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EXPERIMENTAL TESTS OF THE THERMAL BEHAVIOUR OF NEW SUSTAINABLE BIO-PACKAGING FOOD BOXES*

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Abstract

This experimental task was performed using 8 sustainable Bio-Boxes in the thermal chamber in the laboratory. The air is forced from the refrigerator, and it is used to control the temperature inside the thermal chamber.

The goal of the performed task is to evaluate the thermal behaviour of the bio Boxes made from different material, such as sugarcane bagasse and PLA material with respect to time. The test was performed to lower the temperature inside the chamber to its minimum air temperature inside the cold chamber. The results show that the SCB 4 has noticed changes in its mechanical properties (Tensile Strength) and it also shown some moisture absorbing when compared to other Bio boxes. Furthermore, this kind of Bio packaging materials needs more research to improve their mechanical and barrier properties and minimise the use of plastic containers for food packaging industry.

Keywords: bio-boxes, bio packaging, temperature

1. Introduction

Recently, the development of biopolymers has been increasing due to the environmental pollution caused by plastics materials. According to the Eurostat report, during 2006–2015, plastic packaging waste amounts to 15.9 million tonnes in Europe, which represents 19% of total packaging waste produced by the packaging sector. This only proves the necessity for the packaging industry to develop sustainable, renewable, as well as cost-effective materials, to reduce the problem on the environmental pollution and climate changes.

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Biopolymers are more desirable than traditional polymers since they are made from renewable resources. Additionally, these biopolymers are compostable, biodegradable, and considered environmentally friendly. Petrochemical-based polymers such as polyethylene terephthalate (PET), polystyrene (PS), polyethylene (PE), polyvinylchloride (PVC), polyamide (PA) and polypropylene (PP) have been widely used as packaging materials in the food industry for many years due to their large availability, easy processability at relatively low cost. These polymers are the most used worldwide mostly because of their mechanical (tensile and tear strength), barrier (air and moisture) and thermal insulation (heat sealability) properties.

Poly(lactic)acid (PLA) and Sugarcane bagasse (SCB), are bio-based polymers derived from renewable agricultural source (e.g. corn, potato and sugarcane), that had been arousing interest in the food packaging industries in the past few years.

PLA's physical and mechanical properties are very similar to the traditional polymers of PET and PS. PLA has advantages when compared to petrochemical-based polymers, such as the method used to obtain them expends low energy, it is recyclable and compostable, and it also improves the agricultural landfills. High value film and rigid thermoform are the most common form of PLA used for short shelf life products (Auras et al., 2005).

The fibrous residual leftovers from the process of crushing and/or extracting the sugarcane's juice, known as "bagasse", is among the largest agricultural wastes in the world of sugarcane waste products.

Sugarcane is biodegradable and decomposes in three to six months. To create tableware out of sugarcane waste, the fibres are mixed together and heat-pressed into the desired shape. These boxes do not require any external coating because they are not intended to be in contact with a large amount of liquid for an extended period.

Sugarcane boxes made from sugarcane bagasse has the same petroleum-based polyethylene coating as standard for packaging boxes uses. Biopolymers fulfil the environmental concerns, but they also show some limitations in terms of physical performances such as thermal resistance, barrier, and mechanical properties.

PLA has the same mechanical properties when compared to traditional polymers. Mechanical properties were measured once the PLA sample containers were exposed to vegetable oil and it was found that there was a decrease of its tensile stress, a reduction of the elongation at break and an increase of the modulus of elasticity. Thermal properties of PLA which cover some parameters such as glass transition temperature, melting temperature and crystallization behaviour, were stated to be reliant on the polymer microstructure and molecular weight (Ahmed et al., 2009; Shibryaeva et al., 2019). It is necessary to understand the crystallisation behaviour of PLA material since it significantly influences the thermal resistance as well as the barrier and mechanical properties. Many ways including the addition of nucleating agents and plasticizers (Saeidlou et al., 2012), post-annealing of specimens and optimization of material processing parameters can be used to increase the fabric crystallinity (Yang et al., 2010)

PLA based materials have some limitations as performing packaging material. These limits are related with the following factors: rigidity and brittleness of the material with low ability to plastic deformation below glass transition temperature; low heat deflecting temperature; the conditions of high humidity at high temperature (Holm et al., 2006); barrier properties to permeation of low molecular elements, such as water vapour, O_2 and CO_2 (Auras et al., 2006)

However, the thermal property isn't sensible due to the low Tg of ~60 °C. The melting temperatures of PLA are from 190 to 250 °C. Typically, the processing temperatures are from 20 to 100 °C higher than the melting temperatures. One drawback of processing PLA is its tendency to undergo thermal degradation. This drawback can be resolved by combining PLA with other polymers and adjusting the stereochemistry of the polymers

A study where the quality of tomatoes was evaluated in various biodegradable packages, and among the ones tested, is the polylactide coated paperboard with a perforated Master-Bi® bag made of starch. The conclusions of the study were clear, they noticed that the tomatoes quality in biodegradable packages remained as good as the ones stored in low-density polyethylene (LDPE) bags for three weeks (Kantola and Helén, 2001).

The outcome of PLA based biodegradable film packaging on the microorganism and physicochemical quality of green peppers were studied.

There are no significantly differences between the colour, hardness, and ascorbic acid concentration observed among PLA, LDPE, and perforated LDPE after 1 week of storage at 10 ºC. In addition, a lower coliform bacteria counts were found on the peppers in the biodegradable film packaging when comparing to LDPE film packaging. This may be a result of the higher-water vapour transmission rate of PLA films when compared to LDPE films. Rigid trays and packs manufactured from PLA resin are used for apples, cherries, and tomatoes (Koide and Shi, 2007).

The packaging box with a lid is produced by bi-oriented polystyrene, which is obtained from corn starch. Such packaging is decomposable after 47 days, depending on the conditions, and the process does not leave harmful resins traces into the environment.

This box allows a crystal-clear visibility of the inside of the box, and they are appropriate to storage lubricants which resist temperature ranges from 60ºC to 80ºC.

Results for chemical resistance experiments shown that acid and vegetable oil treatment resulted in a limited resistance degradation of PLA. Some tests were made, and it has been shown that when the PLA is immersed in a low acid solution its tensile strength improves.

The tensile strength and the elastics modulus for poly (98% L-lactide and 98% L-lactide), are having high content of L-lactide in the films contributes to a higher tensile strength.

It is more ductile while at the same time the tensile strength is decreased with less L-lactide, and the elasticity modulus is reduced on working time.

Life cycle assessments of bio-based products and biopolymers have shown reduced impacts and favourable results in terms of environmental problems such as greenhouse gas emissions and energy use when compared to hydrocarbon-based polymers (Madival et al., 2009).

The main objective of this experiment is to analyze and evaluate the thermal behavior and its thermal properties of the bio boxes made from different materials such as sugarcane bagasse and PLA material with respect to time, in a thermal laboratory climatic chamber. The purpose of the study of these different materials to overthrow the plastic as the main material used for food packaging, even knowing that its use represents nefarious consequences to the environment.

This work is divided in three main parts:

- Selection of the potential substitute materials of plastic for food packaging: sugar cane bagasse and PLA.
- Evaluate the boxes thermal properties in order to decide if they are suitable to replace the plastic in the food packaging by observing the alterations in the box's structure by performing a complete and functional experiment giving use to the CMAST lab.
- Analysis of results, drawing conclusion and formulation of recommendations for the use of sugarcane bagasse and PLA boxes for fruit packaging.

2. Materials and methods

2.1. Materials

Renewable resources-based boxes are used in this study. PLA and Sugarcane Boxes are produced by Bio Futura B., Netherland. The Bio boxes shown in Fig.1 are 100% made from decomposable material for food packaging. It has different shapes, structure, and coating to the boxes.

Sugarcane bagasse (SCB) consists of 50% of cellulose, 25% of hemicelluloses of lignin. Each ton of sugarcane generates 26% of bagasse (at a moisture content of 50%) and 0.62% of residual ash. The residue after combustion presents a chemical composition dominates by silicon dioxide (SiO_2). Despite being a material of hard degradation and that presents few nutrients, the ash is used on the farms as a fertilizer in the sugarcane harvests. Bio Boxes characteristics are described in the Table 1.

Table 1- Bio boxes characteristics (Bio Futura, 2020)

Bio Boxes	*Material type*	*Dimensions (L*W*H)*	*Temperatures (°C)*	*Certification*	*Capacities (ml)*
SC box 1(VB12)	Sugarcane Bagasse Clamshel	260*90*80	-15 to 220	EN-13432	1800
SC box 2(VA-SH89)	Sugarcane Bagasse Clamshell	125*70*75	-15 to 220	EN-13432	1000
SC box 3 (V3-GB16)	Sugarcane Bagasse Clamshell	135*78*45	-15 to 220	EN-13432	1000
SC box 4 (B001)	Sugarcane Bagasse Clamshell	160*80*90	-15 to 220	EN-13432	600
PLA box 5 (1670)	PLA 0 % Plastics	180*135*45	0 to 40	EN-13432	1100
PLA box 6 (01VWSALAD)	PLA 0 % plastics	120*120*45	-	EN-13432	650
PLA box 7 (VHD-32)	Herbal polymer replacing plastics	140*120*56	-20 to 40	EN-13432	890
PLA box 8 (KD-24)	PLA 0 % Plastics	138*112*45	-20 to 40	EN-13432	650

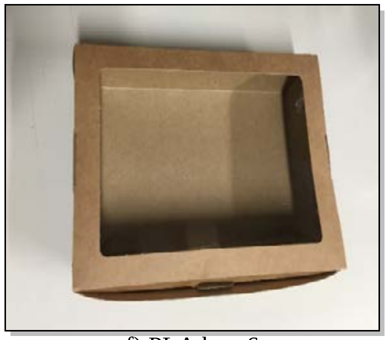
a) SCB 1

b) SCB 2

c) SCB 3

d) SCB 4

e) PLA box 5



f) PLA box 6

g) PLA box 7

h) PLAbox 8

Fig. 1. Different sustainable packaging boxes

2.2. Experimental setup

In the present experimental investigation sugar cane bagasse and PLA Boxes had been used to predict the thermal properties in the CMAST laboratory.

The main components of the experiment consist in a thermal climatic chamber, a Heat Exchanger section with Axial Fan, a Refrigerant pump, Refrigerant water tank, chiller. Bio boxes are placed inside the climatic chamber with data loggers placed in each box. Air from the axial fan is forced to the climatic chamber connected to HXs through pipes. The outlet from the chamber is sent back to the axial fan where the air is forced, and the cycle continues. Fig. 2 shows a schematic diagram of the experimental apparatus set up.

2.3. Methods

The thermal analysis (TA) is normally used to describe analytical experimental techniques which investigate the thermal behavior of bio boxes as a function of temperature. The time taken to complete an experiment test is 7 hours. The climatic chamber keeps the ambient conditions of temperature, humidity and airflow. The Refrigerator is connected to chiller to achieve lower temperature inside the chamber. Airflow is controlled by the axial fan at the speed of 240 rpm. The speed of the fan is controlled by the Electronic control system. During the experiment, it was noticed in the HXs some ice formation in the heat exchanger, specifically in the fins. To keep the air flow from the refrigerator, we can’t allow having the passage blocked with ice. If the passage in the HXs is blocked due to the ice, it will decrease the chillness into the cold chamber, which is going to affect the results.

In order to decrease the ice formation, during the experiment, some interruptions were made in the refrigerator pump. Every 30 minutes the refrigerator pump was turned off for 4 minutes. This procedure will help to maintain the air flow in the HXs. Noticing that the defrosted ice from the fins is going to 3 bottles that are placed next to the refrigerator, connected by silicon/plastic pipes. Easy data loggers were used to store the data from the cold chamber during the experiments.

3. Results and discussion

The new sustainable bio boxes were tested in a climatic chamber for 7 hours to visualize the thermal behaviours of the boxes. It was made an analysis of 4 sugarcane boxes (SCB) and 4 PLA boxes behaviour in the chamber. The experiment started at 10:00 am on 19/11/2019 and the first interruption was made at 11:30 am after noticing large amount of ice formation in the fins at HXs. A total amount of nine interruptions were made during the experiment. At 16:15 the chiller was turned off. The refrigerator pump and axial fan were however running until 17:15. During the experiment, the temperature in the chamber reached a minimum of 6ºC, with 70% rh. The temperature is monitored using easy data loggers which are kept inside each box.

The results are shown in the figures bellow. The Fig. 3 and Fig. 5 represents the variations in the temperature of the bio boxes with time. The Fig. 4 and Fig. 6 provides data about the Relative Humidity of the PLA and SCB boxes variation in function of time.

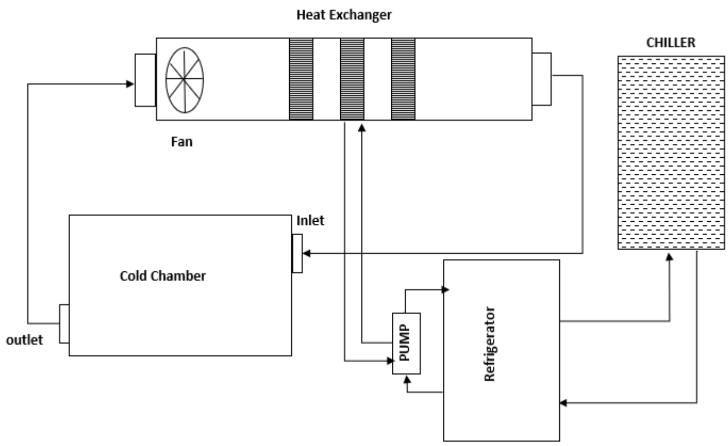


Fig. 2. Block diagram of Experimental apparatus.

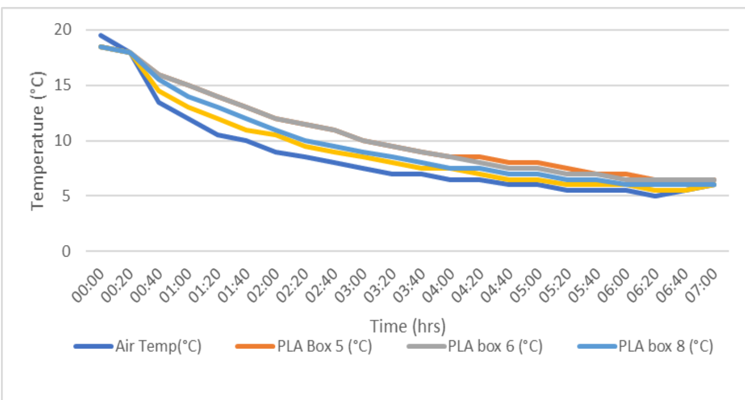


Fig. 3. Temperature evolution of PLA boxes

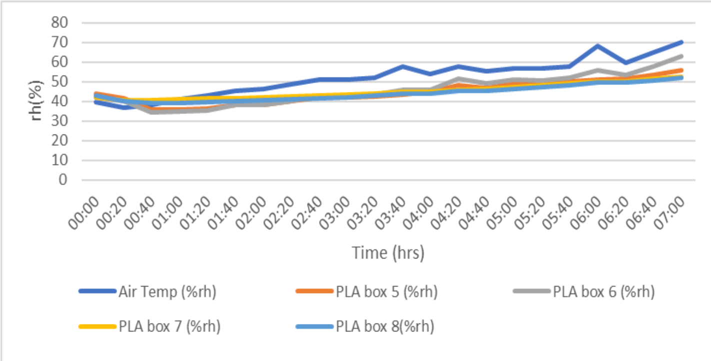


Fig. 4. Humidity evolution of PLA boxes

Table 2 shows the results of PLA boxes at the end

Bio Boxes	***Temperature (º C)***	***Relative humidity (%)***	***Changes occurred at the end***
Air Temp	6.0	70.0	
PLA box 5	6.5	56.0	No
PLA box 6	6.5	63.0	No
PLA box 7	6.0	52.5	No
PLA box 8	6.0	52.0	No

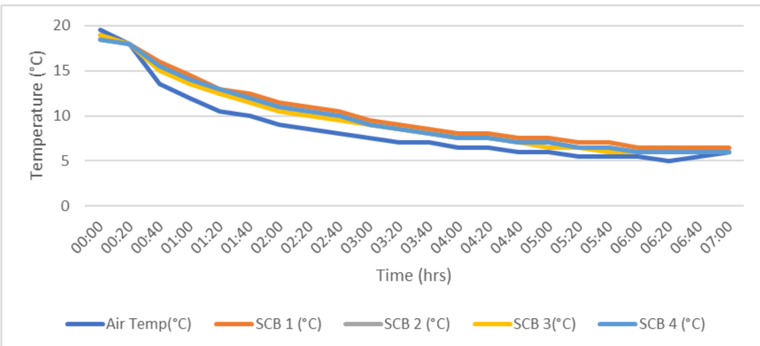


Fig. 5. Temperature evolution of SCB boxes

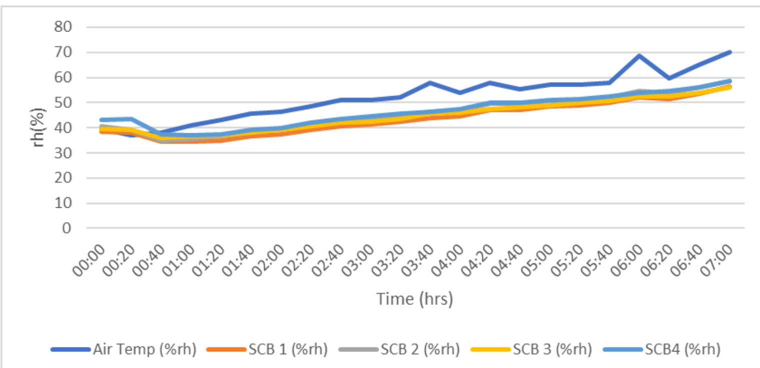


Fig. 6 Humidity evolution of SCB boxes

Table 3 shows the results of Sugarcane boxes

Bio Boxes	***Temperature (º C)***	***Relative humidity (%)***	***Changes***
Air Temp	6.0	70.0	
SCB 1	6.5	56.5	No
SCB 2	6.0	58.5	No
SCB 3	6.0	56.0	No
SCB 4	6.0	58.5	Yes

By the end of the experiment, the minimum temperature reached in the PLA boxes 7 and 8 was 6ºC, exactly the same achieved in the boxes SCB 2,3 and 4. The box SCB 4 absorbed moisture, and it reduced the stiffness of the box, due to the changes in the surface coating of the box, comparing to other SCB boxes. In what concerns PLA boxes, no changes were noticed.

4. Conclusions

During this experimental task, it was investigated the sustainable PLA and SCB containers with the purpose of food packaging.

This work investigated the sustainable PLA and SCB containers used for food packaging. The SCB and PLA are made of renewable resources and it is decomposable. This study found that:

- The Mechanical properties of PLA boxes has remains Constant throughout the experiment, since these boxes withstand temperatures around – 20°C.
- The SCB 4 has observed changes in their mechanical properties due to the wax coating structure compared to other three sugarcane boxes. The SCB 4 has wax coated only inner side. Due to this reason, the SCB 4 absorbs moisture and loses its stiffness at the end of the experiment.

Acknowledgements

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