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Tensile properties of composites with glass fibers and curauá fibers in polyester resin matrix

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ABSTRACT

Synthetic glass fiber is used by several industrial segments, including civil construction in northern Brazil, due to its characteristics and properties that allow lightness and durability to manufactured products. Curauá (Ananas erectifolius), is a plant with flat, hard leaves that occurs in the state of Pará, from which fiber is extracted that may represent great potential for use in composites for the civil construction industry. Thus, polymer composites with polyester resin matrix and reinforcement with short glass and curauá fibers, both 15 mm long and randomly distributed, were produced for comparison of tensile properties. The first results showed better mechanical performance in tensile of the composites reinforced with curauá fibers in relation to composites with glass fibers, on average 53,17%. The water absorption tests of the composites showed similar values, 1.75% with curauá fibers and 1.73% with glass fibers, indicating good wettability of both fibers. The micrographs of the fracture zones in the tensile tests showed better interfacial interaction of the composites with curauá fibers.

Keywords: Ananas erectifolius, Curauá fiber, Glass fiber, Polymeric composite, Tensile tests.

1 INTRODUCTION

Civil construction, which is significantly responsible for the socioeconomic development of Brazil, reflects the same condition in all Brazilian states, being an intensive activity that seeks to transform diverse resources into well-being with the challenge of sustainably managing the high rate of residue generation. Residue from construction works is difficult to degrade or not degradable, as it tends not to have a reduced volume over time, depleting the disposal space more quickly and depriving other uses of this residue after the end of the activities of the works. Even with the coronavirus pandemic, activities in the civil construction sector remained active and in 2021, 48 million tons of construction and demolition residue were generated, an increase of 2.9% compared to 2020[(1-5)].

Glass fiber is a material produced from the union of extremely thin and flexible glass filaments with some resin, usually polyester. The polymer produced mixes the properties of the materials contained in its production, generating a light fiber, highly resistant and with unique and excellent properties for several applications. Glass fibers are used to reinforce polymer matrices and, to obtain molded components and structural composites that are widely used in the civil construction industry due to their advantageous characteristics such as high strength-to-weight ratio, good stability, good resistance to heat, humidity, and corrosion, ease of manufacture and relatively low cost. For these qualities, glass fibers are the most used reinforcement in the manufacture of various composite materials for use in construction works. However, when these materials are discarded in nature as construction and demolition waste, they take decades to degrade(6-9,25).

The concern with the environment, with the sustainable development of sectors such as civil construction and the technological improvement of new materials, brought the need to develop composite materials reinforced with natural fibers. Although natural fibers have high humidity absorption, interest in using these fibers has increased in recent years due to their characteristics such as low cost, low density, good mechanical performance, and biodegradability. The curauá (Ananas erectifolius) native to the Amazon, from the bromeliad family and lignocellulosic nature, is a plant with leaves that can reach a length of more than one meter and a width of approximately four centimeters, easy to grow and have a low processing cost. The chemical composition of curauá is generally composed of 73.6% cellulose, 9.9% hemicellulose, 7.5% lignin, 83.5% holocellulose, 7.9% moisture, and 0.9% ash, these percentages may vary according to the climatic and geographic conditions of the place where the plant was cultivated. The tensile strength of curauá fiber, on average, is approximately 400MPa. But it can vary between 200MPa and 700MPa when the fibers are analyzed individually due to heterogeneity in the dimensions of their length and diameter(10-15). Given this scenario, curauá natural fiber may represent an alternative use as reinforcement in polymeric and cementitious composites in replacement of glass synthetic fibers. Just as planting curauá can be an alternative for generating employment and income for the poorest populations in the regions where the plant can be cultivated.

The analysis of the mechanical behavior is a way to identify the good interaction between the matrix and the reinforcement of composite materials. Thus, polymeric composites with synthetic glass fiber and natural curauá fiber in a polyester resin matrix were developed to evaluate the tensile mechanical and microstructural behavior and the possibility of replacing synthetic fibers with natural fibers for application in several components for use in the civil construction industry.

2 MATERIALS AND METHODS

Curauá fibers (*ananás erectifolius*) are collected in Aurora do Pará, in the State of Pará (Amazon Region, Brazil). Curauá fibers are extracted from the flat, rigid leaves of the curauá plant(15). First, the curauá fibers, in nature, are stretched and carefully combed to remove the nodules formed when the fibers are extracted from the curauá plant. Subsequently, the fibers were cut to a length of 15 mm, Figure 1.

Figure 1. Curauá fiber: a) curauá plant, b) curauá fiber in natura, c) curauá fiber with 15 mm.

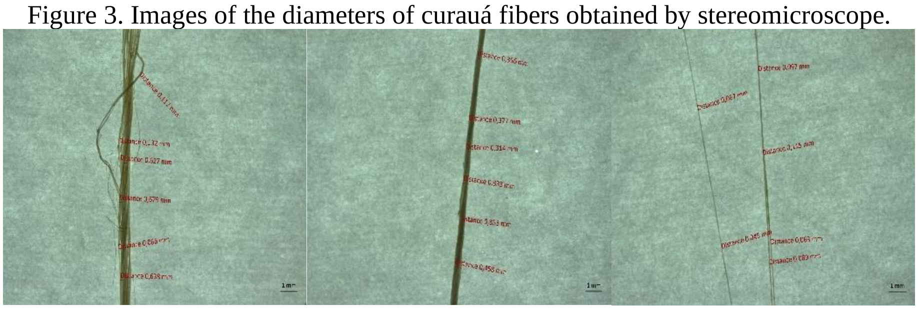
The glass fibers are extracted from a glass fiber cloth with a grammage of 600 g/m². The cloth meshes are undone and then cut to a length of 15mm. An image of the glass fibers obtained by optical stereomicroscope and an image of the cut glass fibers are shown in Figure 2.

Figure 2. Glass fibers: a) before cutting to 15 mm, b) after cutting to 15 mm.

The terephthalic crystal polyester resin and methyl-ethyl-ketone peroxide (MEK) are acquired in the metropolitan region of Belém do Pará.

The average diameter of curauá fibers, from 100 samples, is obtained using an optical stereomicroscope Zeiss Stemi 508 da Carl Zeiss with magnification up to 50X. Figure 3 shows the images of randomly selected curauá fibers, among the 100 samples analyzed, to elucidate its dimensions and morphology.

Figure 3. Images of the diameters of curauá fibers obtained by stereomicroscope.



The specific mass of curauá fibers is obtained by pycnometry following the protocols of ASTM D 854[23]. After 24 hours of immersion in distilled water at 25ºC ± 1, the curuá fibers were dried in an oven at 70ºC until a variation of 0.1% of the waterless mass. This process was performed three times.

Micrographs of the curauá fiber are obtained using a scanning electron microscope (SEM) at TESCAN Vega 3.LM. The qualitatively previous analysis of some chemical constituents is obtained using an Energy Dispersive Spectrometer (EDS).

The diffractometer of BRUKER D2 PHASER is used to obtain the diffractogram and crystallinity index of the curauá fiber. Phase identification was done using the software HighScore Plus of Panalytical and the database PDF: Powder Diffraction File[19].

The water absorption tests are conducted following the protocols of ASTM D570 [22]. Six samples measuring 25 x 25 mm were produced for this test. The samples were taken in an oven at 45°C for 9 hours until their constant masses were obtained. Then, the samples were cooled to room temperature for 24 hours and weighed on a precision analytical balance. After this, the samples were submerged in distilled water for 24 hours to obtain humid masses.

The tensile specimens are manufactured in a silicone rubber mold, following the protocols of ASTM D 3039[21]. Five specimens are fabricated for each experimental condition. The compression molding is performed using a manual laminator. The resin is cured at room temperature of 25°C with methyl-ethyl-ketone peroxide (MEK) at 0.33% v/v in relation to resin and homogenized with a glass rod until the gel time. The fibers are distributed randomly, with 10% fibers in relation to polyester resin volume. The specimens are removed from the mold after four days. Tensile tests are performed on a universal testing machine, Arotec DWD – 100E, with a 2mm/min speed. After tensile tests, micrographs of the fracture zones are obtained by scanning electron microscopy – SEM.

3 RESULTS AND DISCUSSION

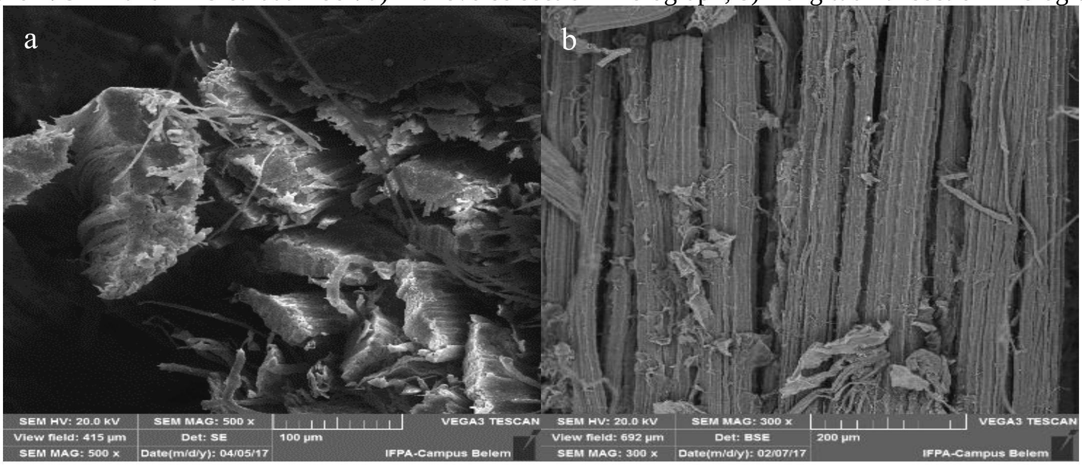
The average diameter and specific mass of the curauá fibers are shown in Table 1. The average diameter showed a smaller variation in the transverse section. The specific mass showed similar values common to lignocellulosic fibers such as timbó-açú (1,55±0,02), juta (1,26±0,06) e tururi (0,97±0,06) [13,14,24].

Table 1 - Average diameter and specific mass.

Fibers	Curauá
Average diameter (mm)	0,46 ± 0,068
Specific mass (g/cm^3)	1,39 ± 0,06

Figure 4a shows the transverse sectional micrograph of the curauá fiber. Although natural fibers have a standardized morphology, they are different in aspects such as total transverse section, the number of fibrocells, and the size of cell walls[12,20,26]. The curauá fiber has a smaller total transverse section area, that is, fewer fibrocells, and has thick cell walls. The micrograph of the curauá fiber longitudinal section, figure 4b, shows the presence of straight filaments parallel to the fibrils and some roughness which are typical of natural fibers.

Figure 4. SEM and EDS curauá fiber: a) Transverse section micrograph, b) Longitudinal section micrograph.



The previous analysis of some chemical constituents of the curauá fiber is shown in table 2. Elements such as C, O, Mg, Al, K, and Ca are common in lignocellulosic natural fibers and these elements vary depending on the species, including in the cell wall of the same fiber. Morphological aspects and chemical composition directly influence the fibers mechanical performance, such as tensile strength[13,17,24-28].

Table 2 – Curauá fiber previous chemical composition by EDS.

Curauá fiber	Elements (%)						
Elements	C	O	Mg	Al	K	Ca	Total
Amount	56,47	43,25	0,06	0,04	0,06	0,13	100

Curauá fiber presents a diffractogram of the crystalline phase of cellulose (lignocellulosic compounds). Variations in the mechanical resistance of natural fibers are related to the crystallinity index, that is, the amount of cellulose in the fiber[10-13,20,27]. Table 3 shows the crystallinity index and Figure 5 shows the diffractogram of curauá fiber.

Table 3. Phases present in curauá fiber and the crystallinity index - Icr (%).

Fiber	Amorphous phase	Crystalline phase	I_{cr} (%)
Curauá	Amorphous	-	62

Figure 5. Diffractogram of curauá fiber, showing amorphous and crystalline phases.

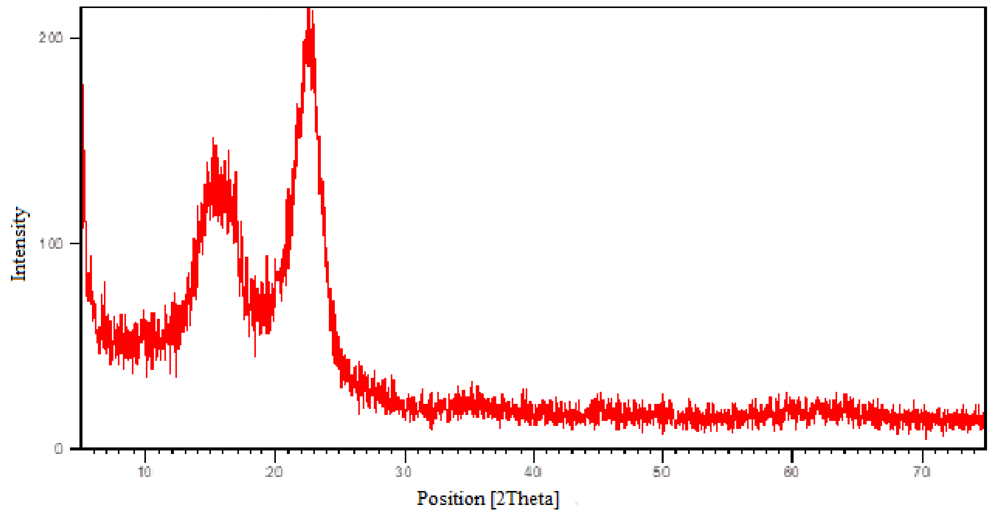


Table 4 shows the average values of the waterless mass, humid mass, and absorption of water obtained in the water absorption tests. The results show the values approach for both composites. The values indicate good wettability and good matrix/reinforcement adhesion of the curauá and glass fibers(7,18,22).

Table 4. Water absorption average values of composites with curauá and glass fibers.

Resine/fiber composites (average values)	Waterless mass (g)	Humid mass (g)	Absorption of water (%)
Curauá	2,50	2,54	1,75
Glass	2,30	2,34	1,73

Table 5 shows the average values of the tensile strength (σ_{max}) obtained in the tensile strength tests(16,29,30). Composites reinforced with 10% fibers improved the mechanical behavior of the polyester resin. The results showed better mechanical performance in tensile to the composites reinforced with curaúa fibers in relation to composites with glass fibers, on average 53,17%. The results also showed an increase in the tensile strength of composites with curauá fibers and with glass compared to polyester resin, on average 57,75%, and 9,76%, respectively. Figures 6, 7, and 8 shows the graphs (stress x strain) obtained in the tensile strength tests.

Table 5. Average values of the tensile strength tests.

Specimens (average values)	σ_{max}(MPa)
Polyester resin	7,058
Curauá fibers composites	16,706
Glass fibers composites	7,822

Figure 6. Stress x strain graph of the polyester resin test.

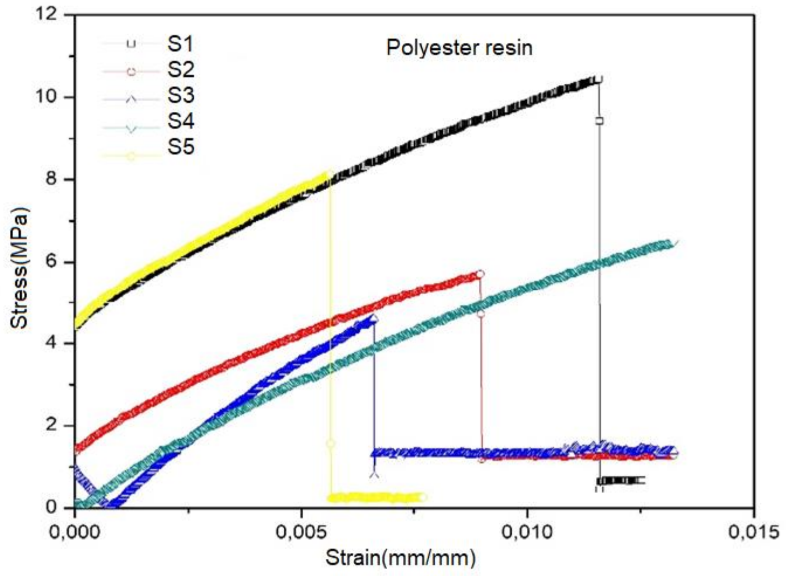


Figure 7. Stress x strain graph of glass fibers reinforced composites.

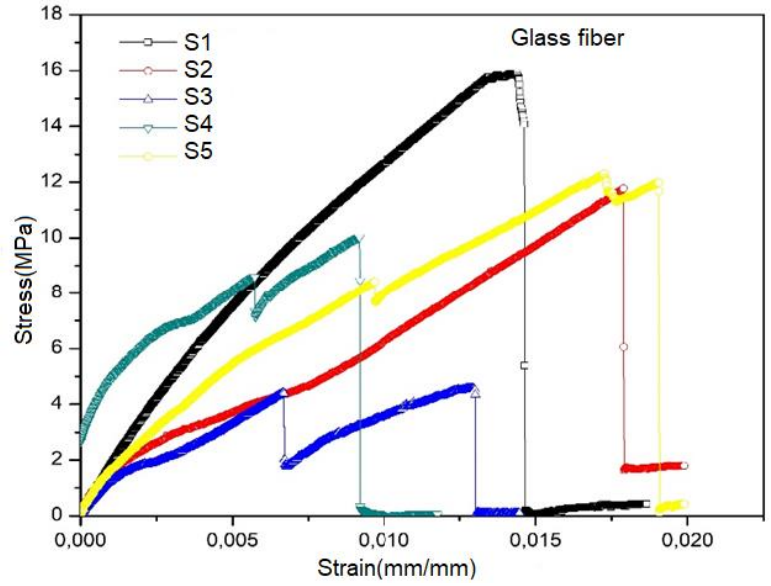
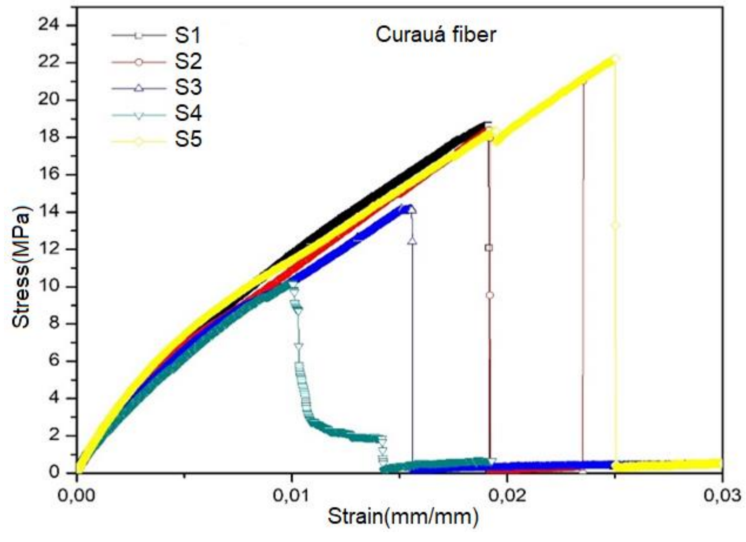


Figure 8. Stress x strain graph of curauá fibers reinforced composites.



Micrographs of the fracture zone of the composite with curauá fibers are shown in figure 9. The micrograph, figure 9a, shows regions where curauá fibers have been pulled out of the resin (red arrow) and regions where the fibers maintained the same orientation in the direction of loading, until failure (orange arrow). This behavior indicates that the matrix has transferred the load to the fiber. The micrograph, figure 9b, shows the presence of voids in the matrix (red arrow) which may have been caused by the manual manufacturing process of the composites. The presence of voids can contribute to the formation of cracks and to the decrease of the mechanical resistance of polymeric composite materials.

Figure 9. SEM micrograph: a) resin/curauá fibers, b) resin/curauá fibers – the presence of voids.

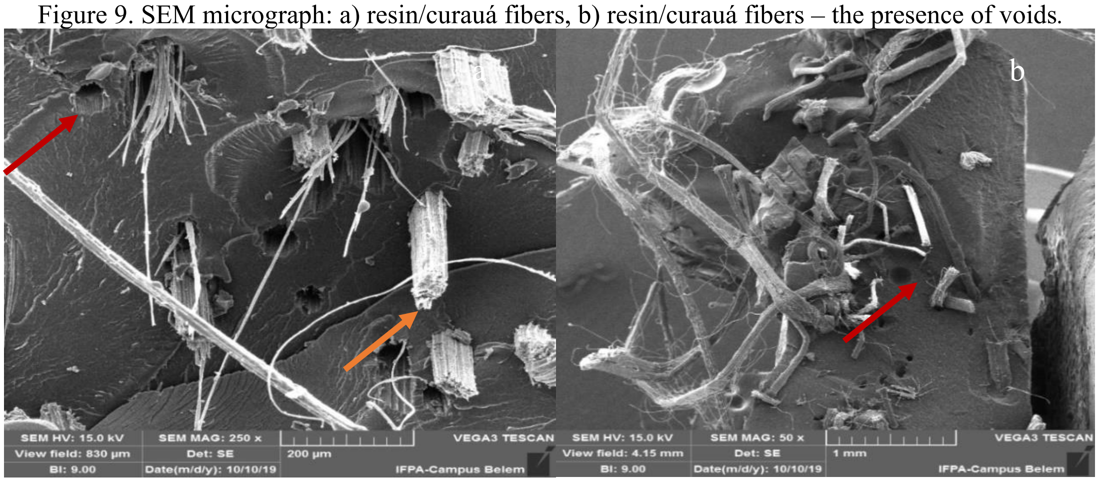
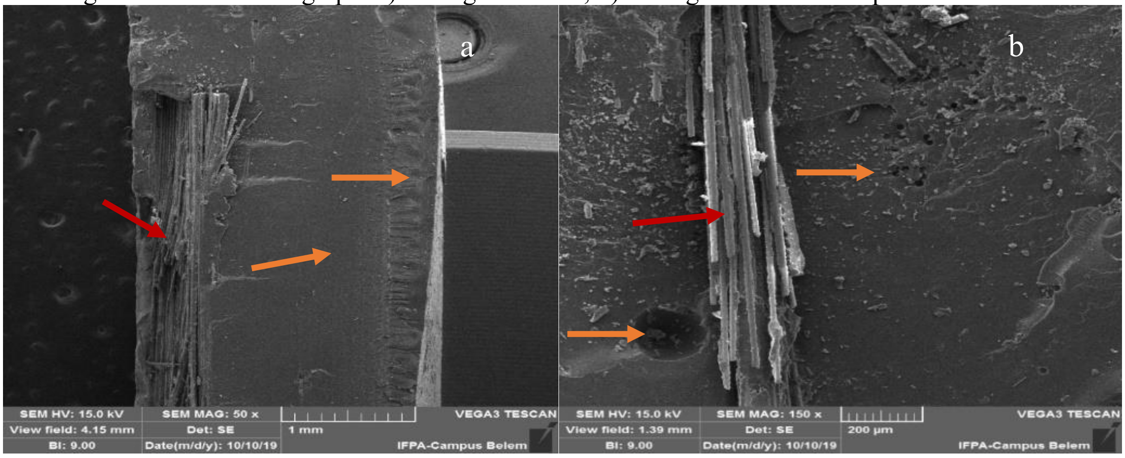


Figure 10 shows micrographs of the composite fracture zone with glass fibers. The micrograph, figure 10a, shows matrix fracture regions without fibers (orange arrow) or another rupture mechanism of the fibers, but it is possible to observe the pulling of fibers perpendicular to the direction of load (red arrow). This behavior can influence the mechanical performance of the composite because indicate little transfer of load from the matrix to the fibers. The micrograph in figure 10b shows regions of fibers perpendicular to the load direction, detached from the matrix (red arrow), and shows the formation of voids and micro voids in the matrix (orange arrow). This behavior may be a consequence of the manual manufacturing process of the composites and can contribute to the mechanical embrittlement of the material.

Figure 10. SEM micrograph: a) resin/glass fibers, b) resin/glass fibers – the presence of voids.



4 CONCLUSION

The first results showed better mechanical performance in tensile of the composites reinforced with curauá fibers in relation to glass fibers composites. The water absorption tests showed similar values for the two composites indicating good wettability of both fibers. The micrographs of the fracture zones showed better matrix/reinforcement interfacial interaction of composites reinforced with curauá fibers. The incorporation of fibers in polymeric composites significantly improved the mechanical properties of the polyester resin polymeric matrix. Curauá fibers polymeric composites can be a viable alternative to replace glasses fibers polymeric composites to obtain materials with application in civil construction works and to reduce environmental impacts caused by construction and demolition residue. Curauá fiber can become an alternative for generating employment and income in the locations where the plant can be cultivated.

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