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Fresh biomass production and partitioning of aboveground growth in the three botanical varieties of *Cynara cardunculus* L.

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ABSTRACT

Fourteen accessions of *Cynara cardunculus* were compared with the aim to evaluate the fresh biomass production and its partition, aiming at its potential use for industrial purposes. At anthesis stage, when plants have the maximum vegetative development, stalks, leaves and capitula were weighed separately. The percentage of dry matter per gram of fresh biomass was also calculated. The first capitulum components of each plant: bracts, flowers and remnant receptacle were also weighed separately. The total fresh biomass ranged between 1188 and 3235 g/plant, with variable values within each botanical variety, whereas the partition of the aboveground biomass was strongly affected by botanical variety. In both cardoons varieties, the percentage of dry matter ranged between 30 and 35% for all components of aboveground biomass, whereas in globe artichoke values ranged between 20% for capitula and 40% for leaves. Regarding capitula components, receptacle weight was of greatest importance in globe artichoke and cultivated cardoon. In wild cardoon flowers weight was more important than the other components. Results suggest that *Cynara cardunculus* var. *scolymus* and *C. cardundulus* var. *cardunculus*, might be considered as double purpose crops if after the capitula (in globe artichoke) or leaves (in cardoon) harvest, the fresh matter remaining is artificially dried and cut. On the other hand, *Cynara cardunculus* var. *sylvestris*, might be incorporated into the culture system as an industry or energy crop due the low inputs management that it requires, its adaptability to the local conditions and its aboveground biomass production.

1. Introduction

Cynara cardunculus L. is a perennial species with an annual reproductive cycle, which is completed each year by the end of the spring. It is native to the Mediterranean Basin (Sonnante et al., 2007) and comprises three botanical varieties, *Cynara cardunculus* var. *scolymus* (globe artichoke), *C. cardunculus* var. *cardunculus* (cultivated cardoon) and *Cynara cardunculus* var. *sylvestris* (wild cardoon) (Lanteri and Portis, 2008). They are completely interfertile and their F_1 hybrids are also fertile (Lanteri and Portis, 2008).

Globe artichoke is mainly grown in Mediterranean countries but its cultivation is also extended in South America, North America and, more recently, in China (FAO, 2008). The immature capitulum (head) is the consumed organ. Although mostly destined to the fresh market, is also frozen, pickled, cooked and canned or preserved in oil. In general, this crop has high sale values generating important economic returns to horticulturists, however, by the end of the productive cycle (late spring), when harvests are discontinued, stalks and leaves are cut and discarded as leftovers.

The cultivated cardoon has been grown from remote times (even before that globe artichoke), nevertheless, the cultivated area is relatively small and limited to Italy, Spain, South of France and a few countries with Italian immigration. The commercial product is the fleshy petiole and part of the central leaf nervure, consumed as a typical ingredient of the northern Italy "Bagna cauda" dish. Leaves are usually cut once a year, in late winter, when capitula still have not been developed. Stalks of uncut plants are usually discarded and remain as stubble.

Wild cardoon is considered the common ancestor of both cultivated varieties (Rottemberg and Zohary, 2005). It is a non-domesticated perennial plant and shows a wide distribution around the world where in some places is naturalized and considered a weed. The plant has spiny leaves and small spiny capitula. It is not cultivated as a commercial crop, nevertheless, capitula are

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sometimes gathered and sold in local markets in Sicily (Ierna and Mauromicale, 2010).

The adult plants of all *C. cardunculus* botanical varieties exhibit vigorous growth along their natural growth cycle; suggesting that this species could be useful for biomass production.

The whole plant can be divided into aboveground parts which dry up in summertime, and the underground parts which stay alive along all the perennial life-cycle (Fernández et al., 2006). In the aboveground part of the plant; fresh biomass is suitable to be used as winter forage for livestock feeding (Cajarville et al., 1999; Fernández et al., 2006), whereas as dry biomass it could destined for energy production. The crop characteristics that support these applications are: relatively low crop input, large biomass productivity, mainly of lignocellulosic composition and high heating value (Fernández et al., 2006).

This affirmation in true only under Mediterranean climatic conditions; in South America, especially in Argentine, agrometeorological conditions are quite different. Summer is rainy, with some rainfalls over 100 mm. The humidity excess right after the end of the productive stage generates the rotting of the aboveground biomass, not enabling for biomass harvest at this stage. To employ the aboveground biomass for energy production or other industrial purposes it would be necessary then, the application of some desiccant product as paraquat (1,1′-dimethyl-4,4′-bipyridylium dichloride) when plants are still at full growth, for example, at anthesis stage.

Cynara pulp shows, for hemicellulose, cellulose and lignin contents, similar properties as eucalypt pulp (Antunes et al., 2000; Gominho et al., 2001); therefore it is seen as an interesting alternative for fibre supply in pulp and paper industries (Antunes et al., 2000; Gominho and Pereira, 2000, 2006; Gominho et al., 2001; Villar et al., 1999). Crude extracts of *Cynara* flowers have been used in some regions of Spain and Portugal, since ancient times, as a natural rennet substitute to make traditional sheep cheese (Freni et al., 2001; Pires et al., 1994). Plant fruits (achenes) can be utilized for oil production for human consumption (Curt et al., 2002; Maccarrone et al., 1999), and also to prepare biodiesel (Benjelloun-Mlayah et al., 1997; Encinar et al., 1999; Fernández and Curt, 2004a; Fernández et al., 2006; Lapuerta et al., 2005). After oil extraction, seed cake could be used for animal feed (Fernández and Manzanares, 1990a). The benefits of the application of *Cynara* extracts in pharmacology are also known; they have antimicrobial, hepatoprotector and antioxidant properties, which are attributed to cynarin, silymarin and other minor compounds (Gebhardt, 1997, 1998; Lombardo et al., 2010). The use of these polyphenolic compounds in cosmetics was more recently reported (Lupo, 2001; Peschel et al., 2006).

Studies of the potential of *C. cardunculus* for biomass production started in the 1980s (Fernández, 1990; Fernández and Manzanares, 1990a,b). The evaluation of *Cynara* as an energy and industrial crop requires the knowledge not only of the produced biomass but also the partition of this biomass. Several studies developed in Europe showed that the average annual production of *Cynara* varieties varies from 15 to 20 t/ha depending on soil and rainfall, with the following biomass partitioning: 40% stalks, 25% leaves and 35% capitula (Dalianis et al., 1996; Fernández, 1992, 1993a,b), showing that *Cynara* can be considered as a renewable source of energy in the European agriculture systems.

The aim of this work was to evaluate the three botanical forms of *C. cardunculus* regarding fresh biomass production and its partition, aiming at its potential use for industrial purposes.

2. Materials and methods

The field experiments were carried out at the Experimental Field Station of Rosario's National University, Argentina (33°01′S; 60°53′W). The station has a temperate climate, loamy soil, an average annual rainfall of 950 mm.

Table 1
Accessions of *C. cardunculus* L. included in the study and their origin.

Accession	Origin	Country
C. cardunculus var. *cardunculus* (cultivated cardoon)		
Florensa	Commercial seed	Argentine
Semence	Commercial seed	Argentine
Cereseto	Local horticulturist	Argentine
Schiavoni	Local horticulturist	Argentine
Zavalla	Local horticulturist	Argentine
C. cardunculus var. *sylvestris* (wild cardoon)		
Pergamino	Locally collected	Argentine
Entre Ríos	Locally collected	Argentine
Route 9	Locally collected	Argentine
Route 2	Locally collected	Argentine
C. cardunculus var. *scolymus* (globe artichoke)		
Feltrin Verde	Commercial seed	Brazil
Feltrin Roxa	Commercial seed	Brazil
Violeta precocce	Commercial seed	Italy
Estrella del Sur FCA	Commercial seed	Argentine
Imperial Star	Commercial seed	USA

Fourteen accessions of *C. cardunculus* L. (Table 1) were compared in a randomized design with three replications. Plants at the stage of four true developed leaves were transplanted in April 2008. Each plot consisted in 20 plants arranged in three rows with between six and seven plants each one. Plant spacing was 140 cm between rows and 80 cm within plants in the row. Fertilization was conducted prior planting incorporating urea at a 150 kg ha^{-1} dose. Herbicides linuron at a 600 g ai ha^{-1} dose (ai = active ingredient), applied a month after plantation and haloxyfop-R-metil-ester at a 30 g ai ha^{-1} dose applied 6 months after plantation were used. Monthly temperature and rainfall recorded during 2008 and 2009 at the site of the experiment are shown in Table 2.

The anthesis stage of the second growth cycle is the moment in which the plants have the maximum vegetative development. At this time, at the end of October, 2009, six plants of the middle row of each plot were cut down and weighed in the open field to determine the total fresh biomass, plants bordering the plot were discarded. Then, stalks, leaves and capitula of each plant were weighed separately. The first capitulum produced for each plant was manually divided into its components: bracts, flowers (including ovaries, pappi and floret scales) and remnant receptacle (eatable portion) which were also weighed separately.

Those variables that did not present a normal distribution (leaves, capitula, flowers and receptacle weights) were transformed by $\sqrt{x}$. Data were subjected to a one-way analysis of variance (ANOVA) and mean values were compared by Duncan's multiple-range test, using the SAS software (SAS Institute and Inc., 1999).

A multiple linear regression analysis was performed to estimate the relationship between the dependent variable total fresh biomass and the independent variables stalks, leaves and capitula weights. The regression model was:

$$Y = \alpha + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3$$

where Y = dependent variable; α = intercept; β_1, β_2, β_3 = partial regression coefficients; x_1, x_2, x_3 = independent variables.

The same analysis was performed to compare the first capitulum weight (dependent variable) and its components: bracts, flowers and receptacle weights (independent variables).

For each aboveground fresh biomass fraction (stalks, leaves and capitula), 5 samples of 100 g each one for each botanical variety were taken and dried in a thermoventilated oven at 60 °C, until constant weight. The percentages of dry matter were calculated.