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GREEN LOOP

Sustainable manufacture systems towards novel bio-based materials

WP4 – Bio-plastic material production

D4.1. Bio-plastic materials specifications definition

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GREEN LOOP Consortium Partners

	Partner	Acronym	Country
1	IDENER RESEARCH & DEVELOPMENT	IDE	ES
2	NATIONAL INSTITUTE OF CHEMISTRY	NIC	SI
3	SLOVENIAN NATIONAL BUILDING AND CIVIL E. I.	ZAG	SI
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Executive Summary

This deliverable titled D4.1 - R*eport of bioplastic material with specification for food and beverage applications* is the result of task T4.1 –Bioplastic *material specifications definition.*

This report provides an overview of the final products expected from the bioplastic value chain as described in the GREEN-LOOP Project, in terms of properties, process and performance. LBRT, which is the leader and producer for WP4, will produce the bottle closures for TDZ, the final user. MYX is responsible for developing the bioplastic that will be tested and defined during the project. Both MYX and LBRT will define objective parameters and conduct several tests to guarantee the quality of the material and the products.

The test to be performed are the following:

- **Biodegradability**
- **Compostability**
- **Characterisation of material**
- **Non-toxicity**
- **Food contact**

This document also gives a description of the current situation in the plastic manufacturing industry and why it is relevant to invest in bio-based materials. Relevant aspects like circularity, sustainability and environmental issues are considered. It also details different elements such as:

- **Specification of TDZ current bottle closure**
- **Legal standards**
- **The industrial production process for LBRT**
- **Material decision process by MYX**
- **Future work and upscaling of the novel manufacturing process**

Finally, a timeline for the future demonstration activities at TRL6 for this value chain is outlined at the end of the document.

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Abbreviations

AI - Artificial Intelligence

ASTM - American Society for Testing and Materials

DMP - Data Management Plan

EVO - Extra Virgin Olive

GA - Grant Agreement

GHG - Greenhouse Gas

GPa - Gigapascal

HDT - Heat Distortion Temperature

ISO - International Standard Organization

MOCA - Materiali e Oggetti a Contatto con gli Alimenti (Materials and Objects in Contact with Food)

MPa - Megapascal

N/mm^2 - Newton per square millimeter (conversion from MPa)

NIAS - Non-Intentionally Added Substances

NTP - Non-Thermal Plasma

PHA - Polyhydroxyalkanoate

PHB - Polyhydroxybutyrate

PLA - Polylactic Acid

T - Task

VICAT - Vicat softening temperature or Vicat hardness

VOCs - Volatile Organic Compounds

WP - Work Package

1. Introduction

The document aims to summarise the methods and the process to achieve the objective of replacing caps currently used for bottles of fruit juice and extra virgin olive (EVO) oil made with fossil-based material with bioplastic

1.1. Current solutions of the materials on the market

The Current bottle closures used by TDZ are made of aluminium and plastic. Specifically, for the fruit juice bottles, the hot pasteurisation of the product creates a vacuum between the mastic and the neck of the bottle, which guarantees the integrity of the product until it is opened. In the case of the EVO oil bottle, we have an aluminium cap with a plastic body inside, which, when closed, adheres perfectly to the dispenser located at the neck of the bottle. In this way, when closing the bottle, the oxygenation of the oil is completely avoided.

To TDZ, their objective is to have a product with a performance equal to the one that the current caps provide. For this reason, it does not put any condition on the aesthetic of the caps that will be designed by LBRT, or on the material choices for the carrier and the fillers that will be selected by MYX.

1.2. Need for new material to boost circularity

The design and development of new biobased, biodegradable, and compostable caps would enable TDZ to bolster the zero environmental impact pillar. Through the development of biobased thermoplastic compounds, TDZ hopes to achieve its circularity and green economy goals, from fruit production to process transformations. In particular, biogenic production of caps allows for a reduction in the use of nonrenewable resources in cap production, as well as a reduction in greenhouse gas (GHG) emissions during cap production and at the end of their life.

Currently, the caps used by TDZ are made from materials with a greater environmental impact than bioplastics. The ability to produce biobased and biodegradable caps enables the packaging to have a lower environmental impact and a more sustainable end of life.Thanks to organic recycling, biodegradable caps at the end of their life became compost. The use of compostable plastics renders mixed waste suitable for organic recycling, allowing a shift from recovery to recycling (a higher-ranking option in the European waste hierarchy). In this manner, biowaste is diverted from other recycling streams or the landfill, and separate collection is facilitated, resulting in the production of more valuable compost that supports the transition to a circular material loop, as shown in figure 1

Composting is the process of biodegradation under aerobic conditions over a period of 6 to 12 weeks. Typically, industrial products are composted in industrial composting plants where controlled conditions (such as temperature, humidity, and aeration) are provided. Microbes, such as bacteria and fungi, can "digest" the chain structure of compostable polymers as a source of nutrition. The end products are water, CO_2, and a small amount of biomass. In spite of the environmental benefits, to maintain market competitiveness it is necessary to ensure that the price of the new caps is comparable to the price of the ones currently in use.

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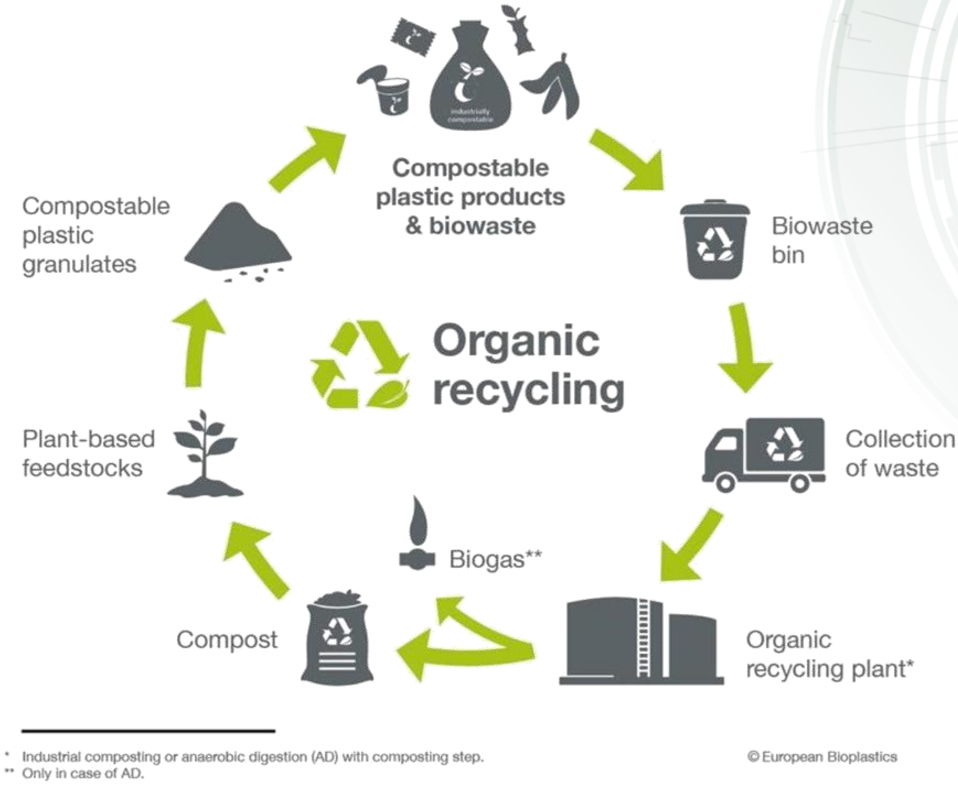

Figure 1. Organic recycling process (adapted from [1])

2. Initial Workflow

The general workflow in the development of bottle closure made with bioplastic is included in the GREEN-LOOP’s Grant Agreement (GA) in the tasks of work package 4 (WPA) . In the following subsections, it will be described the operation conditions and requirements of MYX and LBRT in order to produce the biomaterial and the final product.

2.1. General Framework

The project, managed by LBRT, involves TDZ as the end-user of the caps made by bioplastic. During M09-15, MYX will develop a thermoplastic with low carbon emissions and biobased and biodegradable properties by revaluing and ennobling vegetal residues from agro-industrial supply chains as filler for thermoplastic carriers. IDE will provide upgrades and modifications of equipment in manufacturing lines. ISQ will be responsible for the technical validation and generation of products.

2.2. Standardization

The bio-material prepared by MYX for the bottle closures production in LBRT will be produced considering the following standards as per value chain:

- ASTM D3985 (Oxygen Permeation of Flexible Barrier Materials Using a Coulometric Sensor)
- ASTM D6866 (Determination of Biobased carbon content)
- ASTM F1249 (Water Vapor Transmission Rate)
- ASTM F2476 (Determination of Carbon Dioxide Gas Transmission Rate)
- ISO 16620 (Plastics - Biobased content in plastic products, polymers and additives)

On one hand, ISO 16620 specifies the general principles and the calculation methods for determining the amount of biobased content in plastic products. On the other hand ASTM standards classified as D refer to miscellaneous materials and products, whereas the ones classified with letter F refers to end-use materials and products. Other standards will be considered for the determination of the permeability coefficient with respect to different elements.The bottle caps produced with the bioplastic will be tested in accordance with the following standards to evaluate their final performance:

- ISO 9727-1 to ISO 9727-6
- UNI EN 13432
- MOCA (materials and objects in contact with food) Analysis

ISO 9727 determines all the key physical characteristics of cylindrical cork stoppers (dimensions, mass, apparent density, humidity content, dimensional recovery after compression, extraction force and liquid tightness). UNI EN 13432 is an Italian technical standard that harmonizes with the European ones and defines the requirements that packaging must possess in order to be recoverable through composting and biodegradation.

Finally, MOCA Analysis is relevant for food contact, and is done in conformity with EC legislation:

- Regulation 1935/2004 / EC

- Regulation 10/2011 / UE and subsequent updates and changes
- Regulation 2023/2006 / EC

And the following Italian legislation:

- D. M. 21/03/1973 and subsequent updates and changes
- PR Presidential Decree 777/82 and subsequent updates and changes
- D.lgs. 10 February 2017 n°29

2.3. Data management

The management of this WP’s data will involve several tasks from this and other WPs: task T1.4. “*Inline monitoring and quality controls*”; task T3.3. “*Upgrades and modifications of equipment in manufacturing lines*” and task T7.6. “*Open science and Data management plan*”. Throughout the duration of the project, IRIS will coordinate the collection of data from the three manufacturing lines onto the ICT (Information and Communication Technology) infrastructure that will be connected to the GREEN-LOOP platform for the purpose of optimizing the entire value chain, as well as the market analyses and identification of replication cases performed in WP7.

Moreover, in order to comply with the GDPR, RWTH AACHEN will also publish a Data Management Plan (DMP) that establishes the guidelines for data management (including the data collected, the data processed in the GREEN-LOOP platform, and the results obtained) throughout their entire lifecycle. This information has been published during M06 in GREEN-LOOP’s public deliverable D7.11 "*DMP and open sourcing approach*". At this stage, the experimental data set created for WP4 is related to MYX, and its purpose is to collect and compare the material properties associated with the bioplastic sample materials through the assimilation of data from tables and text.

2.4. Circularity

Developing solutions where the plastic produced is biodegradable and/or compostable is key to ensuring circularity and low environmental impact of the products. Around one-third of food produced is lost or wasted in the agro- industry sector, corresponding to 1.3 billion tons of food per year [2]. One possible solution is food valorisation to produce biomaterials. When making bioplastic from the modification of natural organisms, pre-treatments procedures must be applied, including mechanical, thermal, chemical and biological conversion. In this sense, drying and milling techniques has been utilized to improve the mechanical properties of bio-based materials, and techniques such as injection moulding has been used to finalize the products. The later technique has been enhanced with the inclusion of microwave systems, which has demonstrated to extend the interfacial bounds and mould filling and its applications in moulding for packaging and lightweight composites.

The activities performed in the bioplastic value chain in GREEN-LOOP aim to achieve a reduction in CO_2 emissions that will be evaluated by Life Cycle Analysis (LCA), with the possibility to reuse the material by 50%. Moreover, thanks to the reuse from agro-industrial waste that otherwise would be disposed of as regular waste, it will be possible a reduction of the environmental impact indicator “waste reduction”. Specifically, MYX will develop thermoplastic biocomposites with low carbon emissions, biobased and biodegradable properties by revaluing and ennobling vegetal residues from agro-industrial supply chains as filler for thermoplastic carriers (circular economy).

2.5. Modelling

Modelling will be carried out by MYX as per task T4.3 “*Eco design and manufacture of a bio-composite material*”, supported by AI models from task T2.6. During T2.6, IDE will develop IA models for the optimization of the manufacturing process of bio material thanks to back and forward information about the MYX process covered in WP4.

The material will be characterised to determine physical, mechanical, and technical characteristics. Physical properties refer to observable characteristics of a material and its microstructural features such as shape and size of particles, porosity, density, colour, and melting point. Mechanical tests include experiments on resilience, hardness, fatigue, torsion, traction, compression, and bending of the substance to verify its durability and resistance. The following test will be carried out:

- **Tensile strength:** it defines the stress of material that is measured as force per unit area. The testing involves taking a small sample pulling it with a tensometer at a constant strain rate until it breaks.
- **Tensile modulus:** also known as Young's modulus equation, it is described by the formula **E =** tensile stress/tensile strain **= (FL) / (A * change in L**), where F is the applied force, L is the initial length, A is the square area, and E is Young's modulus in Pascals (Pa).
- **Flexural modulus:** also known as bending modulus, it’s usefule to measure the tendency for a material to resist bending. It’s defined as the change in stress divided by the corresponding change in strain. Ideally, the flexural modulus of a material is equivalent to its Young's modulus, and graphically corresponds to the slope of the linear portion of a stress-strain curve.
- **Flexural strength:** it determines the ability of the material to withstand bending forces applied perpendicular to its longitudinal axis.
- **Elongations:** to calculate the elongation of a material, the change in length is divided by the original length and given in micrometers per meter (μm/m).

Finally, technical features of the material are oftentimes transferred into technical data sheet, which is a document that describes the product composition, methods of use, operating requirements, common applications, warnings and pictures of the product.

2.6. Manufacture

2.6.1 Manufacture by MYX

MYX will produce biomaterial through its patented “PROCESS FOR MAKING COMPOUNDS USING WASTES OF NATURAL ORIGIN AND FIBRES OF PLANT OR ANIMAL ORIGIN”, Italian Patent n.102019000003565, practice number 19036. As per *Figure 2.* MIXCYCLING patented process*, t*he complete process of the invention substantially comprises the following steps in succession:

1. **Preparation of the "charge", that is the recovery of the wastes of natural origin and plant fibres.** The selected fibre is treated with NTP (non-thermal plasma) technology which has the following peculiarities:
    - Make the material more processable in terms of effectiveness
    - No need to add gripping additives to bind the polymer to the fibre
    - Make it easier to handle the material during moulding
    - Improve material surface aesthetic

2. **Selection of the carriers and agglomerating additives.**

3. **Preparation of the blend**, that is a mixture consisting of the charge, carriers and agglomerating additives in which the percentages of the three components usually vary based on the type of grafting wanted and the mechanical/physical characteristics that the compound or the semi-finished final product

4. **Processing the blend to obtain the compound by mixing the various components**

5. **Processing the compound to obtain a semi-finished product by extrusion process.** The granukes are sanitize with NTP technology to reduce the volatile organic substances (VOCs)

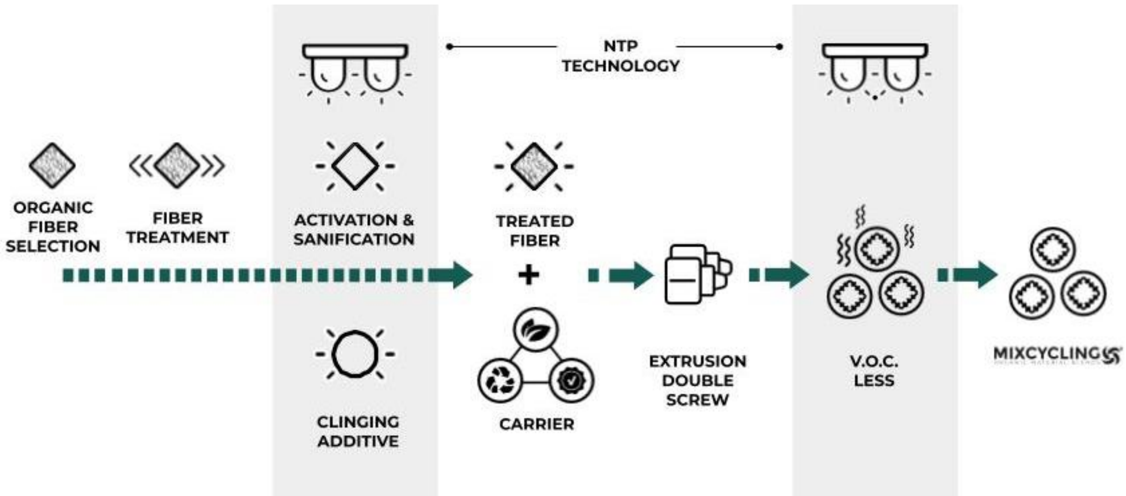

Figure 2. MIXCYCLING patented process

As written in the proposal, MYX bio-plastic will be subject to quality control with thermal testing such as VICAT (to determine the softening point for plastic) and HDT (to assess the temperature at which a polymer or plastic composite deforms under a given flexural load), as well as mechanical characterisation defining properties such as tensile strength, tensile modulus, flexural modulus, elongations and flexural strenght.

2.6.2 Manufacture by LBRT

The bioplastic compound of MYX will be directed to LBRT to produce TDZ caps prototypes. As per Figure 2, the bio-granules will be put into the JSW55-AD injection moulding machine selected for GREEN LOOP, where they will be melted in a chamber at high temperatures. The screw form of the chamber will push the casted material toward the clamping where there are moulds. After being shaped, the products will cool off.

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Based on the type of moulds used, some plastic waste can be generated in the form of “materozze” (sprues) or defective products The resulting waste material can be reused within the same production process or used as secondary material for other productions, depending on the characteristics of the product like colour and composition of the material. The scraps (PP or PE) are put into a grinder to produce granules that are re-introduced in the production cycle. LBRT manages to recycle about 20%-25% of the plastic produced, since only certain shades of plastic can be recycled without creating aesthetic flaws in the final products. Potentially, the bioplastic resulting from WP4 could be reprocessed if the moulds utilized create sprues.

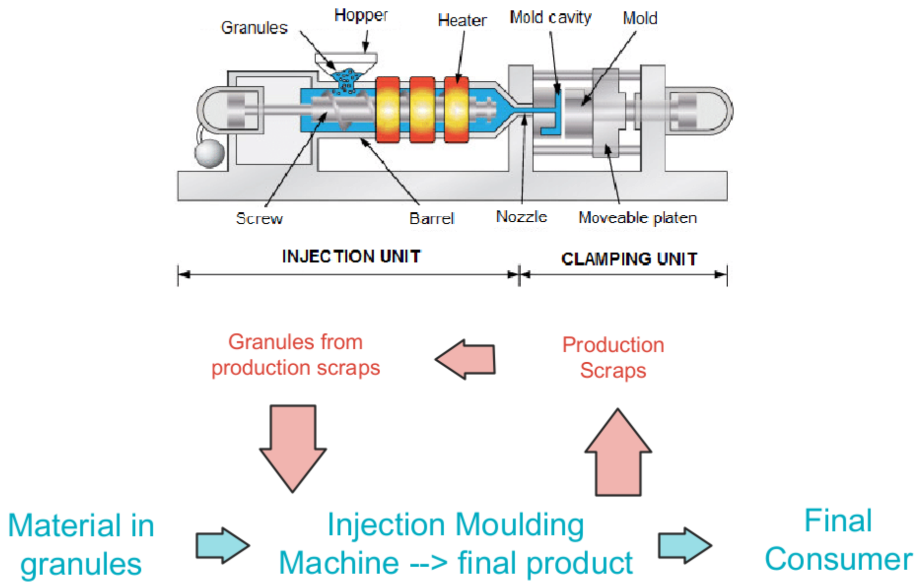

Figure 3. LBRT production process

LBRT will monitor the production cycle, and do the necessary food contact tests on the samples with food simulant) in accordance to UNI EN 13342 and MOCA Certification. Biodegradability and food contact require different tests in order to be certified, and generally it is done by step. First of all, the data sheets of the product and of the various additives are evaluated to identify the necessary tests.

After that, global and specific migration tests are conducted to verify that no chemical substances are transferred from the material to the food, and to ensure that the product complies with the relevant regulations. The bioplastic closures will be tested in laboratory, ehere they will be put in contact with food simulants, substances that simulate the behavior and characteristics of certain classes of foods. Since TDZ is a producer of olive oil and fruit juice, the simulant considered will be acetic acid (food simulant B – for juice) and vegetable oil (food simulant D2 – for oil).

The determination of heavy metals and dangerous substances is also carried out to verify if the material is within the required limits. Upon request, phthalates, aromatic amines and dyes are also monitored, as well as NIAS (Non-Intentionally Added Substances). Once verified the alimentary of the cap, the biodegradability test is carried out. If the material passes the biodegradability test it is possible to proceed with the assessment of disintegration and ecotoxicity. Additionally, LBRT will take into account aesthetic modification in the design of the closures in order to preserve the original performance.

3. Products' properties and Bioplastic specifications

The specifications of TDZ current used bottle caps and the applications of the bio-based material are described in this section.

3.1 General Shape of current products

This subsection describes the characteristics and dimensions for each of the current caps used by TDZ:

3.1.1 Current state and characteristics of the materials used for EVO Oil caps

The oil is bottled automatically through a dosing machine, then the dispenser is inserted manually and the cap is screwed on. At the end of the process, a clamp is used to tighten the crown of the cap. *Table 1* summarize the specifications of the bottle closure, whereas *Figure 4* depicts the oil cap.

Table 1. Description EVO Oil Caps

EVO Oil caps:	
Type of materials	Aluminium
Thickness Aluminium	0,21
Specific Weight	2,7kg/cm³
Outer Diameter	31,5mm
Total Height	24,1mm
Capsule weight without gasket	1,85gr
breaking load	Rp 02N/mm² > 140
Internal Printing	epoxy or polyester paint; complaint to DM21/03/73 and 90/128CEE
External Printing	Vinyl paint complaint to DM21/03/73 and 90/128CEE
Physical proprieties	H12

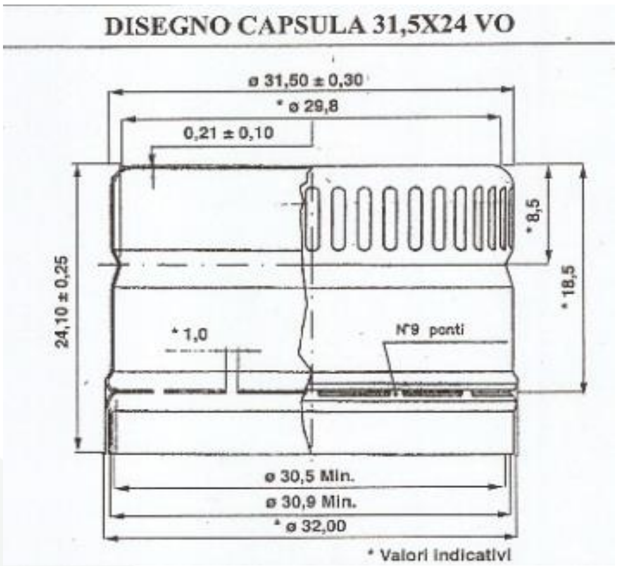

Figure 4. Description EVO Oil Caps

3.1.2. Current state and characteristics of the materials used for the EVO Oil dispenser

The oil dispenser, inserted manually during the bottling process, is entirely made in PE., with its dimensions and key characteristics described in figure 5 and table 2:

Table 2. Description EVO Oil Dispenser

EVO Oil caps:	
Type of materials	Polyethylene
Specific Weight	0,918-0,924 gr/cm^3
Vicat Solving point	93°C
Total Weight	3,10 g
Deformation load in closing	100-130 kg

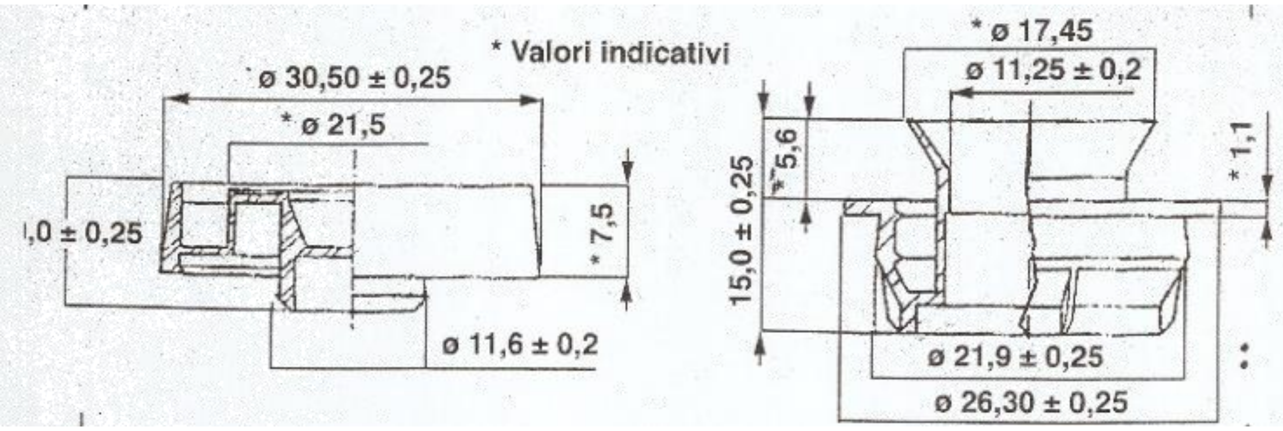

Figure 5. Dimensions of EVO Oil dispenser

3.1.3. Current state and characteristics of the materials used for Juice caps

The juice is bottled automatically through a dosing machine, then the cap is screwed on. After a couples of hours, the bottles are washed with water (usually cold) to clean them.

Table 3. Description of Juice Caps

Juice caps:	
Type of materials	Tin Steel
Specific Weight	4,0 g/cm^3
Thickness	0,14 mm
Tinning	2,8 g/mq
Outer diameter	37,55 mm

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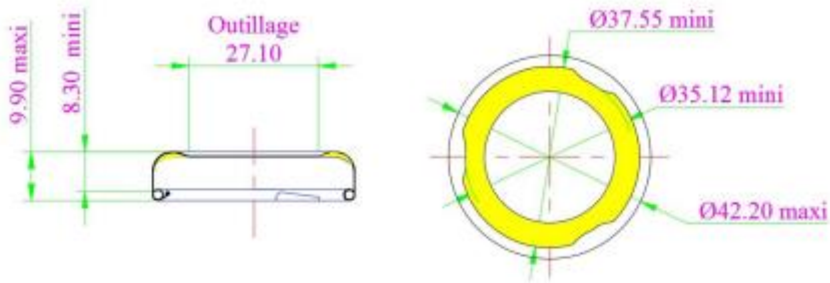

Figure 6. Dimensions of Juice Caps

To seal off the juice bottle by creating a vacuum within, the cap needs resistance to temperatures from 85-95 °C (pasteurisation temperature). This process guarantees a shelf life of at least 2 years.

3.2. Bioplastic requirements definition

As described in the bioplastic value chain in GREEN-LOOP’s GA, the developed material must satisfy some essential requirements

Table 4. Characteristics of material in the bio-plastic value chain

Characteristic	Expected (target) value	Units
Compressive strength	> 80	MPa
Compressive elastic modulus	> 2.5	GPa
Flexural strength	> 71	MPa
Flexural modulus	> 2.3	GPa
Tensile strength	> 49	MPa
Tensile elastic modulus	> 2.3	GPa

3.2.1 Carrier material definition

MYX has started the experimental activity with PHB as carrier. In general, polyhydroxybutyrate (PHB) is one of the most commonly observed forms of PHAs (polyhydroxialcanoates), as it is composed of packed monomers of R-3-hydroxybutyrate (R-3-HB). PHB is the only type of polymer that is fully biodegradable in nature. Bacteria can synthesize PHB as inclusion bodies that accumulate as reserve material when their growth is subject to several different stress conditions. This polymer exhibits properties that are similar to several synthetic thermoplastics, including polypropylene. The advantages of these types of biodegradable plastics are that they are useful for extensive applications and can be produced on a mass scale. This will enable us to replace the petroleum-based plastics that are currently used by the industry [3].

It's an innovative and environmental-friendly alternative to fossil-based thermoplastics, such as PE and PP, used in caps production also with some advantageous characteristics. It exhibits a high degree of crystallinity, a high melting point of about 180 °C, but, most importantly, PHB is rapidly biodegradable, unlike PP. Moreover, it shows:

- Water-insoluble and relatively resistant to hydrolytic degradation
- Gas barrier properties

- Soluble in chloroform and other chlorinated hydrocarbons
- Biocompatible
- Nontoxic
- Similar properties to those of polypropylene (PP)

PHB is a good candidate that can replace PP as actual fossil-based polymer used in caps production. To reach high plasticizing effect, if needed PLA can be blended with PHB thanks to the high chemical compatibility between PHB and PLA.

3.2.2. Filler material definition

The filler is yet to be defined by MYX among the following candidates:

1. Native Corn Starch
2. Chitosan (industrial grade)
3. Mycelium
4. Cork
5. Egg Shell
6. Colofonia
7. Oyster Shell
8. Cellulose

These fillers have been chosen on the base of availability, traceability, chemical compatibility with PHB or PLA. In previous research activities oriented to improve TRL of GREEN-LOOP processes, MYX has carried out some compounding activities in order to know the compatibility of some vegetal residues from agro-industrial supply chains with PHB and the list reported above is a result.

3.3. Bio-plastic GREEN-LOOP target properties

The following tables summarizes the properties that the bio-plastic products should have at TRL6. These are the target characteristics for the development of bio-rubber value chain products in frames of the GREEN-LOOP project. These properties and targets are likely to change during the execution of WP4 as the results obtained during the manufacturing process will help in the development and refining of these products:

Table 5. Technical requirements for the bio-plastic oil caps

Product	Bio-plastic bottle closures	
Chemical Properties	**Value**	**Units**
Natural Fibers content	15 – 45	%
Biodegradable thermoplastic carriers’ content	55 – 85	%
Biobased additives content	< 5	%
Vicant softening temperature	93	°C
Physical Properties	**Value**	**Units**
Specific weight	2.7	kg/m^3
Weight	1.85	g
Mechanical Properties	**Value**	**Units**
Compressive strength	> 80	MPa
Compressive elastic modulus	> 2.5	GPa

Product	Bio-plastic bottle closures	
Chemical Properties	**Value**	**Units**
Flexural strength	> 71	MPa
Flexural modulus	> 2.3	GPa
Tensile strength	> 49	MPa
Tensile elastic modulus	> 2.3	GPa
Standards to address		
ASTM D6866, EN 13432, DM 21/03/73, Council Directive 82/711/EEC		

Table 6. Technical requirements for the bio-plastic juice caps

Product	Bio-plastic bottle closures	
Chemical Properties	**Value**	**Units**
Natural Fibers content	15 – 45	%
Biodegradable thermoplastic carriers' content	55 – 85	%
Biobased additives content	< 5	%
VICAT softening temperature	93	°C
Physical Properties	**Value**	**Units**
Specific weight	4.0	kg/m^3
Mechanical Properties	**Value**	**Units**
Compressive strength	> 80	MPa
Compressive elastic modulus	> 2.5	GPa
Flexural strength	> 71	MPa
Flexural modulus	> 2.3	GPa
Tensile strength	> 49	MPa
Tensile elastic modulus	> 2.3	GPa
Standards to address		
See Annex A: List of standards applicable to the Bioplastic value chain		

4. Future workflow and Upscaling

MYX is responsible for the production of the biocomposite by selecting a carrier plus fibre with determined characteristics. The further development of the biomaterial will follow the work description of the WP4 as described in the Grant Agreement (GA), as well as the general workflow described in section 2 of this document. This will include materials and manufacturing development, lab-scale analysis, and testing activities.

Production of the material will be done by extrusion followed by the grinding of the composite to obtain the compound in granules. The microwave enhancement from IDE applied on LBRT JSW55-AD machine and detailed in task T4.2 “*Upgrades and modifications of equipment in manufacture lines*” will be useful to make a comparison between the samples produced with and without the use of such technology. Given the technical characteristics of the JSW, IDE has concluded that the less invasive section to work on is the hopper. LBRT injection moulding machine has a hopper loader attached to the hopper, consequentially the best option to integrate the MW technology is to substitute the whole hopper by manufacturing a new one. IDE is currently reviewing the design to be able to connect the new hopper on the upper side to the hopper loader and on the lower side to the moulding machine.

Thanks to T4.5 *“Characterization and quality controls”* during [M01-M25], continuous work of data control and upgrades will be done to deliver valid prototypes. The production of these prototypes with the necessary adaptation will be tested in industrial settings by LBRT in order to reach TRL6. All quality characteristics defined previously will be constantly reviewed during M25-M36 in the activities of WP6.

5. Conclusions

According to GREEN-LOOP’s objectives and the technical requirements from TDZ, the end-user, the expected caps made from 100% recyclable biomaterial should equate to the same physical and performance characteristics as the ones currently in use Biobased closures can replace barrier materials in closures (primarily made of aluminium) that play a significant role in the life cycle impact. Several environmental benefits can be attained, including a decrease in CO_2 emissions, a reduction in waste, and an increase in water resource efficiency. In this optic, the dimensions or shapes of the new caps aren’t relevant as long as the quality of the liquid within the bottle stay unchanged.

The next phase of this WP is MYX's lab-scale production of bio-plastic. Testing the combination of PHB carrier and infill should help identify a material combination on which the project should concentrate. The formulation's filler and additive percentages will be adjusted based on test results. MYX will also maintain current production costs in line with average market prices. Last but not least, LBRT will produce closures for the end user and demonstrate their effectiveness in accordance with the requirements and standards outlined in this document.

References and Resources

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Annex A: List of standards applicable to the Bioplastic value chain

- **ASTM D3985** - Global ASTM international standard method for measuring oxygen transmission rates through plastic films and sheeting by using a coulometric sensor.
- **ASTM D6866** - Standard Test Methods for Determining the Biobased Content of Solid, Liquid, and Gaseous Samples Using Radiocarbon Analysis.
- **ASTM F1249** - Standard test method for measuring the water vapor transmission rate through flexible barrier materials used in packaging or industrial applications.
- **ASTM F2476** - Standard Test Method for the Determination of Carbon Dioxide Gas Transmission Rate (CO 2 TR) Through Barrier Materials Using an Infrared Detector.
- **EN 13432** - Packaging - Requirements for packaging recoverable through composting and biodegradation. Test scheme and evaluation criteria for the final acceptance of packaging).
- **ISO 16620-1:2015** - Plastics — Biobased content in plastic products, polymers and additives.
- **ISO 9727-1 (2007)** - Cylindrical cork stoppers - Physical tests Determination of dimensions.
- **ISO 9727-2 (2007)** - Cylindrical cork stoppers - Physical tests Determination of mass and apparent density for agglomerated cork stoppers.
- **ISO 9727-3 (2007)** - Cylindrical cork stoppers - Physical tests Determination of humidity content.
- **ISO 9727-4 (2007)** - Cylindrical cork stoppers - Physical tests Determination of dimensional recovery after compression.
- **ISO 9727-5 (2007)** - Cylindrical cork stoppers - Physical tests —Determination of extraction force.
- **ISO 9727-6 (2007)** - Cylindrical cork stoppers - Physical tests —Determination of liquid tightness.
- **UNI EN 13432 -** Packaging - Requirements for packaging recoverable through composting and biodegradation. Test scheme and evaluation criteria for the final acceptance of packaging).

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