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# Ecodesign of Sustainable Packaging Systems for Fortified Infant Flours in Tropical Environments

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## Introduction

### Context

About 8 million single-serve sachets/year = 24 tons of plastic waste for distribution of one infant flour brand in Madagascar (based on local distributors' surveys).

### Challenge

- Limited waste management in developing countries leads to plastic accumulation in the environment.
- Develop eco-designed alternatives to replace the current multilayer sachet while maintaining product quality.

## Reference system

### Product:

- Infant flour made from Madagascar's local cereals and legumes.
- Fortified with essential vitamins and minerals used to fight child malnutrition.

### Actual packaging:

- Flexible multilayer sachets (PET/metallized PET/LDPE films).
- Ensure stability and 12-month shelf life.
- Non-recyclable and contribute to environmental pollution.<sup>1</sup>

### Objective

Assess a dual packaging system combining a biodegradable primary film and a reusable secondary pack.

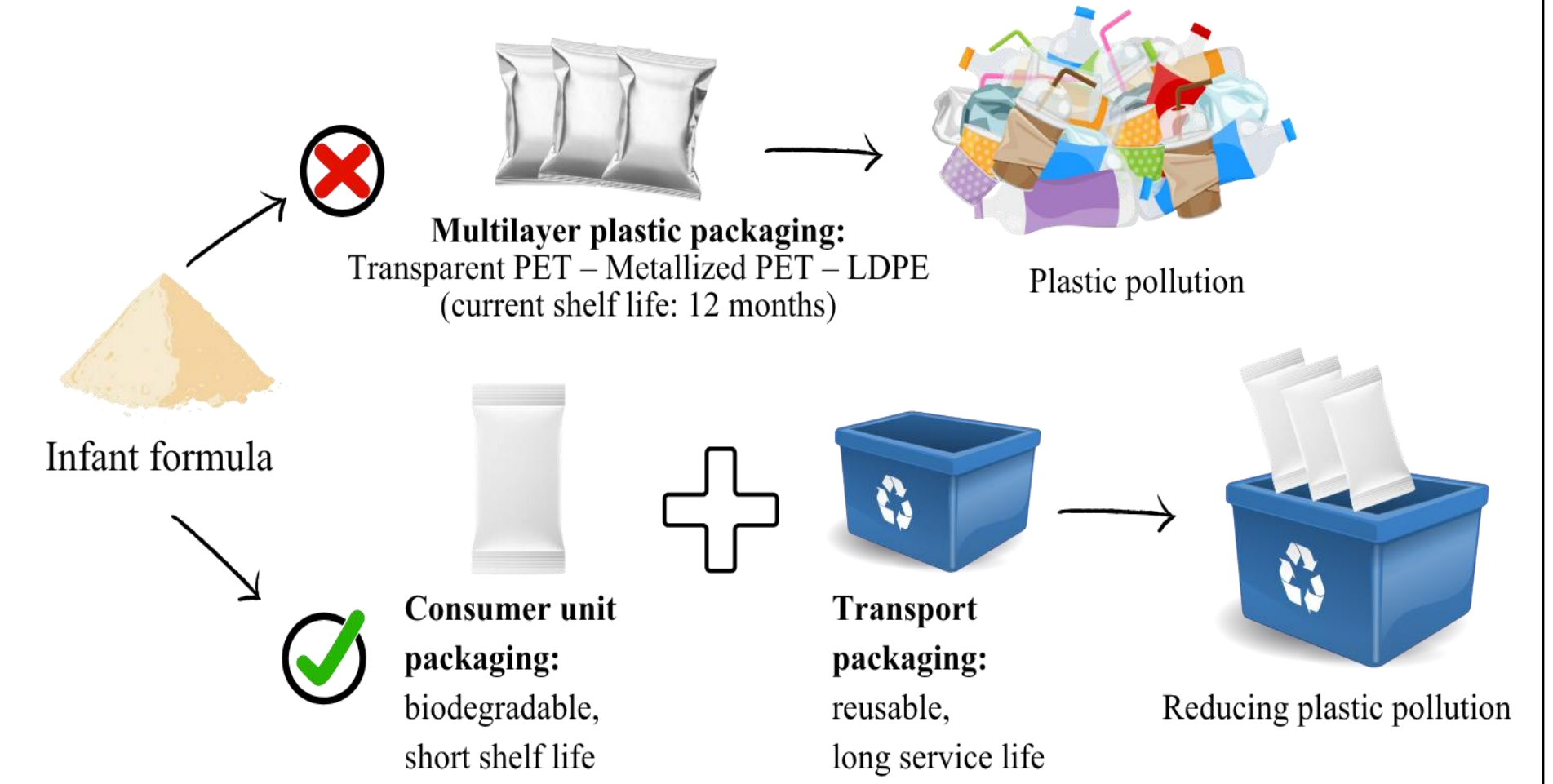


Fig 1: Reducing Plastic Pollution through Eco-Designed Dual Packaging Systems

## 1. Field investigation

### Data acquisition for experimental design

- Mapping production, distribution, and storage chain in Madagascar.
- Identification of environmental stressors.
- Interviews with key stakeholders.

Tropical environments = high temperatures, humidity, no cold chain => accelerating product degradation and making packaging protection crucial.

Humidity	Min	Avg	Max
	30.0 % RH	59.1 % RH	85.5 % RH
Temperature	18.5 °C	24.4 °C	28.8 °C
Dew point	7.5 °C	15.8 °C	24.1 °C

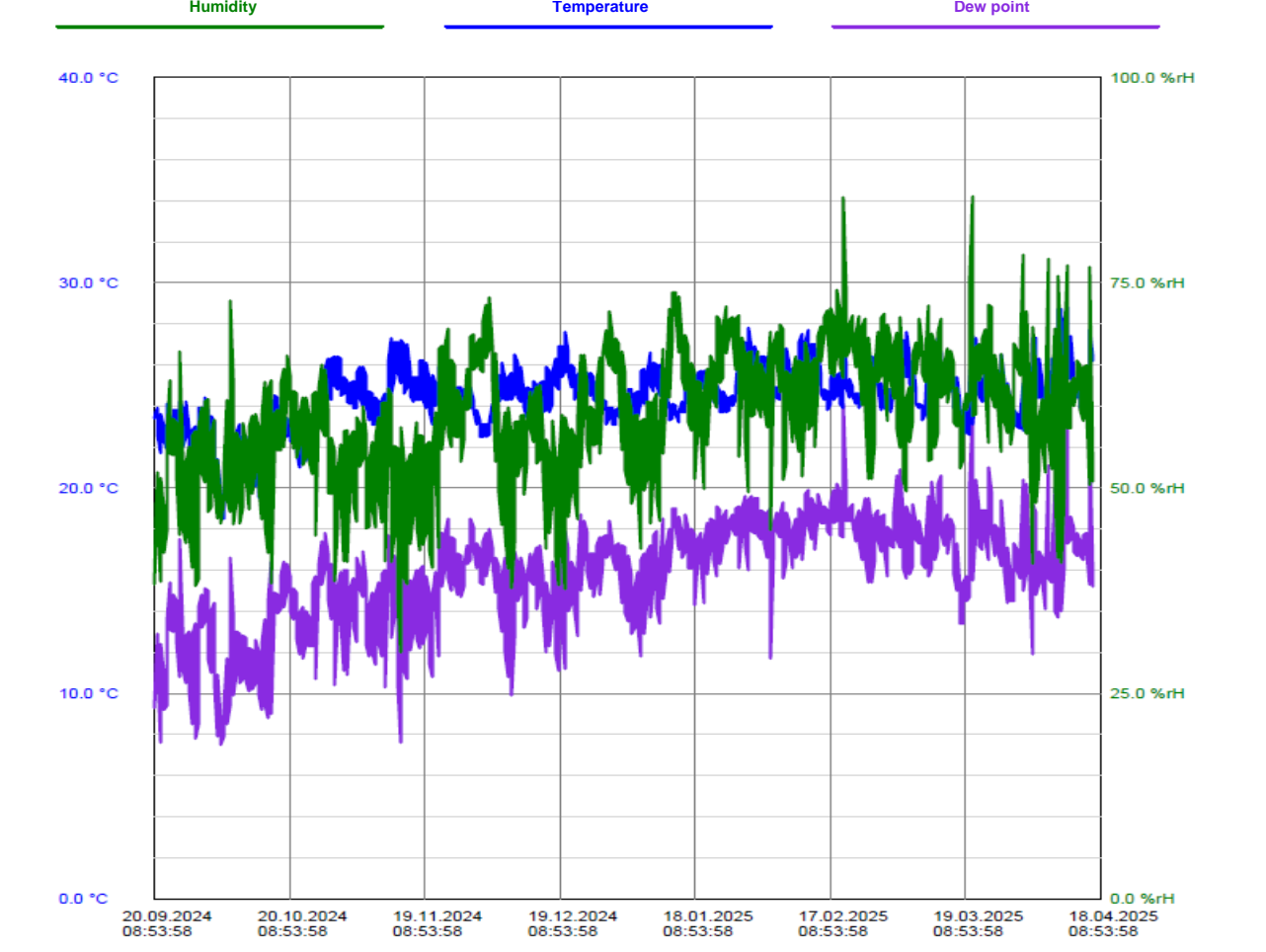
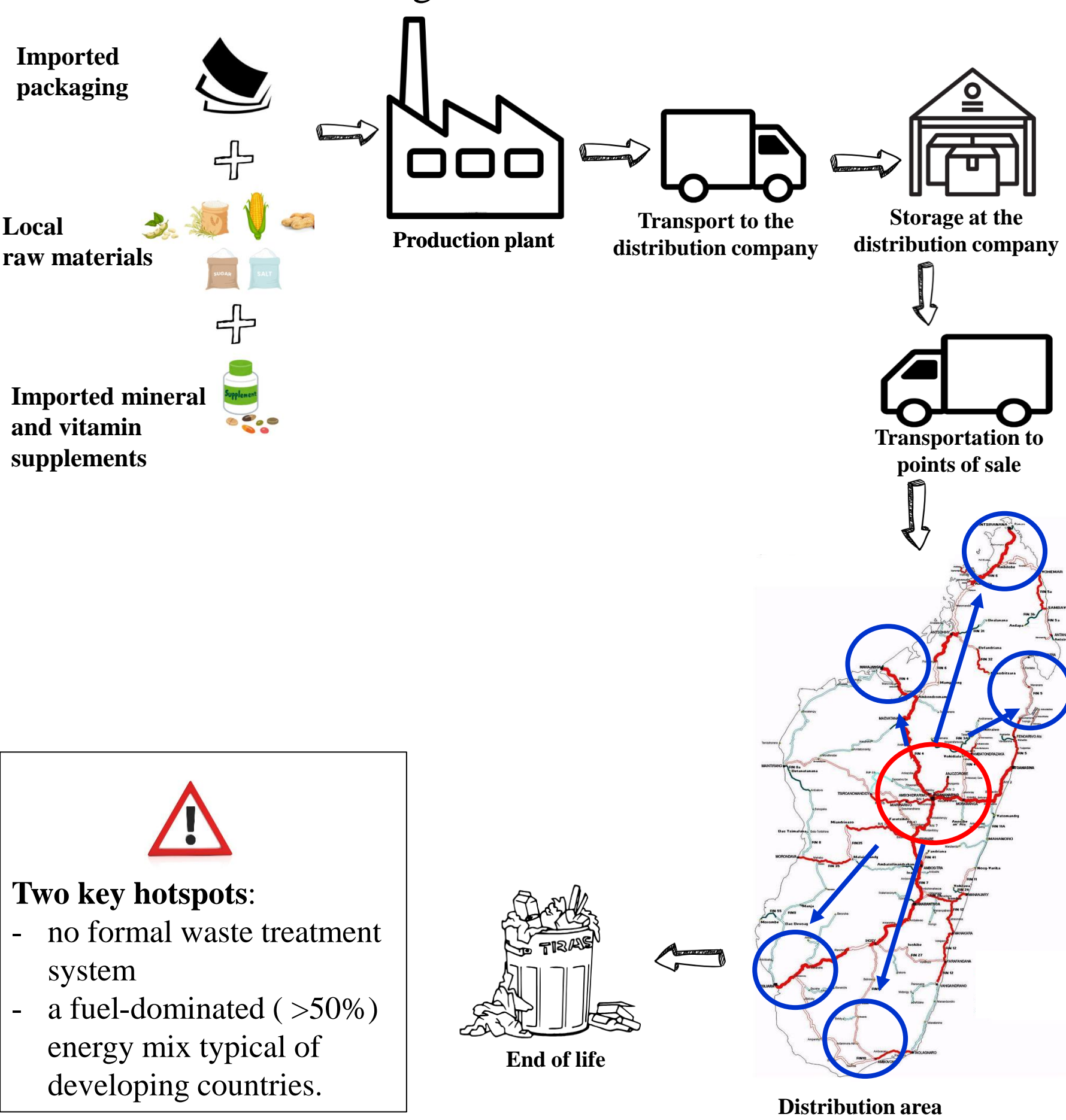


Fig 2: Monitoring of temperature, humidity, and dew point in the product storage room during the hot season (7 months)

## 3. Environmental Impact Assessment

### Preliminary Life Cycle Modelling and Field Work Preparation

- System boundaries: raw material reception to packaging end of life.
- Life Cycle Inventory (LCI) for current multilayer and dual packaging systems.
- Software: openLCA
- Databases: Ecoinvent v3.9.1 + Agribalyse, adjusted with primary field data and site-specific assumptions.
- Impact assessment method: ReCiPe 2016 Midpoint (H).
- Flow diagrams created to visualize material and energy exchanges.
- Planned environmental and socio-economic assessment based on forthcoming data collection.



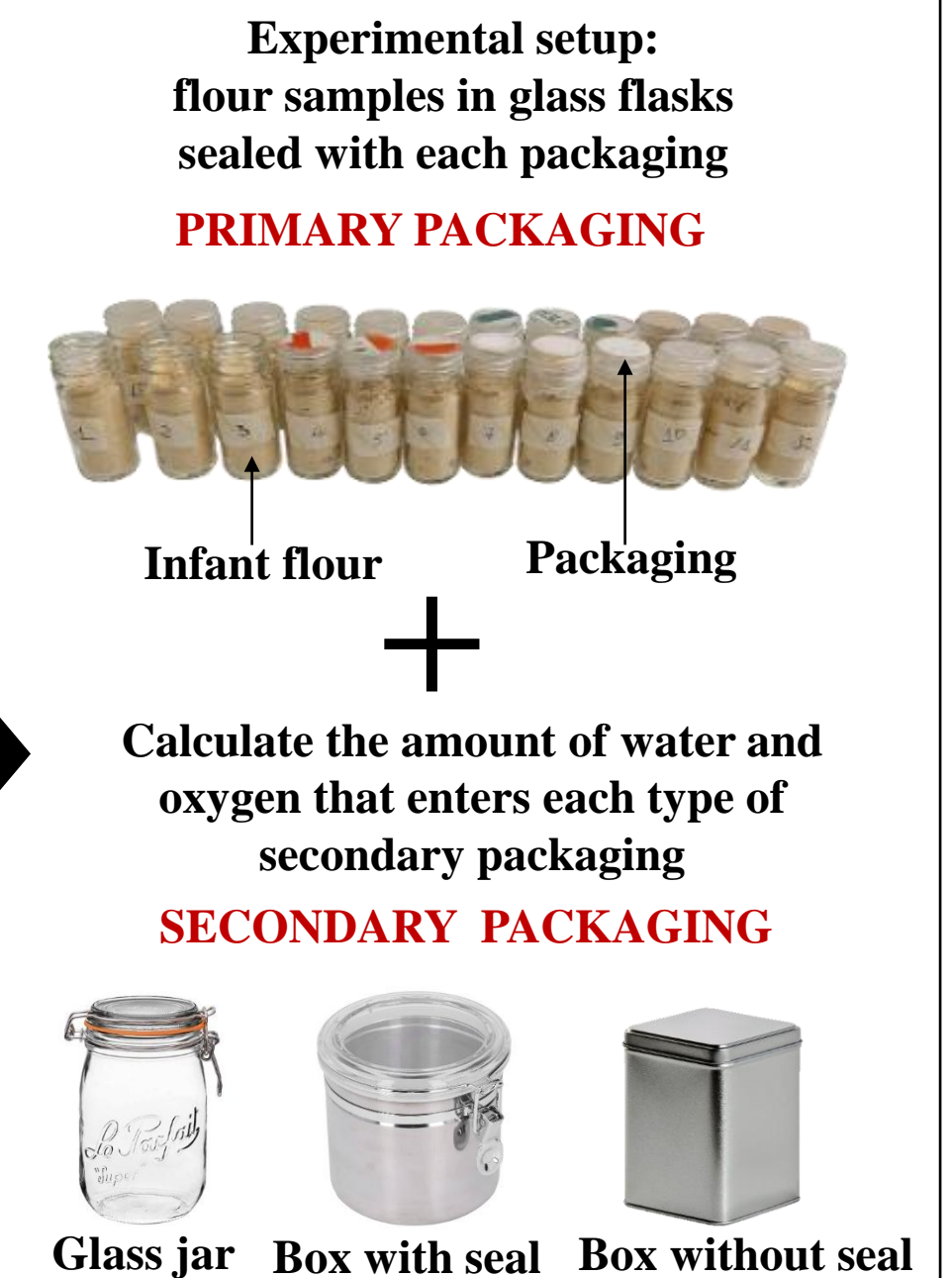
## 2. Model study in laboratory

### Methodology

- Protective performance comparison of biodegradable and dual packaging systems with the multilayer film, based on Water Vapor Transmission Rate (WVTR), Oxygen Transmission Rate (OTR), and product stability indicators.
- Kinetic study under representative tropical conditions in a climate chamber "CLIMACELL EVO 222" (weekly sampling):
  - > 30°C, RH 60%, light: primary packaging
  - > 30°C, RH 80%, darkness: primary packaging
  - > 30°C, RH 80%, darkness: primary packaging + secondary packaging

Tab 1: Selected packagings for comparison with the multilayer film (Biodegradable films supplied by partner GBC according to project specifications)

NP: No packaging (control)
ML: Multilayer film (reference)
PE: Polyethylene
BA: Biodegradable_A: copolyester + mineral fillers
BB: Biodegradable_B: biosourced polyester
BC: Biodegradable_C: biosourced copolyester
BD: Biodegradable_D: starch-based + biodegradable polyesters
KP: Kraft paper
KP + GJ: Kraft paper + glass jar
Kraft or biodegradable (B/C) + box with seal
Kraft or biodegradable (B/C) + box without seal

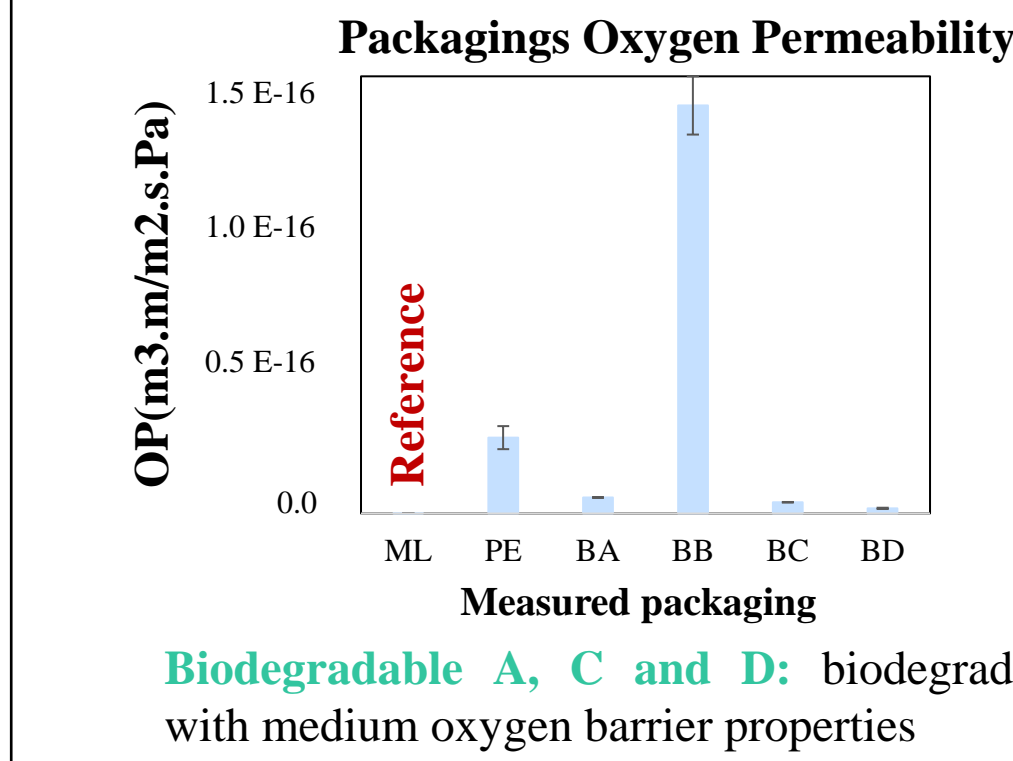


Tab 2: parameters for measuring packaging performance

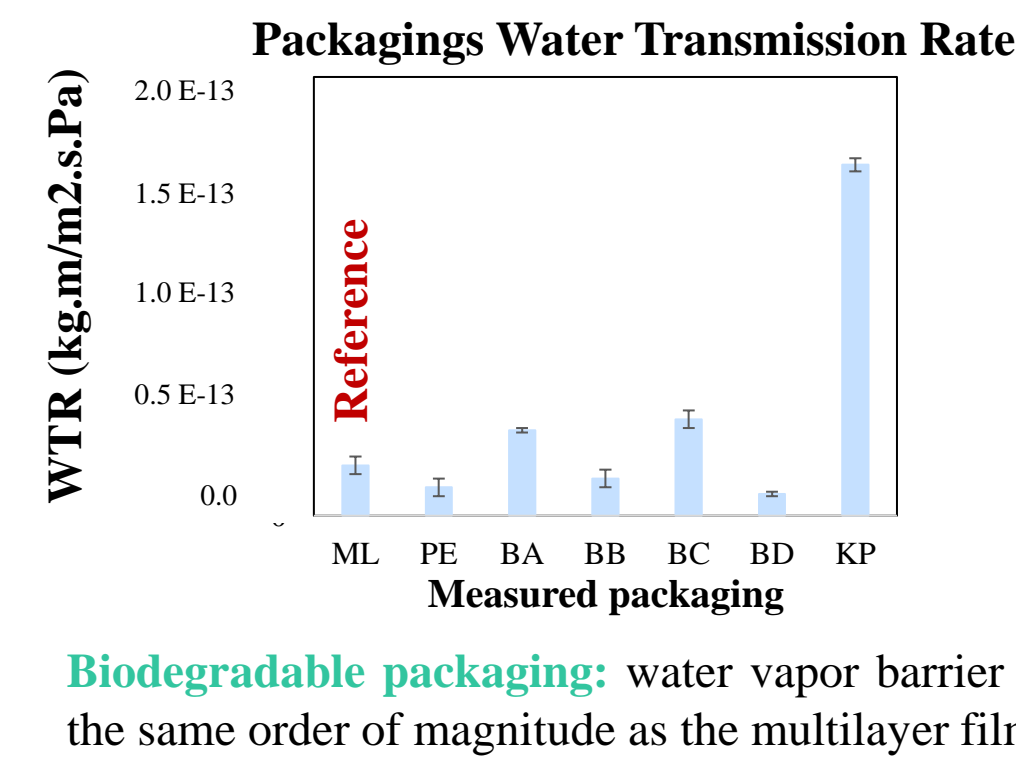
Packaging analyses	Nutritional quality analyses	Food safety analyses
<b>Oxygen permeability (OP):</b> <sup>2</sup> • Gas Permeability Tester (GDP-C, Brügger, Germany) • Parameters: 23 °C, 0 % RH, 1 atm	<b>Partial oxygen pressure (pO<sub>2</sub>):</b> <sup>3</sup> • Fibox 3 LCD trace (PreSens, Germany) • Optical oxygen sensor (PSt3, ruthenium-based)	<b>Water activity (aw):</b> Measured at 25 °C LabMaster-aw (Novasina)
<b>Water Transmission Rate (WTR):</b> <sup>2</sup> • Gravimetric method using anhydrous CaCl <sub>2</sub> • Parameters: 60 % RH, 23 °C	<b>Vitamin E content:</b> <sup>4</sup> • HPLC- DAD-FLUO (Agilent 1260 infinity) • Solvent-assisted extraction and separation using n-heptane / tetrahydrofuran (96.15 / 3.85, v/v) on a normal-phase silica column (4.6 × 250 mm, 5 µm), isocratic mode. • DAD (292 nm) / FLUO (Ex 290 nm, Em 330 nm)	<b>Moisture content (MC):</b> By thermogravimetry using OHAUS MB120, sample heated at 120 °C.
		<b>pH measurement:</b> Measured in aqueous extract (3 g / 20 mL distilled water) using Hach Sension PH3.
		<b>Microbiological analyses:</b> <sup>5</sup> • TAMF: Total Aerobic mesophilic bacteria : Plate Count Agar (PCA), 30°C / 72 h. • YM: Yeasts and molds: YEGC medium, 25 °C / 72 h.

## Results

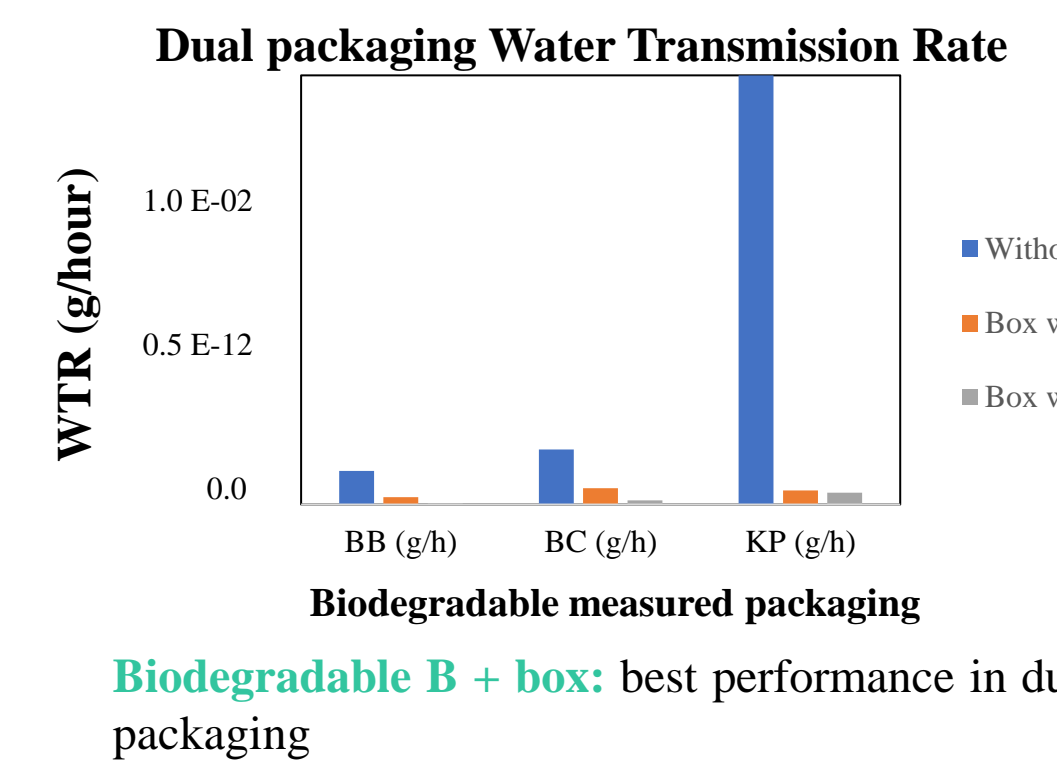
### 1. Packagings properties



Biodegradable A, C and D: biodegradable with medium oxygen barrier properties



Biodegradable packaging: water vapor barrier in the same order of magnitude as the multilayer film  
Kraft paper: insufficient barrier



Biodegradable B + box: best performance in dual packaging

### 2. Product quality

#### a. 30°C, 60% RH, light

Packaging types	Water activity		Moisture content		pH		Microbiological content (CFU/g)		Normalized oxygen partial pressure		Normalized tocopherols content	
	Day 0	Day 40	Day 0	Day 40	Day 0	Day 40	TAMF Day 40	YM Day 40	Day 0	Day 40	Day 0	Day 40
NP	0.31 ± 0.01	0.57 ± 0.01	5.72 ± 0.14	8.86 ± 0.24	6.28 ± 0.06	6.27 ± 0.02	< 10 <sup>5</sup>	< 10 <sup>5</sup>	1.00 ± 0.00	0.88 ± 0.01	1.00 ± 0.00	0.82 ± 0.01
ML	0.31 ± 0.01	0.30 ± 0.01	5.72 ± 0.14	5.87 ± 0.16	6.28 ± 0.06	6.28 ± 0.02	< 10 <sup>5</sup>	< 10 <sup>5</sup>	1.00 ± 0.00	0.42 ± 0.10	1.00 ± 0.00	0.79 ± 0.04
PE	0.31 ± 0.01	0.37 ± 0.02	5.72 ± 0.14	6.32 ± 0.12	6.28 ± 0.06	6.27 ± 0.02	< 10 <sup>5</sup>	< 10 <sup>5</sup>	1.00 ± 0.00	0.82 ± 0.03	1.00 ± 0.00	0.79 ± 0.01
BA	0.31 ± 0.01	0.56 ± 0.01	5.72 ± 0.14	8.19 ± 0.06	6.28 ± 0.06	6.29 ± 0.02	< 10 <sup>5</sup>	< 10 <sup>5</sup>	1.00 ± 0.00	0.85 ± 0.06	1.00 ± 0.00	0.83 ± 0.02
BB	0.31 ± 0.01	0.42 ± 0.01	5.72 ± 0.14	6.82 ± 0.08	6.28 ± 0.06	6.26 ± 0.01	< 10 <sup>5</sup>	< 10 <sup>5</sup>	1.00 ± 0.00	0.81 ± 0.02	1.00 ± 0.00	0.81 ± 0.02
BC	0.31 ± 0.01	0.55 ± 0.01	5.72 ± 0.14	8.01 ± 0.39	6.28 ± 0.06	6.22 ± 0.02	< 10 <sup>5</sup>	< 10 <sup>5</sup>	1.00 ± 0.00	0.69 ± 0.12	1.00 ± 0.00	0.76 ± 0.04
BD	0.31 ± 0.01	0.59 ± 0.02	5.72 ± 0.14	9.31 ± 0.32	6.28 ± 0.06	6.23 ± 0.01	< 10 <sup>5</sup>	< 10 <sup>5</sup>	1.00 ± 0.00	0.84 ± 0.01	1.00 ± 0.00	0.80 ± 0.16
KP	0.31 ± 0.01	0.56 ± 0.01	5.72 ± 0.14	8.93 ± 0.18	6.28 ± 0.06	6.25 ± 0.01	< 10 <sup>5</sup>	< 10 <sup>5</sup>	1.00 ± 0.00	0.89 ± 0.01	1.00 ± 0.00	0.85 ± 0.03

#### Sanitary quality:

Remained generally stable throughout 40 days, although some parameters showed slight variations (aw < 0.7, MC < 10%, pH: 6.28 ± 0.16, TAMF and YM < Malagasy infant flour standard NMG 191-3:2023)

ML: reference; PE: best performance after ML ; BB: best sanitary quality protection among biodegradable films; BC: best nutritional quality protection among biodegradable films.

#### b. 30°C, 80% RH, darkness

Packaging types	Water activity		Moisture content		pH		Microbiological content (CFU/g)		Normalized oxygen partial pressure		Normalized tocopherols content	
	Day 0	Day 40	Day 0	Day 40	Day 0	Day 40	TAMF Day 40	YM Day 40	Day 0	Day 40	Day 0	Day 40
NP	0.31 ± 0.01	0.79 ± 0.01	5.84 ± 0.17	10.89 ± 0.06	6.30 ± 0.03	5.99 ± 0.12	> 10 <sup>5</sup>	> 10 <sup>5</sup>	1.00 ± 0.00	1.11 ± 0.01	1.00 ± 0.00	0.82 ± 0.02
ML	0.31 ± 0.01	0.37 ± 0.04	5.84 ± 0.17	5.04 ± 0.11	6.30 ± 0.03	6.28 ± 0.01	< 10 <sup>5</sup>	< 10 <sup>5</sup>	1.00 ± 0.00	0.96 ± 0.20	1.00 ± 0.00	0.81 ± 0.04
PE	0.31 ± 0.01	0.37 ± 0.01	5.84 ± 0.17	5.16 ± 0.13	6.30 ± 0.03	6.28 ± 0.01	< 10 <sup>5</sup>	< 10 <sup>5</sup>	1.00 ± 0.00	1.09 ± 0.04	1.00 ± 0.00	0.84 ± 0.01
BA	0.31 ± 0.01	0.71 ± 0.02	5.84 ± 0.17	8.81 ± 0.17	6.30 ± 0.03	6.24 ± 0.02	< 10 <sup>5</sup>	< 10 <sup>5</sup>	1.00 ± 0.00	1.25 ± 0.11	1.00 ± 0.00	0.85 ± 0.01
BB	0.31 ± 0.01	0.52 ± 0.01	5.84 ± 0.17	6.43 ± 0.12	6.30 ± 0.03	6.28 ± 0.04	< 10 <sup>5</sup>	< 10 <sup>5</sup>	1.00 ± 0.00	1.08 ± 0.06	1.00 ± 0.00	0.83 ± 0.03
BC	0.31 ± 0.01	0.68 ± 0.01	5.84 ± 0.17	8.51 ± 0.30	6.30 ± 0.03	6.25 ± 0.03	< 10 <sup>5</sup>	< 10 <sup>5</sup>	1.00 ± 0.00	1.03 ± 0.06	1.00 ± 0.00	0.77 ± 0.04
BD	0.31 ± 0.01	0.78 ± 0.02	5.84 ± 0.17	10.66 ± 0.18	6.30 ± 0.03	6.23 ± 0.01	< 10 <sup>5</sup>	> 10 <sup>5</sup>	1.00 ± 0.00	0.56 ± 0.01	1.00 ± 0.00	0.81 ± 0.02
KP	0.31 ± 0.01	0.79 ± 0.01	5.84 ± 0.17	10.81 ± 0.24	6.30 ± 0.03	6.18 ± 0.06	> 10 <sup>5</sup>	> 10 <sup>5</sup>	1.00 ± 0.00	1.00 ± 0.01	1.00 ± 0.00	0.76 ± 0.04
KP + GJ	0.31 ± 0.01	0.39 ± 0.01	5.84 ± 0.17	6.05 ± 0.17	6.30 ± 0.03	6.31 ± 0.01	< 10 <sup>5</sup>	< 10 <sup>5</sup>	1.00 ± 0.00		1.00 ± 0.00	0.77 ± 0.01

Sanitary quality: three particularly unstable conditions after 40 days: no packaging, kraft paper, Biodegradable D (aw > 0.7, MC > 10%, TAMF and YM > Malagasy infant flour standard NMG 191-3:2023)

ML: reference; PE: best performance after ML ; BB: best sanitary quality protection among biodegradable films; KP + GJ: improved barrier effectiveness over standalone primary packaging

## Conclusions

- Biodegradable B film (biosourced polyester) → offers reliable sanitary protection
- Primary packaging alone: insufficient protection under tropical stress (light, oxygen, temperature)
- Dual system (BB + secondary) → ensures integrity, quality and durability



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