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Advancing Circular Economy in Agriculture

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Improved Soil Biodegradability of Chicken Feather via Steam Explosion for Sustainable use in Agricultural Bioplastics

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This project has received funding from the Bio-based Industries Joint Undertaking under the European Union's Horizon 2020 research and innovation programme under grant agreement Nº 101023306

UNLOCK

BBI JU

Bio-based Industries Consortium

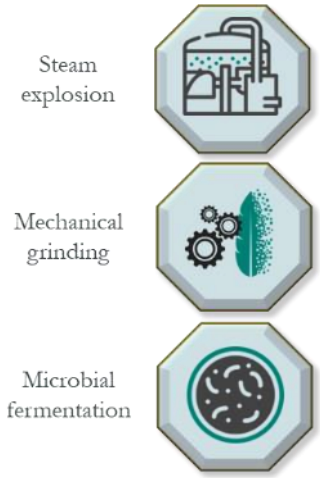
UNLOCK

UNLOCK

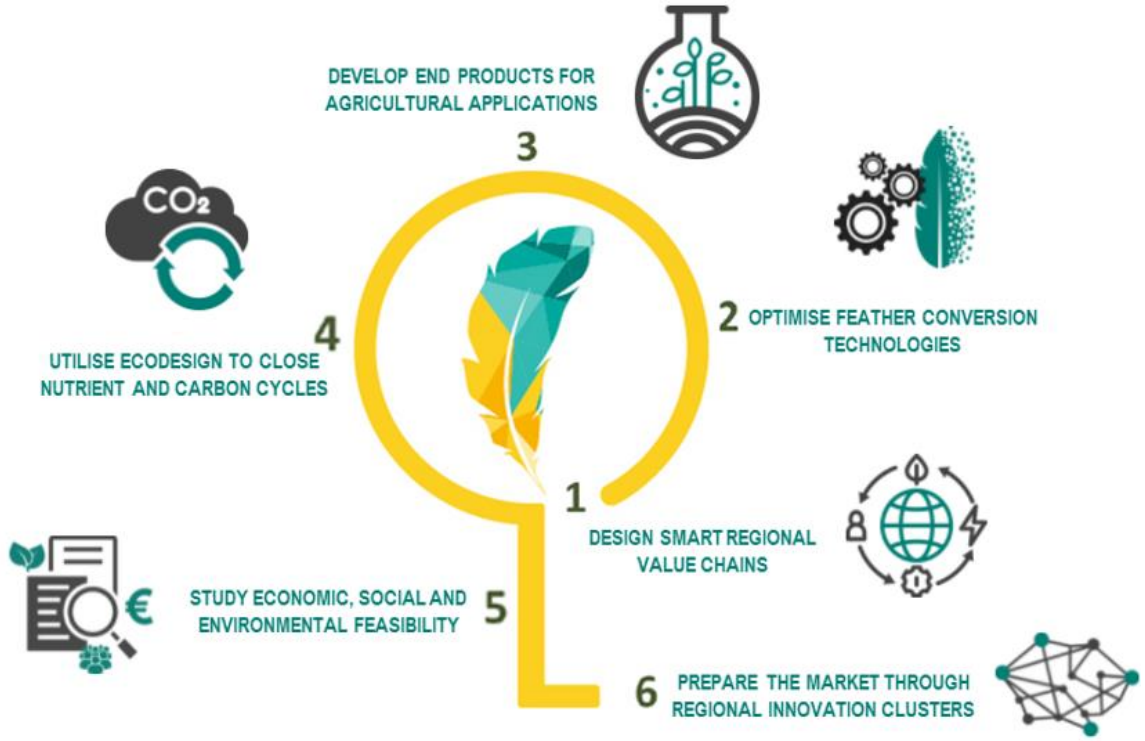
Objective of UNLOCK project

From feathers' storage to treatment efficiency, keratin-based products' performances and market readiness, UNLOCK works on **finding solutions to every hurdle along the value chain and create a feather- based bioeconomy.**

Chicken feathers treatment



Development of a family of bioplastics containing feathers



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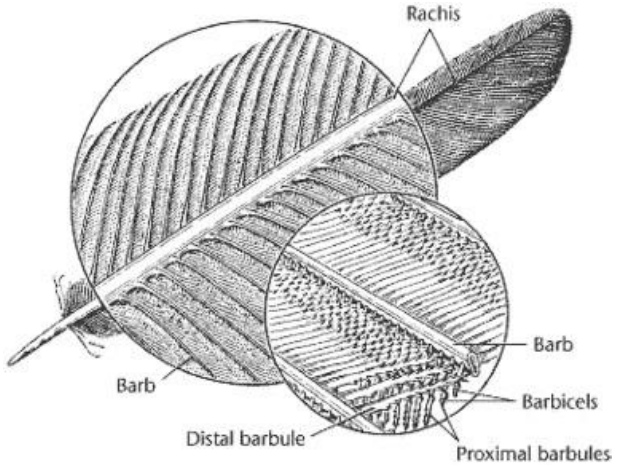
Chicken feathers



Tesfaye et al. (2017). Journal of Cleaner Production 149

Waste management & valorisation routes

- Incineration of feathers residues
- Buried in landfills (slow biodegradation)
- Animal feed production
- Material development (Keratine)

Source: earth911.com

- **Residue** of the poultry industry (around **3,6 million tones per year**)
- **90% composed by Keratine** which is a protein insoluble in water
- Keratine structure makes **difficult the degradation of feathers in soil**

Keratin structure

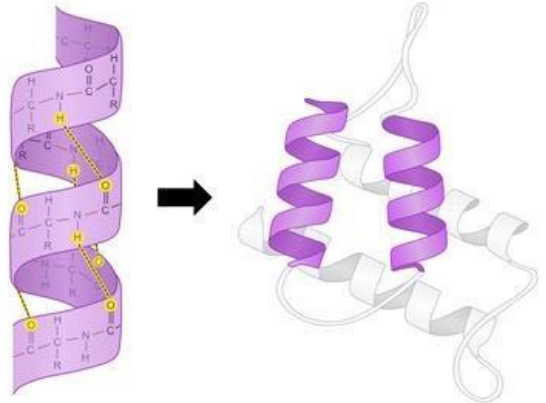
- **Fibrous and insoluble** protein highly **cross-linked mainly with disulphide bonds (S-S)**
- Two ordered conformations: **α-helix** and **β-sheets**
- Other disordered conformations: **Random coil and β-turns**
- **Disulphide bonds → Protect the feather against environmental degradation** by heat, cold, light, water, or biological attack

Decrease disulphide bonds and ordered structures to **enhance biodegradability**

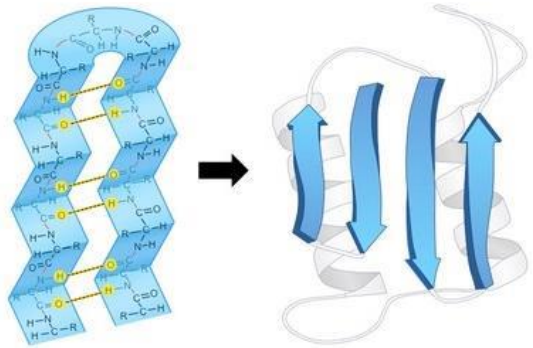
α-Helix structures → 

β-sheet structures → 

α-Helix



β-Sheet

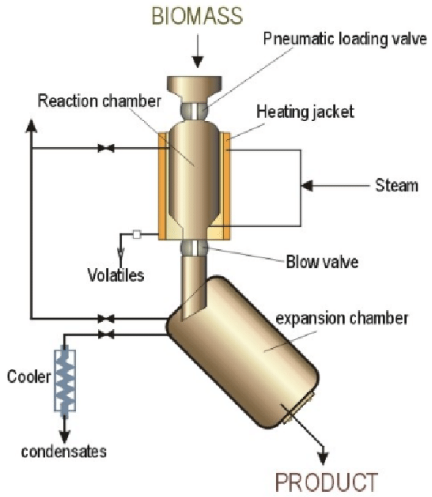


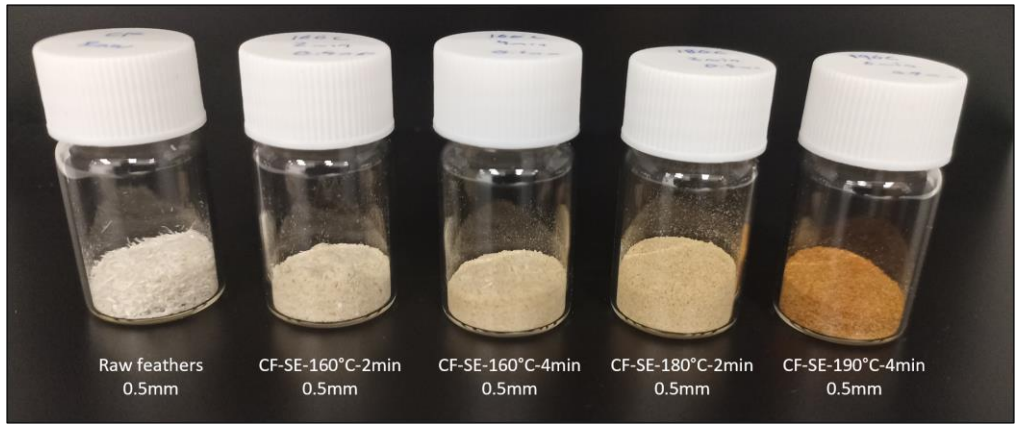
Source: www.learnitaly.us

Steam explosion treatment of feathers

Hydrothermal method which involves both mechanical and chemical effects where chipped **biomass** is treated to **high pressure and high-temperature steam**

processum





Reference	Severity index	Steam explosion conditions	
		Temperature (ºC)	Residence time (min)
Raw Chicken feathers	-	-	-
CF-SE-160°C-2min-0.5mm	**2.07**	160	2
CF-SE-160°C-4min-0.5mm	**2.37**	160	4
CF-SE-180°C-2min-0.5mm	**2.66**	180	2
CF-SE-190°C-4min-0.5mm	**3.25**	190	4

Secondary structure analyse

Reference	α-helix (%)	β-Sheet (%)	β-turns (%)	Random coil (%)
Raw chicken feathers	13±4	**72±3**	10±2	**3±1**
CF-SE-160°C-2min-0.5mm	18±2	**63±4**	3±1	**14±4**
CF-SE-160°C-4min-0.5mm	20±5	**62±2**	5±2	**14±5**
CF-SE-180°C-2min-0.5mm	28±2	**53±5**	3±1	**17±4**
CF-SE-190°C-4min-0.5mm	29±2	**52±1**	4±1	**16±3**

- **β-sheets is the main keratin conformation** as expected for chicken feathers.
- Steam explosion treatment seems to **decrease the β-sheets and β-turns structures**
- Disordered conformations increases: **Random coil**

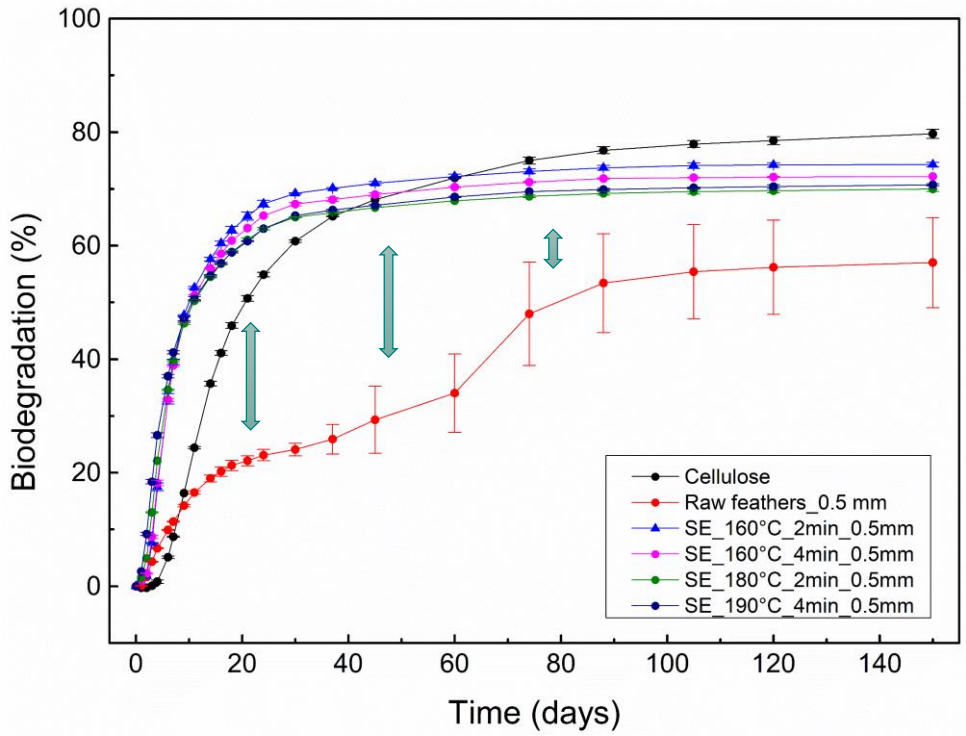
Elemental analysis

Reference	Content (%)				
	N	C	H	S	Others
Raw feathers-0.5mm	14.6	48.2	7.2	**2.3**	27.7
CF-SE-160°C-2min-0.5mm	14.4	48.2	7.3	**2.2**	27.9
CF-SE-160°C-4min-0.5mm	14.3	46.8	7.4	**2.1**	29.4
CF-SE-180°C-2min-0.5mm	14.4	47.6	7.3	**2.0**	28.7
CF-SE-190°C-4min-0.5mm	14.9	48.7	7.3	**1.8**	27.3

- **Decrease of the sulphur content** as a result of the breakage of disulfide bonds of the keratin.

Completed characterization in : Vadillo et al. Enhanced Biodegradability in Soil of Chicken Feather by Steam Explosion for Potential Application in Agricultural Biodegradable Plastics (2023). *Polymers*, 15, 3701. https://doi.org/10.3390/polym15183701

Biodegradation in soil

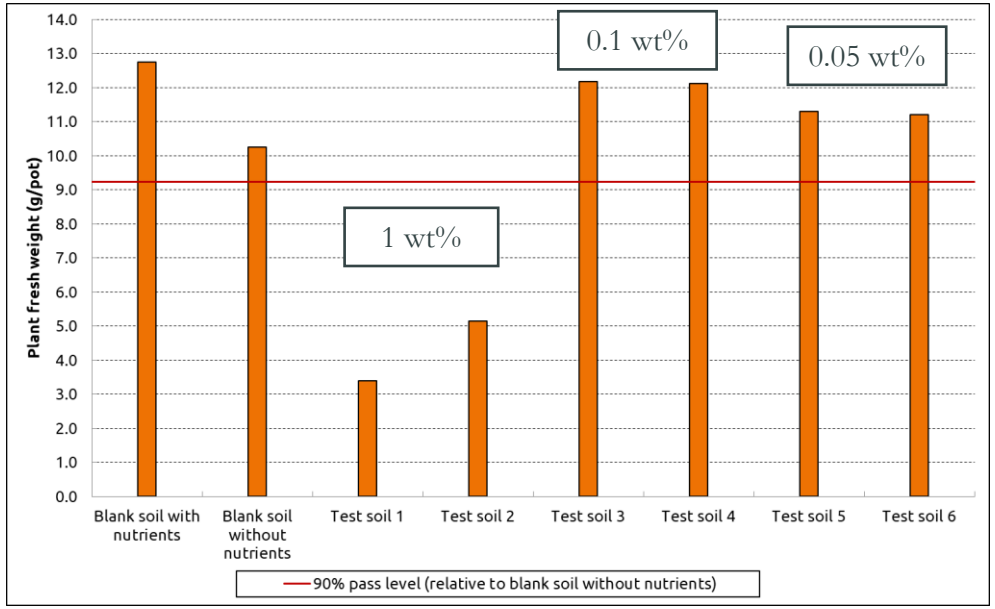


Reference	Biodegradation at 6 days (%)	Biodegradation at 14 days (%)
Cellulose	5.1±0.2	79.7±0.8
Raw Chicken feathers	9.9±0.1	57.1±7.9
CF-SE-160°C-2min-0.5mm	32.1±0.9	71.3±0.4
CF-SE-160°C-4min-0.5mm	32.2±0.3	71.1±0.3
CF-SE-180°C-2min-0.5mm	34.6±0.1	70.5±0.5
CF-SE-190°C-4min-0.5mm	**37.1±0.3**	70.7±0.2

- General **enhance of the relative biodegradation of treated feathers** (60% → ~90%)
- **Increase of the biodegradation rate** when severity index increase → **Faster biodegradation**

Steam explosion treatment successfully **disrupts the ordered structure** of the feathers leading to a **faster a higher biodegradation** in soil.

Fertilizing test



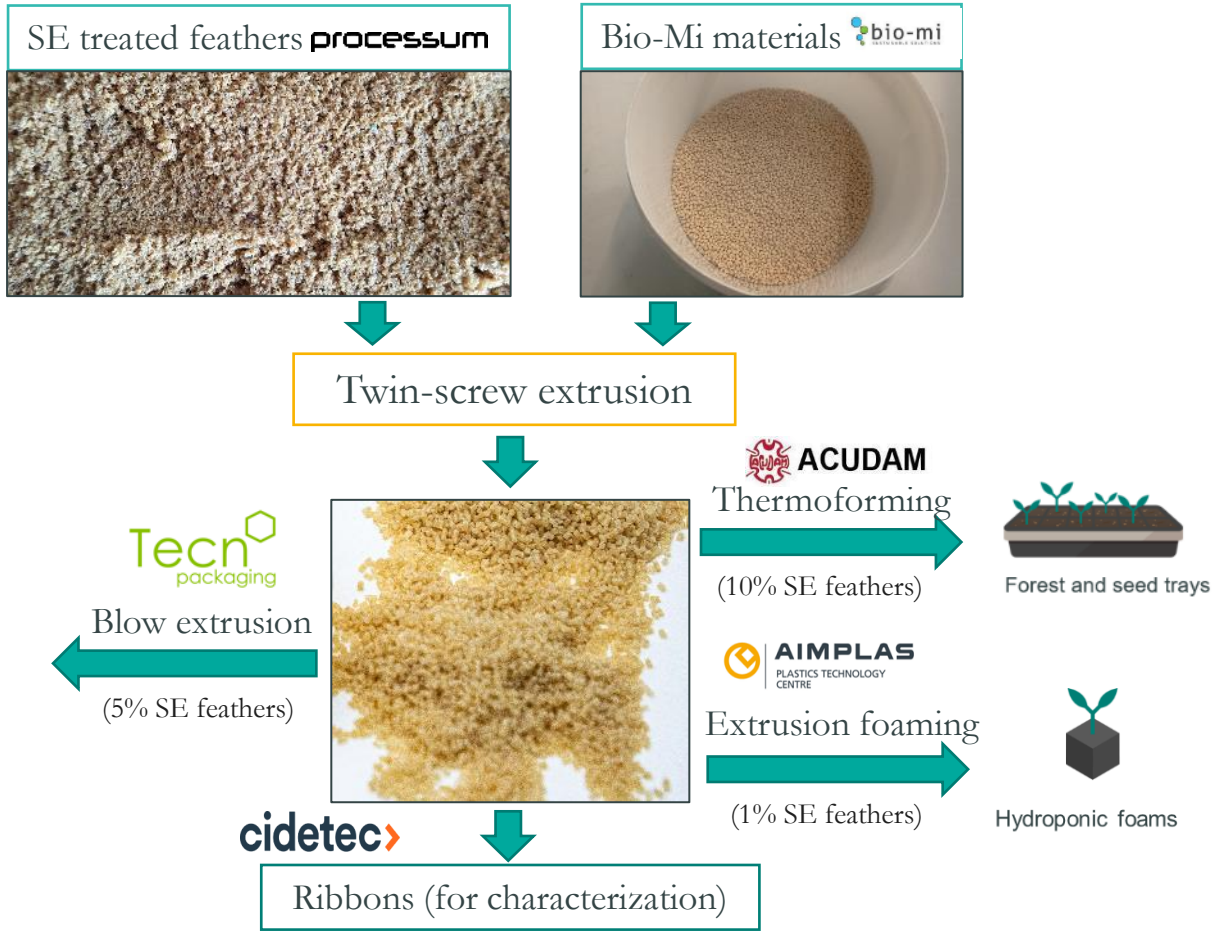
Feather incorporation in low quantities resulted in a **fertilization effect in the soil**

- **Negative effects** were observed for **high feather concentration** (>1%)
- **Positive effects** were observed for both tests with 0.1% and 0.05% of feathers, **similar to blank soil with nutrients**

Preparation of agricultural bioplastics

Bio-Mi prepared **13 different blends** which were **based on different biopolyesters** taking into consideration final applications, mechanical properties, processability, biodegradability in soil as well as price of matrices

System	Composition
UL1	Starch + PBAT
UL2	Starch+PBAT+PLA
UL3	Starch + PBAT + PHAs
UL4	PBAT+PLA+$CaCO_3$
UL5	PBAT+PLA (10 wt%)
UL6	PBAT+PLA (20 wt%)
UL7	PHB+PBSA
UL8	PHBV+PBSA
UL9	PHB+PBS
UL10	PHBV+PBS
UL11	PLA+PSA
UL12	PLA+PCL
UL13	PBAT+PLA (60 wt%)

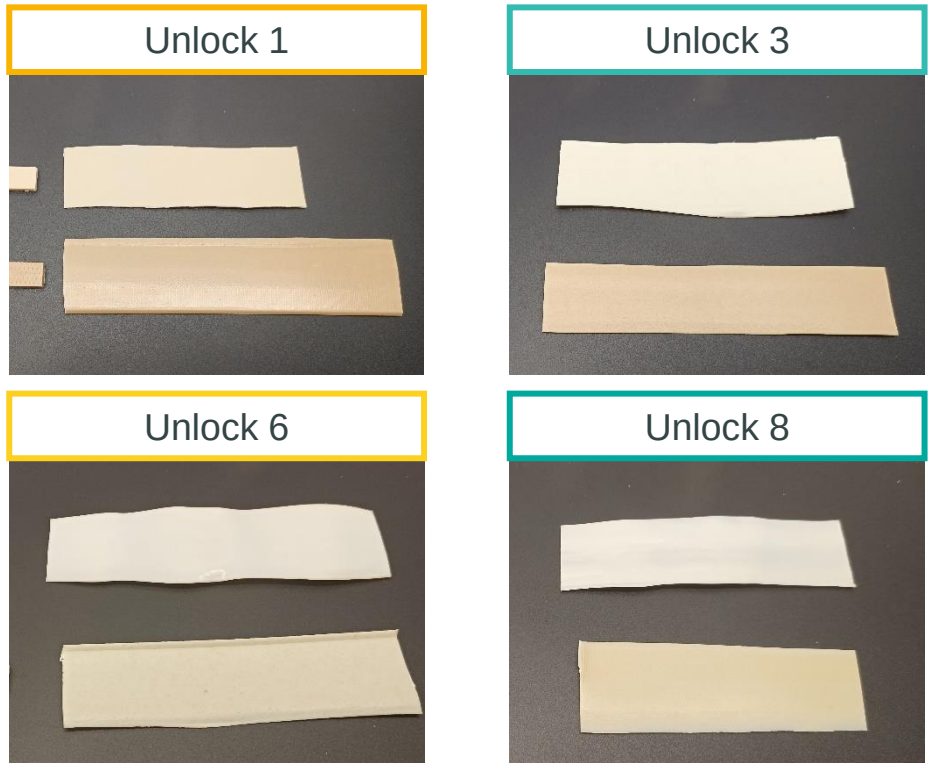


Preparation of bioplastics

Four matrices were selected from the portfolio of BioMi **for agricultural bioplastic preparation**

System
UL1+10%SE-190ºC-4min-0.5mm
UL3+10%SE-190ºC-4min-0.5mm
UL6+10%SE-190ºC-4min-0.5mm
UL8+10%SE-190ºC-4min-0.5mm

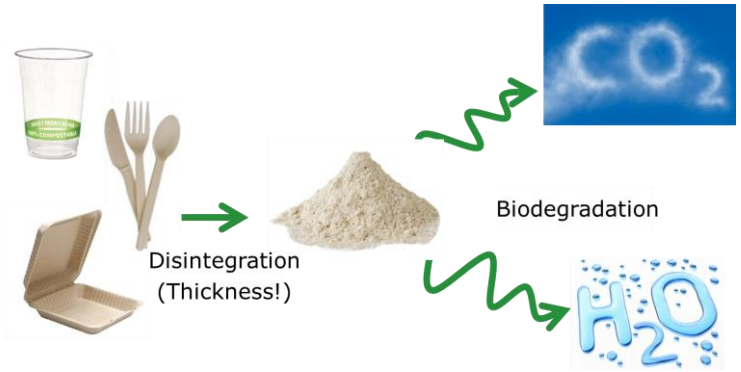
Compounds were prepared at a **10% of feathers treated by steam explosion** for ribbon fabrication (characterization)



Characterization of bioplastics

- The incorporation of treated feathers modify its colour obtaining **ribbons with brownish colour**
- The addition of feathers did **not affect significantly to the thermal stability of the bioplastic**
- The bioplastics containing feathers showed a **higher rigidity and lower elongation** compared with the unmodified matrices

Biodegradation vs Disintegration



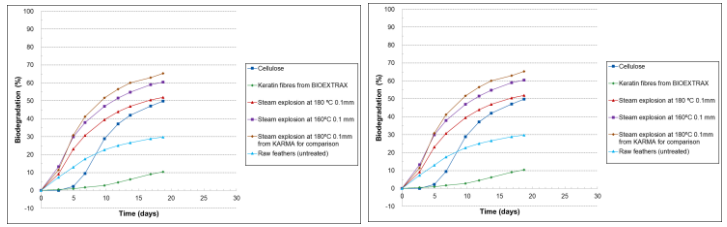
Disintegration

- **Qualitative test**. Physical process
- Test if the material is degrading and fall apart in the desired medium
- The **final shape of the material** is tested. The **thickness** is a key parameter

Biodegradation ≠ Disintegration

Biodegradation

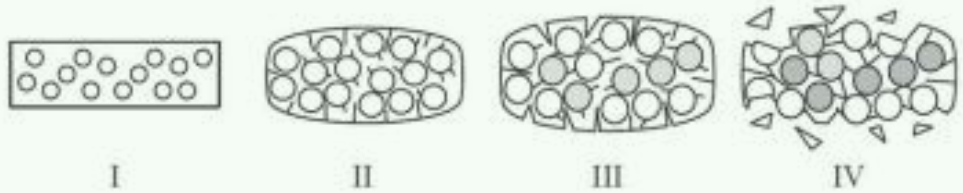
- **Quantitative test**
- **Mineralization** in CO_2, H_2O and biomass
- The **material is tested in powder or grinded** (the results are accelerated)



Disintegration of bioplastics ribbons

- **Slightly faster disintegration** of the bioplastic containing feathers of **easy degradable matrices** (UL1, UL3 and UL8)
- In **polymers with slower disintegration** (UL6), it is **accelerated with the addition of feathers, but not enough** to get a complete disintegration
- In general, all studied biocomposites (with exception of UL6), **disintegrated successfully in less than 50 weeks**

Disintegration mechanism

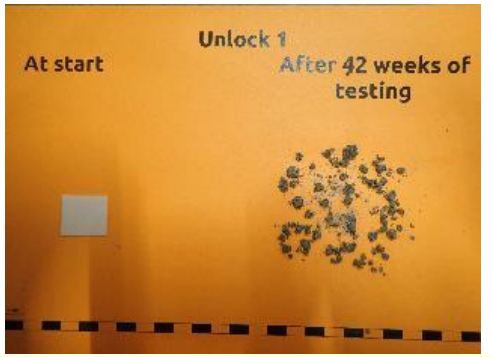


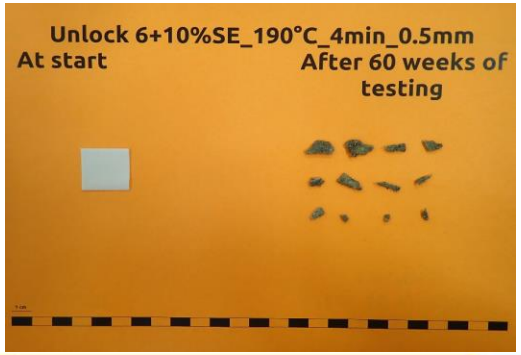
I) Initial material
II) Cracks appear at the interface between matrix and the fibers
III) Hydrolytic degradation of the PLA matrix contact area increases with increased enzymatic degradation
IV) Embrittlement and disintegration

Bayerl et al. Influence of fibre architecture on the biodegradability of FLAX/ ***PLA*** *composites. Int. Biodeterior. Biodegrad.* ***2014****, 96, 18–25*

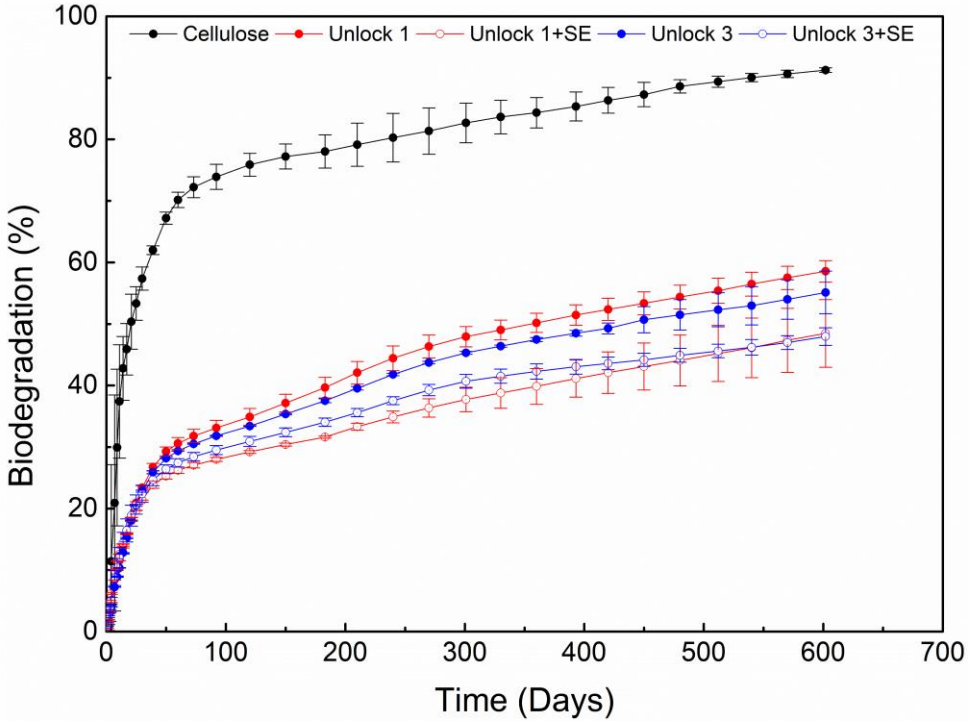
Disintegration test in soil (60 weeks)

System	Shape	Result
UL1	Ribbon	**Complete disintegration** after **44 weeks**
UL1+10% SE feathers	Ribbon	**Complete disintegration** after **42 weeks**
UL3	Ribbon	**Complete disintegration** after **46 weeks**
UL3+10% SE feathers	Ribbon	**Complete disintegration** after **38 weeks**
UL6	Ribbon	15.8% disintegration: Pieces of varying sizes
UL6+10% SE feathers	Ribbon	44.4% disintegration: Small pieces of varying sizes
UL8	Ribbon	**Complete disintegration** after **22 weeks**
UL8+10% SE feathers	Ribbon	**Complete disintegration** after **21 weeks**

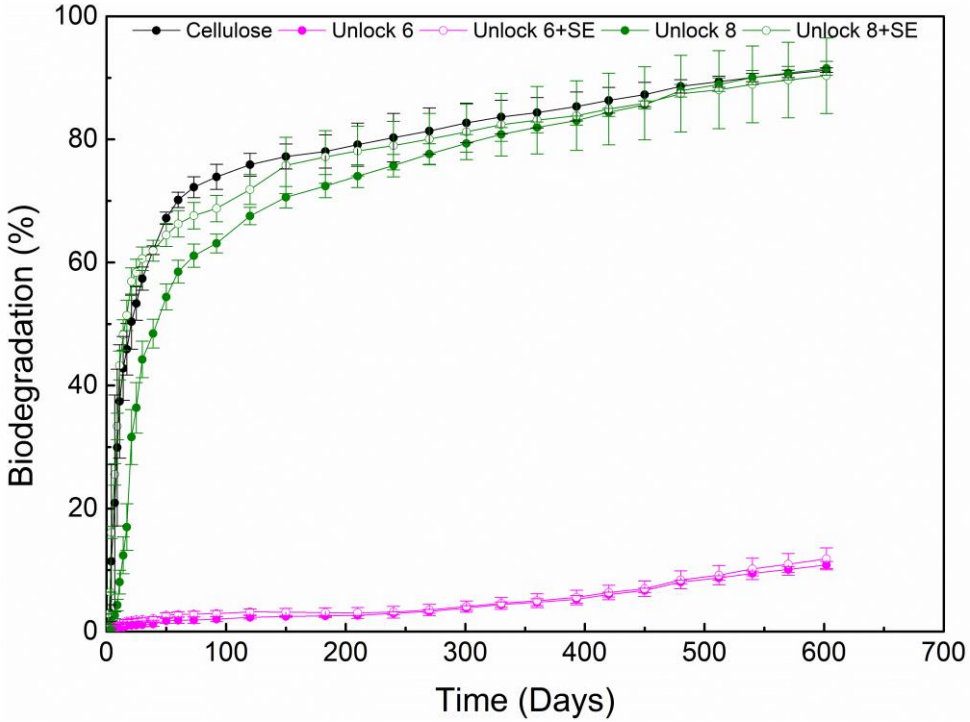




Soil Biodegradation of bioplastics ribbons



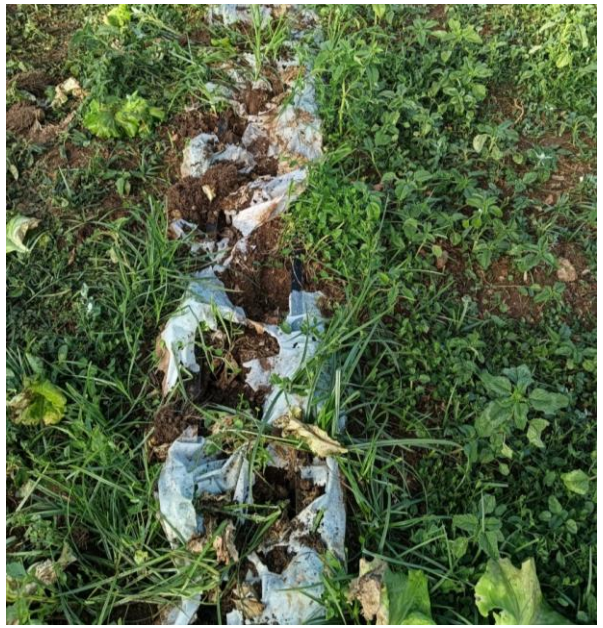
- Both **UL1 and UL3 with and without feathers** showed a **slower but continuous biodegradation** compared to cellulose (not finished yet Day 700)



- **UL8 with a without feathers** showed an **excellent biodegradability** comparable with cellulose whereas **UL6 and UL6+SE** presented **very low biodegradability** due to the presence of PLA (**Industrial composting??**)

Tests in field

Mulch films



Seed trays

SE treated feathers

- SE treatment was **successfully used to treat chicken feathers** from the poultry industry obtaining a **browner coloured** and denser solid
- The characterization performed to the feathers confirmed that the **SE treatment** led to the **disrupt of ordered structures, concretely β-sheet** which is the main ordered structure in chicken feathers as well as to the **breakage of disulphide bonds**
- The treated feathers **showed a higher and faster biodegradation compared with the no treated ones**

Bioplastic prepared from SE feathers

- The disintegration of the bioplastics is **accelerated with the addition of steam exploded feathers** for easy degradable polymers (UL1, UL3 and UL8). In **hardly biodegradable polymers** (UL6), it is also **accelerated, but not enough** to get a complete disintegration.
- The addition of treated feathers did **not modify the biodegradation of the matrices, obtaining similar biodegradation curves**.

Thanks for your attention !

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Questions???

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