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Alternatives to polypropylene bags: description of prototypes developments

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Project: Alternative to PP bags

Partners: WFP, UNHCR and ICRC

Alternatives to polypropylene

Object: description of R&D development of Alternatives to current PP woven bags used in the humanitarian sector for food and non-food delivery

Table of Contents

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Context & objectives

As a first delivery of the project "Alternatives to PP bags", a panorama of alternative solutions to package humanitarian food and non-food items has been established and a prioritization has been proposed based on a multicriteria evaluation and considering the Partners constraints and targets.

The focus has been given on:

- Comply with the functional specifications of the current PP woven bag (food and non-food items)
- Minimize plastic leakages but also water and CO_2 footprints.
- Keep a high reuse rate of the final product (even if very difficult to estimate)
- Favor mature solutions to enable an industrial deployment of the solutions within less than 3 years.

In that context, several options of materials have been identified as possible solutions, and following stakeholders have been selected for further investigations and development:

INCREMENTAL SOLUTIONS	01 - PP with an improved resistance and lifetime	• **AIMPLAS, a private R&D institute based in Spain**
	02 - recycled PP	• **AIMPLAS, a private R&D institute based in Spain**
SOLUTIONS WITH ALTERNATIVE MATERIALS	03 - based on cellulose	
	04 - based on vegetal fibers (Excluding cotton as water and CO_2 footprints can be very high)	• **Ahsanullah University in Bangladesh** • **GIOTTO and SUPSI, respectively a consulting company and a university research unit in Switzerland**

The three R&D entities have worked on developing unique solutions from October 2022 to June 2023.

Below is a summary of their findings:

- Explaining the technical choices that were made in the design.
- Showcasing the performance of the final prototypes developed.

AIMPLAS

Development strategy

Aimplas is a R&D company and is working with a partner, Rafia Industrial, for bags production. Aimplas is targeting lots 1 and 2: extending the lifetime of the bag and increasing the recycled content. For each lot, 2 strategies have initially been proposed by Aimplas:

1) Combination of polypropylene homopolymer (PPH), stiffer, and polypropylene copolymer (PPC), more ductile, with advanced packs of thermal stabilizers and UV filtering to obtain both better mechanical performance with long lasting effect.
2) Bi-layer bag structure of PP where the inner layer ("base layer") gives mechanical strength and the outer layer (coating) protects the food from moisture, leakages, and also improves mechanical properties.

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Then the R&D work consisted in selecting the right polymers to be used for the prototyping and to optimize the concentration of additives to be included to extend the lifetime of the bags. Once done, and as Aimplas was not able to formulate the prototypes, the production of films and bags was done at Rafia Industrial facilities (Figure 1).

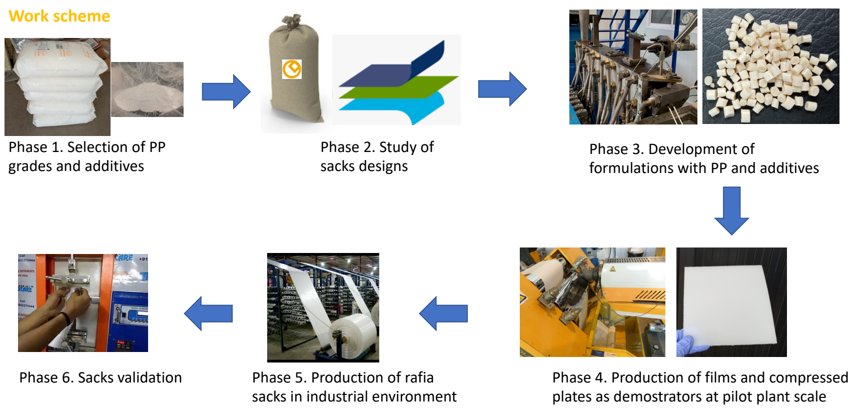

Figure 1: Experimental strategy to develop PP bags with extended lifetime.

Design

Formulation selection

As it was not possible to make the bilayer at lab scale, the 2 strategies were assessed theoretically against several performance criteria (Table 1). The main advantage of the bilayer versus monolayer is the limitation of additives used, as they are necessary only in the external layer of the bag (exposed to the sun), limiting drastically the total quantity of additives and the cost. Based on that comparison, Aimplas team decided to pursue with the bilayer concept.

Table 1: Comparison of monolayer and bilayer bags

Properties	Bilayer	Monolayer
Flexibility in grammage	Favourable	Not favourable
Water barrier properties	Favourable	Not favourable
Material cost	Favourable	Not favourable
Printability	Favourable	Not favourable
Process cost	Not favourable	Favourable
Mechanical properties	Less favourable	Favourable
Tendency in the sacks market	Favourable	Not favourable

The bilayer is composed of 60 g/m^2 of PP polymer and 20 g/m^2 of Aimplas additivated formulation.

Selection of virgin polymer for base layer

3 virgin polypropylene polymers were tested to be used as the base material for PP bag:

1) ISPLEN PP040G1E (used by Rafia Industrial, industrial partner of Aimplas)
2) ICRC PP (sent by ICRC)
3) BRASKEM PPInspire 215 (additional one procured by Aimplas)

The evaluation of the performance was made by UV resistance testing, both at 310 nm and 340 nm (exposure for 1 week maximum, based on ASTM G53 and UNE_EN_ISO 13206), on a film of 100 µm. After 168 h of UV exposure, only ISPLEN polymer remained unbroken. Aimplas decided to pursue the development with this polymer.

Use of recycled PP

Regarding recycled PP, the main findings from Aimplas were that:

- Chemically recycled PP, intended to be used for food contact bags, is today very difficult to find as the demand is exceeding the offer (REPSOL for instance is one supplier) which would additionally make the price of recycled PP very high.
- Post-consumer mechanically recycling scheme for PP is not yet developed enough as the quality is still very variable depending on the origin. Therefore, it cannot be used in bags formulation.
- Pre-consumer mechanically recycled PP can be used. Yet, the incorporation ratio cannot be very high as it could degrade the mechanical properties of the bags.

Multilayer structures are not allowed for food-contact packaging if one layer is composed with recycled material. Pre-consumer recycled PP will be used only for non-food-contact applications (UNHCR, PP sheets for blankets packaging).

Selection and dosage of additives

2 types of additives were selected for the bilayer:

- Antioxidants: 2 different antioxidants were used, one for protection during processing stages and the second for the protection during the use of the product.
- UV stabilizers: PP has poor resistance to UV, which leads to plastic leakages. UV stabilizer can be incorporated to the new formulations to improve the resistance to UV radiation.

An experimental design was made with these additives, included in a matrix composed of virgin PP homopolymer, virgin PP copolymer, recycled PP at different proportions. The mechanical resistance was tested before and after ageing. The total cost of material for the external layer was also assessed. Results are presented in Table 2.

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Table 2: Comparison of bi-layer configurations

	PP homopolymer PP080G2M	PP copolymer PB180G2M	rPP PP RANDOM GRANZA 3000S2531	AO1 Irganox 1010	AO2 Irgafos 168	UV stabilizer Tinuvin 110				
cost (€/kg)	1.50	1.60	1.60	10.20	10.90	31.95				
Nº formulation	(wt%)	(wt%)	(wt%)	(wt%)	(wt%)	(wt%)	Strain at break (t0)	Strain at break (aged)	Price (€)/kg of material	versus ref
1	90	10	0	0	0	0	14	3.3	1.51	0%
2	80	20	0	0	0	0	17	2.4	1.52	1%
3	89.28	9.92	0	0.2	0.1	0.5	12	6.4	1.69	12%
4	88.83	9.87	0	0.2	0.1	1	13	6.1	1.84	22%
5	79.36	19.84	0	0.2	0.1	0.5	12	12	1.70	13%
6	78.96	19.74	0	0.2	0.1	1	14	10	1.85	23%
7	60	40	0	0	0	0	8.9	5.4	1.54	2%
8	54.54	36.36	9.09	0	0	0	15	4.2	1.55	2%
9	59.46	39.64	0	0.2	0.2	0.5	8.7	5.6	1.73	14%
10	59.16	39.44	0	0.2	0.2	1	10	5.9	1.88	25%
11	49.3	39.44	9.86	0.2	0.2	1	8.1	5.4	1.89	25%
12	39.44	39.44	19.72	0.2	0.2	1	11	5	1.90	26%

For virgin PP, a higher ratio of copolymer has been observed to be beneficial for UV resistance as well as the use of additives. Increasing the concentration of anti-UV from 0.5% to 1% has no significant impact. For samples with recycled PP, the use of additives did not lead to additional resistance. According to Aimplas, this could be since recycled PP might have already additives from its "first life". Formulation 5 was the best formula in terms of mechanical resistance without being the most expensive.

Bags production

Production of first industrial batches

The mix of additives and polymer of the external layer of the bag was compounded by AIMPLAS. The bags were then produced at Rafia Industrial facilities. To facilitate the process, the recipes were a little bit modified by Rafia (described in the descriptive sheets of the PP alternatives). Beside this modification, the production of bags went well. In total, almost 2000 bags have been produced with virgin PP (25 and 50 kg bags) and 300 blankets with virgin and recycled PP.

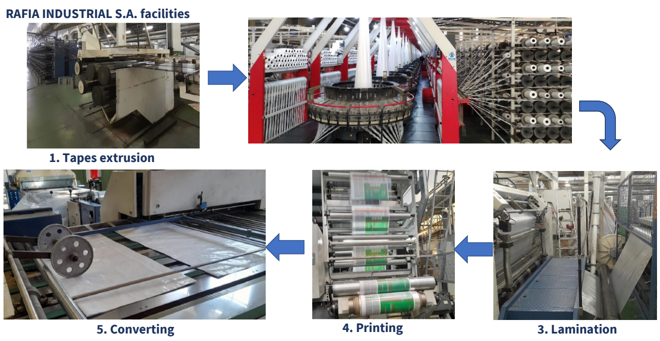

Figure 2: Bags production at Rafia Industrial facilities

Bags performance

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Food contact

The plastic bags will be used in direct contact with food. The compatibility was assessed as regards to EU regulation (general one: 1935/2004 + plastic guidance 10/2011). 2 major aspects must be checked for plastic packaging:

- the products used in the design of the bags must be indicated in the positive list of annex1 of commission regulation 10/2011
- a migration test must be performed, and the products transfer must be below authorized limits.

Regarding AIMPLAS formulation, all products used have a declaration of conformity. The product compatibility with food contact is validated. Food grade assessment was performed for a repeated use with a maximum time of 6 hours at 70°C and was validated (see appendix). Ageing tests are still being performed.

Mechanical strength

The mechanical strength was analyzed (EN ISO 13934-1) before and after ageing according to ISO 21898. For accelerated ageing test, a UVB-lamp 313 nm was used with 8 hours dry period and 4h with condensation. The results are shown in Table 3.

Table 3: Mechanical strength of prototypes before and after ageing

Application	Supplier	Sample	Ref	Tensile strength before ageing (N)	Tensile strength after ageing (N)	Ageing test duration (h)
25kg bag	Aimplas-Rafia	bilayer virgin	U	560	3	125
25kg bag	Rafia	conventional	T	607	N/A	147
50 kg bag	Aimplas-Rafia	bilayer virgin	E	612	N/A	125
50 kg bag	Rafia	conventional	R	576	N/A	176
sheet	Aimplas-Rafia	virgin	F	705	62	300
sheet	Aimplas-Rafia	recycled	S	719	17	125
sheet	Rafia	virgin	A	553	45	300
Std bag	Rafia	monolayer	Std	333	46	300

Bilayer design seems to significantly increase the mechanical resistance at t0 compared to monolayer. This is beneficial to decrease food losses in transport. On a less positive side, the Aimplas prototype bags do not show any lifetime improvements. The quantity of additives was probably too low as it was only added to the outer layer.

For blanket packaging, the sheets are only made of one layer, so, in proportion, the quantity of additives is higher than in the bags, both for Aimplas and Rafia sheets. These are the only samples sustaining the 300 hours test. Nevertheless, the recycled PP sheet does not comply with the full duration of the test.

In the future, to improve this solution:

- bi-layer concept should be kept as the initial mechanical performance is good while reducing the total weight.
- additives should be increased and added also in the fabric base.

Scalability

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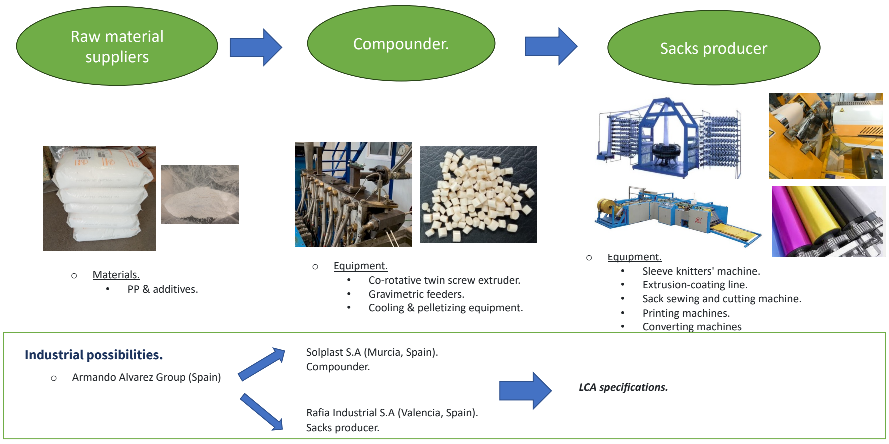

Figure 3: Industrial process necessary to produce the bilayer PP bags

👍 the process is standard, easy to replicate

👎 the performance is dependent on the raw material used. Additives should ideally be adapted each time a new PP is used. => A sensitivity analysis must be conducted.

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Innovation key figures

DESCRIPTION		
Product name	**Bi-layer extended life virgin PP bags or sheets**	
Targeted applications	Food contact packaging 5 to 50 kg bags including flour Sheets for blankets packaging	
Composition	- Internal layer (70%): ISPLEN PP040 (Repsol) - External layer (30%): 76.9% PP (ISPLEN PB089, Repsol), antioxidant 1 (Irganox 1010, BASF): 2%, antioxidant 2 (Irgafos 168, BASF): 1%, UV stabilizer 5.1% (Tinuvin 110, BASF), PE (15%)	
Development status	Currently being tested on the field	
RD partner(s)	AIMPLAS (Spain)	
Industrial supplier(s)	RAFIA INDUSTRIAL (Spain)	
PERFORMANCE		
Density	83 g/m^2	😊
Mechanical properties	Passed. No break at 600 N	😐
Permeability	- WVTR = 2.4 $g/m^2/d$ (required < 5 $g/m^2/d$) - OTR = 928 $cm^3/m2/d$ (required < 1500 $cm^3/m^2/d$)	😊
Food contact	Passed (materials compatible for food contact + migration test)	😊
Cost	18% increase versus ref Reference: 6-7 USD/t of food or 0.38 USD /50kgbag	😐
Biodegradability and plastic leakage	- Not biodegradable (same as reference PP bags) - Plastic leakage decreased due to increased lifetime (TBC)	😐
Lifetime	Similar to conventional PP bags	😐
Carbon impact	- All materials imported. - Carbon impact slightly decreased by design (weight is less) and at use (lifetime increased)	😊
Other limitations / advantages	- Not recyclable - Cultural acceptance is similar to conventional.	😐
SCALABILITY		
Production process description	- Needs to produce the pellets with a *compounder* (someone able to mix different PP and additives and produce pellets). - Can be made in conventional PP bags production that have a *twin-screw extruder*	😐
Raw material availability	Available worldwide. Abundant.	😊
Solution replicability	The performance of the solution varies depending on the type of PP being used. A sensitivity analysis needs to be made.	😐
Intellectual properties	Free of rights.	😊

WAY FORWARD

1. Wait for the results of field tests => go / no go
2. If field tests ok, then test increasing additives content to check resistance to ageing
3. the sensitivity of lifetime according to levels of additives and type of virgin PP. Additionally, PE should be removed to improve recyclability (not initially part of the design)
4. Work with Rafia Industrial to define industrial specifications of bags and suppliers.
5. Short-list suppliers and include specifications in purchase contracts

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OVERALL DESCRIPTION		
Product name	**Bi-layer extended life recycled PP bags or sheets**	
Targeted applications	Non-food contact packaging Sheets for blankets packaging	
Composition	- Internal layer (70%): ISPLEN PP040 (Repsol) - External layer (30%): 59.5% PP (ISPLEN PP089, Repsol), pre-consumer recycled PP: 39.6%, antioxidant 1 (Irganox 1010, BASF): 0.2%, antioxidant 2 (Irgafos 168, BASF): 0.2%, UV stabilizer 0.5% (Tinuvin 110, BASF), PE (0%)	
Development status	Currently being tested on the field	
RD partner(s)	AIMPLAS (Spain)	
Industrial supplier(s)	RAFIA INDUSTRIAL (Spain)	
PERFORMANCE		
Density	83 g/m^2	☺
Mechanical properties	Passed. No break at 600 N	😐
Permeability	- WVTR = 4.4 $g/m^2/d$ (required < 5 $g/m^2/d$) - OTR = 3058 $cm^3/m2/d$ (required < 1500 $cm^3/m^2/d$)	☺
Food contact	Recycled PP cannot be directly in contact with food.	☺
Cost	TBC Reference: 6-7 USD/t of food or 0.38 USD /50kgbag	😐
Biodegradability and plastic leakage	- Not biodegradable (same as reference PP bags) - Plastic leakage decreased due to increased lifetime (TBC)	😐
Lifetime	decreased	☹
Carbon impact	- All materials imported. - Carbon impact slightly decreased by design (weight is less) and at use (lifetime increased). - The recycled plastic is pre-consumer recycled plastic.	☺
Other limitations / advantages	- Not recyclable - Cultural acceptance is similar to conventional.	😐
SCALABILITY		
Production process description	- Needs to produce the pellets with a *compounder* (someone able to mix different PP and additives and produce pellets). - Can be made in conventional PP bags production that have a *twin-screw extruder*	😐
Raw material availability	Available worldwide, abundant, except for recycled PP, which has a limited feedstock.	☹
Solution replicability	The performance of the solution varies depending on the type of PP being used. Moreover, the pre-consumer PP can already contain additives. A sensitivity analysis needs to be made.	😐
Intellectual properties	Free of rights.	
WAY FORWARD		
Due the low interest of using pre-consumer plastic + the impossibility to use it for food contact + a slight increase in price, the recommendation is to leave over this bag design. No significant progress is brought compared to existing virgin PP bags.		

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AUST

Development strategy

Ahsannullah university (AUST) is based in Dhakka, Bangladesh. AUST is working with several factories to produce bags:

- Jute Textile Mills Limited, Khulna, Bangladesh
- Islam Textile, Madhabdi, Narsingdi, Bangladesh
- Local Cutting and Sewing Facility, Tongi, Gazipur, Bangladesh

Ahsanullah University (AUST) aimed at developing a bag in accordance with Lot 4, made of jute fibers. According to AUST, jute is better than polypropylene regarding biodegradability and UV resistance but has lower performance on cost, resistance to water and pest infestation (Table 4).

Table 4: Comparison of jute and PP bags

Properties	Woven Polypropylene Fabric	Woven Jute Fabric
Tensile Strength	Above 600N	Above 600N
Absorbency	Not absorbent	Highly absorbent
Drop test	Can withstand drop test	Can withstand drop test
UV Resistance	Poor UV resistance	Good UV resistance
Shelf life	Good shelf life	Good shelf life
Infestation	No infestation problem	Have infestation problem
Biodegradability	Not biodegradable	Biodegradable
Cost	Low	High
Carbon impact	Made of fossil fuel but light weigth	Made of biomass but heavier

The proposed strategy is to 1) optimize the fabric design to reduce the weight and the cost 2) use a coating to increase the resistance to humidity and pest infestation.

Design

Fabric selection

Following fabric design options were selected for assessment (Table 5).

Table 5: Design options for jute fabric

Criteria	Specification
Fabric Weave	Plain, Rib
Yarn Density (yarns per inch: vertical×horizontal)	8×9 (for coarser yarn count and sacking)
Yarn Count (lb/spondle)	10-12, 24

Commented [A1]: To be updated when reports from AUST received. => show density and mechanical resistance

The density of the fabric (number of yarns) is adapted to the weight of product to be transported, targeting the resistance at 600N. Any over-quality in terms of mechanical resistance results in an unnecessary increase of economic and environmental costs.

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Coating resines/additives selection

The coating AUST is proposing, is made of a resin combined with additives bringing additional functionalities such as plasticity, softness, and insect resistance.

AUST first made a screening of a large list of chemicals of which, following ingredients were selected for further investigations (Table 6, Table 7).

Table 6: Comparison of products suitable as coating resins

Resin alternatives	Tapioca Starch	PVA (polyvinyl-alcohol)	PVAc (Polyvinyl-acetate)	Natural Latex
Sensitivity to microorganisms	High	Medium	Very Low	Low
Processability	Low	High	High	High
Availability	Medium-High	High	High	Medium-High
Price	Low	Medium	Medium	Low
Quantity needed to treat the jute	High	High	High	High
Biodegradability	High	High	Medium	Medium
Expected compatibility in food contact	High	High	High	High

Table 7: Comparison of products selected for specific functional properties.

Content	Plasticizer (Glycerin)	Softener (Silicon Compound*)	Insect resistant chemical (Neem/ Margosa Oil)
Insect Resistant Properties	Low	Low	High
Softness/Flexibility of the fabric	High	Medium	N/A
Cost	High	Medium	Very High
Hydrophobicity	Low	High	High
Added properties to fabric	Flexibility and hydrophobicity	Mainly hydrophobicity	Insect resistant properties

* The silicon compound is an aminopropyl terminated polydimethysiloxane

The concentrations of each coating / additive were selected both according to literature and experience of Ahsannulah University.

Selection of coating process

Applying the resin + additives onto the jute fabric can be made using 3 different techniques:

- Coating: resin is applied directly to the surface of the fabric, but the amount of coating used is higher. The control of the process is quite complex.
- Printing: the coating is printed on the total surface of the fabric, using a screen
- Padding: the bag is plunged into the coating bath and then dried. This is the way the fibers absorbed the best the product.

Table 8: Comparison of coating techniques

Coating technique	Maturity	Complexity of the process	Number of steps	Cost

Coating	High	High	2	High
Printing	High	Low	2	Medium
Padding	High	High	1	Medium

Padding was selected as both giving good results in terms of impregnation and low complexity of the industrial process.

Prototypes

2 prototypes were made by AUST before producing the amounts of bags needed for the field trials. The bags have following characteristics (Table 9, **Error! Reference source not found.**):

Table 9: Jute bags prototypes composition

Prototype name	A : PVAc	B: Latex
Fabric	Jute (density of yarns to be adapted to the application)	Jute (density of yarns to be adapted to the application)
Resin 1	Tapioca starch	Tapioca starch
Resin 2	Polyvinyl acetate	Natural latex
Additive 1	Glycerin	
Additive 2	Aminopropyl terminated polydimethysiloxane	Aminopropyl terminated polydimethysiloxane
Additive 3	Margosa Oil	Margosa Oil
Coating technique	Padding	Padding

Figure 4: Prototyping of the bags

The performance is described in the innovation key figures datasheet. Below a few points of concerns for this innovation.

Density:

The bags density is around 900 g/m^2 i.e. around 10 times higher than the density of PP bags. This criterion is challenging as it will increase the carbon impact of transport and might also affect the processability of the bag: sewing and filling at the food supplier facilities.

Latex availability:

The latex is natural. The product is very sensitive to humidity and must be used quickly to avoid any degradation or phase separation.

Food contact compatibility:

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The jute bags are intended to be in direct contact with food. The compatibility was assessed as regards to EU regulation (general one: 1935/2004 + plastic guidance 10/2011). The plastic guidance was used at that stage because, this is the most advanced and strict guideline in Europe in terms of packaging in contact with food. 2 major aspects have been checked:

- the products used in the design of the bags must be indicated in the positive list of annex1 of commission regulation 10/2011
- a migration test must be performed, and the products transfer must be below authorized limits.

Regarding AUST formulation, all ingredients used are in the positive list, except jute and aminopropyl terminated polydimethylsiloxane. Nevertheless:

1) jute fibers are widely used for food contact applications.
2) aminopropyl terminated polydimethylsiloxane has been assessed by EFSA in 2007 (EFSA Journal (200/), 555-563, 1-31) and classified as a product without restriction for food contact.

Overall migration transfer has been measured at 4.5 mg/dm^2. The smallest bag distributed is of 25 kg with a surface of 0.648 m^2. Total migration would be 11.7 mg/kg of food whereas the maximum authorized amount is 60 mg/kg.

Risk of fungus development

A soil burial test (AATCC 330-IV (20217)) has been performed on the jute bags prototypes to assess the risk of fungus development during storage. The bags were buried in very stringent conditions (28 days, 28°C, 90%HR) and underwent a strong fungus contamination. Even if the tests are not representative of standard storage conditions, it seems that the bags are particularly sensitive to mold, due to the presence of starch. Consequently, AUST decided to modify the formulations and replace the starch by PVAc.

Bags production

Design optimization

After making the prototypes, the design of the bags was further improved, especially to address the molding and the weight issues.

- Molding: Starch was removed from the coating recipe, replaced by natural latex and PVAc.
- Weight: the fabric was made thinner to reach a 450-500 g/m^2.

The weight gain after coating is around 20 to 25%.

Production of first industrial batches

The bags are currently being produced but due to strikes in Bangladesh, the production has not been completed yet.

Scalability

To produce at industrial scale these bags, 3 types of industries would be needed:

- a jute fabric production industry
- a textile dyeing and finishing industry.
- a cutting and sewing industry (for bags only)

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Based on AUST developments, the concept bag can be adapted to a certain extent to the required mechanical resistance in order to decrease the weight and optimize the cost. Still, several industries would be needed to perform the bags which may be too complex for humanitarian organizations to influence the packaging of food and blankets. The only way forward would be to habilitate only a few packaging suppliers to work with food and blanket suppliers, which appear a bit restrictive. Additional information will be brought when the bags production will be over.

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Innovation key figures

OVERALL DESCRIPTION		
Product name	**Jute bags with latex coating**	
Targeted applications	Food-contact packaging from 5 to 50 kg bags Sheets for blankets packaging	
Composition	Fabric: jute fibres Coating: natural latex: 89.7%, PVAc: 7%, softener: 2%, benzoate: 1%, Ammonium Sulphate: 0.3%	
Development status	Prototype has been made. Expecting first industrial batch production	
RD partner(s)	Ahsanullah University (Dhakka, Bangladesh)	
Industrial supplier(s)	- Jute Textile Mills Limited, Khulna, Bangladesh - Islam Textile, Madhabdi, Narsingdi, Bangladesh - Local Cutting and Sewing Facility, Tongi, Gazipur, Bangladesh	
PERFORMANCE		
Density	Around 600 g/m² (coating included)	☹
Mechanical properties	Passed. No break at 600 N	☺
Permeability	TBD but expected to be higher than PP bags	😐
Food contact	TBD (materials compatible for food contact + migration test including MOAH + vegetable oil used for jute process). NB: standard from plastic packaging. No standard found for jute.	😐
Cost	1 $/m2 (50% jute and 50% coating), i.e. 0.57 USD/50kgbag. Processing cost around 20 BDT (0.18 USD/bag) Reference: 6-7 USD/t of food or 0.38 USD /50kgbag	☹
Biodegradability and plastic leakage	Even if jute is biodegradable, the total weight is more than 6 times higher than a PP bag. PVA is fossil-based and is 7% of total coating. Latex even if natural is 90% of the coating. The biodegradability, even if not leading to obvious plastic leakage, might not be better than PP bags, in absolute number.	😐
Lifetime	TBD (expected to be superior to 18 month and increased versus conventional PP bags)	☺
Carbon impact	- Jute production is not intensive, expected to be better than fossil-fuel materials. - Impact of coating TBD - Total weight is 10 times higher than PP bags. - Production is expected to use: 1.39 MJ/m² in addition to conventional jute bags production (drying mainly)	😐
Other limitations / advantages	The coated jute is quite rigid and thick which might make the sewing and filling of jute bags more difficult.	😐
SCALABILITY		
Production process description	An additional operation needs to be implemented to coat the jute fabric with the coating solution (bath and drying).	☹
Raw material availability	Mostly available in Bangladesh and India. The jute industry is slowing down which might decrease competition for feedstocks.	☺
Solution replicability	Preparing a specific liquid solution to coat the jute might not be easily replicable if large quantity of bags is not ordered. The strategy might be here to implement the equipment in a few selected suppliers.	😐
Intellectual properties	Know-how owned by Ahsanullah university.	😐
WAY FORWARD		
Bangladesh has undergone violent strikes of the textile industry and production of the first industrial batch of jute bags has been stopped. Field tests will bring additional elements to state on the scalability of the solution but, at that stage, many points are not favourable to the further development of this solution, especially total weight of the bag, price, production complexity. Biodegradability could be challenged too.		

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GIOTTO-SUPSI

Development strategy

Giotto is a consulting company focused on the textile industries. They work in partnership with the laboratory SUPSI (The University of Applied Sciences and Arts of Southern Switzerland). Their proposed solution is based on vegetal fibres with improved strength and hydrophobic & fungi-bacterial resistance achieved by layer-by-layer technology.

As the solution proposed is still unmature and needs a series of investigation and optimizations, Giotto and SUPSI's work was focused on phase 1 and 2: designing a bag concept and performing the most suitable fabric according to performances criteria, stated by the three organizations. The investigations went through several steps: first the jute fabric selection, second the general formula selection and third a formula optimization.

Design

Fabric design

Based on Table 10**Error! Not a valid bookmark self-reference.**, 4 fabrics were selected according to the following characteristics:

Table 10: Key parameters investigated to select fabric configurations.

Yarn (suitable for food contact only)	Fibres type Fibres length Yarn count (weight per specific length) Twist per meter Yarn treatment (oil content and oil type)
Fabric	Structure (warp and weft) Number of yarns x cm Processing

Layer-by-layer formula development based on hydrophobicity assessment.

The functionalities targeted are the anti-bacterial and hydrophobic properties. Chemicals tested were:

- $AgNO_3$ and ZnO for antibacterial properties
- SiO_2, PAA, cationic polyacrylate for hydrophobic properties

The type and number of layer sequences, the solution concentration and the nature of substrate were also part of the experimental design. The layer by layer was sprayed onto the fabric. The water contact angle and water adsorption duration measurements were used to assess the performance of the samples.

With the most promising combinations, the water absorption lasts more than 30 min compared to less than 2 minutes for the reference, without treatment. The concentration of $AgNO_3$ was the most impactful criteria. Using microscopy (SEM), SUPSI verified the even distribution of Ag ions onto the surface of the matrix.

Zinc oxide was proven to be as efficient as $AgNO_3$.

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Optimization of formula for industrial implementation, robustness

To make the industrial process less complex, dipping instead of spraying was tested, as well as using the jute fabric without removing the vegetal oil used during the manufacturing. Both provided positive results.

Next work consisted in assessing the adhesion strength of the layer-by-layer. The samples either obtained by spraying or by dipping techniques were washed 30 min at 40°C. Analysis of water absorption rate showed that the adhesion of ions on the fabric is not good enough with layer-by-layer spraying technique but remain the same after washing with the dipping technique. It means that removing vegetal oil before layer-by-layer treatment is not necessary, which simplifies the industrial process.

A last optimization consisted in applying the layer-by-layer solution in one single application, using the dipping technique. This method also showed a very good performance in terms of hydrophobicity.

Antibacterial property

Both washed and un-washed samples, a sample using only one single application of layer-by-layer solution, and a reference without layer-by-layer treatment were inoculated with staphylococcus aureus (G+) and klebsiella pneumoniae (G-). All the samples tested show good antibacterial properties compared to the reference. Even a single application of LbL is enough to provide the expected performance and fiber washing before applying the treatment is not necessary either.

Biodegradability versus mechanical resistance

A test was made to assess biodegradability of the jute bags using the composting method (UN EN 14855). In 90% days, jute was degraded at 6% while PP bag was degraded only at 1 %. but, as a comparison, natural jute bag was degraded at 47%. This test showed the effectiveness of the LbL treatment to provide a long-term use of the bags while maintaining the use of natural products.

Bags production

Scalability

The layer-by-layer technique was successful in finding a combination answering the 2 functionalities of hydrophobicity and antibacterial properties. Thanks to the optimization performed, the technique is rather easy to implement at scale.

The final layout has been defined:

- With lowest $AgNO_3$ concentration
- Prewashed not needed.
- 5 bi-layers "one-pot" application technique
- Application by dipping technique

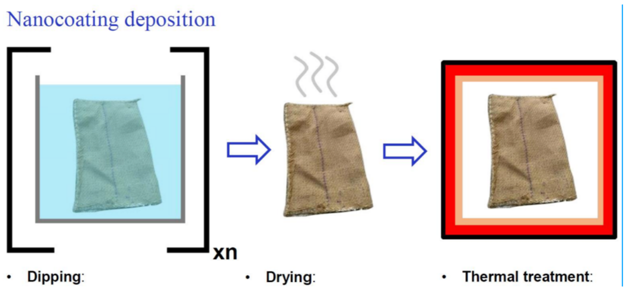

Figure 5: Industrial process to apply LbL treatment

The additional operations needed would be a dipping step and a drying. This would add an additional energy consumption of 1.39 MJ/m^2, to be considered in the carbon impact assessment.

Next step would be to produce prototypes to test in the field.

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Innovation key figures

OVERALL DESCRIPTION		
Product name	**Layer-by-layer coated jute bag**	
Targeted applications	Food-contact packaging from 5 to 50 kg bags Sheets for blankets packaging	
Composition	Fabric: jute fibers Layer-by-layer (for 1 kg of jute): $AgNO_3$ 833 ng, SiO_2 0.833 g, Polyacrylate 0.833 g.	
Development status	Fabric (no prototype has been produced and the innovation was still early stage)	
RD partner(s)	GIOTTO and SUPSI (Switzerland)	
Industrial supplier(s)	GIOTTO works with a German supplier of jute.	
PERFORMANCE		
Density	601 g/m²	😐
Mechanical properties	Passed. No break at 600 N	☺
Permeability	TBD but expected to be higher than PP bags	
Food contact	No tested but no limiting factors a priori	☺
Cost	+ 0.16 €/m² versus reference (without processing costs)	😐
Biodegradability and plastic leakage	yes	☺
Lifetime	TBD (expected to be superior to 18 month and increased versus conventional PP bags)	☺
Carbon impact	- Jute production is not intensive, expected to be better than fossil-fuel materials. - Impact of layer by layer is negligible. - Total weight is 6 times higher than PP bags. - Production is expected to use: 1.39 MJ/m² in addition to conventional jute bags production (drying mainly)	😐
Other limitations / advantages		☺
SCALABILITY		
Production process description	An additional operation needs to be implemented to coat the jute fabric with the layer-by-layer technique, but everything can be done in the same factory.	😐
Raw material availability	Mostly available in Bangladesh and India. The jute industry is slowing down which might decrease competition for feedstocks.	☺
Solution replicability	The solution "recipe" is fixed and a priori the process too. The replicability should be relatively easy. TBD in next steps.	😐
Intellectual properties	IP owned by Giotto-Supsi (license to operate)	😐
WAY FORWARD		
The next step would be to produce the first prototypes to understand more the industrial feasibility and test the bags on the field. At that stage, this is the most viable alternative to plastics.		

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APPENDIX

Appendix 1: Food Grade Analysis AIMPLAS

Laboratory: Aimplas

Standard: EN 1186-13:2003

Exposition duration: 2 * 3 h

Exposition temperature: 100°C for total migration and 70°C for metals migration

Date of tests: 06/07/23 to 31/07/23

Sample	Specific surface dm^2/g	Total migration mg/dm^2	Metal migration	Specific migration (additives)
U (25kg bag)	0.25	2.53	< detection limit	< detection limit
E (50 kg bag)	Identical as sample U			