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Research Article

Ecofriendly Bio-packing Based on Sugarcane Bagasse Fiber for Potential Application in Agroindustry

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Abstract: The concern about waste in the world is growing because of the significant environmental impact. Therefore, new alternatives are used, such as recycling, biodegradable polymer, agroindustry waste reuse, and many others. In this sense, this paper proposes a production of new bio-packing based on the waste production from agriculture (sugarcane bagasse) and the drinking industry (plastic bottles from Polyethylene Terephthalate (PET)) for agriculture products transportation. Then, this new material was characterized by thermal, chemical, morphological, mechanical, antifungal activity, and hydrophobic character to evaluate its characteristics to use as bio-packing. Following this purpose, all samples are characterized in nature and after production by scanning electron microscopy analysis (SEM), thermogravimetric analysis (TG), infrared spectroscopy analysis (FTIR), surface angle contact, mechanical properties, and antifungal activity. The results indicated that the sample with 15% of bagasse presents the best mechanical properties. In addition, the presence of porosity can provide the material with low thermal conductivity. Moreover, the antifungal activity indicates that inhibition of fungus micellar growth was proportional to the decrease of bagasse in bio-packing. Then, which offers an innovative strategy for the use of waste in the production of environmentally friendly packing.

Keywords**:** bio-packing, biocomposites, characterization, mechanical properties

1. Introduction

Climate change has brought to the fore worldwide concern with environmental issues, especially with the aim of improving the sustainability of products, processes, and the use of environmental sources. One of the great environmental concerns is the large number of residues produced by the plastic industry, and the production of non-biodegradable plastics.[1] In this context, new ways of reuse residues are an incredible measure. Thus, novel biocomposite alternatives using plastic residue and biodegradable materials, as natural fibers have become more common.[1-3] These biocomposites have many uses, such as domestic mobiles, aerospace, automobile, packing, and others.[2,3]

The protection of fast maturing during the transportation is crucial, especially when the fruit is destined for exportation, mainly to Europe, as the EC settled that the fruits can not have over 10% of injuries and degenerative processes.[4] Thus, promoting materials, which provide good protection against fungi, control fast-maturing, and are eco-friendly is vital. The use of natural fibers as additives for bio-composite shows great potential for improving

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their performance and technological application due to their low cost, abundance, biodegradability, and high specific strength. Furthermore, due to their low density, natural fibers reduce the mass of the composite.[5-7] This is especially important if such fibers are residues of agriculture processes,[4,8,9] thereby also satisfying ecological parameters and the demands of society, as established by the European Commission Regulation (EC, 1221/2008), in fresh fruits injuries and degenerative processes should not be observed over 10% of fruit.[7] This is the case of sugarcane bagasse fiber, which is widely produced in Brazil as a by-product of the sugar and bioethanol industry.[9,10]

Sugarcane production in Brazil has grown in recent years producing a huge demand for residues.[10] So, providing the reuse of these residues is a relevant solution in the current situation.[11] In this context, the use of fiber in many new materials has been a strategy for the agroindustry. In this way, the production of bio-packing with the proposal of reducing the final cost, health problems, increasing the export of the fruit, and avoiding loss to the agribusiness is a great solution. Additionally, many fungi cause various losses to plantations (close to 50% in each harvest).[12,13]

One of them is the Colletotrichum musae, responsible for anthracnose. Only in the North of Minas Gerais, the loss by the anthracnose is among 30 to 40% of marketable fruit.[14-17] Furthermore, the transportation and export of fruits are often hampered by factors related to the onset of diseases, like those caused by fungi before reaching their destination. Then, the control of fruit transportation is crucial, as some regulatory bodied impose those injuries and the degenerative process cannot over 10% of the fruit.[6,18]

In this context, this research proposes the production of bio-packaging using a polymer synthetic waste, as the Polyethylene Terephthalate (PET) and waste production of sugarcane agriculture, is a great alternative for agriculture products transportation, as this polymer is largely used in the drink industry, produces a large amount of waste, which is most discharged in the landfills or the ocean11, its degradation takes over 100 years, it is very toxic for the environment,[19,20] and the waste of sugarcane production is still too large.[10]

In this approach, this study reports a facile production of bio-packing using waste materials, to minimize the environmental impact. For that, biocomposites based on sugarcane bagasse in PET matrix were produced using different concentrations of sugarcane. Furthermore, to the best of authors' knowledge, the anti-fungicide activity of bio-packing based on PET and sugarcane bagasse fiber seed against Colletotrichum musae has not yet been explored, The morphological, chemical and mechanical properties were evaluated, as the antifungal activity, to verify the potential use of this new bio-packing in the agroindustry.

2. Materials and methods

2.1 *Materials*

In this work, recycled PET obtained from the drink industry was used in the form of pellets. Sugarcane bagasse fibers, which were shorter than 2 mm, were kindly supplied by snack bars in the commercial Centre of Minas Gerais Capital. For the mixture, it was used glycerin as a plasticizer, thus decreasing the melting temperature of PET.

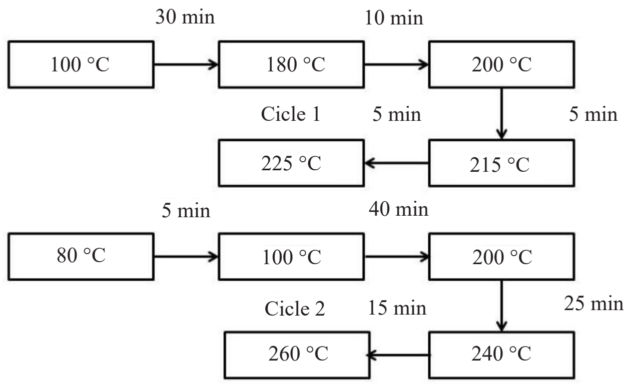
2.2 *Methods*

2.2.1 *Bio-composite production*

All sugarcane bagasse was treated with distilled water for 14 days, changing every 8 h to eliminate glucose. Then, it was dried in a sterilization oven 40 L for 48 h at 120 °C. After, crushed to 2 mm. The mixture was performed by mixing the plasticizer with bagasse and PET letting them hang out for 24 h. Finally, it was placed in a stainless steel mold on 60 mm × 20 mm × 2 mm rectangular, and made the thermal compression at SL 11 SOLAB, using 0.5 ton load as the temperature cycle shown in Figure 1.

2.2.2 *Mechanical and characterization analyses*

Specimens were prepared and tensile tested, following the ASTM D638 standard at AG-X Shimadzu universal testing machine using a 10 kN load cell and velocity of 3 $mm.min^{-1}$. The morphologies of the composites were evaluated using a scanning electron microscope (SEM, FEI-FEG-FIB-QUANTA 3D) coupled with energy dispersion X-ray spectroscopy (EDX, Bruker, 0.8 nm). Before the examination, the samples were coated with a thin gold film by sputtering using a low deposition rate. Images of Secondary Electrons (SEs) were obtained using an accelerating voltage of 15 kV for all samples on two different planes (transversal and superficial). SEM images were collected and the pore size was estimated on the basis of at least 50 random measurements using the open source image processing program (ImageJ v.1.50+, National Institutes of Health, NIH). Thermal characterization was held with Shimadzu, DTG model-60 H in N_2 gas flow with 50 mL.min^{-1} applying a heating rate of 10 °C.min^{-1} from 25 °C to 500 °C. Fourier Transform Infrared (FTIR) spectra were obtained using an attenuated total reflectance method for all samples (ATR, ZnSe crystal prism, 4000-650 cm^{-1} using 32 scans and a 4 cm^{-1} resolution-Nicolet 6700, Thermo-Fischer). In addition, the effect of the bio-packaging hydrophilic/hydrophobic characteristics was evaluated by contact angle measurements. Moreover, the antifungal activity of bio-packing was checked out using agar-well diffusion method according to the Clinical Laboratory Standards Institute M2-A8 (2003) method. The statistical analysis was performed using ANOVA (one way included Tukey's test, $p < 0.05$, software Origin v.8.1, OriginLab Corporation, USA) unless specifically noted.



(a)

Samples	PET (%)	Bagasse (%)
1	100	0
2	90	10
3	85	15
4	80	20

(b)

Figure 1. (a) Temperature cycles 1 (PET) and 2 (PET/Bagasse Fiber), (b) Composition of samples

3. Results and discussion

3.1 *Thermal analysis of bio-packing*

The thermal behavior of samples is shown in Figure 2. It was observed changes with fiber addition. However, no significant change occurred due to the thermal compression process for pure PET and sample 1, as the curves overlap. In addition, the presence of bagasse caused a mass loss in lower temperatures, which does not prevent the use of these biocomposites as bio-packing of foods that demand conservation temperature. Furthermore, no major changes were observed in relation to the start temperature of mass loss in other samples. Sample 1 and recycled PET had an early mass loss, around 360 °C. The three composites showed a mass loss of around 260 °C, close to average between values on the component materials.

3.2 *Morphological analysis of bio-packing*

SEM analysis is shown in Figure 3. PET micrographs were identified with particles around 2 mm. Porosities were not identified in this sample. Therefore, in the case of bagasse was identified a lot of pores, unions of fibrils, which consist of a large number of overlapping cells and are intimately linked.[4,13,14] As well as layered structure formation involves a second thicker layer, where the fibrils formed in the shape of spirals along the fiber axis4. These channels are extremely important in the use of fibers as reinforcement in composite agent, because they facilitate the diffusion of polymer resin into the fiber, providing a better adhesion/interaction.[9,19-21]

In addition, the presence of porosity can provide the material a low thermal conductivity, as it allows the air, which provides low conductivity property by giving them the insulating capacity.[9,20-22] Microscopic analysis still allowed to determine the average diameter of fibers from bagasse as being approximately 300 µm. It was noticed a significant difference between them and sample 1. Moreover, the micrographs of samples 3 and 4 are more similar, when compared to sample 2. Furthermore, sample 2 was observed small porosities scattered. In addition, were noted the presence of gills in all three composites, indicates that the samples conform to a composite laminate. This characteristic, such as the porosity, indicates the application of this material such as bio-packing, especially when a high temperature is conducted.[9,20-22]

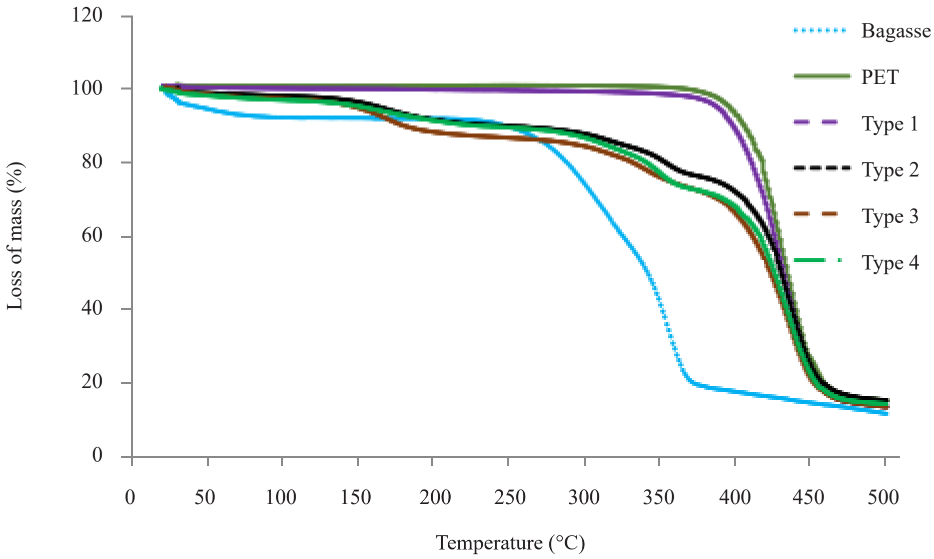


Figure 2. Thermogravimetric analyses of all samples

3.3 *Mechanical behavior of bio-packing*

The tensile test performed according to standard D638 is shown in Table 1. This mechanical property test was conducted to indicate the bio-packing elastic and flexible behavior that is an important parameter for packing use in agriculture transportation. The sample 3 showed the highest tensile strength. The improvement of mechanical behavior is deeply dependent on robust intermolecular bonds.[23] In addition, the values found for all samples were around 20 GPa. Th results were similar to others using fibers in the literature.[9]

Table 1. Values of tensile strength, modulus of Elasticity (E) and tensile of rupture

Samples	Tensile strength (GPa)	Modulus of elasticity (GPa)	Tensile of rupture (GPa)
1	22 ± 1	2.00 ± 0.03	21 ± 1
2	18 ± 1	2.00 ± 0.03	12 ± 1
3	23 ± 1	3.00 ± 0.02	15 ± 1
4	21 ± 1	2.00 ± 0.02	12 ± 1

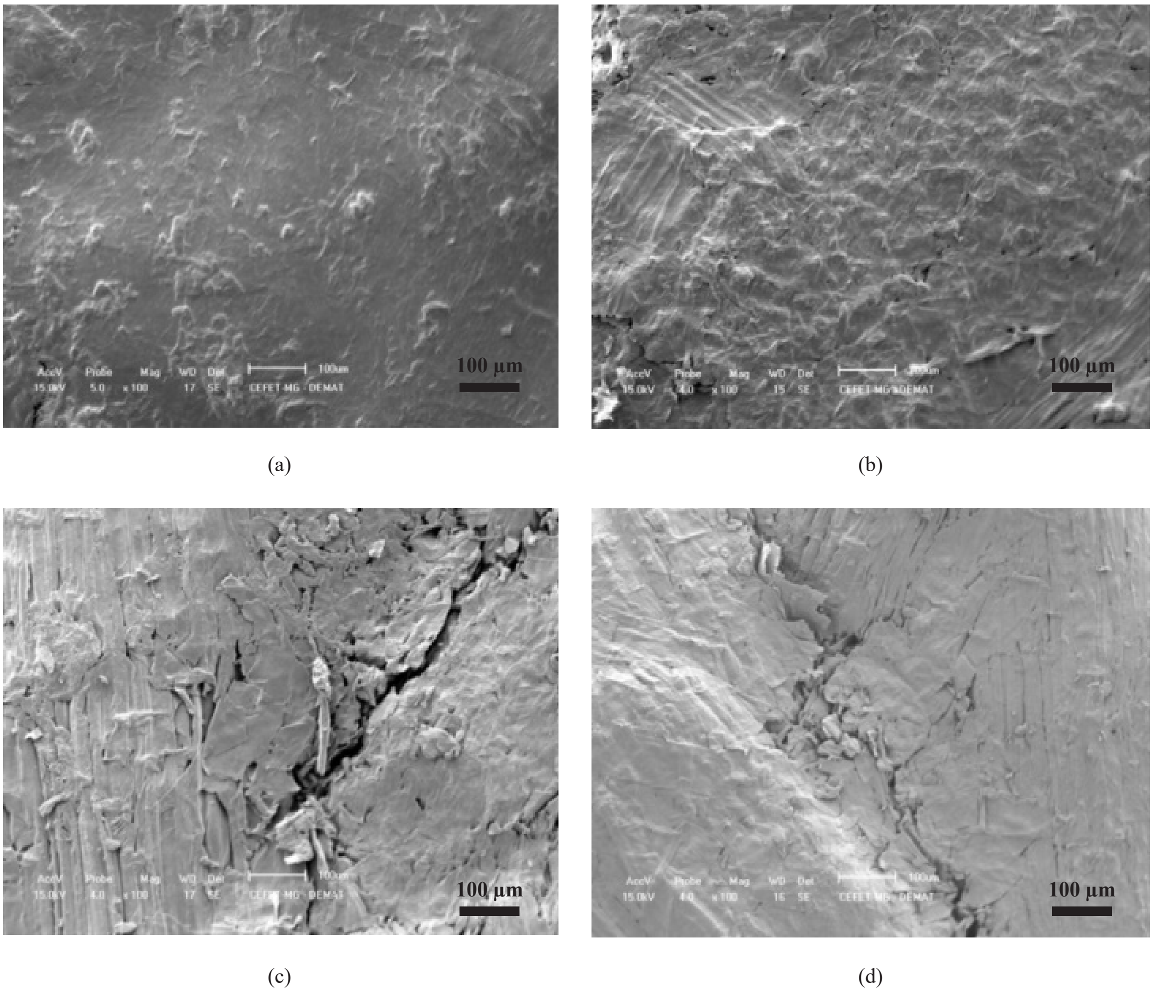


Figure 3. (a) Micrograph of Sample 1; (b) Micrograph of Sample 2; (c) Micrograph of Sample 3; (d) Micrograph of Sample 4 (100×)

3.4 *Spectroscopy analysis of bio-packing based on FTIR*

As a general analysis of the FTIR spectra (Figure 4), the typical PET bands can be identified in all samples: the band at 730 cm^{-1}, the CH stretching of aromatic rings, the band at 1099 cm^{-1} and 1250 cm^{-1} associated with C-O stretching present at PET chain is perceived in all bio-packing samples with a slight difference, mainly, in type 4, where the intensity of absorbance is smaller than other samples, the band at 1600-1700 cm^{-1} is related to C=O stretching present at carboxylic acid groups in the PET chain, presenting in all bio-packing, but with the decrease of intensity comparing with pure PET. Moreover, in the case of type 1, the absorbance of this band is a slight increase than other samples with bagasse. Furthermore, bands related to CH_2 vibrations at approximately 2900 cm^{-1} are perceived in all bio-packing. Similarly, the band at 3300-3500 cm^{-1}, associated with -OH stretching associated with bagasse is presented in all bio-packing samples.[22] However, a slight deviation is perceived compared with pure bagasse may associate with the link between PET and bagasse after thermal processing provided by the plasticizer. In addition, bands related to CH_2 vibrations at approximately 2900 cm^{-1} with a slight difference compared with bagasse are perceived in all samples.[22]

3.5 *Hydrophobic analysis of bio-packing based on contact angle*

Storage of fruits correctly and adequately is essential to transportation, mainly to exportation. Temperature and humidity influence the fruit maturing faster. Moreover, these parameters can provide an environment to the proliferation of fungi and other microorganisms.[19,24] In this context, using hydrophobic protection in fruit storage is an interesting solution. The surface contact angle was evaluated in this research to understand the bio-packing qualitative hydrophobic/hydrophilic behavior to improve the fruit storage (Figure 5). The results of the contact angles indicated the decrease of hydrophobic character to bio-packaging with increasing of bagasse (85 ± 2, 78 ± 2, 74 ± 3, 72 ± 1 °). In addition, the difference between pure PET and type 1 statistically did not exist based on ANOVA. This behavior is associated with porous with the incorporation of bagasse in the PET, which accumulates water, as showed in SEM analysis, but the hydrophobic character is still present.

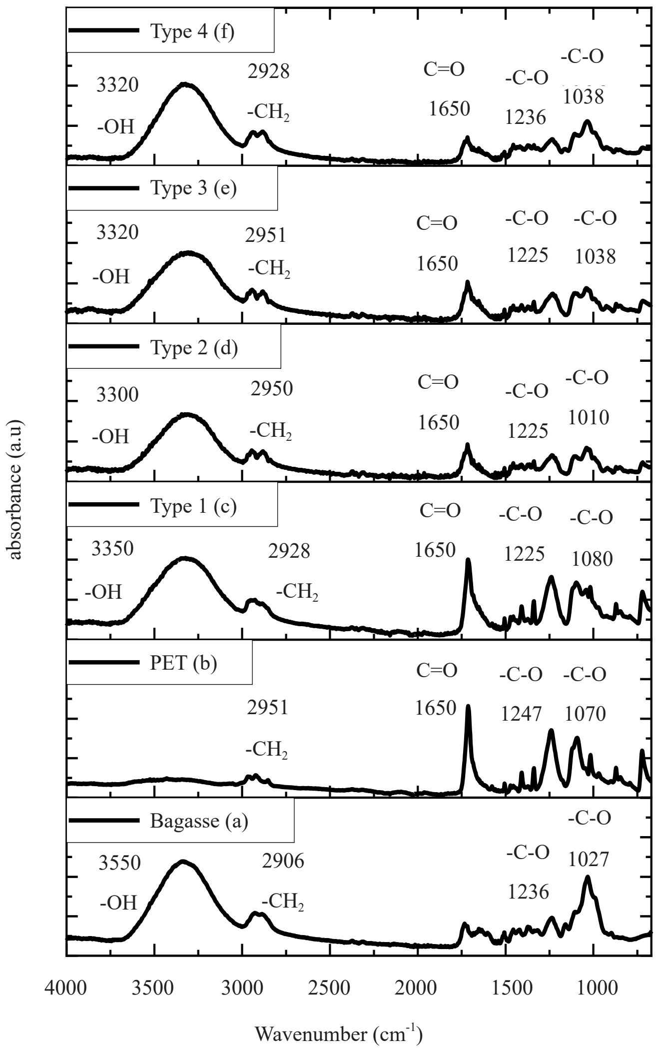


Figure 4. FTIR spectra of (a) Bagasse; (b) PET; (c) Type 1; (d) Type 2; (e) Type 3; (f) Type 4

3.6 *Anti-fungal activity of bio-packing*

One of the major problems in agriculture is the control of diseases, mainly those from fungi attacks. A diversity of fungi causes much damage to plantations, leading to great economic losses.[12] For this reason, developing materials that allow a more excellent protection against this disease and are not harmful to the environment is fundamentally important. Then, this research studied the in vitro antifungal of bio-packings against the Colletotrichum musae, responsible for anthracnose. The inhibition of fungus micellar growth was proportional to the decrease of bagasse in bio-packing (Figure 6), therefore is still similar to the commercial anti fungicide used as a comparative, probably, because of the PET non-reagent and hydrophobic character of biocomposites. These results may be related to the increase of porous in bio-packing with increase of bagasse in PET, which provides ducts to micellar growth.

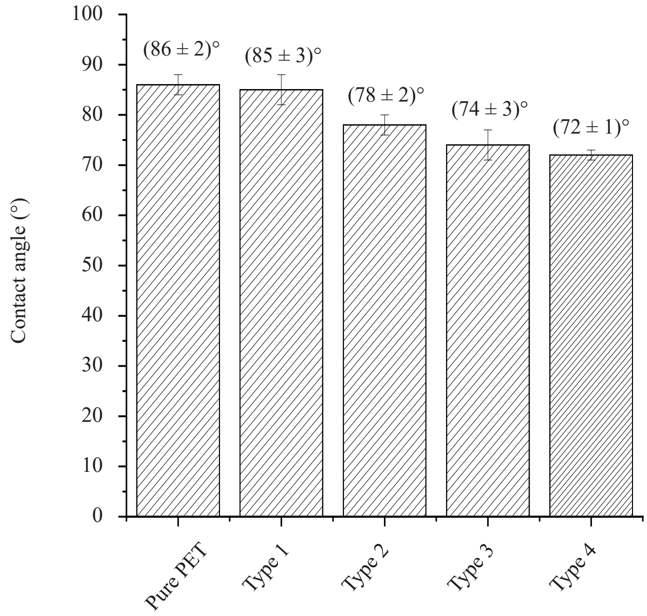


Figure 5. Contact angle

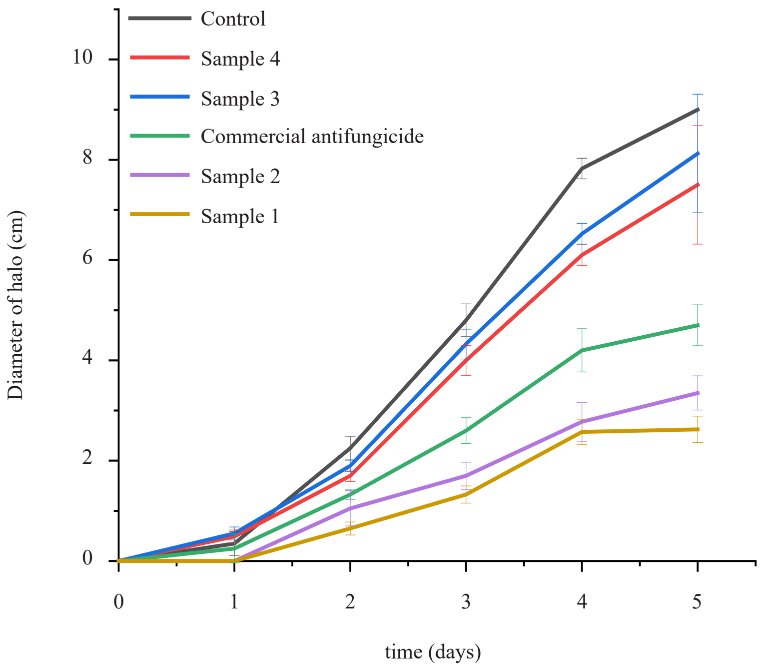


Figure 6. *In vitro* anti-fungicide activity

4. Conclusions

This study presents the production and comprehensive characterization of novel eco-friendly bio-packing. The results showed the manufacturing feasibility of recycled PET bio-composites using sugarcane bagasse by bio-packing transport in the agroindustry. In addition, the results demonstrated that the morphological and physicochemical features were modified by the sugarcane bagasse in the PET matrix. As the composition suitable for this bio-composite is 15% of bagasse, and the mechanical resistance was around 20 GPa. Furthermore, the incorporation of bagasse in the PET matrix decrease of antifungal and hydrophobicity character of bio-packing. Therefore, these bio-composites are promising for potential use as bio-packing in agroindustry.

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Conflict of interest

The authors would like to state that the material in the manuscript is original and has not been published. The article has been written by the stated authors who are ALL aware of its content and approve its submission. The article has not been published previously. The article is not under consideration for publication elsewhere. No conflict of interest exists. If accepted, the article will not be published elsewhere in the same form, in any language without the written consent of the publisher.

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