Large scale cultivation of *Cynara cardunculus* L. for biomass production A case study in Portugal

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Cynara cardunculus L. is a herbaceous perennial plant crop with annual growth cycle.

It is native in the Mediterranean and spread to North Africa and South America.

It is adapted to dry and hot regions, and poor soils., with high biomass productivity

The plant is used traditionally for:

- Food (salads and soup): the blanched petioles of leaves
- Cheese coagulation: the flowers

Multiple potential uses of Cynara

Cynara as raw-material for biorefinaries

Whole plant :
energy

Capitula :
cheese
pulp & paper

Stalks :
pulp&paper
fibrous materials

Fruits (seeds):
oil & biodiesel

Green leaves:
food & feed

- ★ *Cynara cardunculus* has been systematically studied as a biomass crop and as a multiple-use raw-material for energy and industry
- ★ The approach has been multidisciplinary and encompassing the whole-system: production, conversion and use

The first studies were done in the 80's by Professor Jesus Fernandez, Polytechnic University of Madrid

Three European R&D projects in the 90's allowed systematic studies involving teams e.g. from Spain, Portugal, Italy and Greece

Experimental fields, comparative productivity tests, cultivation techniques, biomass characterization and conversion processes (energy, oil, chemicals, pulp&paper) were studied

In Portugal, the studies were carried out by Helena Pereira and Jorge Gominho, from the School of Agriculture, Technical University of Lisbon

Large scale field experiments were carried out under the EU project ECAS (2004-2007) and the raw material tested in commercial or prototype equipments for energy and biodiesel production.

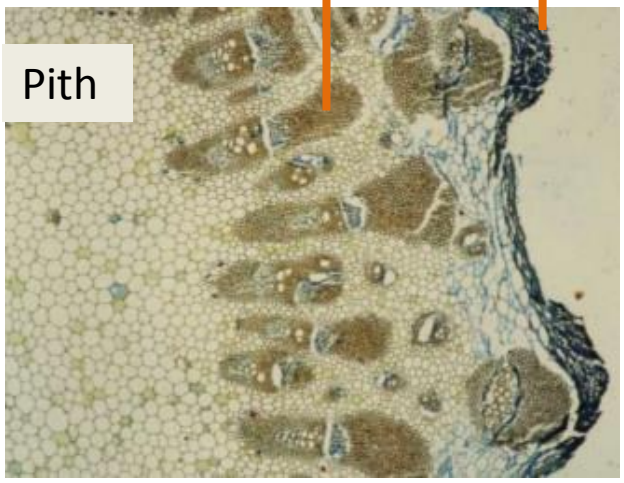
ECAS
Energy crops in the Atlantic space: large scale development opportunities

INTERREG III B Project
(http://www.isa.utl.pt/def/interreg/)

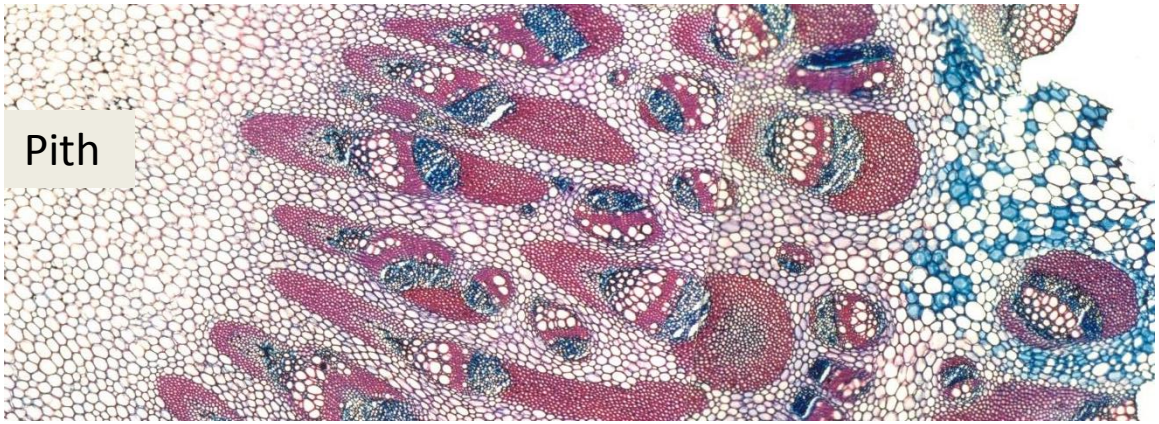
INTERREG
ESPAÑA ESPACIO ATLÁNTICO
FRANCE ESPACE ATLANTIQUE
IRELAND ATLANTIC AREA
PORTUGAL ESPAÇO ATLÂNTICO
U.K. ATLANTIC AREA

Anatomical characterization

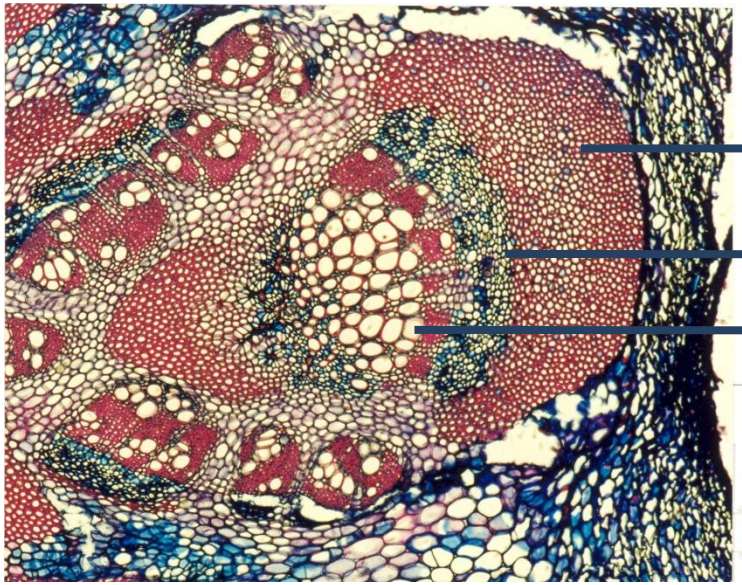
Stalk



Transverse section



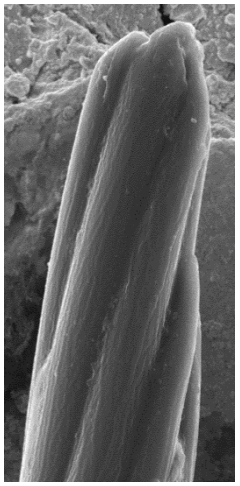
Radial section

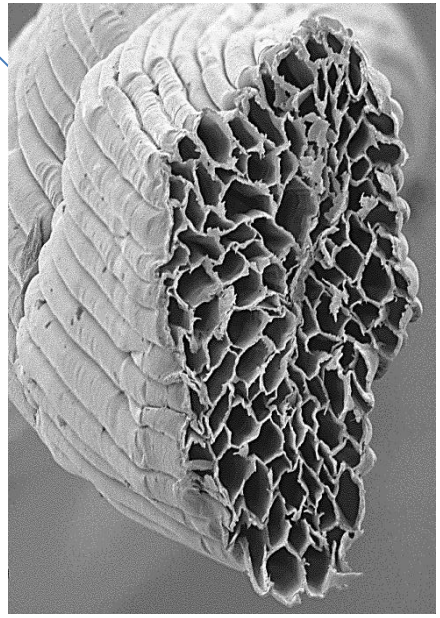


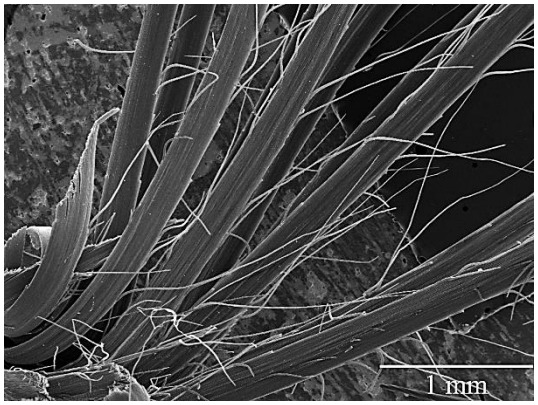
Capitula

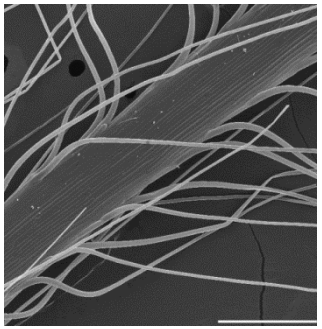
Hairs and pappi

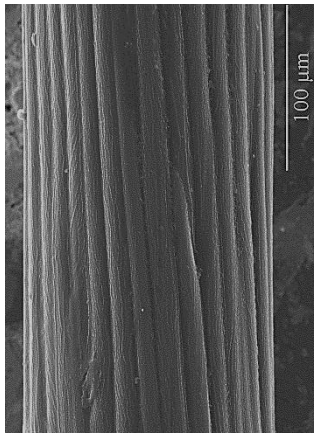
Fruit (seed)

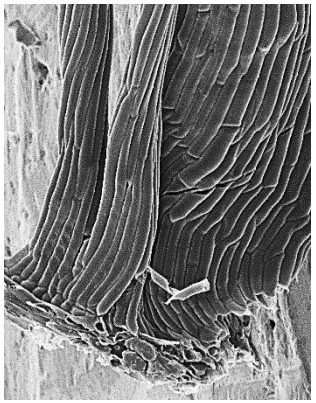












Hairs and pappi represent 7% of the plant biomass.
They are filamentous structures of aligned fibres
(length 1.4 mm and 1.8 mm respectively)

Growth cycle

1st Year

Autumn	**Winter**	**Spring**	**Summer**
Seed germination	Leaves growth	Floral escape	Capitula development

Adaptation to mediterranean conditions

Permanent rain-fed crop with annual cycle and 15 years exploitation potential

Low maintenance costs.

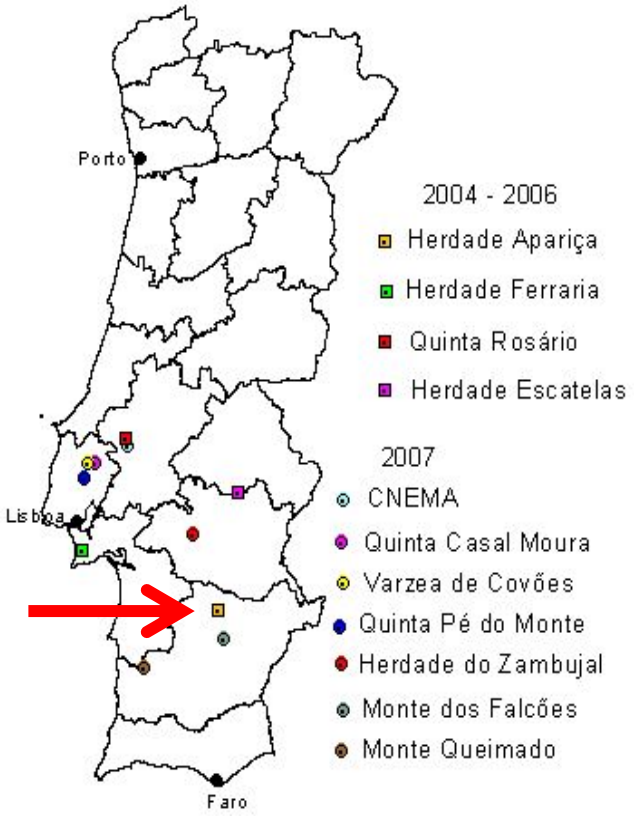
Use of agricultural practices and equipment

High biomass production (10-20 tons/ha/yr) and multi-purpose potential

Field experiments in Portugal

Approximately 200 ha

Installation of Cynara crop fields	Area (ha)
Apariça (Beja)	75
Ferraria (Sesimbra)	15
Escatelas (Estremoz)	15
Rosário (Santarém)	11
Monte dos Falcões (Beja)	17
Monte Queimado (Cercal do Alentejo)	20



Soil preparation and crop installation

Ploughing (40 – 50 cm depth)

Base fertilization

Grading

Seed spacing 0.75 m x 0.12 m

Precision seeding machine (4 lines)

Herbicide speading

Crop development

Biomass production

Biometric data and production

Transepts with 10 m	Nº plants	Max. height (m)	Diameter (cm)	Nº capitula	Estimated production (ton./ha)
Max.	31	3.5	6.0	282	18.4
Min.	11	0.5	0.3	31	1.3
Average	23	2.0	2.3	120	-

Biomass partitioning

	Stalks (%)	Capitula (%)
Max.	65.7	49.0
Min.	51.1	34.3
Average	59.9	40.1

Harvesting

Whole biomass harvest and chipping

Seed + biomass harvest

Corn harvester

Cereal harvester

Baling

Real conditions testing

Production	
Whole-plant chips	***10 ton /ha***
Seed	***1 ton/ha***
Biomass chips	***9 ton/ha***

Costs	
Establishment	***300-350 €/ha***
Harvesting	***150 €/ha***

Difficulties in large scale implementation of Cynara crops:

Low productivity

2006 - 10 ton./ha (15% moisture content)

2007 – 9.5 ton./ha (37% moisture content)

Different density of plants in field

Losses due to harvesting machinery :

- dispersion of material
- the cutting head works at 25 cm above ground

Improvement of the agricultural practice (ex. applications of fertilizers)

Tested uses of Cynara

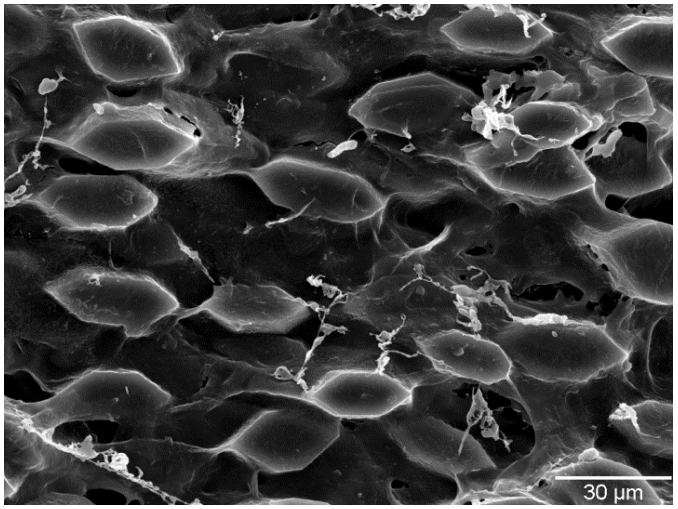
- Bioenergy: combustion
  gasification
- Pulp and paper: whole stalks
  depithed stalks
  hairs and pappi
- Oil and biodiesel

Combustion and gasification

	Cardoon	Eucalypt
HHV (MJ/kg db)	18.84	17.12
Moisture (%)	13.1	9.8
Ash (% db)	6.2	2.1
Vol. Matter (% db)	76.9	87.0
Fixed Carbon (% db)	16.9	10.9
Carbon (% db)	49.3	52.6
Hydrogen (% db)	6.1	5.2
Nitrogen (% db)	1.7	0.3
Sulphur (% db)	0.29	0.07
Chlorine (% db)	0.47	0.01
Oxygen & errors (% db)	36.5	39.7
Al_2O_3 (% of ash)	0.80	0.32
CaO (% of ash)	10.4	49.3
Fe_2O_3 (% of ash)	1.16	5.20
K_2O (% of ash)	13.7	14.0
MgO (% of ash)	5.39	6.30
Na_2O (% of ash)	21.5	3.78
SiO_2 (% of ash)	15.5	1.30
P_2O_5 (% of ash)	1.92	2.40

Cynara biomass had low moisture content and both high heating value and volatile matter, which is attractive for thermal valorisation.

However it has significant quantities of S, Cl and ash content, with high contents in Na, K, P, Ca and Si.



Combustion and gasification

Bench scale gasification

Bench scale combustion

The combustion of *Cynara* revealed low SO_2 emissions due to S retention in the solid phase. However, the release of both NO_X and HCl was substantial suggesting the implementation of primary control measures in the case of the former pollutant.

For reducing HCl levels, the use of an adsorbent like dolomite is necessary, which could also be useful to avoid bed agglomeration. Other strategy might be the co-combustion with forestry wastes.

Oil & Biodiesel

Oil content:	24.2%
Water content :	7.8%
Oil extraction yield:	23.6%
Oil acidity	0.6%
Iodine index	122
Saponification index	200
Cetane index	21.6

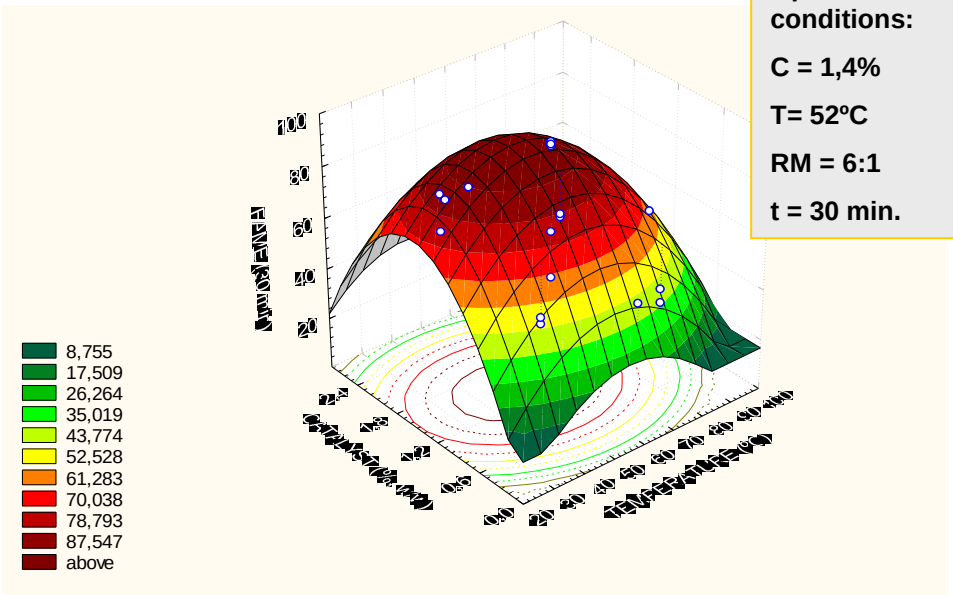
Bench screw press

Fatty Acid composition

C 16:0	Palmitic	10.7 %
C 18:0	Stearic	3.7 %
C 18:1	Oleic	25.0 %
C 18:2	Linoleic	59.7 %

Biodiesel

Lab-scale modelling and optimization of reactions conditions



Optimal conditions:

C = 1,4%

T= 52ºC

RM = 6:1

t = 30 min.

Response Surfaces fitted to FAME production after 30 min reaction time

Production in pilot-scale reactor

Biodiesel

Parameter	Method	Result	Specification DIN EN 14214		Unit
			min.	max	
Ester Content	DIN EN 14103	>99	96.5	-	% (m/m)
Density at 15 °C	DIN EN ISO 12185	883.7	860	900	kg/m3
Viscosity at 40 °C	DIN EN ISO 3104	4.188	3.5	5.0	mm2/s
Flash Point	DIN EN ISO3679	174	120	-	°C
Sulfur Content	DIN EN ISO 20884	< 1	-	10.0	mg/kg
Cetane number	IP 498	51.5	51.0	-	-
Acid value	DIN EN 14104	0.311	-	0.5	mg KOH/g
Iodine value	DIN EN 14111	126	-	120	g Iodine/100g

The Cynara biodiesel was tested in a small bus

Pulp & Paper

Stalks

Chemical composition (% o.d. weight)

	Whole Stalk	Pith	Depithed Stalk
Ash	7.7	5.9	5.8
Extractives	14.6	12.9	13.8
cyclohexane	1.7	1.4	1.6
ethanol	7.2	6.4	5.4
water	5.7	5.1	6.8
Lignin	17.0	20.3	13.6
Klason	15.0	18.8	11.3
Soluble	1.8	1.5	2.3
Polysaccharides	53.0	49.3	54.7

	Fibres	Pith
Length (mm)	1.3	0.2
Width (μm)	18.8	80.1
Wall thickness (μm)	4.8	3.0

Monosaccharide composition
(% of total monosaccharides)

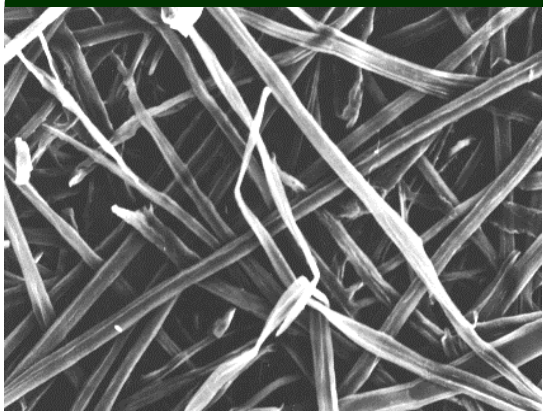
	Whole stalk	Pith	Depithed stalk
Glucose	65.5	63.4	61.1
Xylose	26.0	28.5	29.3
Mannose	3.7	3.3	5.4
Arabinose	2.5	2.4	2.3
Galactose	1.4	1.3	1.5
Rhamnose	0.9	0.7	0.8

- ✓ High ash content
- ✓ High extractives content
- ✓ Low lignin content

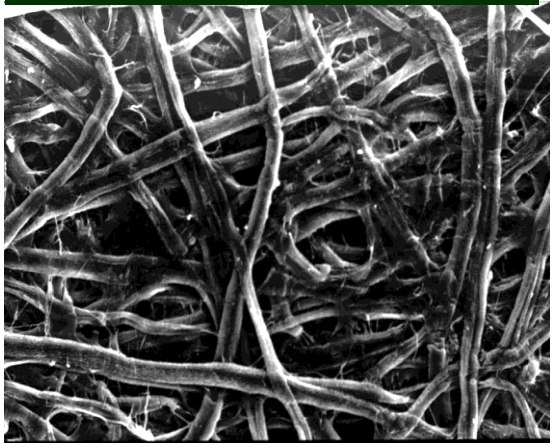
Pulp & Paper

	Total yield (%)	Rejects (%)	Screened yield (%)	Kappa number
Whole stalk				
Kraft	43.5	3.5	40.0	15.0
Soda	45.6	1.9	43.7	22.3
Soda-AQ	47.0	3.2	43.8	25.0
In situ Soda	50.2	2.8	47.4	24.0
ASAM I	49.0	2.1	46.9	15.4
ASAM II	49.6	1.9	47.7	19.8
Depithed stalk				
Kraft				
manually	47.0	5.0	42.0	11.0
mechanically	43.7	0.7	43.0	11.0
Soda-AQ	47.5	1.1	46.4	15.8
ASAM I	51.8	1.2	50.6	15.3
ASAM II	52.4	1.4	51.0	15.0

Unbeaten kraft pulp



Beaten kraft pulp



The *Cynara* stalks can produce well delignified pulps with high yields, low rejects and very good strength properties, especially tensile strength.

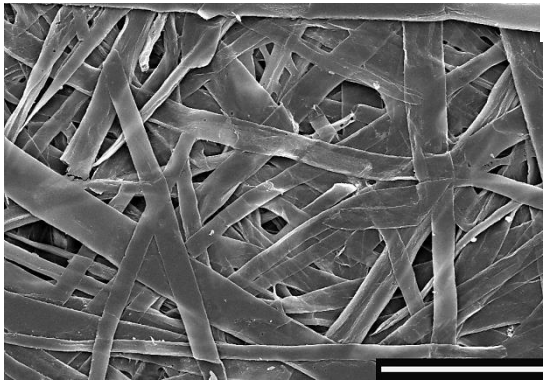
Depithing of the stalks has a positive impact on pulp yield, chemical consumption and on the pulp strength properties.

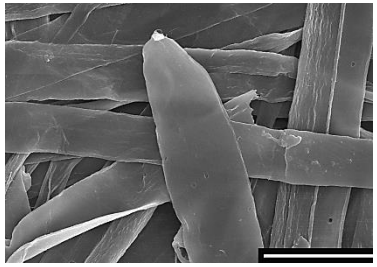
Pulp & Paper

Hairs & pappi

Chemical composition (% of oven dry mass)

	Hairs	Pappi
Ash	1.9	1.1
Extractives	5.4	6.0
Dichloromethane	0.5	0.8
Ethanol	2.8	3.9
Water	2.1	1.2
Lignin	10.6	17.8
Klason	6.9	14.0
Soluble	3.7	3.7
Carbohydrates	76.0	74.5
Rhamnose	-	0.7
Arabinose	0.9	1.7
Xylose	24.4	29.2
Mannose	1.0	1.0
Galactose	0.8	1.4
Glucose	48.9	40.5
Holocellulose	77.5	72.8
α-cellulose	55.2	46.8



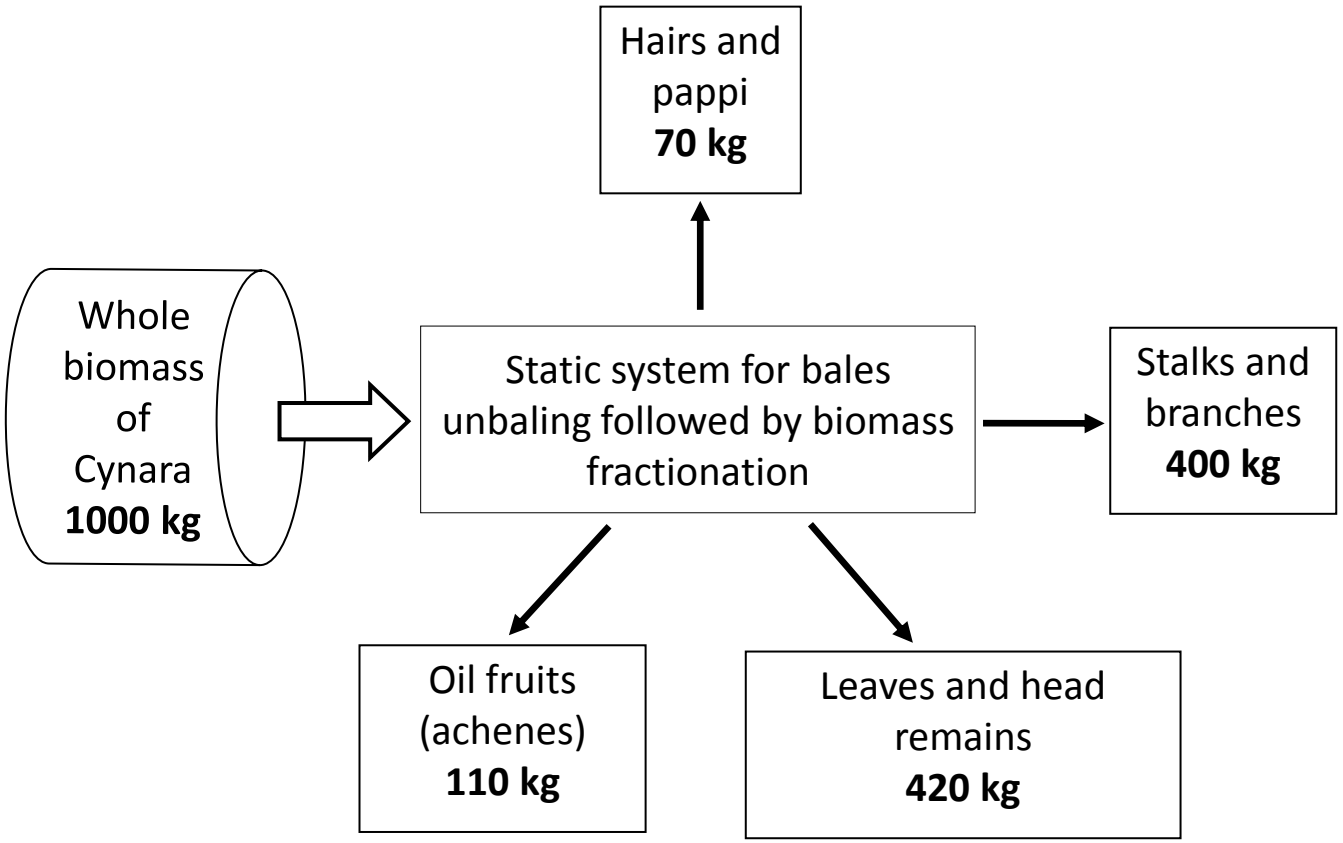


Unbleached kraft pulps of hairs and pappi

Pulp	Yield	Kappa number	HexA	$DP^{0.85}$
	(%)		($\mu mol.g^{-1}$ pulp)	
Hairs	63	7	24.1	1176
Pappi	53	38	35.7	1036
Mixture	59	13	45.9	1212

- ✓ Low ash content
- ✓ Low extractives content
- ✓ Low lignin content
- ✓ High pulp yields

Fractionation of *Cynara*



Conclusions

- ✓ *Cynara cardunculus* is an interesting new crop, with large productivities in harsh conditions (high temperature and low rainfall), with a long life cycle but with annual harvests, that can be cultivated using adapted agricultural practices

- ✓ At harvest, *Cynara* is a multi-functional crop with potential as a whole plant for bioenergy or after component fractionation for energy, oil and biodiesel, and fibre products

- ✓ During the seasonal growth, *Cynara* has the potential to be used as animal fodder and for human consumption

- ✓ The large scale trials advise improvement of pratices i.e. careful soil selection and preparation, fertilization, pest control and harvesting

Our data was published in the following papers:

Gominho J, Lourenço A, Palma P, Lourenço ME, Curt MD, Fernandez J, Pereira H. (2011). Large scale cultivation of *Cynara cardunculus* L. for biomass production - A case study. *Ind. Crops Prod.*. 33 (1): 1-6. *DOI: http://dx.doi.org/10.1016/j.indcrop.2010.09.011*

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Gominho J, Pereira H. (2006). Influence of raw-material and process variables in the kraft pulping of *Cynara cardunculus* L. *Ind. Crops Prod.*. 24: 160-165. *DOI: http://dx.doi.org/10.1016/j.indcrop.2006.03.004*

Quilhó, T, Gominho J, Pereira H. (2004). Anatomical characterisation of a new fibre crop the thistle *Cynara cardunculus* L.. *IAWA J.* 25(2): 217-230.

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