

Review and prospects of geotextiles: role of babassu fibers

Revisão e perspectivas dos geotêxteis: papel das fibras de babaçu

Revisión y perspectiva de los geotextiles: papel de las fibras de babasú

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ABSTRACT

With the increase of global environmental changes and intensive anthropogenic activities, it is extremely important to maintain and improve soil function. Soil erosion is a naturally occurring process that affects all landforms. Different structures and forms of geotextiles are available to geotechnical engineers. Geotextiles in the form of woven and nonwoven structures are mostly used in various geo-engineering applications. This review focus on how the use of geotextiles have grown during the last decades and the importance of a particular material to be base of geotextiles, babassu (*Attalea speciosa* Mart. ex Spreng, Arecaceae)) that is a palm with socioeconomic and ecologic importance found in humid tropical areas in Brazil.

Keywords: geotextiles, erosion, soil stability, babassu fibers.

RESUMO

Com o aumento das mudanças ambientais globais e intensas atividades antrópicas, é extremamente importante manter e melhorar a função do solo. A erosão do solo é um processo natural que afeta todas as formas de relevo. Diferentes estruturas e formas de geotêxteis estão disponíveis para engenheiros geotécnicos. Os geotêxteis na forma de estruturas tecidas e não tecidas são usados em várias aplicações de geoengenharia. Esta revisão enfoca como o uso de geotêxteis tem crescido nas últimas décadas e também a importância de um determinado material para ser base de geotêxteis, o babaçu (*Attalea speciosa* Mart. ex Spreng, Arecaceae)) que é uma palmeira com importância socioeconômica e ecológica encontrada em áreas tropicais úmidas no Brasil.

Palavras-chave: geosintéticos, biomantas, erosão, estabilidade do solo, fibras de babaçu.

RESUMEN

Con el aumento de los cambios ambientales globales y las actividades humanas intensas, es extremadamente importante mantener y mejorar la función del suelo. La erosión del suelo es un proceso natural que afecta a todas las formas de alivio. Los ingenieros geotextiles tienen a su disposición diferentes estructuras y formas de geotextiles. Los geotextiles en forma de estructuras tejidas y no tejidas se utilizan en diversas aplicaciones de geoingeniería. Esta revisión se enfoca en cómo ha crecido el uso de geotextiles en las últimas décadas y también en la importancia de un determinado material para ser la base de los geotextiles, la babassu (*Attalea speciosa* Mart. ex Spreng, *Arecaceae*) que es una palmera con importancia socioeconómica y ecológica que se encuentra en las zonas tropicales húmedas de Brasil.

Keywords: geosintéticos, biomasa, erosión, estabilidad del suelo, fibras de babasú.

1 INTRODUCTION

Environmental changes challenge both biodiversity persistence and human wellbeing. The science and practice of restoration ecology, in collaboration with other disciplines, can contribute to overcoming these challenges. With the increase of global environmental changes and intensive anthropogenic activities, it is extremely important to maintain and improve soil function. Some authors mentioned the utility to employ even phytoremediation plants, which have shown potential to be used in the decontamination of many anthropogenically polluted sites (Wermeier & Noya, 2019).

Soil erosion is a naturally occurring process that affects all landforms. Erosion, whether it is by water, wind or tillage, involves soil detachment, movement and deposition. Soil erosion contributes to the pollution of adjacent watercourses, wetlands and lakes. Soil erosion can be a slow process that continues relatively unnoticed or can occur at an alarming rate, causing serious loss of topsoil. Soil compaction, low organic matter, loss of soil structure, poor internal drainage, salinization and soil acidity problems are other serious soil degradation conditions that can accelerate the soil erosion process (<http://omafra.gov.on.ca/english/engineer/facts/12-053.htm>).

Depending of the case, permeable or impermeable barriers are a need in several engineering works, the last one in waste containment systems and effluents ponds, and compacted soils have been used for that purpose (Macambira, 2002). Slope stability prediction research is a complex non-linear system problem. Chuan et al (2013) made a slope stability calculation of open pit using 3Dslope software. More recently, Wang et al. (2022) using artificial intelligence, made predictions on slope

stability based on visual exploratory data analysis of 77 in situ cases. Nie et al, (2022) propose a method of analysis with combining scaled boundary finite element method (SBFEM), strength reduction method (SRM) and polytree-based mesh refinement algorithm. Others, proposed the use of an ensemble learning techniques for the prediction of slope stability (Zhang et al., 2022).

2 USES OF GEOTEXTILES

Geotextiles are any textile-like material used in civil engineering applications to improve soil structural performance, used to separate, filter, reinforce, erosion protect, or drain (Sabiri et al., 2020; Wu et al, 2020). Reinforcement is probably one of the earliest application of geotextiles (Ingold, 1994). Geotextiles are used to increase soil stability, provide erosion control or aid in drainage. In roads and rail applications, they allow filtration and separation of granular layers. Due to the characteristics of high strength, low cost, and easy to use, geotextiles are widely used in geotechnical engineering such as soft foundation reinforcement, slope protection, and drainage system.

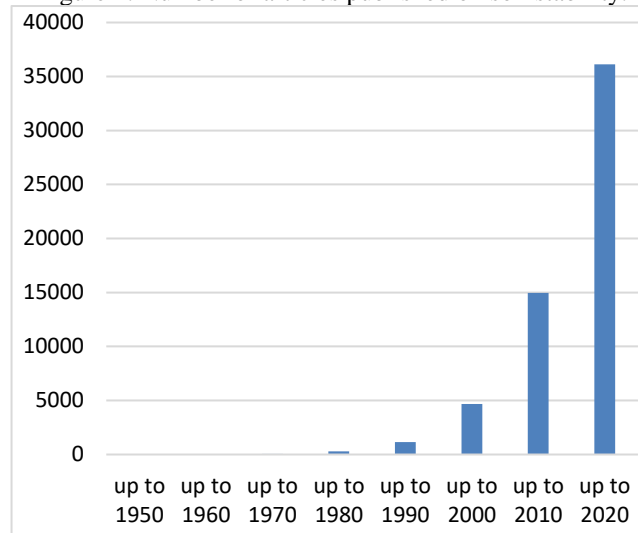
Geotextiles can be produced from polyester or polypropylene polymers and or natural fibers; the synthetic polymers can cause environmental problems. The development of more environmentally friendly and biodegradable geotextiles is of interest for several application purposes. In general, there are two material classes available, which are natural fibers and biodegradable polymers. Geotextile fabrics, made of plant fibers, represent a promising approach and were already successfully installed in several applications (Prambauer et.al., 2019). However, the use of natural fibers also entails some limitations regarding water uptake and stability. Therefore, the potential use of a different material class, which comprises degradable, thermoplastic biopolymers, must be considered. There is only little information available on the use of these biopolymers in connection with geotextiles, thus their suitability regarding biodegradation, price and mechanical properties must be still evaluated.

There are three types of geotextiles: non-woven, woven or knitted. In particular, short-lived geotextiles find application as protection covers against soil erosion and revegetation aids, where plant growth is promoted until a natural green cover has established and the vegetation can take over the protective function.

Making a survey on database Web of Science, with just articles pair-reviewed published as a function of time, it is possible to see that the interest on soil stability, slope

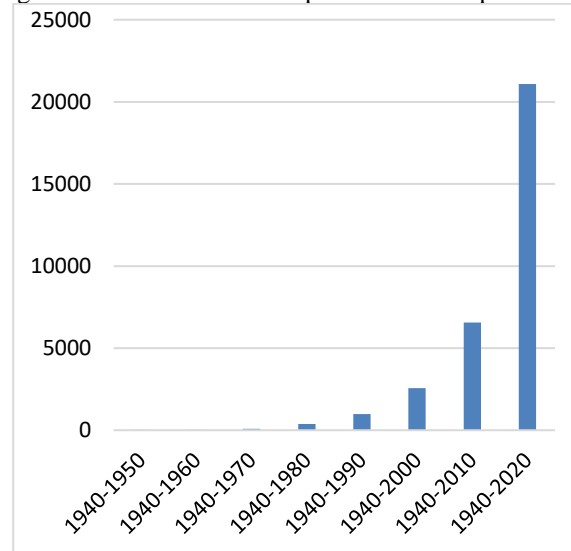
stability and geotextiles correlate as expected. In Fig.1, Fig. 2 and Fig. 3 are displayed respectively those data. Systematically and academic interest on the mentioned subjects started in the last decades of the last century but had an extraordinary increment in the current one. The figures from the 2010 almost triplicate in the following decade.

Figure 1. Number of articles published on soil stability.



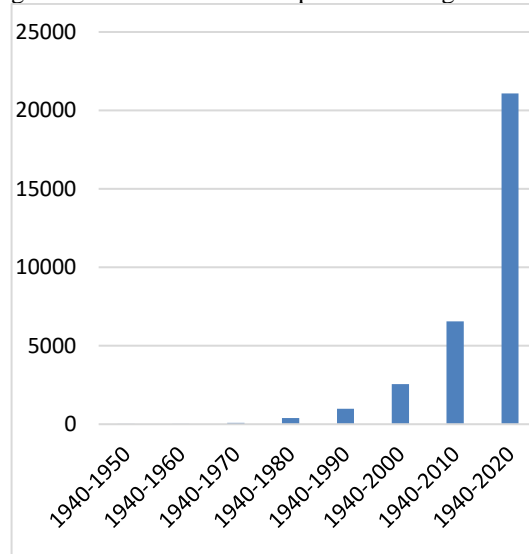
Source: Own Authorship.

Figure 2. Number of articles published on slope stability.



Source: Own Authorship.

Figure 3. Number of articles published on geotextiles.



Source: Own Authorship.

Different structures and forms of geotextiles are available to geotechnical engineers. Geotextiles in the form of woven and nonwoven structures are mostly used in various geo-engineering applications. Nonwovens are predominantly used for drainage, lining systems and asphalt overlay fabrics whereas the wovens are most frequently used for subgrade and base reinforcement, soil stabilization and separation, and sediment walls (Sengupta, 1991). Some functional properties would need to be satisfied by geotextiles:

1. **Mechanical properties.** This category covers properties such as tensile strength, breaking extension, modulus, abrasion resistance, bursting strength, frictional, bending and creep.
2. **Environmental properties.** This category covers chemical resistance, biological resistance, thermal resistance and resistance to UV degradation.
3. **Hydraulic properties.** In-plane water permeability and transverse water permeability properties are in this category.

Geotextiles market share, according to Desai & Kant (2016), were as follows: road construction, 44%, erosion control, 20%, drainage, 16% and others, 20%.

Kalore & Babu (2022) pointed out the importance of the design criteria for nonwoven geotextile to be used as filters with internally stable and unstable soils.

3 NATURAL FIBRE-BASED GEOTEXTILES

A variety of lignocellulosic materials are applicable to produce biobased, biodegradable geotextiles (English, 1994). Methacanon et al. (2010) studied the composition and properties of geotextiles made of long fibers such as sisal and roselle, and short fibers such as reed and water hyacinth. They observed that their applications depend mainly on parameters such as climate condition, soil type and composition or land sloping.

Natural fibre-based geotextiles can compete with polymeric geotextiles on both technical and economic grounds (Leao et al., 2012; Tanasa et. al, 2022). Basu et al. (2019) proposed bioengineering of river earth embankment using natural fibre-based composite-structured geotextiles. Vegetable or plant fibres (from bast fibres, leaf fibres and fruit or seed fibres) have suitable properties to meet technical requirements cost effectively for use as natural geotextiles. Natural lignocellulosic fibers exhibit a good set of mechanical properties and their incorporation into polymers, not only leads to a reduction of the environmental impact of the compounds, but also to an improvement of biodegradability (https://books.google.com.br/books?hl=en&lr=&id=AwXugfY2oc4C&oi=fnd&pg=PP1&ots=gNN7TAZbPQ&sig=MRCPhiG690gliPjYF3yrTixZ69w&redir_esc=y#v=onepage&q&f=false)

Although jute and coir geotextile products are currently available worldwide, Leao et al. (2012) consider that jute, coir and sisal, and also hemp, kenaf and African palm are also suitable raw materials for geotextiles.

Highway construction broke the balance of ecological environment, especially in mountains areas. However, the plant community reconstruction at the highway slope can reduce the destruction effect, especially at the beginning of the project. Yang & Wang (2018), used three types of geotextiles including coir-straw blanket (CB), straw blanket (SB) and nonwoven geotextile net (NG) to paved on highway slopes and the effects on soil erosion, the soil hygrothermal condition and vegetation growth were investigated. The results of field experiments, based on two years of research, showed that in artificial rainfall experiments CB, SB and NG could delay the time to runoff, reduce the runoff and decrease the erosion, effectively. Natural geotextiles effectively controlled runoff and soil erosion, although the effectiveness of the natural geotextiles varied. For runoff control, straw blanket (SB) performed better. For soil erosion control, coir blanket (CB) was the most effective. The geotextiles as mulching material had multiple benefits including

protected the topsoil and seeds from being washed away from the no vegetation covered slope, and enhanced vegetation growth by improving soil conditions, particularly in the beginning stage of slope vegetation restoration.

In Brazil, there is a great variety of vegetal fibers with different chemical, physical and mechanical properties that can be used for the preparation of geotextiles, like babassu (Franco, 2010) and piassava (Elzubair & Suarez, 2012) or jute (Gupta et al., 2018).

4 POTENTIAL OF BABASSU

Babassu is an erect perennial evergreen palm, reaching up a height of 15 to 30 m. The trunk is slender, ringed with leaf scars, 20-50 cm in diameter. It is a palm with socioeconomic and ecologic importance found in humid tropical areas in Brazil, especially in frequently burned and degraded landscapes (Ferrari & Soler, 2015). Babassu is native to Brazil, but also to Guyana, Suriname and Bolivia (USDA, 2010. GRIN - Germplasm Resources Information Network. National Germplasm Resources Laboratory, Beltsville, Maryland). The babassu palm is considered weed in pasture areas of “Cerrado”, the vast tropical savanna ecoregion in Brazil.

Various scientific names are usually found for the babassu in current literature: mainly *Orbignya phalerata* and *Attalea speciosa*, but also *O. speciosa* and *O. martiana*, among others. This multiplicity of names leads to great confusion in the scientific community causing mistakes to be successively propagated. According to Cavallari & Toledo, (2016) it is recommended the adoption of *Attalea speciosa* Mart ex. Spreng as the most suitable name for the babassu and highlight that a broad taxonomic review of the *Attalea* group is necessary.

Babassu is one of the most important non-timber forest resources of rural communities in the Amazon. Araujo et al. (2016) explored the ethnobotanical knowledge and uses of babassu by riverine populations inhabiting the Tucuruí Lake Protected Areas Mosaic in the eastern Amazon, by examining the diversity, purposes and descriptions of its uses and aspects of its extraction. Data were collected in 2010 and 2014 from 193 families. A total of 1,226 use records were cited representing 60 different uses. Records were classified into nine use-categories; utensils and tools were the most important category, followed by construction and human food. Babassu oil has been used in South American countries for cooking and medicinal purposes. It also has industrial applications as a biofuel. In the United States, it's mainly used in skin and hair care products.

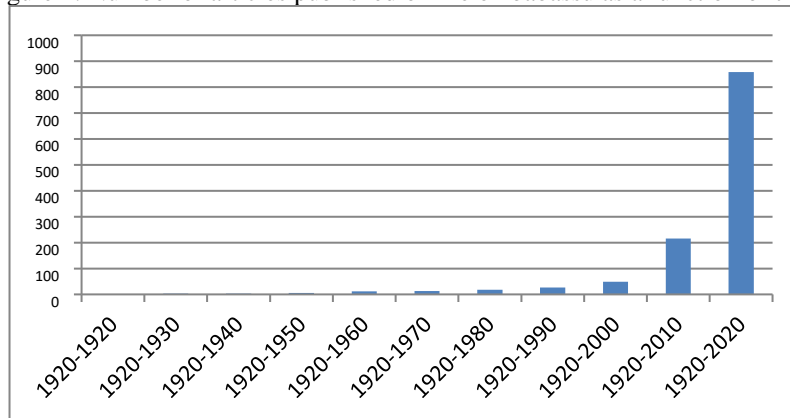
There are several uses for babassu oil; however, its potential for providing other industrial products remains unexploited, due to the lack of scale and production structure. The rudimentary nature of the babassu kernel extraction process employed by the peasantry has been blamed for being one of the key factors of the crisis in the babassu oil industry economy. Pinheiro & Frazão proposed in 1995 the use of a new model, instead the traditional one, for sustainable exploitation of babassu palm forests and integral fruit processing at the village and farm- level. In 2015, Ferrari & Soler established conditions for the preparation of the raw material fruit of babassu for oil extraction by pressing and producing biodiesel by ethanolic transesterification. Oil and press cake were obtained through hydraulic and continuous press, biodiesel was produced and the quality of products was compared. The total of saturated fatty acid in babassu oil was between 78 and 82 %, and the total of unsaturated fatty acids that promote good oxidative stability in the oil was in the range of 17 to 20 %. Oil obtained by cold pressing extraction and its biodiesel had better results in terms of quality. The quality of oils is within the Codex standard and biodiesel from oil extracted by cold pressing had higher oxidative stability.

Babassu is a source of biomass for energy and raw material in the manufacture of handicrafts. The babassu oil corresponds to only 7% of the total weight of the fruit; the other parts like the epicarp, the endocarp, and the mesocarp (93%) are underused as biomass. The babassu endocarp and epicarp have high content of fixed carbon, which makes them more suitable for carbonization and burning than the babassu nuts and mesocarp, which contain less than 5% fixed carbon.

There is a strict relationship between public policies, and their relationship with local economic growth (Pinheiro e al., 2022). The babassu mesocarp is usually transformed into flour and used in animal feed. Also, babaçu by-products (endocarp, mesocarp, epicarp and activated carbon) can be used as a potential adsorptive target species for inorganic and organic molecules (Teixeira, 2008, Silva et al, 2013, Maniglia et al. 2017; Silva et al, 2019).

Although some articles were published as early as 1930 (Lee, 1930) and 1940, the interest in academic studies on babassu and all their multiple uses was very low until the present century. Figure 4 presents the number of articles published in English that appeared on line mainly peer-reviewed works. It is evident the poor academic interest on this palm until the last two decades.

Figure 4. Number of articles published online on babassu as a function of time.



Source: Own Authorship.

In the present century, new applications on babassu were described showing the impact of such increased interest. Raposo et al. (2021) developed formulations for polymeric alginate films with added starch from the babassu coconut mesocarp, fiber removed from the babassu coconut epicarp and glycerol, crosslinked with CaCl_2 , to be used as base materials to manufacture utensils such as biodegradable packaging and shopping bags.

Staufenberg et al., (2015) prepared biomimetic fibre-reinforced composites using babassu nut based on regenerated cellulose fibres (lyocell, L) with two different fineness values as reinforcement embedded in a polylactide (PLA) core matrix and polypropylene (PP) based outer layers. The biomimetic fibre composite reaches a significantly higher impact strength that is 1.6 times higher than the reference sample produced from a PLA/PP/L-blend. At the same time the hardness is slightly increased compared to PP/L.

The influence of thermoplastic starch and babassu mesocarp incorporation on the biodegradation of poly(butylene adipate-co-terephthalate), PBAT, PBAT/TPS blend, and its biocomposite were investigated by Nunes et al., (2019). The incorporation of thermoplastic starch and babassu mesocarp to poly (butylene adipate-co-terephthalate) led to a reduction in PBAT molecular weight on the blends and composite, but the reduction was higher on the blends than in the composite, while addition of thermoplastic starch accelerated biodegradation and incorporation of babassu retarded it. Mitjia et al. (2019) start a multidisciplinary research still in progress, on the viability of the babassu palm eco-socio-system in Brazil, to enabling us to consider the best way to ensure its sustainability.

5 BABASSU AS A COMPONENT OF GEOTEXTILES

Sponga, & Coelho (2005) prepared a vegetal covering for cut slopes by means of geocells of rubberized sisal bioblankets. Costa et al., (2018) studied de degradation during processing of vegetable fiber compounds based on PBAT/PHB blends, using materials obtained by grinding the outer layers of the fruit of the babassu palm tree. Lemos et al. (2017) established the potential of natural fibers supplied by agroindustrial residues from sugarcane, wood and babassu to be used as reinforcement in biocomposites for various applications.

Rodrigues (2019) described the preparation and properties of composite made from babassu coconut epicarp fiber plus polymeric residues. Furtado et al. (2020) prepared a polymeric composite produced from fiber of babassu palm tree treated by mercerization and 5%, 10%, and 20% high-density polyethylene (HDPE) matrix. They studied the physico-chemical characteristics and evaluate the degradation of the polymeric composites. Polymeric composites, were characterized by FTIR, XRD, TG/DTG, SEM, AC impedance and traction test. Traction tests revealed that at a high fiber concentration of 20%, the mechanical resistance of the composites can decrease. After characterization, the materials were subjected to degradation processes via UV radiation. For comparison, a sample of an oxo-biodegradable plastic bag was evaluated under the same conditions. The incorporation of babassu fiber into an HDPE matrix in the formation of a polymeric composite is promising for enhancing photo-oxidation degradation.

6 CONCLUSION

The use of geotextiles, as showed in this work, have grown during the last decades employed in infrastructure, soil, construction, agriculture and environmental applications, been slope protection and restoration one of them. The basic concept of geotextiles dates back to ancient times when textiles consisting of locally available natural fibers were employed to increase the stability of roads and soils. Nowadays, in spite of geotextiles made of synthetic fibers (geosynthetics) are considered a modern achievement, the return to the use of plant fibers appears as a versatile tool for environmental sensitive applications in geotechnical engineering. Mainly in Brazil, babassu fibers seem to have a great potential, no yet explore enough, to be use whether in the stabilization of soil, the

river banks, ground reinforcement for civil infrastructure or filtration of water excess in farmlands and flood protection, hill slopes stabilization and drainage, as plant geotextiles are successfully performing in civil engineering and agriculture and becoming an increasingly viable alternative in many other applications.

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REFERENCES

- Araujo, F.R., González-Pérez, S.E., Lopes, M.A., Viegas, I.J.M. (2016). Ethnobotany of babassu palm (*Attalea speciosa* Mart.) in the Tucuruí Lake Protected Areas Mosaic - eastern Amazon. *Acta Bot. Bras.* 30 (02). <https://doi.org/10.1590/0102-33062015abb0290>.
- Basu, G., Roy, A.N., Sanyal, P., Mitra, K., Mishra, L., Ghosh, S.K.(2019). Bioengineering of river earth embankment using natural fibre-based composite-structured geotextiles, *Geotextiles and Geomembranes* 47, 493-501. ISSN 0266-1144, <https://doi.org/10.1016/j.geotexmem.2019.03.002>.
- Cavallari, M.M., Toledo, M.M. (2016). What is the name of the babassu? A note on the confusing use of scientific names for this important palm tree. *Rodriguésia* 2 67. <https://doi.org/10.1590/2175-7860201667218>.
- Chuan, D., Lanzhu, C., Lan, J., Zhang, H. (2013). Slope stability calculation of open pit using 3Dslope software. *Journal of Liaoning Technical University* (Natural Science Edition) 32, 297 – 300. ISSN 10080562.
- Costa, A.R.M., Reul, L.T.A., Ferna, F.M., Sousa, Ito, E.N., Carvalho, L.H., Canedo, E.L. (2018). Degradation during processing of vegetable fiber compounds based on PBAT/PHB blends, *Polymer Testing* 69, 266-275. ISSN 0142-9418, <https://doi.org/10.1016/j.polymertesting.2018.05.031>.
- Desai, A.N. & Ravi Kant. (2016). 4 - Geotextiles made from natural fibres. In: Editor(s): R.M. Koerner, *Geotextiles*, Woodhead Publishing 61-87, ISBN 9780081002216, <https://doi.org/10.1016/B978-0-08-100221-6.00004-8>.
- Elzubair, A.;Suarez, J C. M., (2012). Mechanical behavior of recycled polyethylene/piassava fiber composites. *Materials Science & Engineering A* 557, 29–35. DOI: [10.1016/j.msea.2012.06.051](https://doi.org/10.1016/j.msea.2012.06.051)
- English, B. (1994). Biobased, biodegradable geotextiles: USDA forest service research update. In: Steiner, P.R., comp. In: *Proceedings of the 2d Pacific Rim bio-based composites symposium; November 6-9, 1994*, Vancouver, Canada. Vancouver, B.C.: University of British Columbia, 204-212.
- Ferrari, R.A.; Soler, M.P. (2015). Obtention and characterization of coconut babassu derivatives. *Sci. agric. (Piracicaba, Braz.)* 72 (4), <https://doi.org/10.1590/0103-9016-2014-0278>.
- Franco, F.J.P. (2010). *Utilization of babassu coconut epicarp fiber in epoxy matrix composites. Study of the effect of fiber treatment*. Thesis (Master's degree). Federal University of Rio Grande do Norte, Natal, RN, Brazil, 2010, 77p.
- Furtado, J.B.D., Furtado, P.A., Oliviera, T.P. *et al.* (2020). Polyethylene/Fiber Composite - Characterization and Degradation. *Revista Virtual de Química* 12 (1), 272-285. DOI: [10.21577/1984-6835.20200021](https://doi.org/10.21577/1984-6835.20200021)

Gupta, A.K. S. (1991). *Geotextiles: opportunities for natural-fibre products*. In: International Trade Centre, International Trade Forum 27(10), 10.

Ingold, T.S. ed. (1994). *Geotextiles and Geomembranes Handbook*. Elsevier Science Ltd, Oxford, 609 pp. ISBN 1 85617 198 1.

Jebakumar, P., Prince, J., Ganesan, N. *et al.* (2022). Ecological Appraisal of Geotextiles in Coastal Erosion Protection Engineering. *Journal of Coastal Research* 38, (2), 345-354. <https://doi.org/10.2112/JCOASTRES-D-21-00067.1>

Lemos, A.L., Mauss, C.J.; Santana, R.M.C. (2017). Characterization of natural fibers: wood, sugarcane and babassu for use in biocomposites. *Cellulose Chem. Technol.* 51 (7-8), 711-718. [https://cellulosechemtechnol.ro/pdf/CCT7-8\(2017\)/p.711-718.pdf](https://cellulosechemtechnol.ro/pdf/CCT7-8(2017)/p.711-718.pdf)

Leão, A.L., Cherian, B.M., De Souza, S.F., Kozłowski, R.M., Thomas, S., Kottaisamy, M., (2012). 9 - Natural fibres for geotextiles, Editor(s): Ryszard M. Kozłowski, In: Woodhead Publishing Series in Textiles, *Handbook of Natural Fibres*, Woodhead Publishing 2, 280-311, ISBN 9781845696986, <https://doi.org/10.1533/9780857095510.2.280>.

Lee, A.P. (1930). The Brazilian Babassu: Tropical forests natural storehouses for great quantities of high-quality oil. *Journal of the American Oil Chemists' Society* 7 (3), 91-93.

Liu, H.Y., Wang, J., Zhang, K. Kong, Y. (2016). Effectiveness of geotextiles for road slope protection under simulated rainfall. *Environ Earth Sci.* 75:1198, <https://doi.org/10.1007/s12665-016-6007-5>.

Macambira, I. Q. (2002). *Hydraulic behavior of lateritic soils for use as impermeable barriers*. Dissertation (Master's) – School of Engineering of São Carlos, University of São Paulo, São Carlos Brazil 123 pp.

Maniglia, B.C., Tessaro, L., Lucas, A.A., Tapia-Blácido, D.R. (2017). Bioactive films based on babassu mesocarp flour and starch. *Food Hydrocolloids* 70, 383-391. ISSN 0268-005X, <https://doi.org/10.1016/j.foodhyd.2017.04.022>.

Methacanon, P., Weerawatsophon, U., Sumransin, N. *et al.* (2010). Properties and potential application of the selected natural fibers as limited life geotextiles. *Carbohydrate Polymers* 82, 1090–1096.

Mitja, D., Sirakov, N., dos Santos, A.M. *et al.* (2019). Viability of the Babassu Palm Eco-socio-system in Brazil: The Challenges of Coviability. In: *Coviability of Social and Ecological Systems: Reconnecting Mankind to the Biosphere in an Era of Global Change*. Springer, Cham. https://doi.org/10.1007/978-3-319-78111-2_14.

Nie, X., Chen, K., Zou, D., Kong, X., Liu, J. Qu, Y. (2022). Slope stability analysis based on SBFEM and multistage polytree-based refinement algorithms, *Computers and Geotechnics* 149, 104861, ISSN 0266-352X. <https://doi.org/10.1016/j.compgeo.2022.104861>.

Nunes, M. A. B. S., Castro-Aguirre, E., Auras, R.A., Bardi, M.A.G., Carvalho, L.H. (2019). Effect of Babassu Mesocarp Incorporation on the Biodegradation of a PBAT/TPS Blend *Macromol. Symp.*, 383, 1800043. <https://doi.org/10.1002/masy.201800043>

Pinheiro, C.U.B., Frazão, J.M.F. (1995). Integral processing of babassu palm (*Orbignya phalerata*, arecaceae) fruits: Village level production in Maranhão, Brazil. *Econ. Bot.*, 49, 31–39. <https://doi.org/10.1007/BF02862274>.

Pinheiro, L.O.; Sales, D. A.; Oliveira, R.J.S.P. (2022). Northern Lagoas program as an inducer of economic growth for the Northern region of Teresina through public policies. *Brazilian Journal of Business*, Curitiba, v. 4, n. 4, p. 1807-1824. <https://doi.org/10.34140/bjbv4n4-015>

Prambauer, M.; Wendeler, C., Weitzenböck, J., Burgstaller, C. (2019). Biodegradable geotextiles – An overview of existing and potential materials. *Geotextiles and Geomembranes* 47(1), 48-59. ISSN 0266-1144, <https://doi.org/10.1016/j.geotextmem.2018.09.006>.

Raposo, A.C.S., Paixao, L.C., Rocha, A.A. *et al.* (2021). Characterization of Biodegradable Films Produced from Mixtures of Alginate, Starch and Babassu Fibers. *Journal of Polymers and the Environment* 29:1212–1226. <https://doi.org/10.1007/s10924-020-01952-z>.

Rodrigues, P.R.B. (2019). *Physical-mechanical performance of a composite made from babassu coconut (Orbignya Phalerata) epicarp fiber and polymeric residues*. Master's Dissertation, Universidade Federal do Tocantins, TO, Brazil. (In Portuguese).

Sponga, M., Coelho, I.C.O. (2005). Vegetal covering in cut slopes by means of geocells of rubberized sisal bioblankets in Brasilia/df, Brazil. *Revista Sociedade & Natureza, Especial* (1), 284-294. ISSN: 0103-1570 (Print). <https://www.redalyc.org/articulo.oa?id=321328500032>

Tanasa, F., Nechifor, M., Ignat, M.-E., Teaca, C.-A. (2022). Geotextiles—A Versatile Tool for Environmental Sensitive Applications in Geotechnical Engineering. *Textiles* 2, 189–208. <https://doi.org/10.3390/textiles2020011>

Teixeira, M.A. (2008). Babassu: A new approach for an ancient Brazilian biomass. *Biomass & Bioenergy* 32 (9), 857-864. <https://doi.org/10.1016/j.biombioe.2007.12.016>

Sabiri, N.E., Caylet, A., Montillet, A., Le Coq, L., Durkheim, Y. (2020). Performance of nonwoven geotextiles on soil drainage and filtration, *European Journal of Environmental and Civil Engineering* 24:5, 670-688. <https://doi.org/10.1080/19648189.2017.1415982>.

Silva, I.C., Sao Pedro, F., Sakuno, I.Y.T., Dake, J.A., Chova, L.G., Martinez, A.L., Torres, I.C. (2013). In: Eds. Learning on handicraft of babassu palms and affirmative action against barriers in ethnic communities. *Proceedings of the 7th International technology, education and development conference (INTED2013)* 4302-4305. ISBN: 978-84-616-2661-8 / ISSN: 2340-1079.

Silva, J.S., Santos, M. L., Silva Filho, E. C. *et al.* (2019). Byproducts of babassu (*Orbignya* sp) as new adsorptive materials: a review. *Revista Matéria (Rio de Janeiro)* 24, (3). <https://doi.org/10.1590/S1517-707620190003.0730>

Gupta, S., GuhaRay, A., Kar, A., Komaravolu, V.P. (2018). Performance of alkali-activated binder-treated jute geotextile as reinforcement for subgrade stabilization, *International Journal of Geotechnical Engineering* 15(3), 299-312. <https://doi.org/10.1080/19386362.2018.1464272>.

Kalore, S.A.; Sivakumar Babu G.L. (2022). Improved design criteria for nonwoven geotextile filters with internally stable and unstable soils. *Geotextiles and eomembranes* ISSN 0266-1144, <https://doi.org/10.1016/j.geotexmem.2022.07.004>.

Staufenberg, G., Graupner, N., Müssig, J. (2015). Impact and hardness optimisation of composite materials inspired by the babassu nut (*Orbignya speciosa*), *Bioinspir. Biomim.* 10 (5), 056006. PMID: 26291183, <https://doi.org/10.1088/1748-3190/10/5/056006>.

Wermeier, K.F.; Noya, M.G. (2019). Phytoremediation plants as an aid in the quality of water drained from green roofs. *Braz. J. Technol.*, Curitiba, v. 2, n. 4, p. 916-929.

Wang, G., Zhao, B., Wu, B., Zhang, C., Liu, W. (2022). Intelligent prediction of slope stability based on visual exploratory data analysis of 77 in situ cases. *International Journal of Mining Science and Technology* ISSN 2095-2686, <https://doi.org/10.1016/j.ijmst.2022.07.002>.

Wu H.; Yao C., Li C., Miao M., Zhong Y., Lu Y., Liu T. (2020) Review of Application and Innovation of Geotextiles in Geotechnical Engineering. *Materials* (Basel) 13(7), 1774. <https://doi.org/10.3390/ma13071774>.

Yang, Y., Wang, J.M. (2018). Effects of geotextiles for highway slope restoration due to plant community in qin-ba mountain areas of South-shaanxi, China. *Fresenius Environmental Bulletin* 27(8), 5742-5751. ISSN : 1018-4619
URL : <https://www.prt-parlar.de/.../>