Project n°:	**COOP-CT-2005-017684**
Project acronym:	**PICUS**
Project title:	**"DeveloPment of a 100 % BIodegradable Plastic Fiber to Manufacture Twines to Stake Creeping Plants and Nets for Packaging AgricUltural ProductS "**

Instrument: **CRAFT project**

Thematic Priority: **SMEs activities**

PUBLISHABLE FINAL ACTIVITY REPORT

Period covered: **from 1st September 2005 to 31st August 2007**

Date of preparation: **October 2007**

Start date of project: **1st September 2005** Duration: **Two years**

Project coordinator name: **Mr. Jose A. Costa**

Project coordinator organisation name: **AIMPLAS** Revision: **Final**

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1. PUBLISHABLE EXECUTIVE SUMMARY

Project objectives.

The PICUS objective has been **to develop a fully compostable fibre to manufacture twines for staking and propping plants and nets for packaging agricultural products. The main innovations** achieved in this project are the following:

- **Development of two new functional compound** to improve the blending properties of different aliphatic polyesters (amorphous and semicrystalline) and the blending properties of one of those polyesters plus another biodegradable material (PVOH). Although the latter option did not provide good results for the two aimed products, it will be useful for other less-restrictive applications. For this approach, optimal coupling agents/peroxide, were selected and new twin screw and barrel configuration was developed in order to minimize the use of chemical reagents and maximize the blend properties.
- **Development of a new synergic blends of biodegradable polymers** (compound), whose characteristics are:
  - Rheological and stretching properties suitable for ESFTW[1] and EMS[2] process.
  - Mechanical, thermal and chemical requirements (in a green house environment during the plant grow for twines and in a hypermarket/house environment for nets).
  - Good mechanical properties to obtain an optimal crushed size when the twine/net has finished its useful life.
  - Fully compostable when it is crushed and mixed with; the waste plant for twines and the organic fraction of municipal solid waste for nets.
- **Development of a methodology to produce easily a biodegradable fibre**, which is cheap to adapt to the requirements of each crop (controlling properties such as flexibility, tensile, biodegradability rate, etc.) and net packaging parameters (number of fiber/cm, strength, etc.).

As a result of all these partial developments, in the end, this project aimed to develop the following final product: *biodegradable fibers*

- with the same advantages that PP fibres, and with better cutting characteristics.
- able to prevent the loss of functional properties during its useful life.
- able to be "on-farm composted" or treated in composting plants (MSW system) after its useful life.

The new plastic fibres developed in this project have demonstrated to fulfil the following criteria:

- 100% biodegradable
- hydrophobic
- easy cutting
- easy processing
- low plastodeformation (creep)
- competitive cost

Contractors involved and Co-ordinator.

The following table shows the contractor's list as well as their role within the consortium.

Participant name	Participant short name	Country	Role in the Project
SME Contractors			
1. HILATURAS MACIA S.L	MACIA	E	Plastic twine manufacture. Extrusion-Stretch-Fibrillation-Twist-Winder process (ESFTW process)
2. ABONOS ORGÁNICOS NACIONALES S.A	ABORNASA	E	Composting. Biodegradability test

[1] ESTFW: **E**xtrusion-**S**tretch-**F**ibrillation-**T**wist-**W**inder process
[2] EMS: **E**xtrusion **M**elt **S**pinning process

Participant name	Participant short name	Country	Role in the Project
SME Contractors			
3. AGRICOLA ALICANTINA S.A	AGRILASA	E	Plastic twine applications. Vegetable crop in greenhouse
4. TERRLOIRE	TERR	F	Packer of agricultural products. User of packaging nets
5. CANTELO NURSERIES LIMITED	CANTELO	UK	Plastic twine applications. Vegetable crop in greenhouse
6. PVAXX RESEARCH & DEVELOPMENT LIMITED	PAVXX	UK	Compounding. Biodegradable polymers. Biodegradability test
7. AUSERPOLIMERI SRL	AUSER	I	Polymers functionalization. Compounding.
8. EXTRICOM GmbH, Blach Extruder & Components	BVT	D	Extrusion process. Extruder screw design and manufacture
9. FOURNE POLYMERTECHNIK GmbH	FOURNE	D	Packaging nets manufacture. Extrusion Melt Spinning process (EMS process)
RTDs			
10. ASOCIACIÓN DE INVESTIGACIÓN DE MATERIALES PLÁSTICOS	AIMPLAS	E	ESFTW and EMS process. Plastic materials and products characterisation. Ecotoxicity tests. ife Cycle Assessment. Recyclability.
11. PERA INNOVATION LIMITED	PERA	UK	Compounding. Plastic materials characterisation.
12. DEPARTMENT OF CHEMISTRY AND INDUSTRIAL CHEMISTRY, UNIVERSITY OF PISA	UNIPI	I	Polymers functionalization. Plastic materials characterisation.

The co-ordinator contact details are the following:

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Work performed and end results. Degree to which the objectives were reached. Impact.

Below an explanation about the objective, the work performed, end result obtained and degree to which the objective was reached can be found. The explanation has been separated by kind of work inside the project:

1. New staking twine meeting the technical specifications and functional requirements.
2. New packaging net meeting the technical specifications and functional requirements.
3. Recyclability: the initial objective of 5 % of industrial scrap (Milestone 9) has been overcome considerably (100% recyclability!)
4. Compostability & Ecotoxicity= Environmentally friendly
5. Economically viability (both products)
6. Regulatory fulfilment.

1. New staking twine meeting the technical specifications and functional requirements.

OBJECTIVE	WORK PERFORMED	END RESULT	DEBREE TO WHICH THE OBJECTIVE WAS REACHED
Technical specifications of the new staking twines.	Taking into account the requisites established for the current twines used on the market, we established the requisites that the new material must fulfil. - The new material must be able to be processed in all steps of the Extrusion Stretch Fibrillation Twist Winder Process. - Physical characteristics especially the weight of the twines (1200 deniers g/km). - The new biodegradable material must have similar mechanical properties than the current twines, above all: • Stress at Yield • Elongation at yield - Compostability according the test standard **UNE–EN 13432**	The biodegradable staking twines obtained fulfil all the technical specifications but before the commercialization it is necessary to optimize the deniers (weight of twines, g/Km). At this moment, the deniers are between (1100 – 3600) g/km if the staking twines are fibrillated or twisted* respectively.	The objective was 100% successful, from the technical point of view.
Contractors involved ▪ **MACIA** ▪ **AUSER/PVAXX** ▪ **BVT** ▪ **AIMPLAS** ▪ **PERA** ▪ **UNIPI**	*Note: Two types of biodegradable staking twines were developed: Fibrillated staking twines and Twisted staking twines.		

OBJECTIVE	WORK PERFORMED	END RESULT	DEBREE TO WHICH THE OBJECTIVE WAS REACHED
Functionality of the staking twines during all the useful life.	Two types of staking twines were obtained: - Staking Twines Fibrillated - Staking Twines Twisted Both products were tested in AGRILASA and CANTELO to study their functionality in tomatoes and cucumber/pepper crops,	Both materials show good mechanical properties after this validation period (3 months). It would be necessary to point out that the fibrillated staking twines are very rigid due to the molecular crystallization	The objective was 100% successful.
Contractors involved			

▪ **AGRILASA** ▪ **CANTELO** ▪ **AIMPLAS**	respectively.	during its degradation process. For this reason, the best biodegradable twines to replace the current twines during the real validation period (8 – 10 months) are the **Twisted Staking Twines.**	

Extrusion Stretch Fibrillation Twist Winder Process to obtain the current and the biodegradable staking twines is shown in the figure 1.

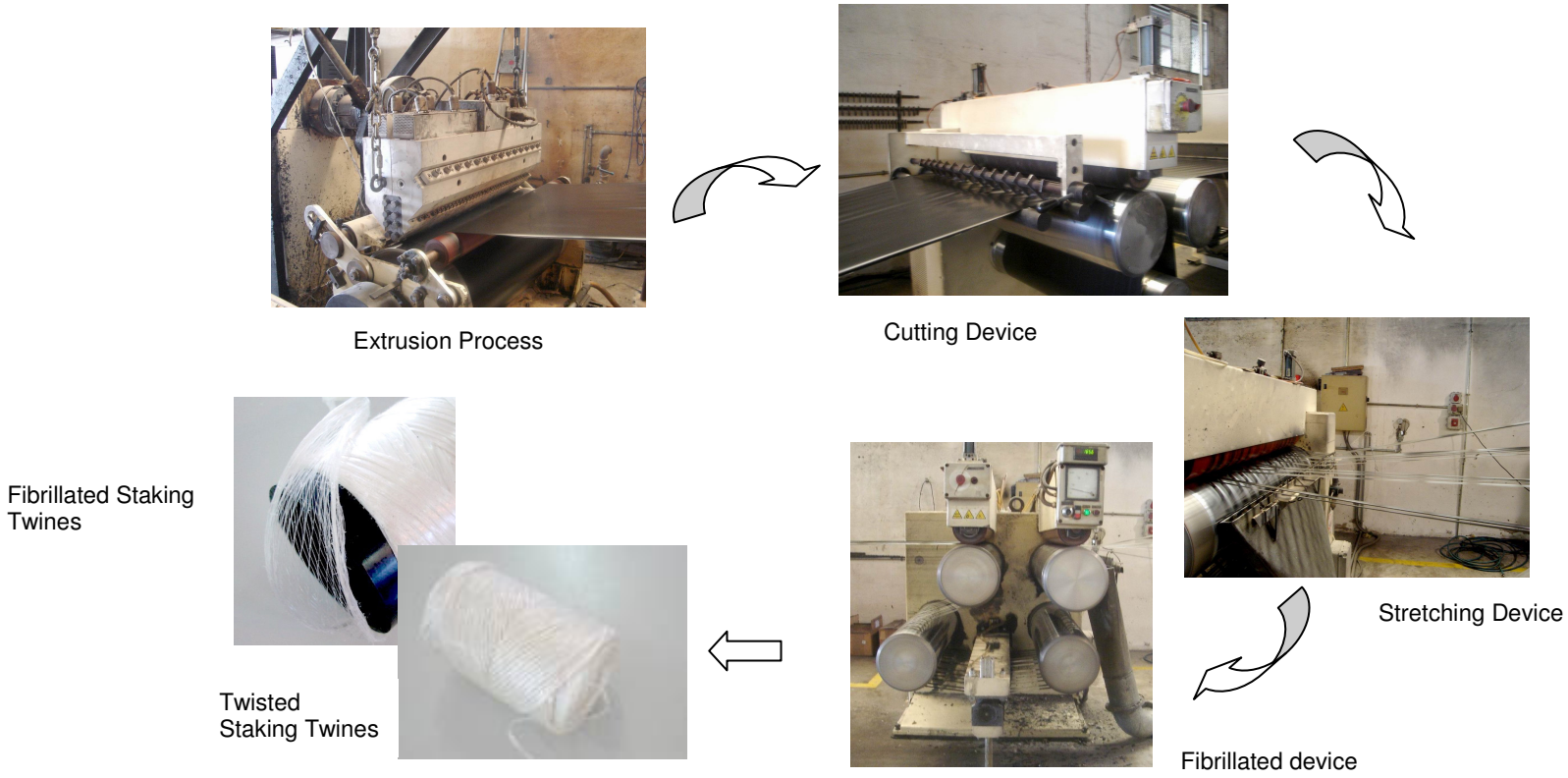


Figure 1. Equipment used to obtain staking twines.

The requisites established for the current twines used in the market and the results obtained with the biodegradable staking twines are summarized in Table 1.

Table 1.Technical requirements from both current staking twines and both bio twines developed

			Current Twines Fibrillated	**Current Twines Twisted**	**Bio Twines Fibrillated**	**Bio Twines Twisted**
Properties	**Test Standard**	**Unit**	**Value**	**Value**	**Value**	**Value**
Material	--		PP		Blend selected to replace twines	
Melt Index (230ºC/2.16 Kg)	ISO 1133	(g / 10 min)	2 - 4		5 – 5.3	
Density	ISO 1133	(Kg / m^3)	900		1249 – 1259	
Deniers	--	(g / Km)	1150	1500	1054	3680
	MECHANICAL PROPERTIES (*)					
Stress at Yield	UNE-EN ISO 527-2	N	319.83 (11.26)	385.58 (9.53)	143.15 (5.50)	250.00* (17.07)
Elongation at Yield	UNE-EN ISO 527-2	%	14.97 (1.67)	17.39 (0.88)	26.54 (3.41)	25.3* (6.67)
Stress at Break	UNE-EN ISO 527-2	N	39.39 (12.57)	280.48 (74.08)	53.32 (18.70)	195.19 (60.88)
Elongation at Break	UNE-EN ISO 527-2	%	46.87 (13.23)	20.28 (1.02)	42.44 (5.22)	60.53 (8.38)

*As can be seen, the two critical parameters in the new biodegradable twines are lower (for the stress at yield) and higher (for the elongation at yield) than the PP values taken as a reference (notice that this specific PP was used as the reference material in the project because there is no standard to be followed). However, after the trials of the industrial validation and based on the experience of the end-users, it was checked that it is possible to use any staking twine which fulfils the following requirements; **stress at yield > 200 N and elongation at yield < 30 %.,** as it is PICUS twines´ case.

These new parameters were fixed after the validation period in the two end-user SMEs, where the functionality of the staking twines were studied in tomatoes and cucumber/pepper crops.

Consequently, it is demonstrated that PICUS staking twines meet successfully with the requirements to be used in the field.

2. New packaging net meeting the technical specifications and functional requirements.

OBJECTIVE	WORK PERFORMED	END RESULT	DEBREE TO WHICH THE OBJECTIVE WAS REACHED
Technical specifications of the packaging nets.	Taking into account the requisites established for the current nets used on the market, we established the requisites that the new material must fulfil. - The new material must be able to be processed in all steps of the Extrusion Melt Spinning Process. - Physical characteristics, especially the mesh configuration (type and dimensions) - The new biodegradable material must have similar mechanical properties to the current nets, especially: -Mechanical behaviour -Melt flow index - Compostability according the test standard **UNE–EN 13432**	The biodegradable packaging nets obtained fulfil all the technical specifications*.	The objective was 100% successful, from the technical point of view.
Contractors involved ▪ **FOURNE** ▪ **BVT** ▪ **AUSER/PVAXX** ▪ **AIMPLAS** ▪ **PERA** ▪ **UNIPI**			
	*Note: New biodegradable packaging nets show even better mechanical properties than the current nets		

OBJECTIVE	WORK PERFORMED	END RESULT	DEBREE TO WHICH THE OBJECTIVE WAS REACHED
Functionality of the staking twines during all the useful life.	The functionality of the new biodegradable nets have been studied, taking into account: - Packaging Process, using the convectional equipment to obtain bags from net in tubular form. - Product validation during its useful life. In the procedure different trials were done in	**-** It is possible to obtain biodegradable bags from net in tubular form in conventional equipment using the same parameters decreasing a little bit the sealing temperature. **-** Mechanical characterization is summarized in the table 2. According to the mechanical behaviour, **the**	The objective was 100% successful.
Contractors involved			

▪ **TERR** ▪ **AIMPLAS**	bags hanged and laid on the ground with different weight in AIMPLAS and TERRLOIRE. The trials lasted 15 days. - Mechanical characterization. Comparative proposed with the mechanical properties of the reference nets and biodegradable nets, before and after the product validation.	**nets obtained with the biodegradable material developed showed better mechanical properties than the reference nets:** The new biodegradable nets are more resistant.	

Product validation with the biodegradable bags hanged and laid on the ground in figure 2.

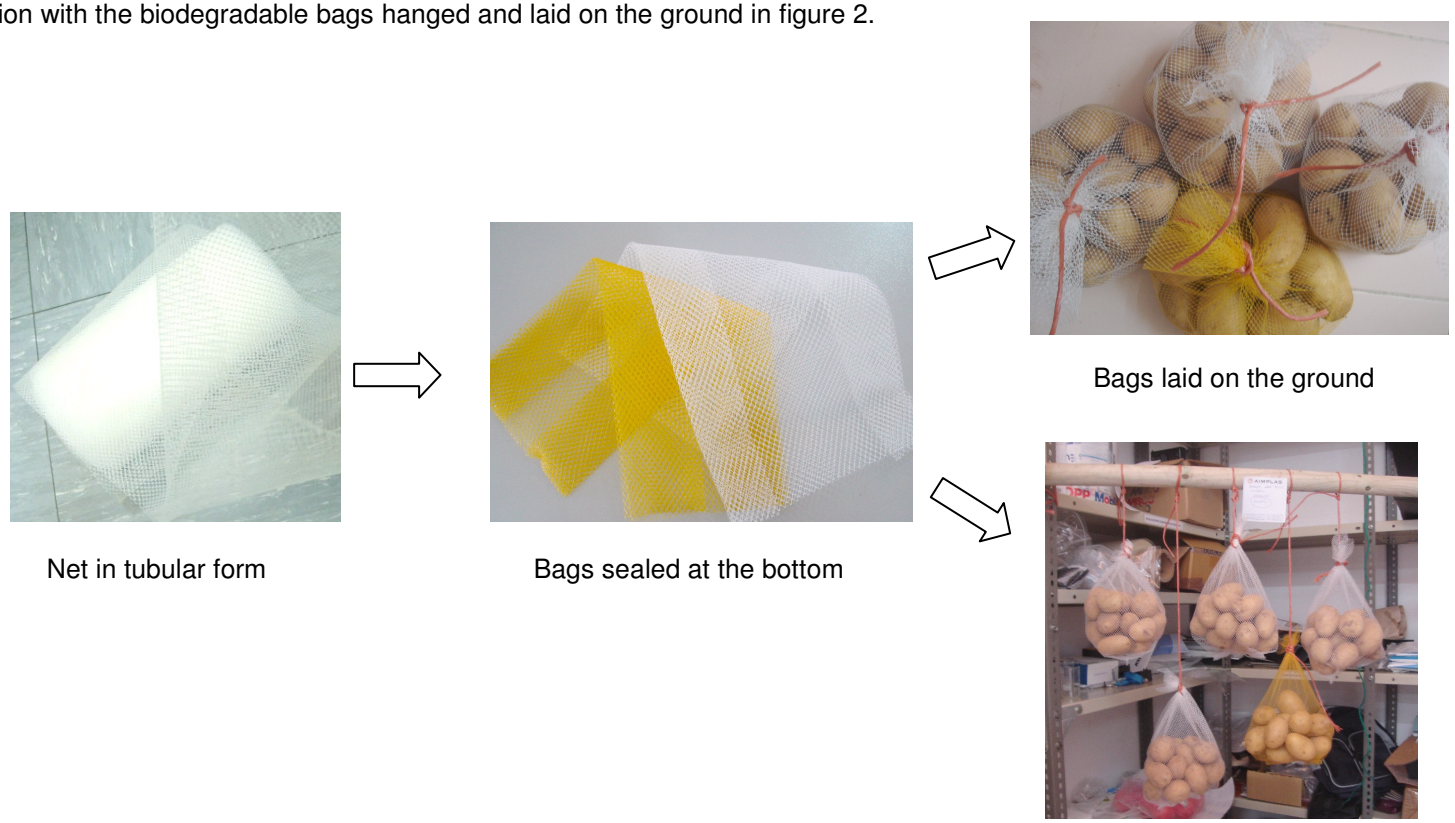
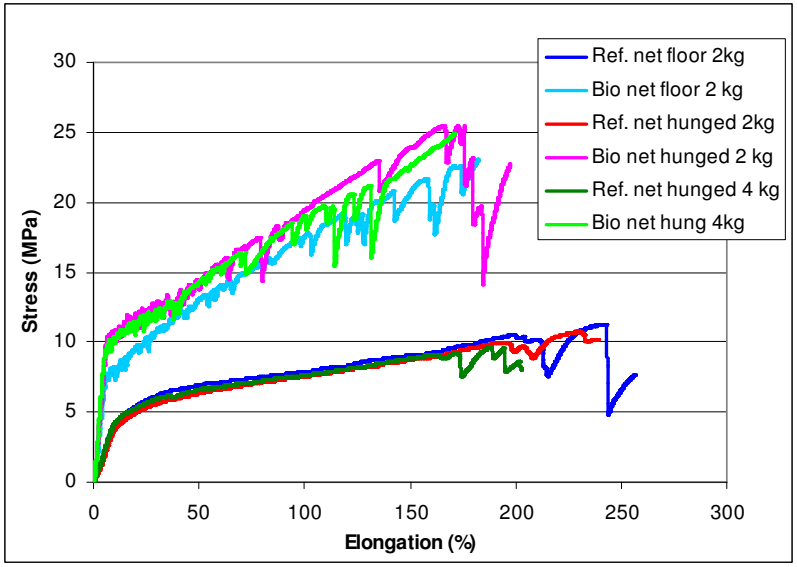


Figure 2. Product Validation of the new biodegradable packaging nets.

Table 2. MECHANICAL PROPERTIES.

		Mechanical Properties (*)	
TRIALS	**DESCRIPTION**	Maximum stress (N)	Elongation (%)
Before validation	Ref. net	15.94 (0.89)	301.37 (41.62)
	Bio net	**32.49 (1.72)**	**317.23 (14.13)**
Validation in AIMPLAS. (All the trials have been done with 2 kg of weight)	Ref. net on the floor	12.28 (0.15)	279.92 (15.41)
	Bio net on the floor	**27.08 (0.39)**	**218.23 (6.91)**
	Ref. net hanged	13.84 (0.07)	296.90 (0.73)
	Bio net hanged	**29.98 (2.93)**	**202.44 (17.37)**
Validation in TERRLOIRE	Ref. net on the floor (2 kg)	10.77 (0.68)	230.20 (17.87)
	Bio net on the floor (2 kg)	**21.40 (2.33)**	**158.69 (33.56)**
	Ref. net hanged (2 kg)	10.84 (0.17)	231.44 (2.76)
	Bio net hanged (2 kg)	**26.06 (0.89)**	**182.85 (9.76)**
	Ref. net hanged (4 kg)	9.58 (0.04)	186.45 (3.11)
	Bio net hanged (4 kg)	**23.77 (1.55)**	**172.02 (1.65)**

(*) In brackets (standard deviation)



The new biodegradable net fulfils all the established requirements in processability, rheological and mechanical behaviour before and after the product validation, thus being able to be used as a commercial product.

3. Recyclability

OBJECTIVE	WORK PERFORMED	END RESULT	DEBREE TO WHICH THE OBJECTIVE WAS REACHED
Recyclability: the initial objective was to recycle at least 5% of the industrial scrap. **Contractors involved** ▪ **MACIA** ▪ **FOURNE** ▪ **AIMPLAS**	To study the recyclability of both blends selected to replace staking twines and packaging nets, it is necessary to analyse the re-processability of both materials in the injection process. The re-processability of the new materials was performed following these steps: ✓ The material selected will be processed to obtain test specimens by injection process. ✓ These pieces were ground to obtain scraps. ✓ These scraps were processed again. ✓ The test specimen obtained was characterized, studying their processability, rheological properties (melt flow rate) and mechanical properties. The material was re-processed five times. The answer parameter in the blend selected to replace twines is the mechanical properties. The answer parameters in the blend selected to replaces nets are the mechanical properties and the melt flow rate.	Both materials selected to replace staking twines and packaging nets are recyclable. *Normally, for **any industrial scrap,** the percentage of recycled material which is **included in the final product is 20 % at the most.*** For PICUS materials, it is **possible to reprocess both materials up to five times in 100%, without loosing the critical requirements**. In other words, the recyclable material could be re-used in 100% to manufacture the same product (twines or nets), without loses of critical properties.	The objective was 100% successful.

Figure 3 shows the mechanical properties in the re-processed samples from the blend selected to replace staking twines and packaging nets, respectively. It can be observed that no relevant changes occurred.

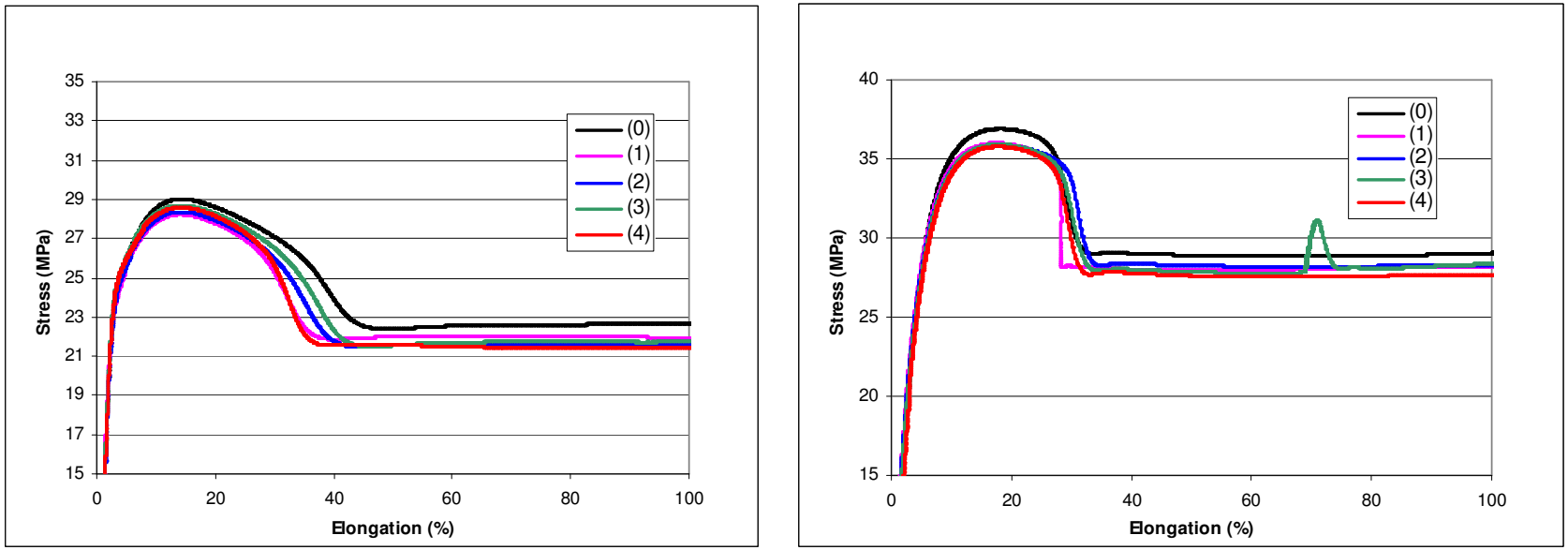


Figure 3. Recyclability to the blend selected: a) to obtain twines. b) to obtain packaging nets.

On the other hand, table 3 shows the MFR of the re-processed sample to replace packaging nets.

Table 3. MFR OF THE RE-PROCESSED SAMPLES

New biodegradable net material (times re-processsed)	MFR (cm^3 / 10 min)
(0)	1.834
(1)	2.697
(2)	2.866
(3)	3.469
(4)	6.556

4. Compostability & Ecotoxicity.

Introduction test standard

The compostability of the material is determined according to the standard **EN 13432:2000** ('Packaging- Requirements for packaging recoverable through composting and biodegradation – Test scheme and evaluation criteria for the final acceptance of packaging'). This standard specifies several stages a material must fulfil in order to be accepted as being compostable:

1) Material characteristics (constituents, organic matter, heavy metals)
2) Biodegradation (for the project, according to ISO 14855-1:2005, 'Determination of the ultimate aerobic biodegradability of plastic materials under controlled composting conditions- Method by analysis of evolved carbon dioxide')
3) Disintegration (in laboratory, pilot or full scale, according to different standards)
4) Compost quality

OBJECTIVE (part 1)	WORK PERFORMED	END RESULT	DEBREE TO WHICH THE OBJECTIVE WAS REACHED
Material Characteristics **Contractors involved** ▪ **ABORNASA** ▪ **AIMPLAS**	In the composition of the material, the main parameters to study are: - Dry solid (% wet basis) - Volatile solids (% dry basis) - Total nitrogen (% dry basis) -Total organic carbon (% dry basis)	The two final blends selected have a very high content in volatile solids. This parameter gives and indications of the organic matter present in the material. So, high values for this parameter are favourable for the biodegradation process.	The objective was 100% successful.

Table 4. Characterization of the blends used to manufacture the Nets and Twines.

	NETS blend	TWINES blend
Dry solids (% wet basis)	99.708	99.6085
Volatile solids (% dry basis)	99.8635	99.9930
Total nitrogen (% dry basis)	0.0763	0.0490
Total organic carbon (% dry basis)	48.9045	50.4610

OBJECTIVE (part 2)	WORK PERFORMED	END RESULT	DEBREE TO WHICH THE OBJECTIVE WAS REACHED
Biodegradation **Contractors involved** ▪ **ABORNASA** ▪ **AIMPLAS**	The duration of these tests was adjusted to 3 months in order to fit in the deadlines of the project. As our main purpose was the comparison between commercial biodegradable materials and the ones obtained in the project, this time scale provides enough data for this aim.	The materials selected for the project reached biodegradation values even higher than biodegradable raw materials. This happens due to the final selected blends are like a 'dilution' of those starting materials. This fact shows that the materials selected fulfil the requirements of EN 13432:2000 (90 % biodegradation in 6 months)	The objective was 100% successful.

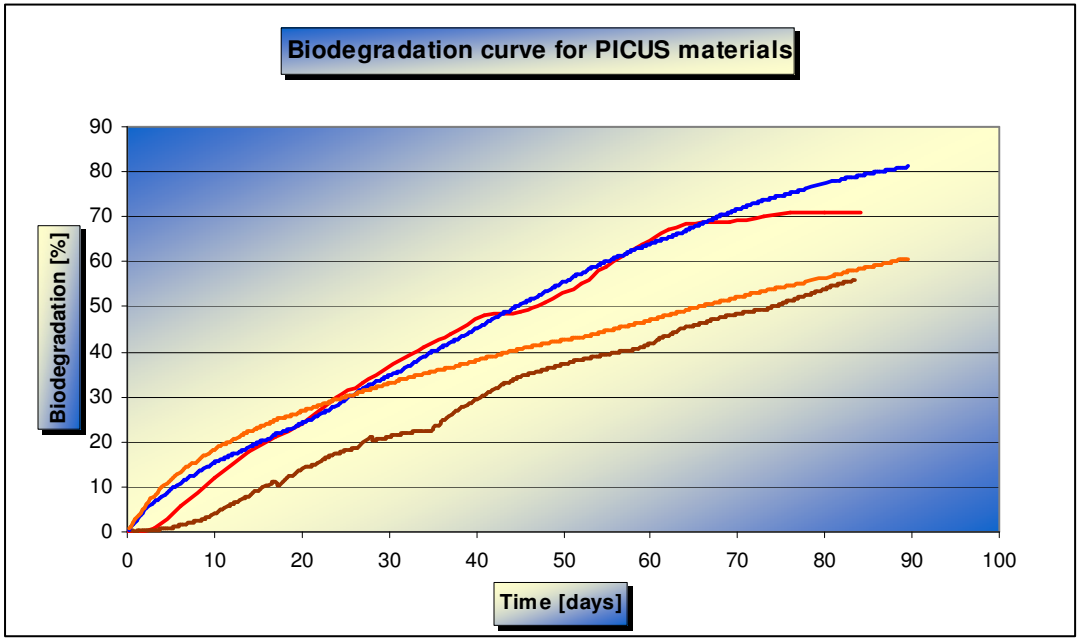


Figure 4. Results of biodegradation test for the two reference biodegradable materials (the two lowest curves) and final blends selected for twines and nets (the two highest curves).

OBJECTIVE (part 3)	WORK PERFORMED	END RESULT	DEBREE TO WHICH THE OBJECTIVE WAS REACHED
Disintegration **Contractors involved** ▪ **ABORNASA** ▪ **AIMPLAS**	The disintegration test is according to standard ISO 20200:2005. This method determines the degree of disintegration of test materials on a laboratory scale. The solid matrix used consists of a synthetic solid waste inoculated with mature compost taken from a commercial composting plant. Pieces of the plastic test material are composted with this prepared solid matrix. The degree of disintegration is determined after a composting cycle, by sieving the final matrix through a 2 mm sieve in order to recover the non-disintegrated residues. The reduction in mass of the test sample is considered as disintegrated material and used to calculate the degree of disintegration.	**The fragments, initially sieved to particles of ≥ 2 mm, fulfilled the standard as the degree of disintegration is > 90% (in weight), or what is the same, the fragments weight is < 10 % in 12 weeks.**	The objective was 100% successful.

a) b) c)

Figure 5. Evolution of Twines blend in disintegration test, at: a) 29 days; b) 50 days; c) 90 days

a) b) c)

Figure 6. Evolution of Bio90PLA10 in disintegration test, at: a) 29 days; b) 50 days; c) 90 days

OBJECTIVE (part 4)	WORK PERFORMED	END RESULT	DEBREE TO WHICH THE OBJECTIVE WAS REACHED
Compostability **Contractors involved** ▪ **ABORNASA** ▪ **AIMPLAS**	Both biodegradable products were evaluated in real composting conditions. These products were mixed with other residues and composted in an industrial composting plant. The quality of the compost was evaluated after a period of three months. A complete characterization of the compost was done, according to the legislation in Spain.	According to the results, any negative influence was observed after the addition of the biodegradable polymer to the compost. All the significant parameters had values similar to blank compost and comply with legislation, guaranteeing their ability to be employed in agricultural applications.	The objective was 100% successful.

OBJECTIVE	WORK PERFORMED	END RESULT	DEBREE TO WHICH THE OBJECTIVE WAS REACHED
Ecotoxicity	To study the ecotoxicity, a evaluation of the growth of two plants (Ryegrass and lettuce) was done. Standard substrate “compost” was mixed in three percentages with the blends selected, to obtain twines and nets in pellets state, for comparative purposes.	The best results, taking into account the studied parameters, were obtained with the mixture 1: 3 ratio (25 % of bio blend / 75 % substrate). Figures 4 show the results in the ecotoxicity	The objective was 100% successful.

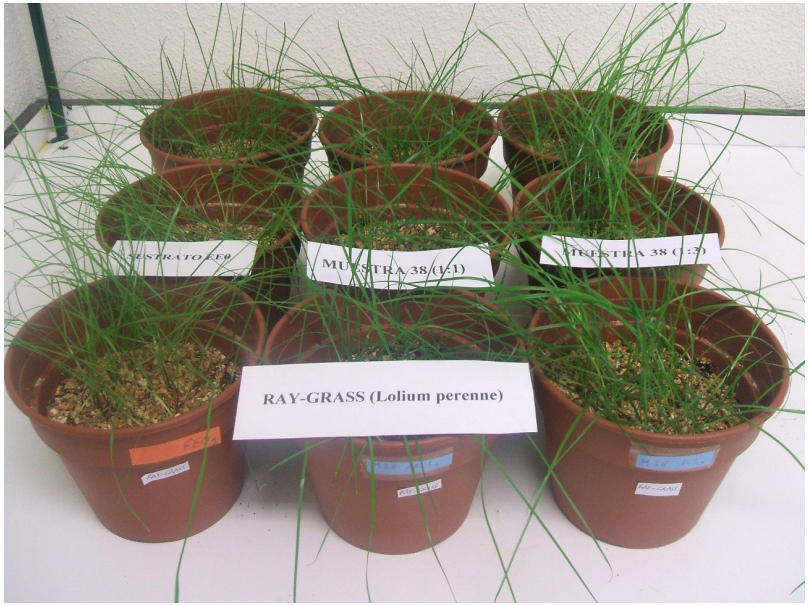
Contractors involved			
▪ **AIMPLAS** ▪ **ABORNASA**	- 100 % substrate. - 50% substrate + 50% bio blend selected. - 75% substrate + 25% bio blend selected. The ecotoxicity was studied taking into account the following parameters: - Visual appearance. - Germination rate. - Plant yield	in the visual characterization.	

Visual Characterization in the growth of both selected plants (lettuce and ryegrass)

Substrate 50% Bio blend 50% Substrate 25 % Bio blend 75% Substrate

Substrate 50% Bio blend 50% Substrate 25 % Bio blend 75% Substrate

a) Lettuce using as bio- blend the blend selected to replace nets.



b) Ryegrass using as bio- blend the blend selected to replace twines.

Figure 7. Visual characterization using bio blend selected. a) Lettuce. b) Ryagrass.

6. Regulatory fulfilment

OBJECTIVE	WORK PERFORMED	END RESULT	DEBREE TO WHICH THE OBJECTIVE WAS REACHED
To ensure that the new twine/net meet the EC Directives.	During the progress of the project a continuous update of the current regulatory standards was developed in order to analyze if our new products (twines/nets) fulfil the requirements of biodegradability/compostability as stated in the standard EN rules. A follow-up of the existing standards and those improvements that took place during the project (related to the evaluation of the biodegradability) was carried out. It was chosen, since the beginning, the standard Taking into account what has previously been stated, in this project the compostability of the material will be tested according to the standard EN 13432:2000.to test the compostability of the material. The aim of this study was to supervise that no new requirements were demanded to those we had taken as a reference at EU/international level.	The two new materials (for twines and nets) meet the standard EN 13432:2000, as can be checked in the objective nº 5, and no new EU/ international standards derogating the current ones have appeared.	The objective was 100% successful.
Contractors involved			
▪ **PVAXX** ▪ **AIMPLAS** ▪ **UNIPI**	---		

2. DISSEMINATION AND USE.

A brief and publishable description of the main characteristics of each of the exploitable results is described below.

- **1. Compounding, ESTFW and EMS processes (material formulation and processing parameters), to obtain the staking twines and the packaging nets.**

-Result description.

100% biodegradable staking twines and packaging nets manufactured with conventional equipment and made up of biodegradable materials available on the market, with the same advantages that PP/HDPE fibres, with better cutting characteristics; able to prevent the loss of functional properties during its useful life and able to be "on-farm composted" or treated in composting plants (MSW system) after its useful life. Thus saving the waste management costs.

-Possible market application/further research. Agriculture, Packaging, Gardening.

-Stage of Development.

Results of demonstration trials available. Commercial optimization pending in order to get the product ready for the market.

-Collaboration sought or offered.

1. License agreement
2. Available for consultancy.
3. Marketing.

-IPR granted or published.

Not yet. Foreseen: trademark and licenses

-Contact details.

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Specific Result URL	---

- **2. Best Practice Guideline for the use and recycling of the developed twine/net.**

-Result description.
Best practice guidelines for the use and recycling of the developed biodegradable twines / nets.
-Possible market application/further research. Manufacture of biodegradable plastic products
-Stage of Development.
Guidelines already written.
-Collaboration sought or offered.
1. Available for consultancy.
2. Marketing.
-IPR granted or published.
Copyright
-Contact details.

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Specific Result URL	---

- **3. Compounding and injection processes (material formulation and processing parameters), for applications using the PVOH from PVAXX.**

-Result description.

100% biodegradable plant pots and tree ties made up of two biodegradable materials (one of them is PVOH), whose blend is injected in a conventional equipment. The final products have the same properties as the current ones with the advantage of innovation, as they have extended the applications of two biodegradable materials, contributing to an environmentally friendly image.

-Possible market application/further research. Household, Gardening

-Stage of Development.

Results of demonstration trials available. Commercial optimization pending in order to get the product ready for the market.

-Collaboration sought or offered.

1. License agreement
2. Available for consultancy.
3. Marketing.

-IPR granted or published.

Not yet. Foreseen: trademark and licenses

-Contact details.

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