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ENZYMATIC PROFILE OF ACTINOBACTERIA ACROSS A DESERTIFICATION GRADIENT IN THE BRAZILIAN SEMIARID REGION

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ABSTRACT

Objective: This study aimed to determine the enzymatic profile for xylanase, amylase, cellulase and pectinase in areas with different levels of desertification, in order to investigate how this process influences the enzymatic variation of actinobacteria.

Method: Soil samples were collected from areas susceptible to desertification with different levels of vegetation cover in the Brazilian semiarid region. The enzymatic activities of 46 actinobacterial strains isolated from these areas were evaluated using specific culture media. Enzymatic indices were calculated and correlated with soil physicochemical properties.

Results: There was a significant difference in enzymatic activity according to the desertification gradient. Xylanase exhibited the highest enzymatic index, followed by pectinase, amylase and cellulase. The open area showed better performance for xylan degradation, indicating that lack of vegetation cover and low nutrient availability influenced this enzymatic activity.

Conclusion: The actinobacterial strains have potential for producing functional enzymes across a desertification gradient. Xylanase was the most frequent, suggesting adaptation of actinobacteria to degradation of complex plant polysaccharides in nutrient deprived soils.

Keywords: Vegetation Cover, Hydrolytic Enzymes, Ecosystem Services, Semiarid.

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PERFIL ENZIMÁTICO DE ACTINOBACTERIA EM GRADIENTE DE DESERTIFICAÇÃO NO SEMIÁRIDO BRASILEIRO

RESUMO

Objetivo: Este estudo teve como objetivo determinar o perfil enzimático para xilanase, amilase, celulase e pectinase em áreas com diferentes níveis de desertificação, a fim de investigar como esse processo influencia a variação enzimática de actinobactérias.

Método: Amostras de solo foram coletadas de áreas suscetíveis à desertificação com diferentes níveis de cobertura vegetal no semiárido brasileiro. As atividades enzimáticas de 46 cepas de actinobactérias isoladas dessas áreas foram avaliadas utilizando meios de cultura específicos. Os índices enzimáticos foram calculados e correlacionados com as propriedades físico-químicas do solo.

Resultados: Houve diferença significativa na atividade enzimática de acordo com o gradiente de desertificação. A xilanase exibiu o maior índice enzimático, seguida pela pectinase, amilase e celulase. A área aberta apresentou melhor desempenho para degradação de xilana, indicando que a falta de cobertura vegetal e a baixa disponibilidade de nutrientes influenciaram esta atividade enzimática.

Conclusão: As cepas de actinobactérias têm potencial para produzir enzimas funcionais através de um gradiente de desertificação. A xilanase foi a mais frequente, sugerindo adaptação das actinobactérias à degradação de polissacarídeos vegetais complexos em solos desprovidos de nutrientes.

Palavras-chave: Cobertura Vegetal, Enzimas Hidrolíticas, Serviços Ecossistêmicos, Semiárido.

1 INTRODUCTION

Desertification is a global problem consisting of the degradation of drylands resulting from factors such as human activity and climate variation (UNCCD, 2012). This process is restricted to the semiarid region of the Northeast in Brazil, where 94% of the area is considered to have moderate to high susceptibility to desertification (Vieira et al., 2015). Semiarid regions have characteristics of arid environments, such as high temperatures and high concentrations of salinity, as well as low availability of nutrients and water scarcity (Divito & Sadras, 2014; Santos et al., 2017).

Desert ecosystems are typical of hostile environments, where water availability directly affects organisms (Vikram et al., 2016). In addition, they present adverse conditions such as aridity, intense ultraviolet radiation and abrupt temperature changes between night and day (Aszalós et al., 2016). Therefore, xerophilic microorganisms adapted to high temperatures and high levels of radiation are predominant populations in these ecosystems, including phyla such as *Proteobacteria*, *Bacteroidetes* and *Actinobacteria*, generally resistant to radiation and desiccation (Vikram et al., 2016; Li Chen et al., 2017). *Actinobacteria* belong to the latter phylum, abundant microorganisms in microbial communities in deserts (Sun et al., 2018).

Antagonistic interactions between actinobacteria and rhizobia can directly impact biological nitrogen fixation and have been described for the semiarid region (Lima et al., 2017; Cavalcante et al., 2017). However, new studies point to a relevant role of actinobacteria in ecosystem services. Silva et al. (2019), for example, highlighted the production of enzymes that aid cross-feeding, an ecological process that contributes directly to the structuring and

functioning of ecosystems, in order to ensure the existence of life, as well as maintain production activities in the soil (Burkhard et al., 2012).

Actinobacteria comprise a group of Gram-positive bacteria with a high concentration of guanine and cytosine in DNA and encompasses several genera, due to their wide distribution, as they are present in terrestrial, marine, mangrove regions and in extremophilic conditions (Ballav et al., 2016).

The soil constitutes the main habitat of this bacterial group, in which they are important components of the microbial community, performing functions such as ammonia fixation, cell tissue decomposition, synthesis of humus (Bhatti et al., 2017), and degradation of carbon-rich substrates that are difficult to decompose, such as starch and cellulose (Tyc et al., 2016; Bhatti et al., 2017). These microorganisms also produce secondary metabolites of economic importance (Lamilla et al., 2016), in addition to an extensive range of bioactive molecules, such as cellulases (Saini et al., 2015).

Production of xylanase by actinobacteria stands out as an extracellular complex that occurs in microorganisms, responsible for the degradation of the hemicellulose xylan (Vaijayanthi et al., 2016). This enzyme is applied in the conversion of xylan in agriculture (Sipriyadi et al., 2016), as well as in the paper and cellulose industry related to other enzymes such as laccases, causing a considerable decrease in the load of chemical effluents released into the environment.

Starch is considered a complex carbohydrate formed by amylose and amylopectin (Singh & Rani, 2014). Amylase is an enzyme that hydrolyzes starch molecules into polymers that are made up of glucose units, being extracted from several microorganisms, including yeasts, bacteria (specially actinobacteria) and fungi (Singh et al., 2016), this diversity of amylolytic enzyme producing organisms attests to the magnitude of this carbon source as a nutritional resource for various living beings that inhabit soil. In turn, cellulose is a complex polysaccharide and one of the main components of the plant cell wall (Irfan et al., 2012), degraded by the cellulase enzyme, and produced by microorganisms such as actinobacteria (Silva et al., 2015). This degradation produces energy compounds that play an important role in the carbon cycle and energy in the biosphere (Bettache et al., 2018).

On the other hand, pectin, present in plant cells and composed of the junction of several mono and polysaccharides, forms an extremely complex bio-macromolecule that is difficult to decompose in nature (Jacob et al., 2008). However, pectinases are enzymes capable of breaking these structures (Hugouvieux-Cotte-Pattat et al., 2014). Pectinases are produced by different organisms, such as bacteria, fungi, plants and insects (Salehghamari et al., 2019). Actinobacteria are active degraders of pectic substances present in the environment, since the pectinases these microorganisms produce are stable and can withstand a wider range of pH and temperature (Kumar & Suneetha, 2015). Some of these enzymes occur in plant tissues and play a role in the plants' biochemical and physiological development (Ward et al., 1989), in addition to helping maintain ecological balance by decomposing and recycling plant waste.

In arid environments, the scarcity of organic matter and nitrogen are critical factors, thus, the cycling of compounds present in the soil becomes essential for maintaining biogeochemical cycles, as well as for the availability of nutrients (Lemos & Megura, 2010). Thus, the existence of actinobacteria capable of cleaving plant polysaccharides such as xylan, starch, cellulose and pectin that favor nutrient cycling, by degrading complex molecules, is fundamental for maintaining the living components of this environment. After all, the actinobacteria phylum produces a diversity of enzymes as a nutritional strategy to obtain carbon and nitrogen sources (Korn-Wendisch et al., 1992).

Therefore, this study aimed to determine the enzymatic profile for xylanase, amylase, cellulase and pectinase in areas with different levels of desertification, in order to investigate how this process influences the enzymatic variation of the actinobacteria.

2 METHODS

Soil samples were collected from areas susceptible to desertification with different levels of vegetation cover (open, intermediate and conserved area). This site represents a spot inserted in the Médio Jaguaribe microregion and is located between the municipalities of Jaguaribe, Jaguaretama and Morada Nova, all in the State of Ceará totaling an area of 3239.40 km^2. The climate of this region is characterized as Hot Semiarid Tropical (BSh, according to Köppen-Geiger Climate Classification), with average annual rainfall of approximately 800 mm. It has a dry period often characterized by lack of rain, average annual temperatures between 23 and 27°C and average insolation of 2800 h $year^{-1}$ (Sudene, 2019). The location of each sample, the level of vegetation cover and the geographic coordinates of each collected point (latitude on the left and longitude on the right) are shown in Table 1. All samples were provided by the Desert project (Evolução da perda de biodiversidade em áreas sob processos de degradação), Projects MEC/MCTI/CAPES/CNPq/FAPs N° 03/2014.

Table 1: Location, vegetation cover level and geographic coordinates of the collected soil.

Location	Vegetation cover	Collection point	Geographical coordinates	
Jaguaribe	Open	1	-38,7076	-5,861
Jaguaribe	Intermediate	1	-38,6888	-5,861
Jaguaribe	Conserved	1	-38,629	-5,861
Jaguaribe	Open	2	-38,7219	-5,861
Jaguaribe	Intermediate	2	-38,731	-5,861
Jaguaribe	Conserved	2	-38,642	-5,861
Jaguaretama	Open	3	-38,7423	-5,861
Jaguaretama	Intermediate	3	-38,7423	-5,861
Jaguaretama	Conserved	3	-38,82	-5,861
Morada Nova	Open	4	-38,5234	-5,861
Morada Nova	Intermediate	4	-38,5019	-5,861
Morada Nova	Conserved	4	-38,5031	-5,861

Source: Elaborated by authors (2020).

2.1 Chemical Characterization and Electrical Conductivity of the Soil

The chemical analysis and electrical conductivity of the soil were performed according to Teixeira, Donagemma, Fontana and Teixeira (2017). For the chemical characterization, the soil attributes evaluated were: pH in water in the ratio of 1: 2.5 (soil: water), availability of nitrogen, carbon and organic matter, using the Mehlich 1 extractor, colorimetry and flame photometry analyzes, respectively. The electrical conductivity of the soil saturation extract in water (EC) was observed using a conductivity meter, and calcium carbonate equivalent. To convert the values to decisiemens per meter (dS/m) the methodology of Richards (1954) was adapted.

2.2 Actinobacteria

A total of 46 strains isolated from the soil of Meio Jaguaribe were used, having as main requirement the diversity in terms of cultural aspect. The strains were previously coded as "MJ", indicative of Meio Jaguaribe, followed by the number (MJ01-MJ47). The actinobacterial strains were: MJ-01, MJ-05, MJ-06, MJ-09, MJ-10, MJ-11, MJ-12, MJ-13, MJ-14, MJ-15, MJ-29, MJ-30, MJ-31, MJ-32, MJ-33, MJ-34, MJ-35, MJ-36 (open area), MJ-02, MJ-03, MJ-04, MJ-07, MJ-08, MJ-16, MJ-17, MJ-18, MJ-19, MJ-20, MJ-21, MJ-22, MJ-23, MJ-24 MJ-37, MJ-38, MJ-39 (intermediate area), MJ-25, MJ-26, MJ-27, MJ-40, MJ-41, MJ-42 MJ-43, MJ-44, MJ-45, MJ-46 and MJ-47 (conserved area). These strains are maintained on casein dextrose (CD)

medium tubes at 25°C in the Environmental Microbiology Laboratory (LAMAB) of the Biology Department at the Federal University of Ceará, making up the Collection of Semi-arid Actinobacterial Culture.

2.2.1 Strain cultivation

The selected strains were inoculated on Petri dishes containing CDA medium (Clark, 1965). The pH was adjusted to 6.5 ~ 6.6. The strains were then inoculated into CD broth and incubated at 28°C on a shaker at 150 rpm for 14 days. The plates were incubated in BOD at 28°C for 14 days.

2.3 Enzymatic Activity

The evaluation of enzymatic activity was performed using Xylan-Agar culture media (Kumar et al., 2012), Cellulose-Agar (Couri and Farias, 1995), Starch-Agar (Alariya et al., 2013) and Pectin-Agar (Minotto et al., 2014). The actinobacteria were inoculated in the respective culture media in the form of spots and placed in BOD at 28°C for 10 days. To reveal xylanolytic and cellulolytic activities, 10 mL of Congo red solution were added to each plate and, after 15 minutes, the supernatant was discarded and 10 mL of NaCl (2M) were added, which after 30 minutes the excess was discarded and the presence of a hydrolysis halo around the colony was observed and measured with the aid of a digital caliper, the size of the halo and the colony. To evaluate the production of amylase and pectinase, 10 mL of lugol solution was added to each Petri dish, allowing it to act for 1 minute, and the reading was also done by viewing the halo.

2.3.1 Determination of the enzymatic profile

The enzymatic indices (EI) of xylanase, cellulase, amylase and pectinase were obtained from the ratio between the diameter of the hydrolysis halo (Dh) and the diameter of the colony (Dc), using the following equation: EI = Dh/Dc (Florencio, Couri & Farinas, 2012).

2.4 Statistical Analysis

All tests were performed in quadruplicate and two assays were performed, totaling eight repetitions. Data normality was assessed using the Shapiro-Wilk test ($p \leq 0.05$) and variance homogeneity using the Levene test. Data on the effects of soil characteristics on enzymatic activity were evaluated using Pearson's Correlation Coefficient. Data on cellulolytic, amylolytic, xylanolytic and pectinolytic activities were subjected to a multivariate analysis of variance (MANOVA), at $p \leq 0.05$, run on SPSS Software (IBM Corp. Released 2011. IBM SPSS Statistics for Windows, Version 20.0. Armonk, NY: IBM Corp.).

3 RESULTS AND DISCUSSION

Once the normality of the data for the chemical characterization of the soil was tested (Table 2), a higher contribution of organic matter (OM) was detected in the conserved area, where there is greater vegetation cover. N content ranged from 0.27 to 3.15 g kg^{-1}, OM changed from 16 to 39.6 g kg-1 and there was variation in OC from 9.28 to 28.19 g kg^{-1}.

With regard to Electrical Conductivity (EC) (Table 2), it can be seen that the samples from the open area can be classified as non-saline, while the samples from the intermediate and

conserved areas were identified as slightly saline, based on the classification by Richards (1954).

Regarding pH, it was observed that the open area is strongly acidic, the intermediate area is moderately acidic and the conserved area is practically neutral.

Table 2: Chemical characterization and electrical conductivity of the soil collected in the Meio Jaguaribe Microregion, located in the municipalities of Jaguaribe, Jaguaretama and Morada Nova-CE, in the open, intermediate and conserved areas.

					Electrical Conductivity	
Samples	**N (g kg^{-1})**	**C (g kg^{-1})**	**Organic Matter**	**pH**	**dS/m**	**Rating**
Open 1	0,41	13,32	23,0	5,9	0,7046	Non-saline
Open 2	0,41	9,28	16,0	4,4	0,7859	Non-saline
Open 3	0,27	11,08	19,1	4,9	0,803	Non-saline
Open 4	0,83	10,99	19,0	4,7	0,9135	Non-saline
Intermediate 1	1,39	20,8	35,9	6,4	1,761	Non-saline
Intermediate 2	4,85	42,05	72,7	6,6	2,24	Slightly saline
Intermediate 3	0,83	16,6	28,7	6,1	1,005	Non-saline
Intermediate 4	1,38	25,09	43,4	5,3	2,04	Slightly saline
Conserved 1	1,53	10,18	17,6	7,4	3,03	Slightly saline
Conserved 2	3,15	28,19	48,7	6,5	1,208	Non-saline
Conserved 3	1,95	22,89	39,6	6,4	2,47	Slightly saline
Conserved 4	0,53	14,44	25,0	6,0	2,236	Slightly saline

Source: Prepared by the authors (2020).

3.1 Enzymatic Profile

According to the analyzed data, there was a significant Pearson correlation (p = 0.13) between the ability of actinobacteria to degrade cellulose and the organic matter and organic carbon contents of the soil, exhibiting higher values in the conserved and intermediate areas, since they presented higher values of OM and OC. On the other hand, this enzyme did not express a significant correlation with soil pH or EC. The amylase enzyme activity by microorganisms, in turn, was not influenced by the chemical characteristics of the soil analyzed.

The expression of xylanase, however, was affected by all soil characteristics (p = 0.000), r = -0.205, r = -0.282, r = -0.283, r = -0.352 and r = -0.329 for nitrogen, OC, OM, pH and EC respectively, being more influenced by pH and EC, showing that an increase in pH and EC decreased enzyme production. On the other hand, the increase in EC positively interfered with the production of the pectinase enzyme (Pearson coefficient r = 0.140, p = 0.007), exhibiting higher values in the conserved area.

According to the data analysis, there was a significant difference between the enzymatic productions (p = 0.000). The xylanase enzyme stood out from the others with the highest EI values (mean = 3.64), followed by pectinase (3.03), amylase (2.67) and cellulase (1.88).

The expression of the cellulase enzyme among the actinobacteria presented a significant difference between the three areas studied (p = 0.000). The intermediate and conserved areas exhibited the highest EIs of 2.42 and 2.18, respectively, while the open area presented the lowest values (1.55).

Analyzing Figure 1, it can be seen that the highest production of the cellulase enzyme occurred in the intermediate area, where 07 of the 17 strains tested showed the ability to degrade cellulolytic compounds with an average Enzymatic Index value of 2.18, highlighting strain MJ 20 (*Streptomyces*) with IE of 3.12. This strain was able to grow in all the tested parameters for pH, salinity and temperature.

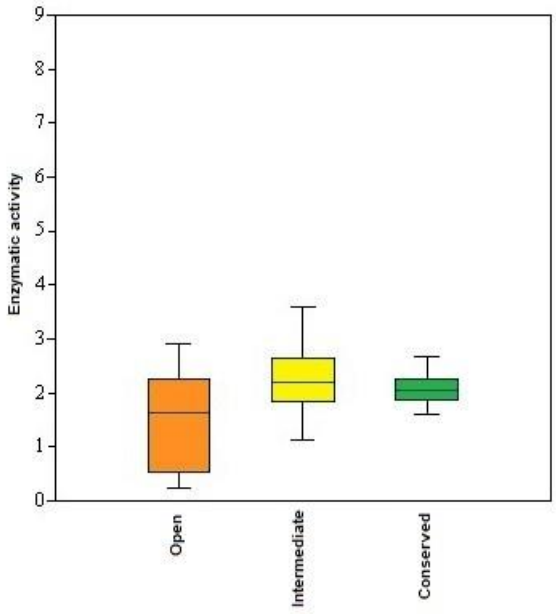

Figure 1: Cellulolytic activity of actinobacteria from the middle Jaguaribe microregion in open, intermediate and conserved areas.
Source: Prepared by the authors (2020).

The open and conserved areas did not show statistical difference (p = 0.288) between them, but were significantly higher (p = 0.000) than the EI values presented by the strains from the intermediate area.

Looking at Figure 2, we can see the highest amylase production in the open area, where 07 of the 18 strains tested were able to degrade amylolytic compounds with an average Enzymatic Index value equal to 2.99, emphasizing strain MJ 29 with IE of 4.36. This strain was able to grow in the acidic pH ranges (4.0 and 5.0) and neutral (7.0), at all the NaCl concentrations used and at a temperature of up to 45°C, being classified within the genus *Nocardia*.

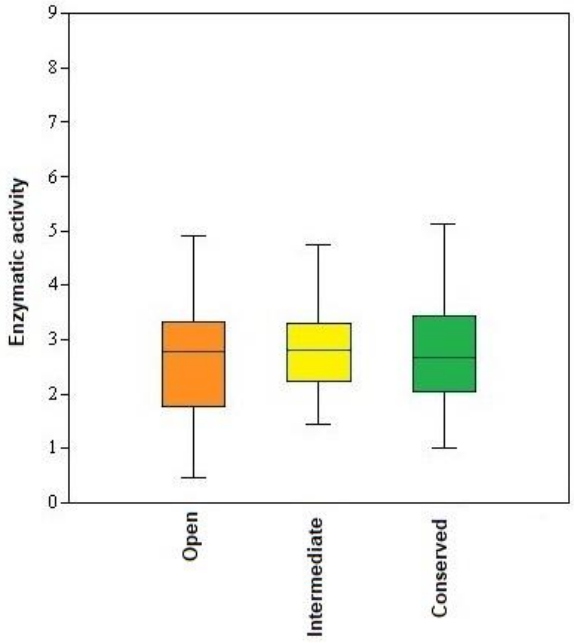

Figure 2: Amylolytic activity of actinobacteria from the Middle Jaguaribe microregion in open, intermediate and preserved areas.
Source: Elaborated by the authors (2020).

The detection of the xylanase enzyme was not significantly different between the areas (p = 0.444). Looking at Figure 3, it can be seen that the highest xylanase production is in the open area, where 07 of the 18 strains tested were able to degrade xylanolytic compounds with an average Enzymatic Index value equal to 4.31, highlighting strain MJ 20 with the highest IE (6.93).

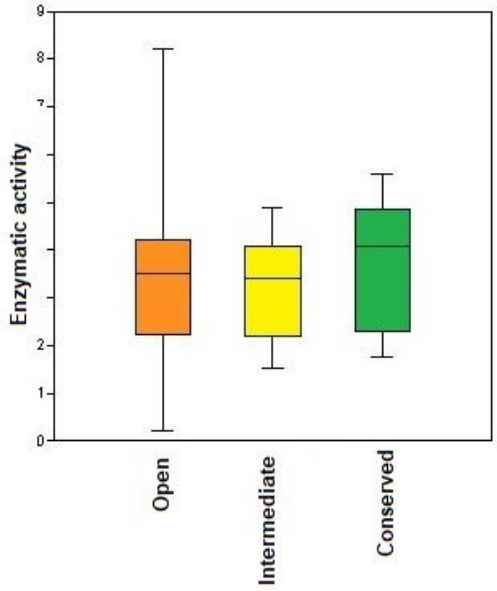

Figure 3: Xylanolytic activity of actinobacteria from the Middle Jaguaribe microregion in open, intermediate and conserved areas**.**
Source: Elaborated by the authors (2020).

With regard to the pectinase enzyme there was no statistical difference between the open and intermediate areas (p = 0.978), while the conserved area stood out statistically (p =0.000) exhibiting the highest enzymatic production (mean of 4.03). On the other hand, analyzing Figure 4, it can be seen that the greatest variations in EI's for the above enzyme occurred in the open area, where 09 of the 17 strains tested showed the ability to degrade pectinolytic compounds, highlighting strain MJ 06 with IE of 5.37. It is also noteworthy that this strain was able to grow in all the tested parameters for pH, salinity and temperature and was classified within the genus *Actinomadura*.

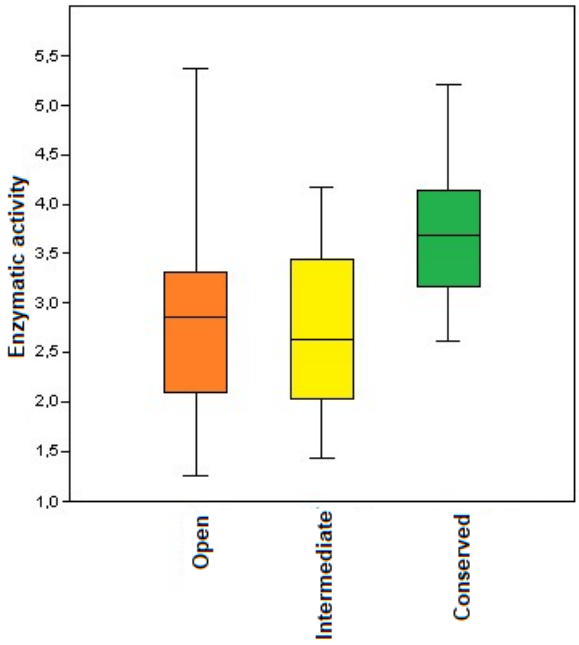

Figure 4: Pectinolytic activity of actinobacteria from the Middle Jaguaribe microregion in open, intermediate and conserved areas.
Source: Elaborated by the authors (2020).

The results of this study show that the enzymatic activity of actinobacteria is correlated with soil characteristics, which are influenced by vegetation cover. The absence of vegetation affects soil characteristics, generating stressors, such as soil pH, which interfere with the production of microbial enzymes. This enzymatic activity may be a response of actinobacteria in relation to the loss of vegetation, decrease in organic matter and soil pH, indicated by the high rates presented in the open and intermediate areas for the enzymes cellulase, amylase and xylanase. Regarding the latter, it can be said that actinobacteria from more saline and acidic regions, as is the case in desertification environments, produce this enzyme as an adaptive mechanism, since high EC can limit crop productivity and act as a yield constraint (Zhang et al., 2016). The expression of the pectinase enzyme was more influenced by soil salinity, exhibiting the highest production in the conserved area, and according to Nithya et al., 2017, actinobacteria isolated from arid soil have the potential for enzyme production strongly influenced by the variation in pH and temperature.

It is possible to infer that these strains are adapted to soils in the semiarid region, which have characteristics such as high thermal amplitudes, low moisture and are oligotrophic, reducing the availability of resources and affecting soil diversity and agricultural production. The open area presented the greatest diversity of genera, as well as extreme minimum and maximum values of EI's for amylolytic, xylanolytic and pectinolytic activities. In addition, the

functional diversity of soil microorganisms is strongly affected by ecosystem disturbance or stress (Caldwell, 2005; Chroni et al., 2009).

Current research with native actinobacteria from the semiarid region of Ceará (Brazil) found the ability to synthesize extracellular enzymes capable of degrading substrates containing cellulose, starch and xylan (Silva et al., 2015; Alves et al., 2016; Lopes et al., 2018; Sousa et al., 2018; Silva et al., 2019).

The ability to degrade cellulose, the most abundant polysaccharide in plant biomass, was observed in 52.17% of the strains evaluated in this study. The highest EI obtained for the cellulase enzyme was 3.12 by strain MJ 20. The values found here were higher or similar to those reported for the semiarid region of the State of Ceará. In a study carried out at the Ubajara National Park, cellulase production was observed in 21 actinobacterial isolates and only 03 had IE higher than 2.0 (Silva et al., 2015). Similarly, 30 strains out of a total of 39 tested were considered cellulolytic enzyme producers, with a maximum enzymatic index of 3.3 when evaluated in the same region (Alves et al., 2016). Sakure et al. (2015) recorded positivity for this enzyme in 8 of the 10 strains studied, isolated from the rhizosphere region of medicinal plants in India, highlighting strains A3 and BF5 which were classified within the genus *Streptomyces* and grew at concentrations up to 7.5% NaCl, supporting the result of strain MJ 20 which was also classified within this same genus and grew at all salinity concentrations tested. In addition, studies with actinobacterial isolates over the past 50 years have demonstrated the capacity and efficiency of the *Streptomyces* genus regarding the production of cellulolytic enzymes (Ishaque & Kluepfel, 1980; Thé Berge et al., 1992; Ramirez & Coha, 2003; Arora et al., 2005; Das et al., 2007; El-Sersy et al., 2010; Chu et al., 2011).

The degradation of starch, the most important organic substance in terms of energy storage (Minotto et al., 2014), was observed in 60.86% of the isolates cultivated in the present study, highlighting strain MJ 29 which obtained IE of 4.36. The occurrence of amylases in actinobacteria is commonly observed in genera such as *Nocardia* and *Streptomyces* (Vigal et al., 1991). Our results are similar to the findings of Karanja et al. (2012), who observed amylolytic degradation with EI between 3.4 and 5.2 for all *Streptomyces* species isolated from soils in Kenya. In the literature, reports on amylases produced by actinobacteria in desert soils are still limited, one of the studies was carried out by Ruchika (2016) who described three amylase-producing actinobacteria from the Thar desert soil, classified as *Streptomyces*. In the semi-arid region of Ceará (Brazil), the authors Silva et al. (2015) and Alves et al. (2016) characterized strains in relation to the production of this enzyme. Lopes et al. (2018), when evaluating 58 strains from the Aiuaba Conservation Unit, semi-arid region, found only 02 strains with IE higher than 3.0. On the other hand, Alves et al. (2016), working with 39 strains from the Lower Acaraú region, Semi-arid, found amylase production in 36, obtaining EI up to 6.02. Nithya et al. (2018) examining 23 native strains from desert soil, obtained the best amylolytic yield in a strain identified as *Streptomyces*, at pH and temperature ranges similar to those used in this research. It is noteworthy that of the total of 28 strains capable of synthesizing amylase in this study, 19 were classified within this same genus.

Xylanase production is an important factor in the recycling of agricultural waste, since it is the second most abundant natural polysaccharide, usually found in the plant cell wall, between lignin and cellulose (Mohamed et al., 2017).

The xylanase decomposition capacity of strain MJ 20 was greater than the results found in the literature, Omar et al. (2017) for example, isolating strains from a mangrove in Malaysia, obtained a maximum enzymatic index of 3.35, while Sipriyadi et al. (2016) found xylanase production in actinobacteria isolated from forest soil in Indonesia, with an EI ≤ 3.25. It is also noteworthy that the aforementioned strain belongs to the *Streptomyces* genus and was able to grow in alkaline pH ranges (9.0), temperatures up to 45°C and concentrations up to 3.5% NaCl, similar to the result of Sanjivkumar et al. (2018) who, when testing a strain of this same genus

for xylanase production, obtained the highest value under conditions of pH 8.0, 40°C temperature and 1.5% NaCl.

It is interesting to highlight this result in a desertification area, since the low availability of nutrients and the metabolic requirements of microorganisms are directly related to the release of enzymes in the soil. Authors such as Caldwell, (2005) and Chroni et al. (2009) have already reported that the ability of microbial communities to maintain functional diversity through disturbances, stress or succession may be more important for ecosystem productivity than taxonomic diversity. This is reflected in the xylanolytic activity that was strongly influenced by the deprivation of nutrients in the open area. Ramanjaneyulu et al. (2016), stated that the physicochemical characteristics of the soil can influence the production of xylanase by microorganisms such as fungi, bacteria and actinobacteria. In their study, these authors found the highest occurrence of these organisms in a soil with pH 5.1, consistent with the results found here, since the open area, where all soil samples showed acidity in pH, exhibits a higher concentration of xylanase enzyme producing organisms.

Pectinases are lytic enzymes active in the composting process, acting on the degradation of organic matter, in addition to contributing to the natural carbon cycle (Pedrolli et al., 2009; Wei et al., 2000). Research on pectinases produced by actinobacteria has been documented around the world. In 2013, 10 *Streptomyces* strains isolated from India were considered pectinase producers (Arijit et al., 2013); Of a total of 95 actinobacterial isolates analyzed in Ethiopia, 33 strains showed pectinolytic activity (Oumer & Abate, 2018); Isolates of actinobacteria from a lake in a province of Iran were investigated for their pectinases and 15 strains demonstrated this activity mainly when subjected to high temperatures and a wide pH range (Salehghamari et al., 2019). In this study, 45.65% (21 isolates) of the investigated strains demonstrated the ability to degrade pectinolytic compounds and the highest enzymatic activity occurred in the open area, since strain MJ 06 obtained an enzymatic index of 5.37. It is important to note that in this area the pH ranges were high, as well as that the aforementioned strain grew up to a temperature of 45°C and, according to Kumar & Suneetha (2015) the pectinases produced by actinobacteria have good resistance to high temperatures and extreme pH. Our results are more expressive than some already documented, Borah & Thakur (2020), for example, found pectinase production in only 21.73% of a total of 46 endophytic actinobacterial strains isolated from a region of India. Similarly, a study conducted in the Amazon showed that only one actinobacterial strain produced the pectinase enzyme with IE of 2.2 (Oliveira et al., 2017)4.

4 CONCLUSIONS

The actinobacterial strains showed potential for the production of cellulases, amylases, xylanases and pectinases. The open area, in turn, presented higher minimum and maximum values of EI's for amylolytic, xylanolytic and pectinolytic activities, revealing a better performance for the degradation of xylanolytic compounds. After all, the xylanase enzyme was the most frequent among the representatives of the actinobacteria in the three areas studied in relation to the other enzymatic activities, thus inferring that the lack of vegetation cover, low nutrient availability and chemical characteristics of the soil influenced this enzymatic activity.

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