# STATE OF THE ART OF *Cynara cardunculus* L. AS AN ENERGY CROP

J. Fernández, M.D. Curt
Department of Plant Production: Botany and Plant Protection. Polytechnic University of Madrid. 28040 Madrid (Spain).
Tel.: +34915492692, Fax: +34915498482, E-mail:j.fernandez@upm.es

ABSTRACT: An up-to-date review of *Cynara cardunculus* L. as an energy crop is presented. Plant description, cultivation, crop management, yields, biomass applications and issues under concern are discussed.
Keywords: cynara cardunculus, biomass production, energy crops.

## 1 PLANT DESCRIPTION

One of the possible non-food crops that might be used to produce biomass in lands set-aside in application of the CAP, is the thistle *Cynara cardunculus* L., which exhibits excellent characteristics regarding biomass production and adaptation to the Mediterranean region. The species *C. cardunculus* has been traditionally grown for horticultural purposes and in that context it is commonly known as 'cardoon'. If the species is grown for energy purposes, the common name 'cynara' is preferable.

*Cynara cardunculus* is botanically related to the artichoke (*Cynara scolymus* L.); like that, it is a member of the *Compositae* botanical family, the same as the sunflower or the safflower. It is a perennial herb (vivacious) with annual growth cycle, well adapted to the Mediterranean climates that are characterized by hot and dry summers.

Cynara has a vertical root system, able to explore several soil meters in depth. It usually exhibits several outstanding roots (Figure 1), which are originated from the primary root. In the upper part of the root system, the diameter of the main roots is rather large. The main roots branch profusely and the branches are more and more thin and fibrous. It was shown that the main roots can attain over 7 m soil depth at the end of the first growth year. Secondary roots and following root branches run horizontally at different soil depths, giving rise to a tangled root mass. At the beginning of the second cycle and other development cycles, several vegetative buds appear on the basal plant part that links roots and shoot. The growth of those buds give rise to new shoots (Figure 2), hence the upper part of the root system becomes more and more wide. After several years of growth, it is a sort of stump that may reach 20-30 cm diameter.

Basal leaves are rosulate, with wide base, sometimes with marginal spines, and with patent and fresh rib; they are very large and may reach 80 cm in length and 35 cm in width; the adaxial surface of the limb is green, moderately pilose to glabrescent, while the baxial surface is pale greyish to whitish green, moderately to densely woolly. Young leaves developed by plantlets are simple, entire or irregularly lobated; adult leaves are pinnatifid with an undetermined number of segments; an individual may develop leaves with very different number of segments.

By springtime, cynara develops a long stem (2-3 m high), actually a floral scape (Figure 3), that is often richly branched, densely to slightly lanate to subglabrous, ribbed, and occasionally with spines. Cauline leaves (leaves on the stem) are decurrent, pinnatifid and similar to the basal leaves.

The basic type of inflorescence is the capitulum, commonly known as 'head', in which the flowers ('florets') are found on a flattened surface, the 'receptacle', surrounded by bracts. Between head florets, there are receptacular bristles similar to rigid white hairs. Each plant may develops many heads, organized in corymb-like groups. The head is ovate to globular, 33-75 x 32-95 mm size, and contains numerous tubular florets, about 5 cm long, dark or pale lilac or bluish. The species *Cynara cardunculus* is typically alogamous but self-fertilization (autogamous) may also occurs. It is diploid with 34 chromosomes (2n).

At maturity, cynara heads contain numerous fruits attached to the receptacle. A plumose crown of hairs, the pappus, -piece for fruit dispersal- is attached above each fruit. The kind of fruit is the achene (one-seeded dry fruit), the same as the sunflower; like the later, the fruit is commonly known as 'seed' although it is a true fruit. Cynara achene is obovate, laterally compressed, 6-8 mm long, 3-4 mm wide. Its structure is also similar to the sunflower; it has a two-piece dry wall -dry pericarp or 'husk'-, greyish brown to dark brown, that represents about 45% (w/w) of the fruit and contains one seed, the 'kernel', rich in oil and protein as storage compounds for seed germination. Whole fruits contain about 25% oil and 18-20% protein. Oil composition is similar to sunflower; on average 10% palmitic, 3% stearic, 25% oleic, 60% linoleic, as main fatty acids. Anti-oxidant compounds have been also found in the seed, which help to preserve the oil as well as the viability of the seed. Seed capacity to germinate may extend for 5-7 years.

## 2 DEVELOPMENT CYCLE

Fruits ripen and disperse in summertime and are ready to germinate whenever the soil moisture and temperature are favourable, usually at the beginning of autumn (September-October), when rainfalls occur. Plantlets soon develop a leaf rosette, which keeps growing in size and in number of leaves until spring. During this time, carbohydrates produced by photosynthesis accumulate in the roots. In mid or late spring, a stem rises from the middle of the rosette that carries several heads. Leaves and shoots dry up in summer while root and buds on the basal part of the stem remain alive.

Beginning autumn, some remnant buds –about two to four buds- sprout and a new growth cycle starts. Several rosettes develop vigorously from the stump thanks to root reserves. Because of that, the growth of the rosette in this cycle is more quickly than in the first one. Rosette diameter may reach nearly 1 m, hence the ground is rapidly covered by the canopy competing weeds, as long as the plant density is adequate (≈15,000 plants/ha). Except for the sprouting, the steps of this second growth cycle, as well as the following cycles, are the same as for the first growth cycle, that is, carbohydrate accumulation in the roots, stem elongation, blossom, fruit ripening, and shoot drying. The life span of a single plant and so, the total number of possible development cycles, remains unknown. Experiments carried out by UPM have shown that the crop duration is at least 15 years.

## 3 CROP REQUIREMENTS

### 3.1 Climate

*Cynara cardunculus* is a species native to the Mediterranean region; accordingly, it shows a great adaptation to the Mediterranean climates, which are characterized by moist and mild (cold) winters and dry and hot summers.

Seedlings are frost-sensitive but once cynara is at the rosette stage and has several well-developed leaves, it tolerates the low winter temperatures of the Mediterranean climates. Young plants at the rosette stage -with 4-6 well-developed leaves- endure temperatures below -5ºC. This is why the early sowing -two or three months before frost may occur, depending on the growth speed- is strongly recommended for those areas with risk of freezing, provided that soil water conditions are well enough to sown.

As any other crop grown in rainfed conditions, the productivity of cynara is closely related to the amount of water available. Cynara performs well when the precipitation accumulated in the period comprised between sprouting and blossom is about 450 mm. Lower precipitation may result in the reduction of biomass production.

### 3.2 Soil

Cynara requires deep soils, moderate limy, with light texture, preferable loamy with capacity of retaining water along the soil profile (1-5 m) without excess, because cynara plants are sensitive to water-logging. Cynara grows well in basic soils, and is moderately tolerant to salinity. The presence of gravel and stones does not affect the plant growth but for crop mechanization, no stony soils are preferable.

## 4 UP-TO-DATE KNOWLEDGE ON THE SUBJECT OF CYNARA AS AN ENERGY CROP

Studies of the potential of cynara for biomass production started in the decade of the 1980's on the initiative of the Agroenergy Group of the Polytechnic University of Madrid (Spain). Research on cynara as an energy crop has been carried out in Spain and other European countries with the support of the EU Commission, in the framework of several R&D Programmes [1-4]. Results obtained from EU projects have been reported in articles of general scope [5-9] as well as in specific articles concerning to the cynara biomass productivity in the Mediterranean region [10-15], crop mechanization [16-17], biomass combustion [18-24], oil and bio-diesel production [25-28], use of cynara biomass for animal feeding [29-30] and paper-pulp [31-33]. Other scientific teams not directly involved in those projects, have also contributed to the knowledge of cynara, particularly in the subject of biomass productivity [34-38], thermo-chemical treatments [39-40], bio-diesel production [41-42] and paper pulp [43]. The proposal of cynara as an energy crop is a matter of growing interest because it might be cultivated in lands under Mediterranean climate, set aside for food purposes in accordance with the Common Agricultural Policy (CAP). Knowledge of cynara as an energy crop is summarized next.

### 4.1 Crop management

In Mediterranean conditions, sowing of cynara can be done in autumn or spring. The date of sowing should meet the requirements of mild temperature and high soil moisture. It should be taken into account that young plants with 4-6 well-developed leaves are more tolerant to unfavorable weather conditions (frost or heat) and that the plantlets will need about 1-2 months of mild weather to reach that stage. In good weather conditions, the autumn sowing is preferable. If the risk of early frosts is high, spring sowing is recommended.

The labours needed for the establishment of the crop (first growth cycle) are: basal fertilization, soil preparation (subsoiling, ploughing and harrowing), sowing, pre-emergence herbicide treatment, and pest control. If the crop is sown in spring, no significant biomass production will be expected in summer; therefore, harvesting is not required. In case of autumn sowing, the biomass production at the end of the establishment year is usually low; the crop can be harvested according to economic criteria. In the years following the crop establishment, the labours needed for the crop are: restoration fertilization, pest control, harvesting and biomass transport. Detailed description of cynara management techniques are given by Fernández et al. [8, 45, 46].

### 4.2 Ecophysiological issues

Studies conducted so far have shown several ecophysiological characteristics in relation to the adaptation of cynara to Mediterranean conditions, explaining the high productivity of the crop.

- Capacity of photosynthetizing during wintertime. Average $CO_2$ assimilation rate at 5ºC was estimated at 6 mmol $m^{-2}s^{-1}$, about 30% of the rate at 25ºC [12, 45].
- Ten-month period of active biomass production. Accumulation of carbohydrates (inulin) in roots extends from autumn to spring; storage compounds are used later for the growth of the floral scape and buds sprouting.
- Capacity of uptake nutrients from deep soil layers. The large soil volume explored by the root system of cynara prevents losses of nutrients that, otherwise, might happen by lixiviation; additionally, this characteristic allows the recovering of euthrophicated soils [45].
- Adaptative mechanisms for dry conditions:
    - Very deep root system to explore the soil in depth and to extract water accumulated along the soil profile in the rainy seasons (autumn to spring).

- Aerial plant part that dries up in summer, when high temperatures and low precipitation coincide, but the underground plant part remains alive.
- Osmotic adjustment by inorganic ions ($Na^+$, $K^+$), this resulting in tolerance to moderate salinity conditions [47].

4.3 Yield and components of the yield

Results of R&D European projects have shown that the expected biomass yield of cynara ranges from 10 to 20 t dm $ha^{-1}$ $year^{-1}$ if the crop is well established and the annual precipitation is about 500 mm $year^{-1}$ [7,8]. Table I shows briefly the values of productivity obtained in several European experiments conducted within the framework of the Project '*Cynara Network*' [8]. Precipitation values are also shown, given that in rainfed conditions, the biomass production is strictly related to the water available for the crop. However, not only the amount of annual precipitation is important, but also the actual distribution. The water regime may also modify the pattern of biomass partitioning of the crop. Values obtained for biomass production of cynara in a ten-year Spanish experiment ranged between 3.4 (280 mm) and 25.2 (765 mm) t dm $ha^{-1}$ $year^{-1}$ [13].

Table I. Productivity of cynara grown for two consecutive years. Multilocal experiment carried out in the framework of the EU Project 'Cynara Network' [8]. pp, annual precipitation.

| Site | 1994-95 | | 1995-96 | |
|---|---|---|---|---|
| | pp (mm) | Biomass (t dm/ha) | pp (mm) | Biomass (t dm/ha) |
| Madrid (Spain) | 280 | 6.5 | 529 | 23.1 |
| Tebas (Greece) | 490 | 28.6 | 324 | 33.4 |
| Forly (Italy) | 752 | 17.5 | 837 | 24.6 |
| Policoro (Italy) | 316 | 7.5 | 722 | 15.6 |
| Sicily (Italy) | 387 | 15.9 | 654 | -- |
| MEAN | 445 | 15.2 | 646 | 24.2 |

Biomass partitioning into plant organs vary with the degree of development of the plant under concern. In poor-developed plants most of the biomass weight is in the basal leaves and heads, whereas in well-developed plants it is in the shoot biomass (floral scape with heads). Average values of biomass partitioning for both situations are given in Table II, according to UPM results [7,8].

As regards the head biomass, the partitioning into receptacle, bracts, hairs (scales+pappi) and fruits, also varies with the degree of development, meaning in this case, the head size. The head weight ranges from 10 g dm to 40 g. On average, the head receptacle represents 18% of the head dry weight, the bracts 25%, the hairs (made up of high quality cellulose fiber) 25% and the fruits, 32% [7].

Table II. Biomass partitioning of cynara as a function of the final yield, according to UPM experiments. Mean values expressed in % on dry weight basis (n=7 plots).

| Plant fraction | Yield | | | Mean |
|---|---|---|---|---|
| | Low | Average | High | |
| Basal leaves | 48.8 | 36.1 | 21.4 | 35.4 |
| Cauline leaves | 6.2 | 12.0 | 20.7 | 13.0 |
| Shoot | 9.9 | 18.3 | 27.8 | 18.7 |
| Heads | 35.1 | 33.6 | 30.1 | 32.9 |
| Biomass production (t/ha): | | | | |
| Dry Biomass (0 % moisture) | 5.1 | 10.2 | 18.7 | 11.3 |
| Fresh biomass (15 % moisture) | 6.0 | 12.0 | 22.0 | 13.3 |

4.4 Harvesting

The harvesting of the crop produce is carried out in summer, once it is dried, and before seed dispersal. Harvesting mechanization has been undertaken by means of conventional machinery but the optimization of this crop operation is under way. Up to now, the machinery used to harvest the whole biomass has been: i) drum mower+rotobaler, ii) Claas prototype mower-baler, and iii) forage harvester. When the separative harvesting was experimented, a conventional sunflower combine harvester (to pick up the seeds), followed by a swather and a conventional straw baler, were used. The efficiency of the conventional sunflower combine harvester in seed separation is poor because the proportion of the seeds to the lignocellulosic biomass (≈10%) is very different from that of sunflower. Specific machinery should be developed for a separative biomass harvesting (seeds and lignocellulosic biomass) of cynara.

4.5 Properties of cynara lignocellulosic biomass as a solid fuel

The lignocellulosic biomass of cynara (fruits not included) has similar characteristics to other herbaceous biomasses, like straw. Factors that may affect the properties of the harvested material are: i) Chemical soil characteristics, ii) Type of compounds used as mineral fertilizers, iii) Harvesting method (incidentally, soil particles may contaminate the biomass). Characterization of cynara as a solid fuel has been performed in several experiments designed for biomass production, regardless the factors that affect the quality of the crop produce. That plant material -harvested by conventional mechanical methods resulting in a high contamination of the biomass by soil particles- had the following solid fuel characteristics:

- Moisture: 10-15%
- LHV (Low Heating Value): 15-16 MJ/Kg (dry basis)
- High content of ash (5-20% attributable to soil contamination), potassium (2-2.5%) and chlorine (0.3-1.7%) (probably, as a result of fertilizing with KCl)
- Slagging problems at temperatures over 750ºC (soil contamination may have affected).

Further experiments are needed to improve the characteristics of the cynara biomass for solid fuel applications. Lines of research that shall contribute to that are the following:

- Development of specific machinery for cynara harvesting
- Knowledge of the effect of mineral fertilization on biomass quality
- Blending cynara biomass with ligneous biomass (pellets)
- Use of additives (e.g. Mg or Ca compounds).

4.6 Seed oil and biodiesel production from seed oil

The achenes of cynara (henceforth, seeds) contain about 25% oil as an average; 33% seed oil has been reported as a maximum figure [26]. Fatty acid profile is similar to common sunflower oil: 11% palmitic, 4% stearic, 25% oleic and 60% linoleic. Seed oil can be easily expelled by cool pressing (20-25ºC); in this way, the oil composition is not altered by the extraction method and can be used for food applications. Biodiesel from cynara oil has been produced by several authors [27,41,42] by transesterification with either methanol or ethanol in the presence of a catalyst. Properties of cynara biodiesel meet the standard requirements for biofuels (EN-14214). Biodiesel produced with ethanol has been reported better than biodiesel produced with methanol [27].

As the crop produce consists of two kinds of materials: lignocellulosic biomass and oil seeds, a double application of the harvest: solid biofuel and biodiesel, has been envisaged. In this way, the crop cost would be shared between the two applications. Accordingly the raw material of cynara -the cynara oil-, might be much cheaper than other conventional oils used for biodiesel, like rapeseed or sunflower oils [27].

## 5 NEW OBJECTIVES

Much work has been done since the 1980's to develop the energy orientation of the species *Cynara cardunculus*. Results are promising but the challenge has not finished yet. Some of the new targets for cynara energy crop that should be achieved are the following:

- Increase of biomass productivity
- Increase of the seed oil content
- Improvement of the quality of the harvested biomass for fuel purposes
- Development of specific harvesting methods

These objectives have already been set in the project 'Global process to improve *Cynara cardunculus* exploitation for energy applications' supported by the Commission of the EU for the Sixth Framework Programme, SUSTDEV-2004-1.2.5 ('Energy from crops'), CT nº 019829. The overall objective will be to obtain a higher quality biomass for thermic uses in co-firing and for manufacturing biodiesel.

## 6 CONCLUSION

The cultivation of *Cynara cardunculus* for energy purposes might represent an interesting alternative to several million hectares of lands in the Mediterranean region, most of them set aside of cereal production, but to reach that objective, R&D on further agronomic issues - plant breeding, crop management, harvesting methods, machinery- and on the improvement of the quality of the biomass for soil fuel, must go on.

## 7 ACKNOWLEDGEMENTS

Results quoted in this work were obtained in the framework of several R&D projects financed by the Commission of the European Union [1-4].

## 8 REFERENCES

[1] Lignocellulosic biomass production from annual energy crops. Project EN3B-0065-E. D.G. XII, Energy from Biomass R&D Programme. 1986-88.

[2] Production and utilization of *Cynara cardunculus* L. biomass for energy, paper pulp and food industry. Project JOUB-0030.E. D.G. XII JOULE Programme. 1990-92

[3] Cynara Network. Project AIR3-CT93-1089. D.G. VI, AIR3 Programme. 1993-96.

[4] Bio-Energy Chains from Perennial Crops in South Europe (BIO-ENERGY CHAINS). Project 2001-05 ENK6-CT2001-00524. 2001-05

[5] Fernández J, Manzanares P. *Cynara cardunculus* L. a new crop for oil, paper pulp and energy. In: Grassy G., Gosse G., dos Santos G. (Eds). Proceedings of the 5$^{th}$ International Conference on Biomass for Energy and Industry. Barking: Elsevier Science Publishers Ltd., (1990), 1184-1189.

[6] Fernández J. Lignocellulosic biomass production from annual energy crops. Report EUR 12631 EN-C. Commission of the European Communities, Luxembourg (1990), 54 pp.

[7] Fernández J. Production and utilization of *Cynara cardunculus* L. biomass for energy, paper-pulp and food industry. Final Report JOUB 0030-ECCE, Commission of the European Communities, Brussels, (1993), 92 pp.

[8] Fernández J. *Cynara cardunculus* Network. Final Report AIR CTT 921089, Commission of the European Communities, Brussels, (1998), 248 pp.

[9] Dalianis C., Christou M., Sooter C. Kyritsis S., Zafiris C., Sanmiotakis G. Adaptation and biomass productivity of *Cynara cardunculus* in abandoned, marginal fields. In: Hall D.O., Grassi G., Scheer H. (Eds). Proceedings of the 7$^{th}$ European Conference on Biomass for Energy and Industry. Bochum: Ponte Press (1994), 1235-1240.

[10] Fernández J., Curt M.D. Nutrient extraction by the harvestable biomass of *Cynara cardunculus* L. In: Chartier P. Ferrero G.L. Henius U.M., Hultberg S., Sachau J., Wiinblad M. (Eds). Proceedings of the 9$^{th}$ European Bioenergy Conference, Biomass for Energy and the Environment. Oxford: Pergamon, (1996), 467–472.

[11] Dalianis C., Panoutsou C. Dercas N. Spanish thistle artichoke *Cynara cardunculus* L., under Greek conditions. In: Chartier P., Ferrero G.L., Henius U.M., Hultberg S. Sachau J., Wiinblad M. (Eds). Proceedings of the 9$^{th}$ European Bioenergy

Conference, Biomass for Energy and the Environment. Oxford: Pergamon (1996), 663- 668.

[12] Curt M.D., Aguado P.L., Fernández J. Adaptation of *Cynara cardunculus* photosynthesis to winter mediterranean temperatures. In: Kopetz H., Weber T., Palz W. Chartier P., Ferrero G.L. (Eds). Proceedings of the 10th European Conference on Biomass for Energy and Industry. Rimpar: Carmen (1998), 846-848.

[13] Fernandez, J. Hidalgo, M., Monte, J.P., Curt, M.D. *Cynara cardunculus* L. as a perennial crop for non irrigated lands: yields and applications. Proceedings IVth Int. Congress on Artichoke. Ed V.V. Bianco et al., ISHS. *Acta Horticola* (2005), 681: 109–115.

[14] Piscioneri H., Sharma N., Baviello G. Orlandini S. Promising industrial energy crop, *Cynara cardunculus*: a potential source for biomass production and alternative energy. *Energy Conversion and Management* (2000), 41:1091-1105.

[15] Veríssimo L., Fernández J. Water use efficiency of the cardoon (*Cynara cardunculus* L.) crop. In: Kyritsis S., Beenackers A.A.C.M, Helm P., Grassi A., Chiaramonti D. (Eds). Proceedings of the 1st World Conference on Biomass for Energy and Industry. London: James and James Science Publishers Ltd., (2001), 1870-1872.

[16] Pari L. *Cynara cardunculus* harvesting mechanization. In: Chartier P., Ferrero G.L., Henius U.M., Hultberg S., Sachau J. Wiinblad M. (Eds). Proceedings of the 9th European Bioenergy Conference, Biomass for Energy and the Environment. Oxford: Pergamon, (1996), 895–900.

[17] Fernandez, J., Marquez, L., Venturi P. Technical and economic aspects of *Cynara cardunculus* L.: an energy crop for the Mediterranean region. *MEDIT*, (1997) 1: 48-51.

[18] Fernández J., Curt M.D. Estimated cost of thermal power from *Cynara cardunculus* biomass in Spanish conditions. Application to electricity production. In Chartier P., Beenackers A.A.C.M. and Grassi G. (Eds). Biomass For Energy Environment Agriculture And Industry. Proceedings of the 8th European Biomass Conference. Elsevier Sci. Ltd. (1995), 342-350.

[19] Cabanas A., Sáez F., González A., Escalada R. Gas chromatography and mass spectrometer (GC-MS) for measurement of polycyclic aromatic hydrocarbons from biomass combustion of *Cynara cardunculus*. In: Chartier P., Ferrero G.L., Henius U.M., Hultberg S. Sachau J. Wiinblad M. (Eds). Proceedings of the 9th European Bioenergy Conference, Biomass for Energy and the Environment. Oxford: Pergamon (1996), 1252–1257.

[20] Martinez J.M., Escalada R. Murillo J.M., Carrasco J.E. Feasibility Study of the fluidized bed combustion of *Cynara cardunculus* biomass in BAFB pilot plant. In: Kopetz H. Weber T., Palz W., Chartier P., Ferrero G.L .(Eds). Proceedings of the 10th European Conference on Biomass for Energy and Industry. Rimpar: Carmen (1998), 1420-1423.

[21] Saez, F., Cabañas A., González A., Escalada R. Identification and quantification of polycyclic aromatic hydrocarbons in biomasa combustión emissions (*Cynara cardunculus*). In: Kopetz H., Weber T., Palz W., Chartier P., Ferrero G.L. (Eds). Proceedings of the 10th European Conference on Biomass for Energy and Industry. Rimpar: Carmen, (1998), 1417–1419.

[23] Coulson M., Dahl J., Gansekoele E., Bridgwater A.V., Obernberger I., Van de Beld L. Ash characterization of perennial energy crops and their influence on termal processing. In: Van Swaaij W.P.M., Fjällstrom T., Helm P. and Grassi A. (Eds.) Proceedings of the 2nd World Biomass Conference on Biomass for Energy, Industry and Climate Protection ETA-Florence and WIP-Munich pub. (2004), Vol II, 359-362.

[24] Dahl J., Obernberger I. Evaluation of the combustión characteristics of tour perennial crops (*Arundo donax, Cynara cardunculus, Miscanthus x giganteus and Panicum virgatum*). In: Van Swaaij W.P.M., Fjällstrom T., Helm P. and Grassi A. (Eds.) Proceedings of the 2nd World Biomass Conference on Biomass for Energy, Industry and Climate Protection. ETA-Florence and WIP-Munich pub., (2004) Vol II, 1265 – 1270.

[25] Fernández, J., Hidalgo, M., Sánchez, G., Curt, M.D. Towards a varietal screening of *Cynara cardunculus* for oil production. In: Kopetz H, Weber T, Palz W, Chartier P, Ferrero GL (Eds). Proceedings of the 10th European Conference on Biomass for Energy and Industry. Rimpar: Carmen (1998), 849-852.

[26] Curt M.D., Sánchez G, Fernández J. The potential of *Cynara cardunculus* L. for seed oil production in a perennial cultivation system. Biomass and Bioenergy (2002), 23 (1):33-46.

[27] Fernandez J., Curt M.D. Low cost biodiesel from *Cynara* oil. In Van Swaaij W.P.M., Fjällstrom T., Helm P. and Grassi A. (Eds.) Proceedings of the 2nd World Biomass Conference on Biomass for Energy, Industry and Climate Protection ETA-Florence and WIP-Munich pub., (2004), vol II, 109-112.

[28] Curt, M.D., Sanchez, G., Fernández, J. *Cynara cardunculus* a source of silymarin. Proceedings IVth Int. Congress on Artichoke. Ed V.V. Bianco et al. ISHS. *Acta Horticola* (2005), 681:461-467.

[29] Cajarville C., González J., Repetto J.L., Rodriguez C.A., Martinez A. Nutritive value of green forage and crop by-products of *Cynara cardunculus*. *Annales De Zootechnie* (1999) 48: 353-65.

[30] Cajarville C., González J., Repetto J.L., Alvir M.R., Rodriguez C.A. Nutritional evaluation of cardoon (*Cynara cardunculus*) seed for ruminants. *Animal Feed Science and Technology* (2000) 87: 203-214.

[31] Pereira H., Gominho J., Miranda I., Pais S. Chemical composition and raw-material quality of *Cynara cardunculus* L. biomass. In: Hall DO, Grassi G, Scheer H (Eds). Proceedings of the 7th European Conference on Biomass for Energy and Industry. Bochum: Ponte Press (1994), 1133-1137.

[32] Gominho J., Fernández J., Pereira H. *Cynara cardunculus* L. A new fiber crop for pulp and paper production. *Industrial Crops and Products* (2000), 13:1-10.

[33] Gominho J., Pereira H. An overwiew of the research on the pulping aptitude of *Cynara cardunculus* L. In: Kyritsis S., Beenackers A.A.C.M., Helm P., Grassi A., Chiaramonti D. (Eds). Proceedings of the 1st World Conference on Biomass for Energy and Industry. London: James and James Science Publishers Ltd (2001), 1187-1190.

[34] Foti S., Mauromicale G. Raccuia S.A., Fallico B., Fanella F., Maccarone E. Possible alternative utilization of *Cynara* spp. I. Biomass, grain yield and chemical composition of grain. *Industrial Crops and Products* (1999), 10:219-228.

[35] Maccarone E., Fallico B., Fanella F., Mauromicale G., Raccuia S.A., Foti S. Possible alternative utilization of Cynara spp. II. Chemical characterization of their grain oil. *Industrial Crops and Products* (1999), 10:229-237.

[36] Gherbin P., Monteleone M., Tarantino E. Five year evaluation on cardoon (*Cynara cardunculus* L. var. altilis) biomass production in a Mediterranean environment. *Italian Journal of Agronomy* (2001), 5(1-2):11-19.

[37] González J., Perez F., Gil J.L. Productivity experiments of cardoon (*Cynara cardunculus* L.) in the South-West of Spain. In: Kyritsis S., Beenackers A.A.C.M., Helm P., Grassi A. Chiaramonti D. (Eds). Proceedings of the 1st World Conference on Biomass for Energy and Industry. London: James and James Science Publishers Ltd (2001), 1722–1724.

[38] González J., Rodríguez M.C., Ayuso A., González D. Screening *Cynara cardunculus* L. plants in field trials to optimise biomass yields in Southwestern Spain. In :Van Swaaij W.P.M., Fjällstrom T., Helm P. and Grassi A. (Eds.) Proceedings of the 2nd World Biomass Conference on Biomass for Energy, Industry and Climate Protection (2004) (vol II). ETA-Florence and WIP-Munich pub., 224–226.

[39] Encinar J.M., González J.F., González J. Steam gasification of *Cynara cardunculus* L.: influence of variables. *Fuel Processing Technology* (2002), 75:27-43.

[40] Encinar J.M., González J.F., González J. Fixed-bed pyrolysis of *Cynara cardunculus* L. Product yields and compositions. Fuel Processing Technology 2000:68:209-222.

[41] Encinar J.M., González J.F., Sabio E., Ramiro M.J. Preparation and properties of biodiesel from *Cynara cardunculus* L. oil. Industrial and Engineering Chemistry Research (1999), 38 (8):2927-2931.

[42] Encinar J.M., González J.F., Rodríguez J.J., Tejedor A. Biodiesel fuels from vegetable oils: Trans-esterification of *Cynara cardunculus* L. oils with ethanol. Energy and Fuels (2002), 16 (2):443-450.

[43] Antunes A, Amaral E, Belgacem MN. *Cynara cardunculus* L.: chemical composition and soda-anthraquinone cooking. *Industrial Crops and Products* (2000), 12 (2):85-91.

[45] Fernandez J. El cardo como cultivo energético. Boletín informativo del Servicio Agrario de la Caja de Burgos. Junio (2000), 19- 27.

[46] Fernandez J., Curt, M.D., Aguado P.L. Industrial applications of *Cynara cardunculus* for energy and other uses. In Pascual-Villalobos M.J., Nakayama F.S., Bailey C.A., Correal E., and Schloman W.W. Jr (Eds.) Industrial Crops and rural development. Proceedings of the 2005 annual meeting of AAIC. Pardo Comunicación S.L. (2005), 153-163.

[47] Benlloch-González M., Fournier J.M., Ramos J., Benlloch M. Strategies underlying salt tolerance in halophytes are present in *Cynara cardunculus*. *Plant Science* (2005), 168 (3): 653-659.


**Figure 1**. Detail of the root system of cynara.

**Figure 2**. Plant of cynara sprouting from stump.

**Figure 3**. Floral scape of cynara three meters high.