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The real reasons for choosing bushing fiber (*Luffa cylindrica*): A bibliographic review

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***Abstract*— *Growing environmental issues and the search for alternatives to synthetic fibers have led to the development of composite materials made from natural fibers. Luffa Cylindrica has an important prominence in scientific research due to its properties presenting excellent results for the use of reinforcement in matrices. Therefore, this work aims to analyze the physical, chemical and mechanical properties of bushing fiber based on scientific articles. The publications were selected from a search in the databases, CAPES Periodicals, Scielo and Google Scholar, from 2003 to 2021. Thirty-three works were selected that deal with the properties of Luffa Cylindrica, with twelve articles from the years of 2017 to 2021. It was concluded, with this review, that Luffa Cylindrica encompasses ideal qualities for use as reinforcement of composite materials, as it abundant in nature, low cost and low weight, is non-toxic and has physical and chemical stability.*

I. INTRODUCTION

The use of plant fibers in composite materials is expanding every year due to the growing concern for the environment [11]. This is mainly due to the fact that these fibers have biodegradable characteristics, are less aggressive to the environment, have a great variety and availability in biodiversity, compared to the reinforcement materials currently used, they have a lower cost and are harmless to the health [23]. Therefore, natural fiber becomes an excellent alternative for use as reinforcement in composite materials [1].

Natural fibers exhibit important results of their properties when used as reinforcement in polymeric materials. Luffa sponge is a lightweight natural material that has the potential to be used as a sustainable alternative material for various engineering practice applications [10]. In addition, loofah (*Luffa cylindrica*) is an economic reinforcement material, as they are among the largest and most diverse families of plants, being cultivated all over the world, for supporting a variety of environmental conditions [23].

The bushing has been successfully used as a biotechnological tool in a variety of systems, purposes and applications such as: packaging, sound and vibration insulation, impact energy absorption, manufacture of insoles, slippers, sieves, belts and filters of car oils, bath sponges and hats [10, 12, 23, 25]. In addition, it is also widely used in various other fields such as pharmaceutical engineering, environmental engineering, industrial, medicinal products [4, 8] and adsorption materials in water treatment plants [5], in which its chemical stability stands out and good moisture absorption [25].

Luffa cylindrica (LC) is a subtropical plant abundant in China, Japan and other Asian countries, as well as in Central and South America, belonging to the Cucurbitaceae family [1, 2, 5]. The plant reaches a length of approximately 10 m. The fruit has a cylindrical shape, with a length of 15 cm to 100 cm and a diameter of 8 cm to 10 cm [23].

The fruit of the loofah plant has a fibrous vascular system, in which it is arranged in the form of a multidirectional network, which forms a natural blanket, with yellow color when ripe and dark brown when dry [23]. The bushing can be presented in two ways, with a density range of 15 to 30 kg/m^2 which is considered low density (LD), while in the density range of 31 to 65 kg/m^2 it is considered high density (HD) [22].

The literature demonstrates several articles that present the advantages of using bushing fiber. A comparison study shows that *Luffa* sponge has better energy absorption capacity per unit mass than other cellular materials with similar plateau stress at various strain rates [10].

Another study investigated potential for the development of new epoxy composites reinforced with the fibers in question. In this research, they concluded that the grafting of *Luffa* fibers with furfuryl alcohol and alkaline treatment significantly improved the thermal, mechanical and water resistance properties of the composites [11].

Finally, the work on immobilized cells demonstrated an efficient performance in the removal and biodegradation of toxic metals, dyes and chlorinated chemicals in which *Luffa* was considered a good support for the development of biofilms for wastewater treatment [12].

This article aims to carry out an analysis of the physical, chemical and mechanical properties of the loofah (*Luffa cylindrica*) based on literature data. This article is justified by the fact that through the study of natural fibers it will be possible to understand the best and most efficient application of their use in polymeric matrices, taking into account that their biodegradability can contribute to a healthier ecosystem and their low cost and performance serves the economic interests of various industries.

II. METHODOLOGY

The research was carried out from March to August 2021 with an extensive review in the Databases, Capes Periodicals Portal, Scielo and Google Scholar. The following keywords were used in the searches: bushing properties, bush, *Luffa cylindrica* property, *Luffa cylindrica* physical, chemical property and mechanical property.

An analysis of works developed in the country and published in indexed National and International Journals was carried out, from 2017 to 2021 to compose the results and the discussion. From this search, 33 articles related to the properties of *Luffa cylindrica*, published in indexed scientific journals, were selected from the bibliographic research. After selecting the articles, a thorough reading was carried out, from which the main information of the texts discussed was extracted and analyzed. The other articles were not included, because even when they were rescued, they were studies not related to the criteria adopted in this work.

Also in the composition of this review, articles were selected between the years 2004 and 2016 for literary basis and support in the discussion.

III. RESULTS AND DISCUSSION

Of the 33 articles evaluated, 12 articles were about chemical, physical and mechanical properties in the years 2017 to 2021, as shown in Table 1. According to the results obtained, all works presented in their investigations the mechanical properties related to the bushing. Two articles characterized the bushing by chemical property and two studied its physical properties.

3.1 MECHANICAL PROPERTIES OF THE BUSHING

The works 1, 2 and 3 investigated the mechanical properties, specifically of *Luffa cylindrica* by the tensile strength method. Article 1 analyzed low and high density Luffas, 15 kg/m^3 to 30 kg/m^3 and 31 kg/mm^3 to 65 kg/m^3, respectively. Article 2 studied Luffa fibers with and without alkaline treatment (2% aqueous NaOH), and article 3 evaluated fibers submitted to chemical pre-treatments.

For the tensile strength measurements of article 1, the Luffa sponge fibers were air-dried until their moisture content varied from 8% to 10% by weight (% by weight) and cut into 30 mm long sections. Subsequently, tensile tests were conducted on a universal testing machine (Shimadzu Corporation, Shimadzu AG-X Plus, Kyoto, Japan) with a load cell of 1 kN and a crosshead speed of 0.5 mm/min. Tensile tests proved that high density fibers have lower mechanical strength than low density *Luffa* fibers. The authors concluded that the probable reason for this behavior may be the high crystallinity of cellulose in the high density sponge [22].

Table.1: Articles from 2017 to 2021 related to Luffa Cylindrica properties.

No.	Properties	Methods	Reference
1	Mechanics	Tensile strength	[22]
2	Mechanics	Tensile strength	[23]
3	Mechanics, Physics and Chemistry	Tensile strength, diameter and roughness	[24]
4	Mechanics	Compressive strength, flexibility modulus and water absorption	[25]
5	Mechanics	Compressive strength	[26]
6	Mechanics	Tensile strength	[27]
7	Mechanics	Tensile and flexural strength	[28]
8	Mechanics	Tensile strength, flexural strength, and impact strength.	[29]
9	Mechanics	Non-destructive impulse excitation	[30]
10	Mechanics and physics	Physical, mechanical and abrasive wear and water absorption	[31]
11	Mechanics	Compressive strength and modulus of elasticity	[32]
12	Chemistry and Mechanics	Tensile strength and modulus of elasticity	[33]

Article 2 performed the mercerization with 2% aqueous NaOH on the *Luffa* fibers and carried out the tensile test on samples from both alkaline and untreated samples. For this, a Shimadzu SLBL machine with a load cell of 500 mN was used. In this study, mercerization was found to increase the fiber's mechanical strength. This result is probably due to the fact that the crystallinity index of *Luffa cylindrica* fiber increases with chemical treatments [23].

Research 3 presents the tensile properties of Luffa fibers with and without chemical surface pretreatments. Where the chemical surface pretreatments used in this work were sodium hydroxide, silane and calcium hydroxide, for this they used an Instron universal testing machine type 5500 R with applied pressure of 0.4 MPa using pneumatic gripper in a cell of load of 1.0 kN and crosshead speed of 0.1 mm min^{-1} at room temperature (21 °C).

The authors observed that the pre-treatments performed on the Luffa fiber removed most of the non-crystalline constituents, which resulted in an increase in the overall strength of the fiber. *Luffa* fibers treated with $Ca(OH)_2$ showed the highest tensile strength (~ 719 MPa), this fact may be associated with the removal of impurities from the fiber surface due to these treatments, which generates a greater mechanical interlock with the polymer matrix [24].

Articles 4 and 5 investigated the mechanical properties of the bushing using the compressive strength method. Research 4 studied high density (35 to 65 kg/m^3) and low density (15 to 35 kg/m^3) *Luffa cylindrica*. Article 5 evaluated high density *Luffa cylindrica* subjected to three types of softening treatment methods, which are alkaline hydrogen peroxide, alkaline acetic acid and alkaline urea. Both researches studied the properties of the bushing for use in mattress filling.

In addition to the uniaxial compressive strength test of *Luffas Cylindricals*, research 4 evaluated their flexibility and water absorption module. The authors demonstrated that the compressive strength of the columns of the high-density bushing was significantly higher than that of the columns of the low-density bushing. This result is justified by the fact that high density fibers have relatively more methylene and a lower amount of lignin, which favors good flexibility and resilience to the macromolecules and microfibrils chain. On the other hand, low density fiber contains more lignin, which indicates more stiffness. Finally, both types of materials showed good water desorption, in which they concluded that the use of Luffa filling material to prepare mattresses is suitable for its proper use [25].

Research 5 also performed uniaxial compression on the samples, but researched bushings submitted to three types of chemical treatment methods. The authors concluded that the three methods were able to reduce peak stress and improve the uniformity of high density *Luffa*. The fiber compression resilience after treatment with 18% NaOH - 6% $CO(NH_2)$ showed the highest compression resilience. This process is a result of the shrinkage of the cell wall of the fiber, which evolved from a hexagonal cell lumina to an open lattice with an irregularly shaped wrinkled structure, which provides the fiber with excellent elasticity [26].

Through the results of the strength of the bushing, it was observed that there is a difference in the mechanical behavior of the fibers depending on their density. Another important point is the influence of chemical treatment on the mechanical properties of the samples. In the first two works, the fiber is studied to be used as reinforcement in matrices, resulting in a study that the low density *Luffa cylindrica* is more resistant to traction. In the second study, the high density *Cylindrical Luffas* were submitted to a chemical treatment, obtaining an improvement in the compressive strength. In this case, the objective was to study luffa for mattress filling, with the result that the chemically treated fiber has become an excellent material option for applications of products subjected to compression.

The third and fourth articles aimed to study bushings for filling mattresses, so their focus was the study of the compressive strength of these fibers. Differently from article 1, where low density *luffa* presented better results, article 4 showed that the high density bushing presented itself as the most suitable material for its purpose. The fourth article presented three types of chemical treatments in its fibers, in which, as reinforced in article 2, the treatment to which they are submitted improves both the tensile strength and the compressive strength of the fibers studied.

Studies on the mechanical behavior of fiber traction and compression are extremely important. In this sense Chen et al. [16] studied these parameters at different locations on a *luffa* sponge. The result showed that single fiber is a porous composite material consisting mainly of cellulose fibrils and lignin/hemicellulose matrix, and its elastic modulus and strength are comparable to wood. Furthermore, it shows that the inner surface has stronger mechanical properties than the central part.

Other research has shown the stiffness, strength and energy absorption characteristics of the *luffa* sponge through a series of compression tests on *luffa* sponge columns. Stress-strain curves show an almost constant plateau stress over a long strain range, which is ideal for energy absorbing applications. The spongy *luffa* material has been found to exhibit remarkable rigidity, strength, and energy absorbing capabilities that are comparable to those of some metallic cellular materials in a similar density range [7].

Shen et al. [10] investigated the effect of strain rate of *luffa* sponge material with a wide density range. It was found that the compressive strength, plateau stress and specific energy absorption of the spongy material *luffa* are: all load rate sensitive; that the energy absorption capacity per unit mass at high strain rates of *luffa* sponge is greater than that of many commonly used metallic foams; and that luffa sponge has the potential to be used as an alternative sustainable material for various engineering applications such as packaging, sound and vibration insulation, and impact energy absorption.

3.2 MECHANICAL PROPERTIES OF THE BUSHING AS REINFORCEMENT IN A MATRIX

In addition to the studies carried out directly on the bushing fiber, research was found where the mechanical properties of the bushing are investigated as reinforcement in a matrix. Articles 6, 7, 8 and 9 evaluated the properties of *Luffa cylindrica* as an epoxy resin reinforcement.

The articles 6 and 7 investigated the mechanical properties of composites (*Luffa cylindrica* and epoxy resin). For this, article 6 carried out tensile creep tests in linear viscoelastic regime and article 7 studied the behavior of moisture absorption and swelling in thickness and its effect on tensile and bending properties.

In research 6, 30% by weight fraction of fibers were added to the resin, continuously allocated, oriented parallel to the longitudinal direction of the layer. Then the samples were tested at four stress levels corresponding to 5%, 8%, 10% and 15% of the static tensile strength of the composite. The authors compared the pure resin with *Luffa cylindrica* composite and epoxy resin and concluded that there is a tendency for the creep response to increase linearly with the application of tension. As well as the reduction of creep deformation occurs as it increases with the application of stress. This implies that the greater the applied load, the greater the effect of the fibers to contain creep [27].

Article 7 studied composites with three different weight ratios of luffa fiber (6.5, 13 and 19% by weight), where they evaluated the effect on the tensile and bending properties of these samples that were subjected to different environments, distilled water and salt water (5% NaCl) and temperature below zero (-25 ºC). The results showed that under all environmental conditions, tensile and flexural properties decrease compared to dry composite samples.

Where, maximum degradation of properties occurs in case of distilled water environment followed by salt water and sub-zero environment. This is confirmed in the scanning electron microscopy images of the composites, which show that the fiber has a great tendency to swell and absorb more moisture in a distilled water environment, which possibly causes detachment of the matrix fiber and matrix cracking [28].

Articles 8 and 9 investigated the mechanical properties of epoxy composites with fibers subjected to chemical treatments. Article 8 studied the effect of mechanical properties on fibers treated with alkali (5% concentration), benzoyl chloride and potassium permanganate ($KMnO_4$) (0.05%) at room temperature. Article 9 investigated the effects of surface treatments of luffa fibers by hornification and mercerization methods.

Article 8 used double layer composites with 13% *Luffa cylindrica* fiber in its research. In this study, only the outer core of luffa fibers was used. It was observed that the mechanical properties of *Luffa cylindrica* fibers were significantly improved by modifying the fiber surface by different chemical methods. The improvement in all mechanical properties occurs due to the rough surface of the fiber produced by the removal of natural and artificial impurities, and fibrillation of the fiber which facilitates the mechanical anchoring between the fiber and the matrix. The best results were achieved in the case of the composite of fibers treated with benzoyl chloride [29].

For chemical modification of luffa fibers of article nine, 97% sodium hydroxide (analytical grade) was used, and for the hornification process, the fibers were placed in water at a temperature of 100 °C for three hours, until they reached their maximum absorption capacity, since for mercerization, the fibers were immersed in an aqueous solution of NaOH 2% by weight for 90 min. The composites in this research had 20% of the luffa weight fraction, in which the non-destructive impulse excitation technique was used to obtain the mechanical properties of the manufactured composites.

The results showed that the elastic modulus values are higher in luffa/epoxy composites made from fibers treated with mercerization and hornification, in which this may be related to higher crystallization values of the treated fibers and efficient removal of non-cellulosic components from the amorphous regions [30]. A previous study emphasizes that the effect of the mercerization treatment by weight of NaOH on the fibers produces only a small increase in flexural strength, and the best results were obtained with the 5% NaOH solution [1].

Among the four articles that investigated the properties of *Luffa cylindrica* as an epoxy resin reinforcement, three [27, 28, 29] presented methods widely used and widespread in the literature, such as tensile and flexural strength tests, on the other hand, the research 6 obtained its mechanical property through the impulse excitation method, in which it is used to measure the damping of the specimens. Thus, the impulse excitation technique is shown to be an effective method for the characterization of composite materials.

The fiber weight fractions used in research on *luffa*/epoxy composites were 6.5%, 13%, 19%, 20% and 30%. It was noted that with the addition of fibers in the epoxy matrix, the mechanical strength values increased compared to the epoxy resin without luffa fibers as a reinforcement phase, as these fibers absorb the efforts of the matrix. All the chemical treatments studied in the articles resulted in an increase in the mechanical strength of the composites. On the other hand, article 7, which subjected the fibers to different environments, noted that the composites had higher degrees of degradation in the samples, which resulted in lower mechanical strength, which was mainly noticed in the fibers subjected to the environment of distilled water.

Previous studies confirm the manufacturing efficiency of composites made of epoxy resin and *Luffa cylindrica*. One article demonstrated that the mechanical response of the composite was improved compared to the pure polymer, due to the insertion of natural fibers. This fact can be explained by the nature of the reinforcement material and its contribution to the overall behavior of the composite. This improvement concerns the stiffness of the material, which optimally increased by 48% for a mechanically applied pressure of 4.6 kPa during curing. Furthermore, the chemical treatment led to an improvement in stiffness of up to 30% (coating: acetone/CH_3 COOH 1%) [20]. In agreement, Saw et al. reports that epoxy can be covalently bonded to modify *luffa* fibers, which can be used to generate epoxy composites with improved mechanical and thermal properties [11].

In a recent research, two articles were found (10 and 11 in Table 1) which the authors carried out a study using polyester as a matrix of composites with bushing fiber. In article 10, a study was carried out on the mechanical behavior of luffa fiber reinforced polyester composites with and without the addition of microfillers of $Al_2 O_3$, $CaCO_3$ and TiO_2. In article 11 the composites were tested experimentally and numerically as faces of sandwich panels, formed by cores of vegetable bushing impregnated with polyester resin and expanded polystyrene.

In article 10, a research was carried out the mechanical characterization of traction and bending of the constituent composites with the following compositions: polyester + Luffa fiber (0% by weight); polyester + Luffa fiber (5% by weight); polyester + Luffa fiber (10% by weight); polyester + Luffa fiber (5% by weight) + $Al_2 O_3$ (5% by weight); polyester + Luffa fiber (10% by weight) + $Al_2 O_3$ (5% by weight); polyester + Luffa fiber (5% by weight) +

$CaCO_3$ (5% by weight); polyester + Luffa fiber (10% by weight) + $CaCO_3$ (5% by weight); polyester + Luffa fiber (5% by weight) + TiO_2 (5% by weight); polyester + Luffa fiber (10% by weight) + TiO_2 (5% by weight) [31].

The authors concluded that the addition of microfilms improved the mechanical properties of luffa fiber based composites. It was also found that composites filled with microadditives have excellent tensile strength compared to unfilled composites. Polyester composites with 5% by weight luffa fiber plus 5% $CaCO_3$ obtained the highest tensile strength. This may be due to good particle dispersion and strong interface adhesion. In the flexural test, the highest flexural strength was obtained in the composite filled with 10% luffa fiber plus 5% $CaCO_3$. This may be due to the good compatibility between the filler and the matrix [31].

In work 11, the loofah impregnated with polyester resin was used as cores of a polyester composite reinforced with ramie yarns. Where the bushing was compared with expanded polystyrene cores. For this, the loofah cores were cut and placed in polyester resin until their absorption at room temperature. The results demonstrate that the core of vegetable bushing impregnated with polyester resin presented higher values of compressive strength and modulus of elasticity compared to reinforced polyester. This fact may be related to the reticulated structure of the bushing. The authors observed that two types of failures occurred the panels with a bushing core, by detachment of the faces and by shear of the core. However, they claimed that they were excessive deformations in the test and that it would not happen under normal conditions of use [32].

Thus, according to the studies mentioned above, the addition of fibers in polymeric matrices proves to be an excellent alternative for reinforcement in composites, especially when combined with chemical compounds. Article 11 presented the use of the bushing as part of a composite system for panels to be used in the construction sector, in which the tests showed that *luffa* achieved superior results to the synthetic material, in which the bushing reveals a new alternative for use and consequently, the reduction in the use of synthetic material.

A study demonstrated the preparation of composites with short fibers and *Luffa cylindrica* mats with polyester matrix by compression molding. In which the surface treatment of *luffa* fibers with 2% NaOH for 90 min was considered the best treatment with reference to the highest fracture energy in which they exhibited the best tensile properties, although still inferior to those of other plant fiber composites. However, no significant increase in the tensile strength of composites was observed compared to composites of untreated fibers [19].

In this current review, the most investigated polymer matrices for making composites with bushings were epoxy resin and polyester. However, in older studies we can find, for example, vinyl ester matrix and polycaprolactone in the literature. Tanobe et al. [13] used a sequence of organic extraction and chemical treatments in order to increase the interfacial compatibility between *Luffa cylindrica* fibers and the vinyl ester matrix and evaluated their mechanical properties. The tensile strength and Charpy impact tests showed an increase in the strength of the composites when compared to the matrix. The best results were obtained for fibers treated with 1,2,4,5-benzenetetracarboxylic dianhydride (PMDA) in vinyl ester matrix composites, which showed an increase of 30% for tensile strength and 250% for impact strength [13].

Another form of reinforcement is the cellulose nanocrystals prepared by acid hydrolysis of *Luffa cylindrica* fibers. These cellulose nanocrystals were used as a reinforcement phase for the processing of bio-nanocomposites using polycaprolactone (PCL) as a matrix. In which mechanical behavior was evaluated both in the linear and non-linear ranges of these unmodified and chemically modified nanocrystals. Chemical grafting promotes more homogeneous dispersion of nanocrystals within the PCL, as shown by the significant improvement in elongation at break compared to unmodified nanoparticles. This effect was more pronounced for modified nanoparticles and probably in part due to the increased crystallinity of the PCL matrix [14].

In addition to the polymeric matrices, a current study was found in which the matrix of the bushing composite was made of cement. Article 12 studied the esterification of vegetable bushing fibers to verify their performance in the cement matrix. In which the content of bushing fibers used in the matrix was 3% by weight and the esterification reactions were carried out with the modifying agents octanoyl chloride, lauroyl chloride and stearoyl chloride, using toluene as solvent and pyridine as catalyst. The modification with octanoyl chloride reduced the absorption (65%) and changed less the tensile strength of the fibers, with an increase of 67% in the modulus of elasticity, being, therefore, considered the best condition for the treatment of vegetable bushing fibers [33].

3.3 CHEMICAL PROPERTIES OF THE BUSHING

As seen in Table 1, two current articles were found that reported the chemical properties of *Luffa cylindrica* in their studies. The first study published in 2017 by Souza et al. [33] showed that the chemical components of the vegetable bushing fibers used in their study were 70.8% (±

0.5) of cellulose, 14.7% (± 0.7) of lignin and 17.2% (± 0.8) of hemicelluloses A and B. Kalusuraman et al. [24] obtained the following results for the chemical composition of the bushing: 73.92% of cellulose, 21.85% of lignin, 9.75% of moisture content, ash contente of 4.07 and wax contente of 0.48.

The result of the research demonstrates that the content in greater proportion was cellulose, this in the fiber plays a substantial role in its tensile strength. The literature confirms that the tensile strength of fibers is due to cellulose and its compressive strength to lignin [12]. Both components are found in considerable amounts in this fiber, which makes it an excellent alternative for reinforcement in composite material matrices.

Past studies have also evaluated the chemical composition of *luffa*. Tanobe et al. [3] reports in their study a characterization of chemically treated Brazilian sponge gourds, in which he concluded that the cellulose content was similar to that reported for sisal, jute, hemp and abacá (Manila), the lignin content was similar to that of hemp, banana and abacá (Manila), while the ash content was similar to that of agave, bagasse and abacá (Manila).

Siqueira et al [5] observed that the chemical composition of luffa fibers depends on several factors, such as plant origin, climatic conditions, soil nature, among others, ande the cellulose content varies from 55 to 90%; the lignin content is in the range of 10 to 23%; the hemicellulose content is around 8 to 22%; extractives approximately 3.2% and ash 0.4%. Seki et al. [9] concluded in his study that the elemental chemical constitution varies between the different parts of the fruit. The outer part of the fruit is the richest in cellulose (80%), in correlation with a high oxygen/carbon molar ratio. The average cellulose contents of the different anatomical parts appear to be higher than those of wood fibers and the percentages of lignin are low (10%).

Saeed & Iqbal [12] concluded that the fibrous network of bushing sponge is mainly composed of cellulose (60%), hemicelluloses (30%) and lignin (10%) and that the functional groups on the surface of the fibers were predominantly acidic (carboxylic, lactonic, enol, phenolic), indicating that they were available for ion exchange reactions. Finally, the results showed few current studies related to the chemical properties of the bushing, on the other hand, previous articles define well the characterization of this fiber.

3.4 PHYSICAL PROPERTIES OF THE BUSHING

Kalusuraman's articles et al. [24] and Patel & Dhanola [31] studied the physical properties of *Luffa cylindrica* between the years 2016 to 2021 as shown in Table 1.

Kalusuraman et al. [24] concluded that the surface roughness values of *luffa* fibers were the highest (4.86 μm) for untreated fibers, while they decreased for all surface treated fibers in descending order from those for treated NaOH, followed by that treated with silane and the lowest for fibers treated with Ca $(OH)_2$.

The physical properties of luffa fiber are density 820 kg/m^3, diameter 25-60 μm and crystallinity index 59.1 [31]. Patel & Dhanola [31] observed in their study that the void content of composites (luffa/polyester) increases with increasing fiber and microadditive filler weight; however, the void volume fraction of plain luffa-based composites decreased substantially with the addition of $CaCO_3$ and TiO_2. They also observed that hardness increases with fiber loading in microadditive filled composites, while in unfilled composites it decreases.

Studies from previous years also evaluated the physical properties of the bushing. Bal & Lallam [2] concluded through microscopic scanning analysis that luffa is structured in a fibrous microsponge system that offers fast and good accessibility to a fluid, suggesting the efficient use of this material in the absorption of liquids. The fiber retention capacity for aqueous solutions increases significantly with alkaline treatment or dry grinding of the shots, as these treatments increase the removal of compounds such as lignin and lead to extensive fibrillation of plant fibers.

The literature describes that the bushing sponge has a fibro-vascular characteristic, similar to a net, has macropores of approximately 800 mm, created by rough and jagged fibers of 200 mm with continuous hollow microchannels.The sponge luffa is remarkably light, with a specific gravity of 0.92 g/cm^3, a specific surface area of 850 m^2/m^3, a void volume of 92%, a high porosity of 79 - 93% and a high specific pore volume of 21-29 cm^3/g. In addition, the large voids that provide for the growth of immobilized cells fixed at high densities offer the prospect of high metabolite yields [12].

Chen et al. [22] demonstrate that luffa sponge fibers had relatively higher moisture recovery compared to common fibers. The possible explanation for the results could be the porous structure, the superficial grooves and the superficial micro-cracks in the *luffa* sponge fiber bundles. Moisture recovery of high density luffa fiber bundles (7.1 - 9.3 %) was lower than that of low density luffa fibers (10.2 - 10.9%). Finally, Laidani et al. [21] show in their study that *Luffa cylindrica* is a fibrous resource rich in cellulose, in which the physical characteristics are comparable to wood pulp.

IV. CONCLUSION

Due to the essential characteristics of *Luffa cylindrica* fiber, such as one for use in composites, there is a need for investigations into this material for a better understanding of its applications. In this sense, this research sought information about this fiber, in which it can provide data for the best use of luffa in the various segments of the industry.

In this article, several works were reviewed regarding investigations on the mechanical, chemical and physical properties related to *Luffa cylindrica*. Thirty-three articles were selected, of which twelve are from the years 2016 to 2021. Works related to mechanical properties were the most found, and eleven articles investigated this property.

The concepts that were put in this work are of special importance for the understanding of both the specific properties of the bushing and its properties as a load in composite materials. An important data addressed is the variation of chemical treatments on the fibers, which depending on the purpose of application of the bushing can improve the properties of the same or the composite material.

Finally, the present work can improve the understanding of the bushing regarding its mechanical, physical and chemical behavior in its various applications. Knowing that the luffa sponge has good characteristics such as: abundance in nature, low cost, low weight, non-toxicity, physical and chemical stability, it is concluded that this fiber becomes an important resource for use in engineering.

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