Cardoon as a multipurpose energy crop: Opportunities and challenges

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Cynara cardunculus L.

- Member of *Asteraceae.* Native to Mediterranean region. 2n=24.
- Cultivated as a vegetable since ancient times (Mediterranean region).
- Perennial herb ~2 m high. Taproot.
- Leaves basally rosulate, wide base, pinatifid lamina, green to pale greyish.
- Gross heads in corymb-like groups. Dark to pale lilac florets, nectariferous.
- Fruit an achene like sunflower.
- Common names: cardoon (vegetable), cynara (field crop).

Further info: Bot. J.Linn. Soc. 109 (1992): 75-123

▶ TRADITIONALLY CROPPED FOR:

- **BLANCHED LEAF PETIOLES**

  Labour intensive crop ⇒ vegetable.

  Tenderness and flavour are ensured through artificial blanching.

- **VEGETABLE COAGULANT (RENNET)**

  Fresh flowers are used as a vegetable rennet for milk clotting, in order to manufacture valuable regional cheeses.

Further info: Int. Dairy Journal, 18(1)(2008): 93-98.

Natural development cycle

PLANTLETS (autumn)

SPROUTING (September)

ROSETTE (winter)

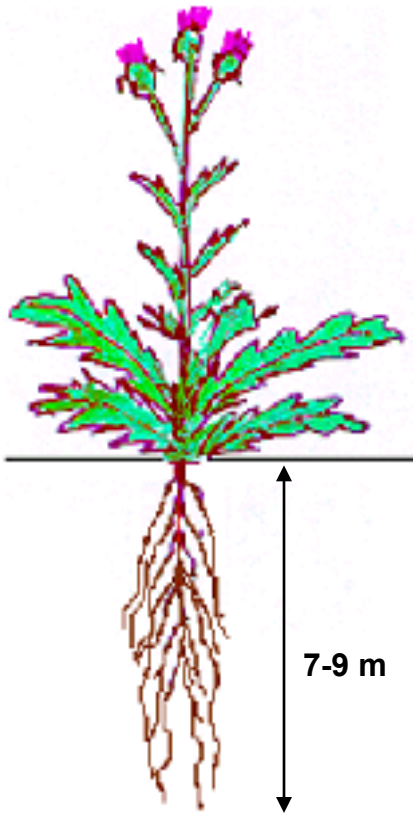
ELONGATION (spring)

BLOSSOM (June)

DRYING (August)

FRUITS ('seeds')

Strategies of adaptation to Mediterranean conditions



- **Very deep root system**

  Use of water fallen in autumn, winter & spring.

- **Perennial with annual growth cycle**

  The aerial biomass dries up during summer. Re-growth in early autumn.

- **Moderate salt tolerant**

  by osmotic adjustment by inorganic ions (Na^+ and K^+)

- **Photosynthesis during wintertime**

  At 5ºC, CO_2 assimilation rate ~6 $mmol.m^{-2}.s^{-1}$ (~30 % max. at 25 ºC)

- **10-month period of active biomass growth**

  Accumulation of carbohydrates (inulin) in roots.

- **High efficiency in fertilizers uptake**

  from deep soil layers. Use of lixiviated nutrients.

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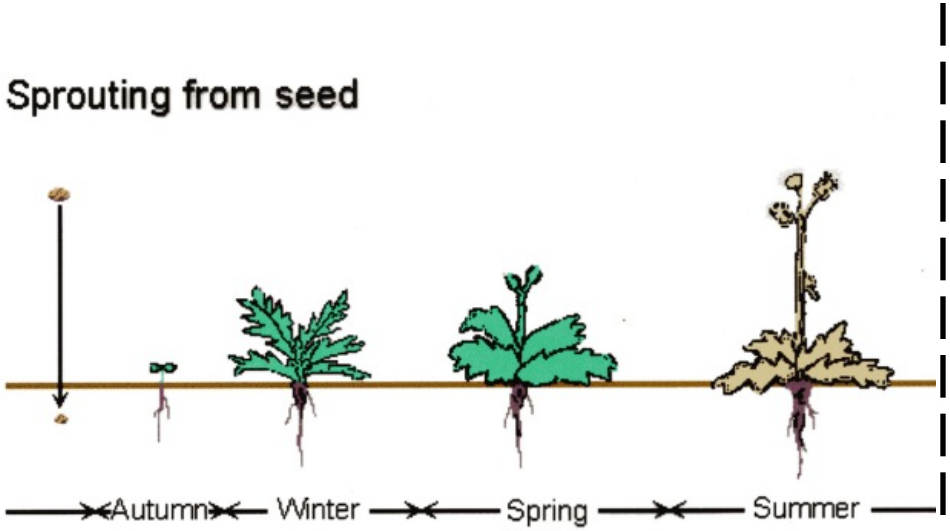
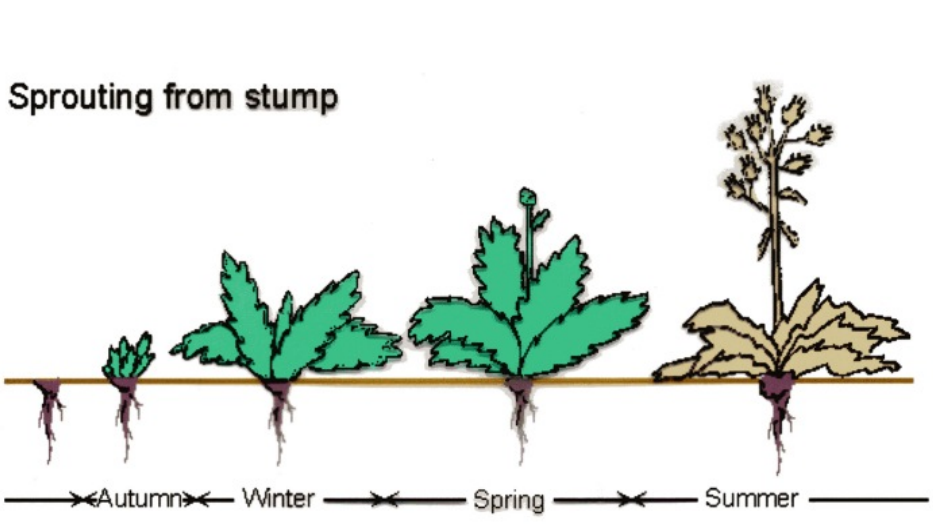
CYNARA AS AN ENERGY CROP





Establishment of the crop

(1st growth cycle)

Standard productive cycle

(2nd & following growth cycles)

Further info: Ind.Crops Prod. 24(2006): 222-229; **Ind. Crops Prod. 33(2011): 1-6.**

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Crop management

- **FIRST YEAR (Establishment)**
  - **Basal dressing dp. soil fertility** (gn. 500 kg 9:18:27)
  - **Ploughing** (subsoiling) **and harrowing**
  - **Sowing** (4-5 kg seeds/ha) (planting frame: 1 x 0.8)
  - **Herbicide treatment** (e.g.1.5 kg linuron+0.4 kg alachlor per ha)
  - **Pest control** (dimethoate)
- **SECOND & FOLLOWING YEARS (production)**
  - **Restoration fertilization** (e.g.~ 12.6 N ,3.5 P_2O_5, 20.8 K_2O kg/t dm)
  - **Pest control** (dimethoate)
  - **Harvest** (dry biomass, ripe seeds)

Further info: Biomass &Bioenergy 36 (2012): 404-410

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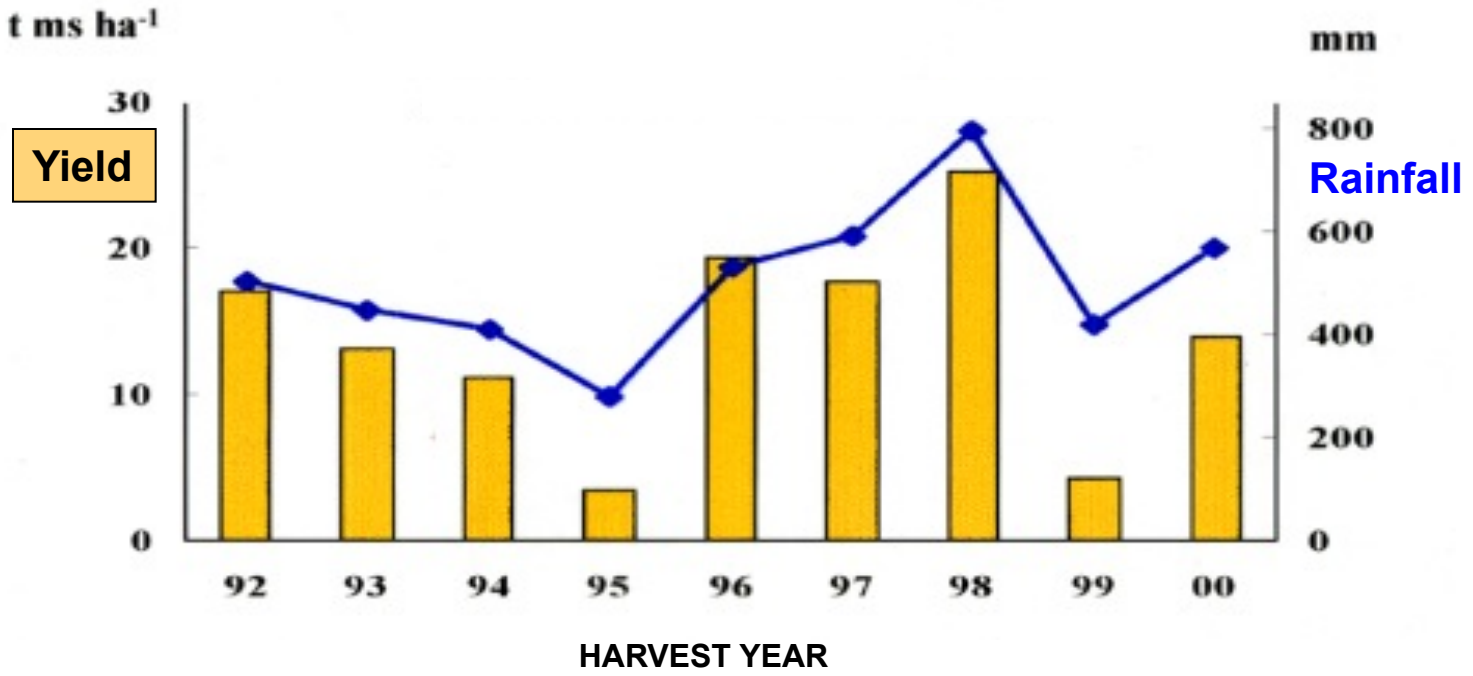
Yields → as a rainfed crop, yields depend on rainfall

PERENNIAL CROP OF CYNARA, Madrid (Spain)

Mean: 14 t d.m./ha.year (~ 470 mm/year)



Further info: Acta Horticulturae 681(2005): 109-115; Biomass Bioenerg. 33(2009): 810-816. Ind.Crops Prod. 24: 222-229; Italian Journal of Agronomy (2001), 5(1-2):11-19.

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Crop produce

Heads ~ 33%

Stem~33 %

Cauline leaves ~14%

Basal leaves ~20%

Biomass partitioning is linked to plant growth
(dry weight basis)

Further info: Proc. 15th EU Biomass Conf. 2007, pp. 654-656

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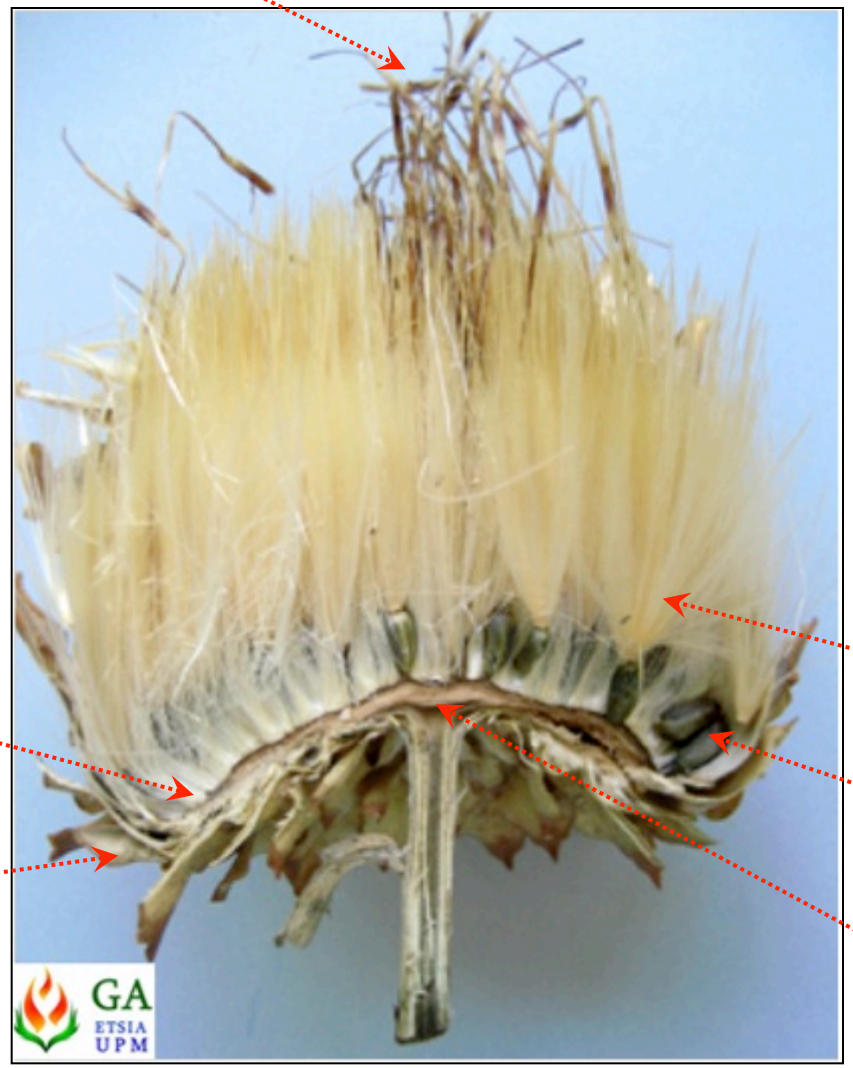

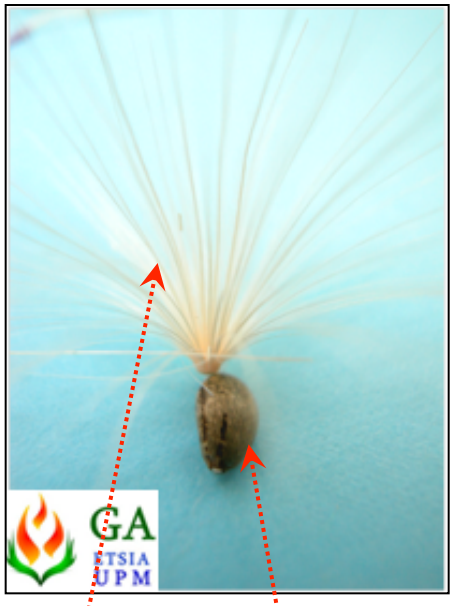

Florets
11.2%

Pappi
10.9%

Achenes
25.5%

Receptacle
18.4%

Floret scales
(hairs) 8.7%

Bracts
25.2%

Further info: *Ind.Crops Prod. 24(2006): 222-229.*
Global Change Biology Bioenergy 2(2010): 113-129

Harvesting (conventional machinery)

Harvest time: Aug-Sept

Combined harvester

Oil seeds

Baler

Baling

Lignocellulosic biomass

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Milled biomass, ρ_a~0.20 g/cm^3

Pellets, ρ_a ~1.12 g/cm3

► SOLID BIOFUEL

- Low moisture content at harvest: 10–15 % → No drying is required
- Low apparent density of milled biomass → densification
- Calorific power (LHV): 15-16 MJ/kg
- Chemical characteristics ~ straw.
- Ash, 5% (→10% if soil contamination); K, 2.5 %; Cl, 0.3% (KCl fertilizer affects K, Cl)

Further info: Biomass & Bioenergy 41(2012): 145-156; Fuel 87 (2008) 58–69

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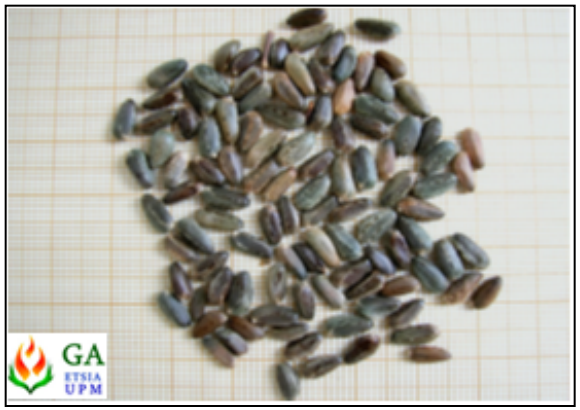
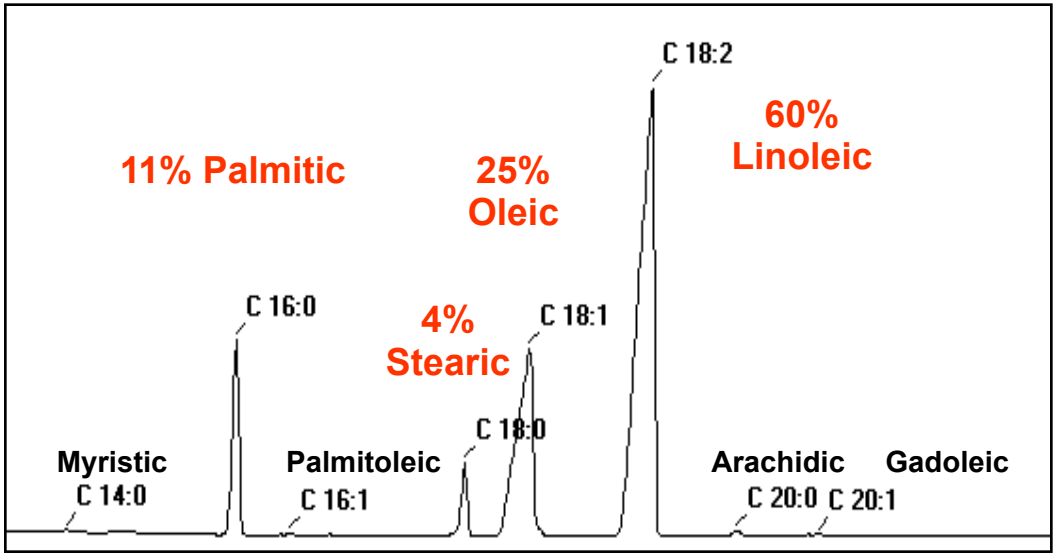
► LIQUID BIOFUEL: SEED OIL



- **Yield in oil seeds:** 1.0-1.2 t/ha in average conditions (450 mm/y).
- **Seed oil content:** ~ 20-25% (w/w seeds at equilibrium moisture).
- **Fatty acid oil profile:** ~ sunflower oil.



Further info: Biomass & Bioenergy 23 (1)(2002) :33-46; **Ind. Crops Prod. 10 (3): 219-228 Biomass and Bioenergy 35(2011): 3167-3173**

BIODIESEL FROM CYNARA OIL

- Biodiesel can be prepared by **transesterification** with methanol or ethanol in the presence of a catalyst (common industrial procedure).
- Cynara biodiesel **meets** the standard for biofuels (EN-14214).

Properties	Ethyl esters	Methyl esters	EN-14214
Density 15ºC (g cm^{-3})	0.8794	0.889	0.86-0.90
Viscosity 40º (mm^2 s^{-1})	4.479	5.101	3.5–5
Flash point (ºC)	184	182	> 101
Cloud point (ºC)	-5	-4	--
Cold filter plugging point (ºC)	-10	-10	≤ -10**
Cetane number	66	59	> 51
Carbon residue (% m/m)	0.28	0.36	< 0.3
Iodine index	109	117	<120(140*)
Phosphorus (mg kg^{-1})	< 5	< 5	< 10
Sulphur (% m/m)	< 0.02	< 0.02	< 0.02

Further info: Industrial &Engineering Chemistry Research (1999), 38 (8):2927-2931; Energy &Fuels (2002), 16 (2):443-450.

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▶ PAPER PULP

- The stalks of cynara have succesfully being tested for paper pulp.
- Stalks can be cooked by standard Kraft pulping 44-47% yield with Kappa 11-15.
- Depithing is recommended as a pre-treatment to improve product quality.

Further info: Ind. Crops Prod. (2000), 13:1-10; Ind.Crops Prod. 29(1)(2009): 116-125

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PHARMACOLOGICALLY ACTIVE COMPOUNDS

• **Cynarin**: Antioxidant, hepatoprotector and inhibitor of the cholesterol synthesis. Also present in artichoke.

• **Silymarin**: Compound usually obtained from *Silybum marianum*, traditionally used in the treatment of liver diseases.

Silybum marianum. **The achenes contain 4-6% silymarin**

Cynara fraction	Silymarin content (%)
Fresh leaves (Spring)	1.68
- Fresh petioles& ribs	1.96
- Leaf lamina	1.56
Dry stalks (August)	0.90
Dry leaves (August)	1.23
Achenes	1.07
Seed oil	0.01
Presscake	1.21
Lees	0.08

Further info: Acta Horticulturae 681(2005): 461-467. Ind. Crops Prod. 51(2013): 145-151.

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▶ GREEN FORAGE

- At the rosette stage, high nutritive value for ruminants.
- Compatible with harvest of biomass in summertime. Root reserves support the development of new leaves and allow the completion of the development cycle in the same year.
- Final yield in biomass decreases.

⇒ Cynara may represent a punctual forage resource.

Further info: Annales De Zootechnie (1999) 48: 353-65;
Animal Feed Science and Technology (2000) 87: 203-214.

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OPPORTUNITIES	CHALLENGES
Mediterranean crop	Plant breeding
Dry-farming in Med. conditions	Biomass quality (solid biofuel)
Perennial	Variability of yields (dp. rainfall)
Annual growth cycle	Mechanization
Multipurpose crop	Pest control

OPPORTUNITIES	CHALLENGES
Mediterranean crop	New accessions (in vitro culture plants)
Dry-farming in Med. conditions	Biomass mixtures (cynara+wood) Aditives in combustion; specific beds in fluidized bed (gasification)
Perennial	Not to harvest in drought cycles Awareness of the relationship yield vs rainfall
Annual growth cycle	I+D+i mechanization. Development of prototypes → industry
Multipurpose crop	Crop surveillance. Preventive treatments

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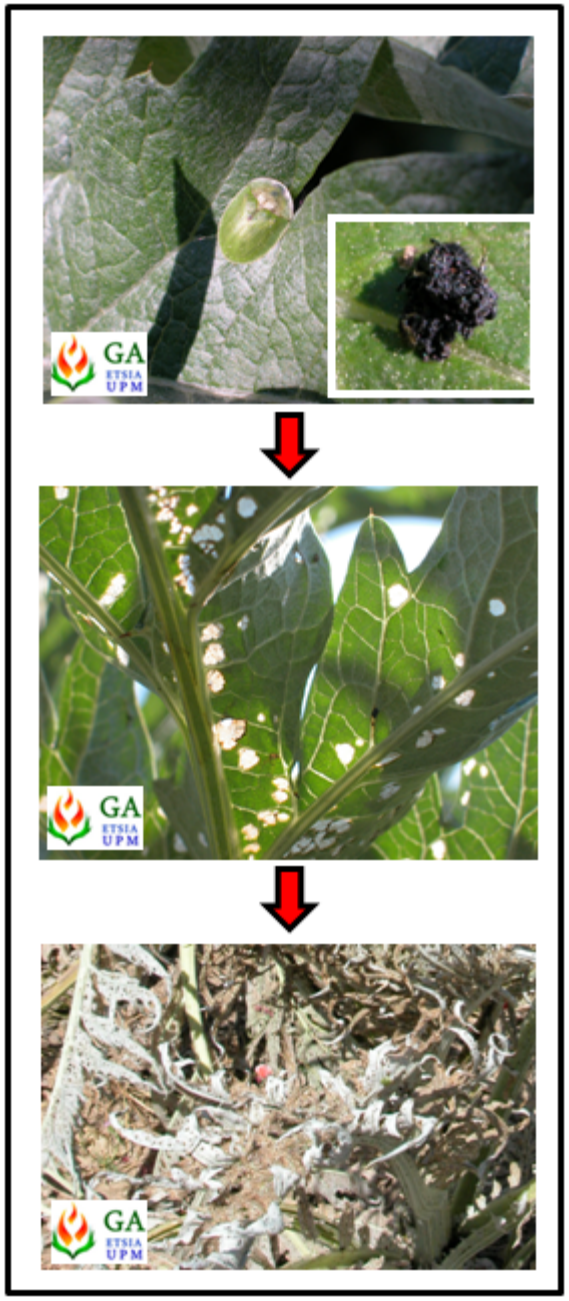

HEAD BY CRA-ISMA

I+D+i mechanization.
Development of prototypes → industry

Crop surveillance.
Preventive treatments

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CONCLUSIONS & RECOMMENDATIONS

- Cynara has been proved to be a versatile crop in dry-farming of the Mediterranean region (pp. 350-750 mm),
- A number of cynara applications has been identified.
- Traditional applications include vegetable and plant rennet.
- The development of Cynara as an energy crop (field crop) is under way; much knowledge has been gained in the past decades.
- The biorefinery concept can be applied to cynara: lignocellulosic plant fractions for solid biofuels, oil seeds for biodiesel and residues for nutraceutics.
- RECOMMENDATIONS to be developed as R+D+I topics are:
  - PLANT PROTECTION
  - DEDICATED VARIETIES (PLANT BREEDING)
  - CROP MECHANIZATION

THANKS FOR YOUR ATTENTION

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www.grupodeagroenergetica.com

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