pearson's correlation), assuming a significance level of 5%. Cluster analysis of the cities was carried out using the complete-linkage method, and was used as a reference for the Euclidean distance and Pearson's coefficient. All the variables under study were considered when forming the groups, except for the severity of the gummosis.

Temperature and rainfall data were obtained from the Ceará Foundation for Meteorology and Water

Table 1 - Geographical and climate data from 2006 to 2016 and the occurrence of gummosis in the districts under study

District	LAT[a]	LONG	ALT	RF	TX	TM	TA	Gummosis[b]
Ribeira do Pombal, BA	10°50’	38°32’	228	675	33.14	20.93	12.21	1
Acaraú, CE	2º54’	40º60’	13	1260	29.60	23.80	6.00	0
Alto Santo, CE	5º33’	38º04’	160	537	31.80	22.20	9.60	2
Beberibe, CE	4º12’	38º09’	12	992	28.50	21.40	7.10	0
Crato, CE	7º15’	39º27’	426	1188	26.50	17.00	9.80	1
Pacajus, CE	4º10’	38º03’	74	984	28.80	22.20	6.60	1
Mauriti, CE	7º18’	38º42’	524	674	32.10	21.10	10.90	2
Jaguaribe, CE	05°54’	38°37’	184	458	37.04	23.99	13.05	1
Jaguaruana, CE	04°47’	37°46’	20	736	34.71	21.83	12.88	1
Barra do Corda, MA	05°30’	45°14’	153	944	35.47	20.92	14.56	2
Buique, PE	08°37’	37°09’	798	602	34.2	19.53	14.54	4
Pio IX, PI	6º32’	40º48’	700	754	31.70	20.10	11.80	3
São Raimundo Nonato, PI	09°01’	42°42’	353	1016	34.05	18.12	15.93	3
Canto do Buriti, PI	08°07’	42°58’	308	678	34.55	20.74	13.81	3

([a]) LAT = latitude south, LONG = longitude west, RF = mean anual rainfall in mm, TX = maximum temperature, TM = minimum temperature, TA = thermal amplitude; ([b]) Occurrence of gummosis based on the scale: 0 = no occurrence, 1 = rare occurrence, 2 = frequent occurrence, 3 = generalised occurrence and 4 = generalised high-severity occurrence

Table 2 - Values of the correlations between the occurrence of gummosis and the climate variables under analysis

Climate variable	Severity of gummosis
Thermal amplitude	0.72**
Altitude	0.79**
Maximum temperature	0.45^{ns}
Minimum temperature	-0.48^{ns}
Rainfall	-0.42^{ns}
Latitude	0.57*
Longitude	0.25^{ns}

*Significant at 5%; **Significant at 1%; ^{ns}not significant

Resources (FUNCEME) and the National Institute of Meteorology (INMET). The monthly average for these values was calculated for 2006 to 2016. However, not all the districts under analysis had weather stations, making it necessary to use data from nearby stations. The geographical data for each district were obtained where the disease occurred, while for the remainder, the data refer to the locations of the weather stations. Climate data for the cities of Alto Santo, Pio IX, Ribeira do Pombal and Buique were obtained from the stations at Quixeré CE, Campos Sales CE, Euclides da Cunha BA and Arcoverde PE respectively.

RESULT AND DISCUSSION

The occurrence of cashew gummosis in the northeast of Brazil has been monitored since it was first reported, always raising the question of why its occurrence is limited to certain areas. The coastal region, where until recently the largest commercial orchards were concentrated, has always been characterised as free of, or having a low incidence of the disease, while the southeast and southwest of the state of Piauí, the middle Jaguaribe and the Serra do Catimbau in Pernambuco are noteworthy for having medium to high incidence and severity of the disease. Some regions are notable for the complete absence of the disease, and others for its constant occurrence (i.e. endemic). The endophytic characteristic of the causal fungus in the cashew (CARDOSO *et al*., 2009) excluded the possibility of the pathogen being absent in the escape zones, later confirmed by the occurrence of the disease in some plants of specific clones (e.g. BRS 265), even at sites thought to have zero occurrence.

A first study, aimed at characterising these relationships with gummosis, attempted to correlate the level of occurrence with climate and geographical classifications (VIANA *et al*., 2016), however it was realised that there was a need to include new regions that represented greater extremes of occurrence, such as the transition zone between the agreste region and the backlands of Pernambuco and the north of Bahia. On the

other hand, new statistics could be used to interpret the data, providing a more robust analysis.

Based on the above, a degree of occurrence characterising an epidemic (grade 4) was included, to differentiate it from the endemic occurrence already seen, and the Köppen climate classification was removed.

The Euclidean distance to the locations under evaluation (Figure 1) allowed a division into four distinct groups, showing epidemic and endemic occurrence in groups I (Buíque, Mauriti and Pio IX) and III (Ribeira do Pombal, Canto do Buriti, Alto Santo and Jaguaribe) respectively. Intermediate regions like the remaining locations, were placed in the other groups.

From the principal component analysis, of the total of eight generated eigenvalues, the first three were greater than one, explaining 87.64% of the variance contained in the eight original variables (Table 3). Analysing the weight distribution for each variable, it can be seen that the first principal component (CP1) is more correlated with latitude, altitude, thermal amplitude and gummosis, explaining 47.68% of the original variance. Whereas, the second principal component (CP2) showed a high value for the coefficients of rainfall, maximum temperature and minimum temperature, explaining 23.18% of the original variation. However, the third principal component (CP3) retained only 16.78% of the original variance, and was explained only by the greater value for the coefficient of longitude.

For the two-dimensional plane formed by the components CP1 and CP2, which retained 70.86% of the total variance (Figure 2A), it can be seen that the districts of Buíque, São Raimundo Nonato, Canto do Buriti and Pio IX, which had the highest occurrence of gummosis, were those with the highest values for thermal amplitude, altitude and latitude; while the districts of Pacajus and Beberibe had a lower occurrence of gummosis due to their lower thermal amplitude, altitude and latitude. In addition to these results, it can be seen that the districts of Jaguaruana and Alto Santo, which have the highest values for maximum and minimum temperature together with the lowest values for rainfall, thermal amplitude, altitude and latitude, had the lowest occurrence of gummosis.

In the two-dimensional plane formed by the components CP1 and CP3, which retained 64.46% of the total variance (Figure 2B), it can be seen that the districts of São Raimundo Nonato and Canto do Buriti, in addition to having the highest values for thermal amplitude, altitude and latitude as factors that most contribute to the occurrence of gummosis, are also among the districts with the highest values for longitude. However, the district of Pio IX, with an epidemic occurrence of gummosis, had a low value for longitude.

Based on the data obtained here and in earlier studies, it can be concluded that thermal amplitude, altitude and latitude are the key environmental factors in the occurrence of cashew gummosis (Figure 2), these three climate and geographical factors being responsible for more than 80% of the components involved (Table 3). Considering the component related to host susceptibility, the results are of great epidemiological and practical importance for exploiting the cashew crop in regions with a high risk of occurrence and severity. It is extremely

Figure 1 - Dendrogram showing the grouping of districts with the Euclidean distance, considering climate variables (i.e. rainfall, maximum and minimum temperatures and thermal amplitude), latitude and longitude, excluding the occurrence of gummosis

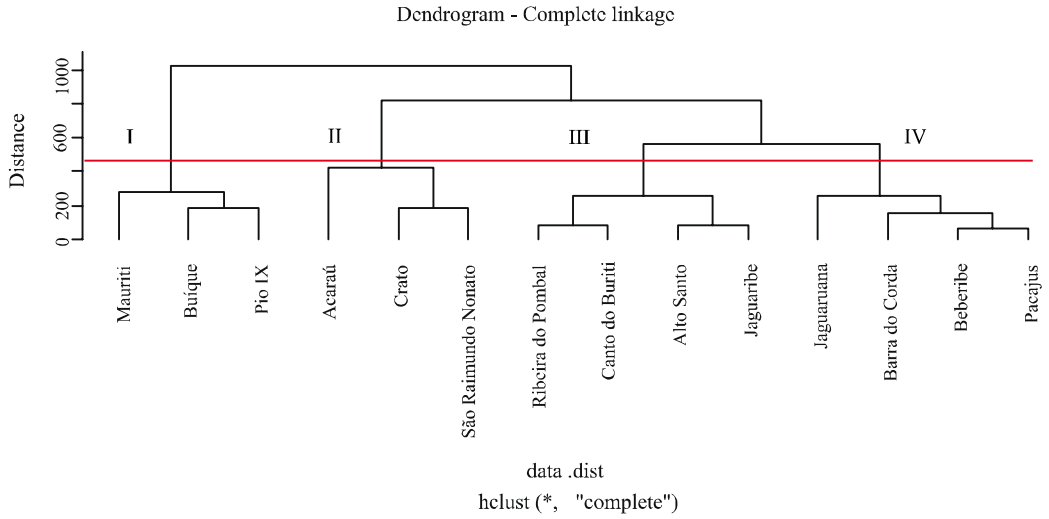
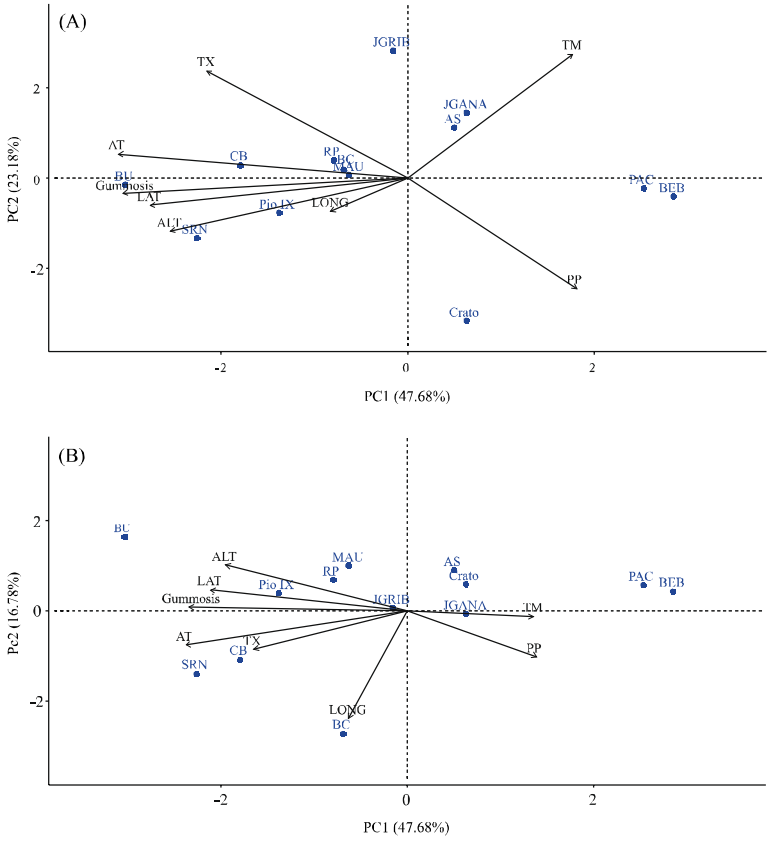


Table 3 - Coefficients for the principal components, eigenvalues and percentage variance explained by the components, based on the correlation matrix for seven climate variables in the occurrence of gummosis

Climate Variable	Principal Component		
	CP1	CP2	CP3
LAT	-0.41	-0.13	0.15
LONG	-0.12	-0.16	-0.78
ALT	-0.38	-0.25	0.33
RF	0.27	-0.53	-0.33
TX	-0.32	0.50	-0.28
TM	0.26	0.59	-0.04
TA	-0.46	0.11	-0.25
Gummosis	-0.46	-0.07	0.03
Eigenvalue	1.95	1.36	1.15
Explained variance (%)	47.68	23.18	16.78
Cumulative variance (%)	47.68	70.86	87.64

Climate variables: LAT - latitude; LONG - longitude; ALT - altitude; RF - rainfall; TX - maximum temperature; TM - minimum temperature; TA - thermal amplitude

Figure 2 - Graphical representation of the principal component analysis (PCA), relating dimensions 1 and 2 (A), and 1 and 3 (B), corresponding to the variables LAT (Latitude), LONG (Longitude), ALT (Altitude), RF (Rainfall), TX (Maximum temperature), TM Minimum temperature), TA (Thermal amplitude) and Gummosis. Abbreviations of the districts: RP - Ribeira do Pombal; ACAR - Acaraú; AS - Alto Santo; BEB - Beberibe; Crato - Crato; PAC - Pacajus; MAU - Mauriti; JGRIB - Jaguaribe; JGANA - Jaguaruana; BC - Barra do Corda; BU - Buíque; Pius IX - Pius IX; SRN - São Raimundo Nonato; CB - Canto do Buriti



important to introduce resistant clones into these regions, since with susceptible clones, the risk of a gummosis epidemic is practically assured. Biochemical and ecophysiological studies into the effect of these factors on the manifestation of the disease are necessary to clarify the host-pathogen relationship.

CONCLUSIONS

1. Thermal amplitude, altitude and latitude are the key environmental factors in the occurrence of cashew gummosis;
2. Rainfall volume and maximum and minimum temperatures are not directly related to the occurrence of cashew gummosis;
3. The municipalities with similar climate variables also have a similar occurrence of cashew gummosis.

ACKNOWLEDGEMENTS

The authors would like to thank the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES) and the Conselho Nacional de Pesquisa e Desenvolvimento Tecnológico (CNPq) for their partial funding of this study. Thanks also go to the Fundação Cearense de Meteorologia e Recursos Hídricos (FUNCEME) and the Instituto Nacional de Meteorologia (INMET) for providing the meteorological data.

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