Revista Brasileira de Climatologia
ISSN: 2237-8642 (Eletrônica)

THE INFLUENCE OF ENVIRONMENTAL FACTORS ON THE PRODUCTION OF GUM ARABIC (*ACACIA SENEGAL*, FABACEAE) – A META-ANALYSIS

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ABSTRACT: The gum arabic obtained from the trunk and branches of the woody species *Acacia senegal* and *Acacia seyal* is a polysaccharide exudate with numerous biochemical properties, whose production can suffer impacts from several environmental factors. Thus, the aim of this study is to evaluate the effect of some environmental factors on the production of this exudate. For this study, we compared the production of the gum in the rainy and dry season through a meta-analysis, using studies published in several databases. Moreover, a meta-regression was performed to evaluate the influence of environmental variables on the effect of precipitation on gum production. We used 13 papers that met the criteria for this meta-analysis. We observed that the production of gum Arabic is higher in the rainy season than in the dry season. In addition, we noticed an effect of the minimum temperature and air relative humidity on the best production of gums

KEYWORDS: Gum exudate, Climate change, Gum production.

A INFLUÊNCIA DE FATORES AMBIENTAIS NA PRODUTIVIDADE DE GOMA ARÁBICA (ACACIA SENEGAL, FABACEAE) EM UM ESTUDO DE META-ANÁLISE.

RESUMO: A goma arábica obtida do tronco e ramos das árvores de *Acacia senegal* e *Acacia seyal*, é um exsudado polissacarídico com inúmeras propriedades bioquímicas, cuja produção pode sofrer impactos de diversos fatores ambientais. Assim, o objetivo desse trabalho foi avaliar o efeito de alguns destes fatores na produção deste exsudato. Para esse estudo comparamos a produção da goma em período chuvoso e de seca através de uma meta-análise, utilizando para isso trabalhos já publicados em diversas bases de dados. Para complementar, foi realizada uma meta-regressão para avaliar a influência das variáveis ambientais no efeito da chuva sobre a produção da goma. Ao todo foram usados 13 trabalhos que atendiam aos objetivos da meta-análise. Foi possível observar que a produção da goma arábica é maior na estação chuvosa quando comparada a estação da seca. Além disso notou-se um efeito da temperatura mínima e umidade do ar sobre a melhor produção.

PALAVRAS-CHAVE: Exsudato gomoso, Mudanças climáticas, Produção de goma.

LA INFLUENCIA DE FACTORES AMBIENTALES EN LA PRODUCTIVIDAD DE LA GOMA ARÁBIGA (ACACIA SENEGAL, FABACEAE) EN UN ESTUDIO DE META-ANÁLISIS

RESUMEN: La goma arábica obtenida del tronco y ramas de los árboles de *Acacia senegal* y *Acacia seyal*, es un exudado polisacárido con innumerables propiedades bioquímicas, cuya producción puede sufrir impactos de diversos factores ambientales. Así, el objetivo de este trabajo fue evaluar el efecto de algunos de estos factores en la producción de este exudado. Para este estudio comparamos la producción de la goma en período lluvioso y de sequía a través de una meta-análisis, utilizando para ello trabajos ya publicados en diversas bases de datos. Para complementar, se realizó una meta-regresión para evaluar la influencia de las variables ambientales en el efecto de la lluvia sobre la producción de la goma. En total se utilizaron 13 trabajos que atendían a los objetivos de la meta-análisis. Es posible observar que la producción de la goma arábiga es mayor en la estación lluviosa cuando se compara la estación seca. Además se notó un efecto de la temperatura mínima y humedad del aire sobre la mejor producción

PALABRAS CLAVE: Exudado gomoso, Cambio climático, Producción de goma.

ISSN: 2237-8642 (Eletrônica)

L'INFLUENCE DES FACTEURS ENVIRONNEMENTAUX SUR LA PRODUCTIVITE DE LA GOMME ARABIQUE (ACACIA SENEGAL, FABACEAE) DANS UNE ETUDE DE META-ANALYSE

RESUME: La gomme arabique obtenue à partir du tronc et des branches d'*Acacia senegal* et d'*Acacia seyal*, est un exsudat polysaccharidique aux nombreuses propriétés biochimiques, dont la production peut subir les impacts de plusieurs facteurs environnementaux. Ainsi, l'objectif de cette étude était d'évaluer l'effet de certains de ces facteurs sur la production de cet exsudat. Pour cette étude, nous avons comparé la production de gomme pendant la saison des pluies et la saison sèche à travers une méta-analyse, en utilisant pour ce travail des travaux déjà publiés dans plusieurs bases de données. En outre, une méta-régression a été réalisée pour évaluer l'influence des variables environnementales sur l'effet de la pluie sur la production de caoutchouc. En tout, 13 articles répondant aux objectifs de la méta-analyse ont été utilisés. Il a été possible d'observer que la production de gomme arabique est plus élevée pendant la saison des pluies par rapport à la saison sèche. En outre un effet de la température et de l'humidité minimum de l'air sur la meilleure production a été noté.

MOT CLÉS: Exsudat de gomme, Changement climatique, Production de caoutchouc.

INTRODUCTION

Exudate gums are polysaccharides produced by plant epithelial cells when the cortex is assaulted by either physical injury or microbial attack. In general, the production of exudate gums is a plant defense mechanism (ANDRADE et al., 2013), and they have colloidal properties, thickening agents (water-biding capacity), gelling agents, emulsifiers, stabilizers, binders (LÓPEZ-FRANCO et al., 2009) and it is biodegradable.

Acacia gum (AG) (AG, E414), also known as gum arabic, is an edible dried gummy exudate (Figure 1) obtained from the trunk or branches of *Acacia senegal* and *Acacia seyal*, rich in soluble and low-viscosity fibers (WILLIAMS and PHILLIPS, 2000; SANCHES et al., 2017). *Acacia senegal* (family Leguminosae, Mimosoidea) has a long list of at least nine synonyms that indicates a taxonomic difficulty in its identification. The gum is found in arid regions of the sub-Saharan belt, from Senegal to East Africa, and beyond Pakistan and India (CECIL, 2005).

Figure 1 - Trunk of *Acacia senegal* showing the exudate. Source: R. Peltier in Harmand et al., (2012).

Acacia gum is mainly harvested in Arabia, Egypt and Asia since antiquity and has a long exportation history. The gum is harvested from *Acacia senegal* or *Acacia seyal* found in the Sahel region along with the area covering arid and semi-arid areas of Mauritania, Senegal, Mali, Burkina Faso, Niger, Nigeria, Chad, Cameroon, Sudan, Eritrea, Somalia, Ethiopia, Kenya and Tanzania. Global exports of AG were around 60,000 tons in 2009 (Commodity Trade Statistics Database (COMTRADE / DBS), 2011, SANCHES et al., 2017), but it may reach 100, 000 tons. This production may be affected by environmental factors such as sudden temperature changes, soil pH, water availability, air humidity and the presence of microorganisms. For this reason, research and monitoring techniques for the best production conditions have been carried out to increase production by plants of these species.

Among the techniques, the use of meta-analysis is adequate to combine data from different studies, thus increasing the power of statistical prediction in a single combined result, providing a reliable estimate of the treatment effect on the condition tested (RODRIGUES and ZIEGELMANN, 2010). Therefore, it is important to consider the environmental effects on the production of this exudate.

MATERIALS AND METHODS

DATA SAMPLING

Data collection was carried out in the ISI Web of Science, Scopus and Google Scholar databases. We searched academic documents (e.g. papers, reports, monographs, dissertations and theses), using the terms "gum production" AND "environmental factors"; "gum production" AND "temperature" AND "rain"; "gum production" AND "rain" AND "plant"; "gum production" AND "temperature change" AND "plant"; "factors affecting" AND "plant", "*acacia senegal*" AND "gum production"). In addition to gum production, environmental variables, such as temperature (minimum, maximum and average), precipitation, air relative humidity, average altitude of the study area and availability of water resources (distance from the study area of the nearest water body) were considered.

Papers about gum production by *Acacia senegal* (published between 1992 and 2016) were selected based on the data about the average yield of gum per tree before and after the effects of precipitation and precipitation variations.

In studies where the mean and standard deviation of the variables were presented in graphs, the WebPlotDigitizer (ROHATGI, 2017) was applied for data extraction. Studies that did not report the environmental variables, the geographic coordinates of the sampled environments were extracted through the WorldClim (HIJMANS et al., 2005), EarthEnv (DOMISCH et al., 2015) and UnData databases (UNSD, 2017).

In all studies, the plants were cultivated and monitored for periods ranging from 5 to 10 years. All studies were conducted in Africa, specifically in regions of Nigeria, Sudan, and Kenya (Figure 2).

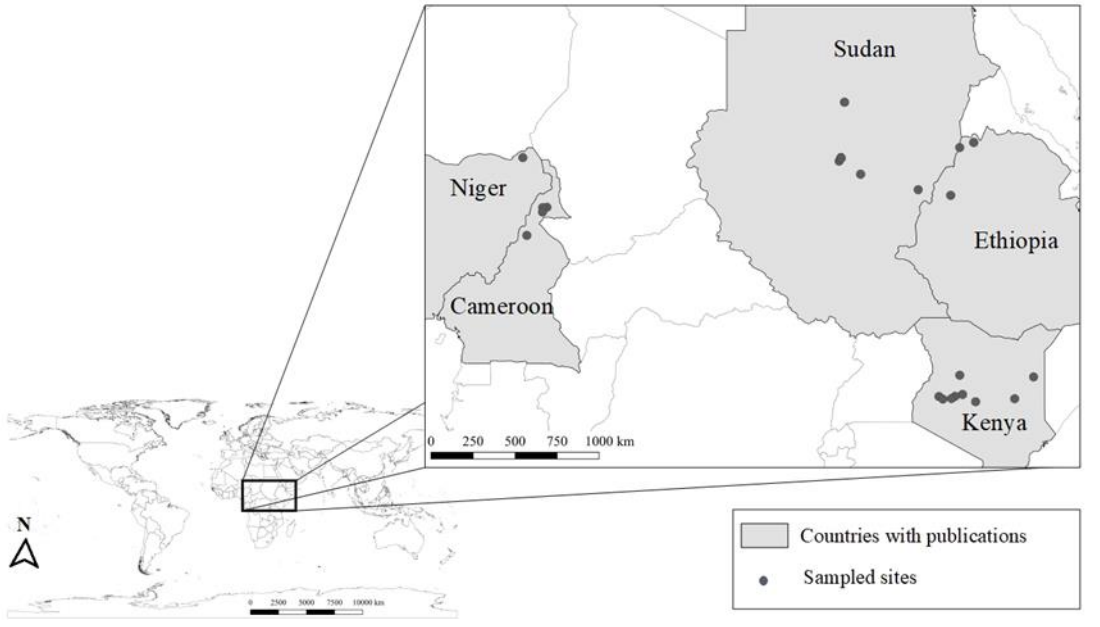

Figure 2 - Countries where the analyzed studies were carried out (grey) and the specific locations (dots) of each study.

DATA ANALYSIS

A critical issue when conducting a meta-analysis is the high level of heterogeneity and the potential non-comparability of the studies assembled in the metadata. As a good practice, the studies included in the meta-analysis should satisfy a criterion of minimum consistency for the dependent variable between observations (SMITH and PATTANAYAK, 2002). Thus, in cases of high heterogeneity, a meta-regression was performed to evaluate the relationship between gum production and environmental variables such as temperature (maximum, minimum and average), altitude, availability of water resources and relative humidity of the sampling sites.

In the present study the production of gum arabic (amount of gum produced (g) per *Acacia senegal* tree) was considered as an event and the presence of precipitation as a treatment. Thus, when there is no effect of precipitation on production, the difference between the dry season (control) and the rainy season (treatment) will be zero (cumulative effect = 0). In case of a positive effect (accumulated effect >0), the production in the control (dry) was higher than in the treatment (rainy). While for negative effect (cumulative effect <0), the production in the treatment (rainy) was higher than in the control (dry).

As measures of effect, the average production was used in each season or the Pearson's r (when present). When Pearson's r was available, the standardized effect size (Cohen's d) and respective variance were calculated according to Borenstein et al., (2009), where:

$$d = \frac{2r}{\sqrt{(1-r^2)}} \quad \text{(Equation 1)}$$

the variance of *d* was calculated using:

$$Vd = \frac{4\left(\frac{(1-r^2)^2}{n-1}\right)}{(1-r^2)^3} \quad \text{(Equation 2)}$$

Where *n* is the number of trees sampled in each study.

In the presence of mean and standard deviation, the Cohen's d was calculated using the metaphor package available in the R software (WOLFGANG et al., 2015). Cohen's d is used as a standardized effect size between groups, which makes the studies comparable to each other. In our study, the effect size determines whether the production of gum arabic is influenced by precipitation. The cumulative effect was estimated using the random effect model proposed by DerSimonian and Laird (1986) using the standardized effect between groups.

For the random model, the I^2 estimate (i.e. variability between studies) was observed and the I^2 statistic was used to infer the percentage of variance attributed to the heterogeneity. The values of I^2 vary from 0% to 100%, with 0% indicating absence of heterogeneity, between 25% and 50% low heterogeneity, between 50% and 75% moderate heterogeneity and I^2 above 75% indicating presence of heterogeneity (BORESTEIN et al., 2009).

Posteriorly, the precipitation effects were used as a response variable to perform the meta-regression, where the environmental variables: temperature (minimum, maximum and average), air relative humidity, mean area of study site and water availability were used as independent variables to determine possible influences of these on the effects of precipitation. To perform the meta-regression, the data were transformed to the extent required for the assumptions of the analysis.

RESULTS AND DISCUSSION

The initial search resulted in 258 studies, of which 13 met the criteria required for the study objective (Figure 3). We selected complete papers (abstracts were excluded), thematic with the production of gum (studies on chemical and medicinal properties, influence of microorganisms and other uses were removed). A total of 21 studies were removed due to absence of quantitative metrics related to gum production; papers with no environmental information and geographic coordinates were also ignored for this study.

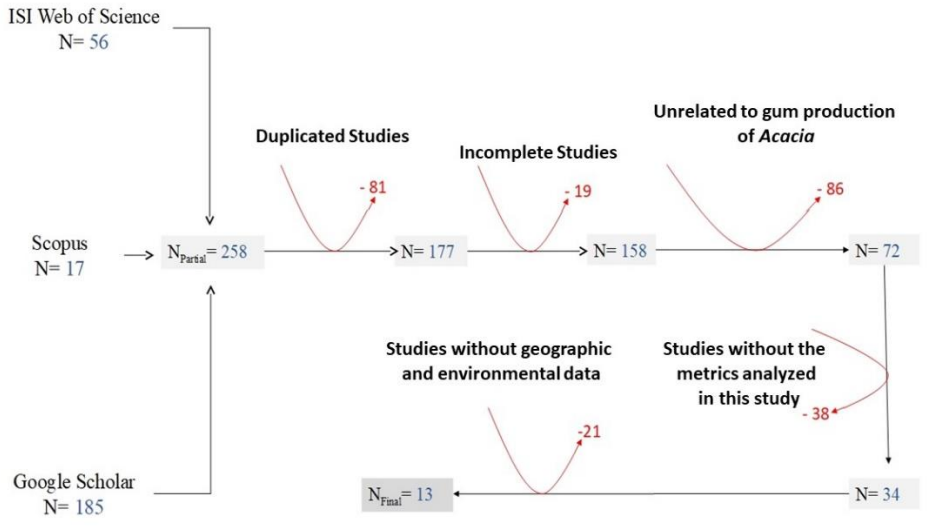

Figure 3 - Selection procedure of studies used in the study.

Of the 13 studies analyzed, 84% were performed after the 2000s, contributing to the study more than once in the data presentation (Table 1).

Table 1 - Characteristics of the studies included in the meta-analysis.

Reference[1]	Country	Number of sampled trees per study		
		Total (n_t)	Dry season (n_s)	Rainy season (n_c)
Dejene *et al.* 2004 (1)	Ethiopia	345	345	345
Fadl *et al.* 2004 (2)[2]	Sudan	1000	500	500
Wekesa *et al.* 2015 (3)	Kenya	480	480	480
Atta *et al.* 2011 (1)	Niger	120	120	120
Wekesa *et al*. 2009 (2)	Kenya	240	240	240
Elamin *et al*. 1996 (1)	Sudan	13	13	13
Alemu *et al*. 2013 (1)	Ethiopia	6	6	6
Ballal *et al*. 2005 (6)	Sudan	1440	1440	1440
Doyo 1994 (4)	Kenya	109	109	109
Harmand *et al*. 2012 (2)	Cameroon	20	20	20
Chiveu *et al*. 2009 (2)	Kenya	20	20	20

Gaafar *et al*. 2006 (1)	Sudan	266	266	266
Raddad *et al*. 2006 (1)	Sudan	40	40	40

[1]Number in parenthesis refers to the number of environments and/or seasons that were investigated, consequently this number shows the number of times the study was included in the meta-analysis.
[2]Study selected 500 random plants in the same population for each sampling season.

A high heterogeneity was observed between the studies with I^2 of 99.87 % and $\tau 2$ of 4.8312, not explained by the methodology of collection or metrics of the data, but by the difference between the sampled population in the studies.

The relationship between the production of gum arabic and the presence of precipitation was high (Cumulative effect <0) (Q (df = 25) = 19873.9620, p-val <0.0001) (Figure 4).

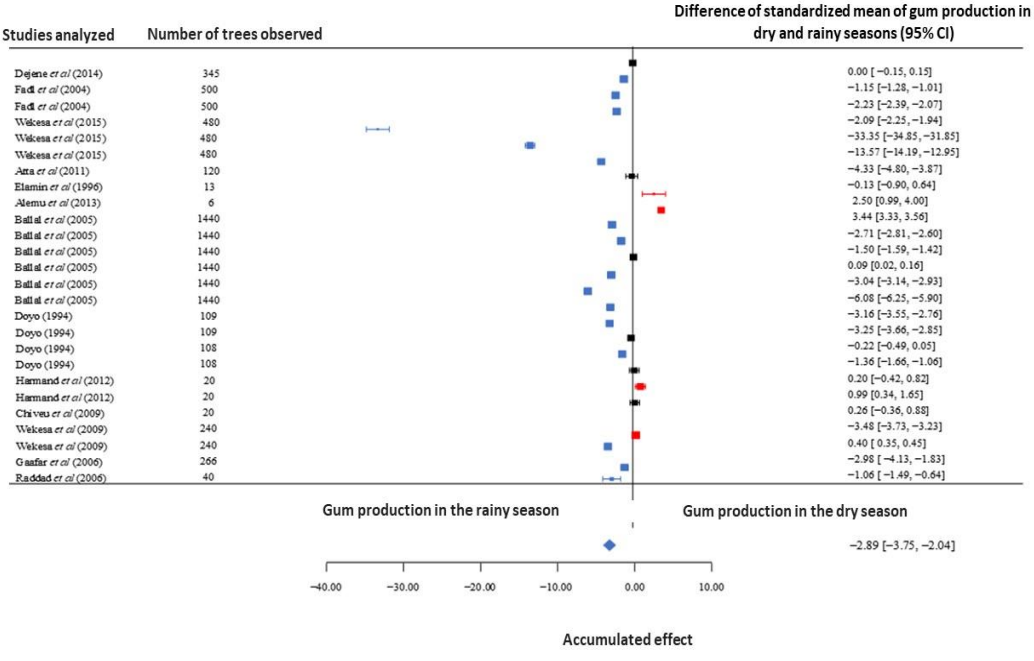

Figure 4 - Forest Chart indicating the accumulated effect of each study based on the standardized mean difference, with a 95% confidence interval of the studies analyzed. Studies with more production of gum arabic in the rainy season appear in blue, while studies with more production in the dry season appear in red. Studies with no significant difference between seasons appear in black.

Climate change has been defined by the United Nations Convention on Climate Change (UNFCCC) as "a climate change that is directly or indirectly attributed to human activity by changing the composition of the global atmosphere" (UNFCCC, 1992). In sub-Saharan Africa, land use is dramatically

ISSN: 2237-8642 (Eletrônica)

affected by the consequences of climate change. This is the observation of the international scientific community and also the concern of global conventions such as the UNFCCC (KHALIFA et al., 2016).

Agriculture is always susceptible to unfavorable climatic conditions and climatic events. Despite the technological progress (such as improved crop varieties and irrigation potential), temperature and precipitation are still important determinants of agricultural productivity and sustainability (AMIN et al., 2015).

The relationship between the production of gum arabic was strongly affected by the presence of precipitation (Figure 4). The effects of climate change on productivity has influence on temperature and precipitation volume, often limiting crops and planting areas (KANG et al., 2009). This agrees with the study by Elkarin et al. (2016), who mentioned that climate change directly affects agricultural production, since agriculture is inherently sensitive to climatic conditions and is one of the sectors most vulnerable to the risks and impacts of these variations. In addition, precipitation variability possibly has more significant impact on livelihoods, particularly in terms of the frequency of drought. Recent droughts have affected the production of gum from the northern state of Kordofan and led to the breakdown of the agroforestry system of gum arabic, reducing gum production and thus threatening the stability of agricultural soils in this region (KHALIFA et al., 2016).

Most of the land in Sudan is very sensitive to changes in temperature and precipitation, which are reflected by abrupt climate changes, resulting in loss of local crops and livestock, changes in cropping patterns, water scarcity and increased incidence of diseases and pests (POUDEL and SHAW, 2016). Productivity is mainly driven by precipitation, with more than 70% of people in Sudan directly dependent on climate-sensitive resources for their livelihoods. Drought is one of the most critical climatic phenomena the country faces, as consequence of recurrent series of dry years in the Sudano-Sahel region (KHALIFA et al., 2016).

The analysis of data available in the literature regarding the production of gum arabic and the presence of precipitation does not allow interactions among the various potential environmental variables, such as maximum, minimum and average temperature, air relative humidity, average altitude of the study area and availability of water resource. Thus, to obtain marginal effects, given the interference of potentially relevant intervening characteristics, we used a meta-regression analysis (Figure 5).

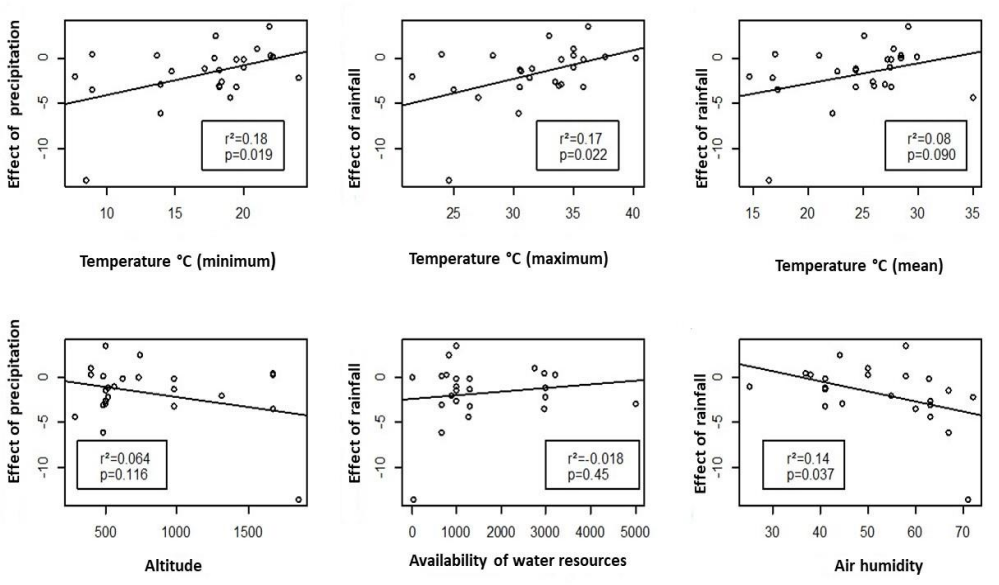

Figure 5 - Meta-regression between the effect of precipitation on the production of gum arabic and the environmental variables: temperature (minimum, maximum and average), air humidity, average altitude and availability of water resource.

We observed that the variables minimum, maximum and average temperature presented a positive relationship, although not always significant ($r^2 = 0.18$, $p = 0.019$, $r^2 = 0.17$, $p = 0.022$, $r^2 = 0.08$, $p = 0.09$, respectively). Similar results were obtained using air relative humidity as a predictor variable ($r^2 = 0.14$; $p = 0.037$), i.e., low temperatures followed by increased precipitation and relative humidity were favorable conditions to increase the amount of gum produced in the period analyzed. The average environmental factors of the study area ($r^2 = 0.064$; $p = 0.11$) and availability of water resources ($r^2 = -0.018$; $p = 0.45$) were not significant.

Plant growth and development and water availability may be affected by changes in temperature and precipitation patterns, eventually affecting crop yields (POUDEL and SHAW, 2016). Moreover, climate change has a significant impact on agriculture, mainly through the effect on crop yields (LOBEL et al., 2007; LOBEL et al., 2005). Most of these studies that sought to understand the physical effects of climatic variables on crop yield were conducted through crop simulation models. However, small changes in climate variables, specifically temperature, are often excluded (LOBEL et al., 2007). Therefore, regression models based on historical yield data and climate data are relatively accurate for predicting changes in yields due to climate change.

Assessing the seasonal and long-term water availability is not only important to sustain human life, biodiversity and the environment, but also useful for water managers and farmers to better allocate available water when needed (KANG et al., 2016), thereby increasing productivity. Khalifa et al., (2016) found that rainfall fluctuations, frequent cycles of drought, dust storms and winds have a direct impact on the productivity of agricultural crops of Sudan, due to their negative impact on the growth and development of

agricultural crops. For several decades, researches have accumulated evidence of environmental impacts on biological systems (ELITH and LEATHWICK, 2009). Not the least of which are the effects on biological diversity and ecosystem services, with potentially serious implications for food security (WALTHER et al., 2002).

Lastly, this study summarizes the use of statistical models and the discussions regarding variations in the climatic scenarios for the Acacia plantations and impacts on productivity variation in relation to water availability, air relative humidity and temperature. The significance of this study and its perspectives extrapolates the analyses beyond the production of gum arabic. The use of these exudates are in different application areas and should not be limited to just one species. These data allow to evaluate and to propose techniques of planting and extraction in different conditions beyond those adaptable for *Acacia senegal*.

CONCLUSION

In conclusion, we found that the productivity of gum arabic is influenced by environmental factors, mainly influencing the effect of precipitation (rainfall), and thus increasing its productivity. The heterogeneity between the studies (randomized model) was found through I^2 of 99.87 % and $\tau 2$ of 4.8312. The meta-regression with the effect of precipitation and the environmental variables (in rainy and dry seasons): temperature (minimum, maximum and average), air relative humidity, average altitude and availability of water resources showed a positive relationship for effects of minimum temperature and air relative humidity variables. Through these data, as a way of improving/increasing the productivity of these gums, artificial irrigation techniques can be applied, giving farmers, especially in the dry season, a sustainable level to avoid serious stress to trees due to overexploitation.

Furthermore, future analyzes with other species producing this type of exudate (including the Brazilian ones such as the cashew tree (*Anacardium occidentale*, L) of the Northeast region) should be carried out to provide better conditions of production of these gums.

ACKNOWLEDGEMENTS

We thank the Universidade Estadual de Goiás for the Master's scholarship granted and Coordenação de Aperfeicoamento de Pessoal de Nível Superior (CAPES) for the PhD scholarship grant.

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