Polyphenol profile and content in wild and cultivated *Cynara cardunculus* L.

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Abstract

The species *Cynara cardunculus* L. is native to the Mediterranean Basin, where its commercial production makes a significant contribution to the agricultural economy. It contains phenolic acids and flavones, which play an important role in diet, because of their beneficial effects on human health, and in industrial processing, due to the browning phenomenon. The quantitative and qualitative profile of these compounds is affected by different factors, such as genotype, environmental conditions, crop management and processing procedures. As a consequence, these are relevant for defining the quality of the product. Therefore, our aim was to review the main factors that influence polyphenol biosynthesis and degradation in *C. cardunculus*. From available data in literature, the genetic background appears to be the main factor, followed by environmental effects. However, crop management also could be a valuable tool to enhance the polyphenol content. *C. cardunculus* also provides substantial quantities of polyphenol-rich by-products, which could be considered as a natural source of health-promoting compounds and an added value for the farming business.

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Introduction

Cynara cardunculus L. is a complex species consisting of the globe artichoke [var. *scolymus* (L.) Fiori], the cultivated cardoon (var. *altilis* DC.) and the wild cardoon [var. *sylvestris* (Lamk) Fiori]. The three types (wild cardoon, cultivated cardoon and globe artichoke) are fully cross-compatible and inter-fertility and their F_1 hybrids are fully fertile (Basnizki and Zohary, 1994; Mauromicale and Ierna, 2000). The *Cynara* L. is a relatively small genus taxa (Wiklund, 1992) of the daisy family Asteraceae (ex Compositae), native to the Mediterranean region, sharing its distribution with the olive (*Olea europea*). *C. cardunculus* is a heminyptophytie, perennial rosette plant, which renews itself year after year by means of lateral shoots arising just below the soil surface. The wild type is a robust thistle with a characteristic rosette of large spiny leaves, branched flowering stems, and blue-violet flowers. In Sicily there are few areas where wild cardoon plants have white and pink flowers. The wild cardoon is distributed over the west and central part of the Mediterranean Basin (from Portugal to west Turkey), as well as The Canary Islands and Madeira. In post-Columbian times, it colonized some parts of the New World and is a weed in parts of Argentina, Chile and California (Basnizki and Zohary, 1994). Crude aqueous extracts of the flowers of var. *sylvestris* are used in Portugal, Spain and Italy as a successful replacement for rennet in cheese making. Globe artichoke is an important vegetable in Mediterranean countries, where about 80% of the world surface (128 Kha) is cultivated. Italy (50 Kha), Spain (13 Kha), Egypt (9 Kha) and France (9 Kha) are the leading countries. In the other parts of the world, Peru (7 Kha), Chile (5 Kha), Argentina (4 Kha) and USA (3 Kha, mainly in California) are the main producers (FAO, 2012). For the first time, it has been reported in China in 2001, where 9 Kha are cultivated. The globe artichoke is widely consumed raw, boiled, steamed or fried, and used in many recipes, since it tastes good and is perceived as a healthy and nutritious vegetable, but other possible uses are: fresh and dry biomass and forage for livestock feed, preparation of alcoholic beverages and medications from leaves dry extracts and inulin extraction from roots (Foti *et al*., 1999; Maccarone *et al*., 1999; Gominho *et al*., 2001; Fernández *et al*., 2006; López-Molina *et al*., 2006). Globe artichoke is described in the pharmacopaea and health-promoting functions are currently reported. The cultivated cardoon has been cultivated as a vegetable since ancient times but the land area devoted to this crop has never been large (2-3000 ha), localised in Spain, Italy, France and Greece (Ierna *et al*., 2012). The commercial product is the enlarged petioles, central rib and a small part of the leaf border (two thirds of the inferior part of the leaf is utilized) harvested at the beginning of the winter after a bleaching period, which usually takes about one month. The plant, which can grow up to 2 m high, has the leaves of the basal rosette petiolata, very large, coriaceous, bright green and tomentose above and white-tomentose beneath. The stem is the floral scape as a corymbose cyme. The flowers are grouped in large globular non-edible capitula with the colour of corolla blue, lilac or whitish.

The natural cycle and some biologic and morphologic traits of the three *C. cardunculus* botanical varieties are perfectly adapted to Mediterranean climate conditions. During their natural cycle, the seed germinates with the first rain after the dry and hot summer, plants develop a leaf rosette in autumn and pass the winter at this stage. In spring, the floral stalk develops, in May the first capitulum appears, in June flowering, and in July, the fruit ripens. The type of fruit is the cypsela (achene). Since it is an indehiscent fruit with dry pericarp that acts as a dispersal unit, the fruit of the Asteraceae is commonly called seed, in spite of the fact that the seed is only the kernel that is inside the cypsela. During the summer the parts of the plant above ground dry off and the part underground enters a dormant state until a new cycle begins with the leaf burst from the buds with the autumn rainfall. Because of its deep root system, the plant is able to extract water and nutrients from very deep soil zones and, in non-irrigation conditions, uses the rainwater accumulated during autumn, winter and early spring.

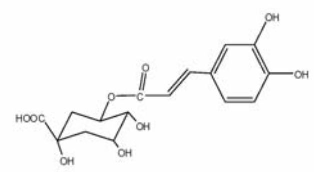
Potential health-promoting effects have been related to the polyphenols present in *C. cardunculus* (Gebhardt and Fausel, 1997; Jimènez-Escrig *et al*., 2003). Recently, the nutritional value and health-promoting properties of globe artichoke polyphenols were reviewed (Lattanzio *et al*., 2009; Ceccarelli *et al*., 2010). These compounds are affected by different factors, such as genotype, environmental conditions, crop management and processing practices. In this paper, for the first time, the main factors that influence the polyphenol biosynthesis and degradation in *C. cardunculus* are reviewed.

Polyphenol compounds in *C. cardunculus*

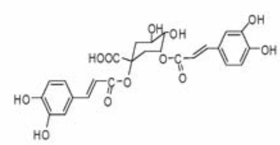
Polyphenols are a large group of secondary metabolites widely distributed in plants, which can be divided into two major subgroups: phenolic acids and flavonoids (Manach *et al*., 2004).

Phenolic acids

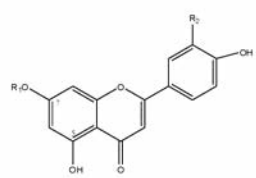
Phenolic acids consist of two subgroups: hydroxybenzoic and hydroxycinnamic acids. The latter chiefly consist of coumaric, caffeic and ferulic acids, that are rarely found in the free form (Manach *et al.,* 2004). *C. cardunculus* species are a good source of esters of quinic acid and caffeic acid (or caffeoylquinic acids) (Figure 1). The main compounds are 5-*O*-caffeoylquinic acid (or chlorogenic acid) and 1,5-*O*-dicaffeoylquinic acid, followed by minor components (1 and 3-*O*-caffeoylquinic and 1,3-*O*-dicaffeoylquinic acids) (Schütz *et al*., 2004; Lattanzio *et al*., 2009; Lombardo *et al*., 2010; Pandino *et al*., 2010). The caffeoylquinic acids have a relevant role as structural and functional components of plant cell walls (Faulds and Williamson, 1999), as bioactive components of the human diet, and act as precursors for processes, which lead to a loss of quality (Shahidi, 1997). The quality loss is due to the browning phenomenon, which occurs through oxidative degradation by polyphenol oxidase or to formation of iron-chlorogenic acid complexes (Lattanzio *et al*., 1994, 2009). This phenomenon is especially important in fresh-cut products, post-harvest handling and storage, and represents a limiting factor to processing artichoke for both industrial and minimally processed products (Gimenez *et al*., 2003; Lattanzio *et al.*, 2003; Todaro *et al.*, 2010; Amodio *et al*. 2011). The food industry, in order to prevent enzymatic browning, have often used synthetic antioxidants, such as butylated hydroxyanisole and butylated hydroxytoluene, acidifying agents and calcium solutions, for extending shelf-life (Choi *et al*., 2000; Martin-Diana *et al*., 2007; Rico *et al*., 2007). However, the perceived safety problems with synthetic antioxidants led to an increased interest for the recovery and exploitation of natural antioxidants, such as caffeoylquinic acids, from agricultural and industrial waste (Heilmann *et al*., 1995; Fukumoto and Mazza, 2000; Peschel *et al*., 2006). The globe artichoke, producing a huge amount of agricultural and industrial waste (~80-85% of the total plant and ~60% of the whole head, respectively), represents an important source of caffeoylquinic acids (Lattanzio *et al*., 2002; Llorach *et al*., 2002; Lombardo *et al*., 2010; Pandino *et al*., 2011b). In addition, the cardoon forms are also rich in caffeoylquinic acids (Pinelli *et al*., 2007; Pandino *et al*., 2010, 2011b). These compounds, when consumed with the diet, are well absorbed after metabolism (Manach *et al*., 2005; Azzini *et al*., 2007) and have been related to a decrease in risk of chronic diseases including cancer and cardiovascular disease (Kinnula and Crapo, 2004; Holst and Williamson, 2008). Nakajima *et al*. (2007) also reported that some caffeoylquinic acids inhibit lipid peroxidation and exhibit neuroprotective activities, while other researchers their demonstrated anti-HIV (Human Immunodeficency Virus) effects and antiviral activity (McDougall *et al*., 1998; Slanina *et al*., 2001; Li *et al*., 2005). The caffeoylquinic acids play an important role in plant cell-walls. Faulds and Williamson (1999) reported that they are implicated in providing structural support for the plant cell-wall by bridging certain polymers in the cell-wall. This explains the high content of caffeoylquinic acids in the floral stem, which provides mechanical support of immature inflorescences of *C. cardunculus* (Pandino *et al*., 2011b). Moreover, they are precursors of lignin, protecting the inner parts from biotic and abiotic stressors. Consequently, this process involves a decrease of caffeoylquinic acids content, as found in the outer bracts of capitulum of globe artichoke (Fratianni *et al*., 2007; Lombardo *et al*., 2010; Pandino *et al*., 2011c).



5-*O*-caffeoylquinic acid (chlorogenic acid)



1,3-*O*-dicaffeoylquinic acid (cynarin)



Luteolin 7-*O*- rutinoside	R_1=rut	R_2=OH
Luteolin 7-*O*- glucoside	R_1=glc	R_2=OH
Luteolin 7-*O*- glucuronide	R_1=glr	R_2=OH
Luteolin 7-*O*-malonylglucoside	R_1=malonylglc	R_2=OH
Apigenin 7-*O*- rutinoside	R_1=rut	R_2=H
Apigenin 7-*O*- glucoside	R_1=glc	R_2=H
Apigenin 7-O- glucuronide	R_1=glr	R_2=H

Figure 1. Mono- and di-caffeoylquinic acids and flavones detected in *Cynara cardunculus.*

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Flavonoids

Flavonoids are the largest group of plant polyphenols and consist of six subclasses: flavonols, flavones, isoflavones, flavanones, anto-cyanins and flavanols (Manach *et al*., 2004). In *C. cardunculus* the most representatives are flavones (apigenin, luteolin and their conjugates), followed by minor components such as flavanones (Figure 1) (Sanchez-Rabaneda *et al*., 2003; Schütz *et al*., 2004; Lombardo *et al*., 2010; Pandino *et al*., 2010). In particular, *C. cardunculus* represents a good source of aglycone apigenin and luteolin, since they are not distributed widely in food plants, being reported only in a restricted number of vegetables and herbs (Table 1). The main anthocyanins in globe artichoke are cyanidin glycosides (Aubert and Foury, 1981; Schütz *et al*., 2006). These impart the violet colour in the external bracts of certain globe artichoke genotypes and in the flowers of *C. cardunculus*, playing an important role in the appearance of fresh globe artichokes and acting as visual signals for pollinating insects (Pietta, 2000; Lattanzio *et al*., 2003). As for luteolin and apigenin conjugates, they also can protect plants from solar ultraviolet (UV) radiation and scavenge UV-generated ROS (reactive oxygen species) (Shirley, 1996). Apart from their roles in the ecology of plants, flavonoids are important components in the human diet, since they possess chemical radical scavenging properties (Wang *et al.,* 1997; Einbond *et al*., 2004; Mertens-Talcott *et al*., 2008;Vinson *et al*., 1995; Van Acker *et al*., 1996; Brown and Rice-Evans, 1998; Pietta, 2000; Valentão *et al*., 2002; Jimenez-Escrig *et al*., 2003). Aljančić *et al.* (1999) have also reported antimicrobial activities of these compounds. These results were supported by Kukić *et al.* (2008) and Zhu *et al.* (2004), who investigated *C. cardunculus* extracts against tested strains of bacteria and fungi. Gebhardt (1998, 2001) observed that the aglycone luteolin inhibits cholesterol biosynthesis and biliary secretion, while Petrowicz *et al*. (1997) studied in *vitro* and in *vivo* the effects of artichoke leaf extract, rich in flavones, on lipoprotein metabolism. Recently, Shukla and Gupta (2010) reviewed the important role as a chemopreventive agent that the aglycone apigenin has for cancer prevention, such as breast, thyroid and colon cancer. The apigenin derivatives have antispasmodic and anti-inflammatory activities (Carle *et al*., 1992). In addition, the flavones exhibit other biological effects, such as inhibition of UV-induced skin carcinogenesis and vasomodulating (Birt *et al.,* 1997; Rossoni *et al*., 2005), which are well documented *in vitro* (Williamson *et al*., 2005).

Factors affecting polyphenol content and profile in *C. cardunculus*

Polyphenol compounds in the plant depend upon, both quantitatively and qualitatively, environmental conditions (temperature, light, soil, *etc*.), crop management strategies, biotic stressors (*i.e.* fungi and insects), post-harvest handling, storage, industrial and domestic processing, harvest time and plant factors, such as genotype and plant part (Beckman 2000; Tomás-Barberán and Espin, 2001, Kalt, 2005; Ezekiel *et al*., 2011).

Genotype and plant part factors

In *C. cardunculus,* the genetic background appears to be the main factor affecting its qualitative and quantitative profile of polyphenolic compounds (Moglia *et al.,* 2008). In the literature, there are clear examples showing the variation of total polyphenol content (TPC) and qualitative and quantitative profile amongst different globe artichoke cultivars and botanical varieties of *C. cardunculus*. Lombardo *et al.* (2012) analysed 17 cultivars of globe artichoke and found that the TPC in the whole head ranged from 11.9 (*Spinoso di Palermo*) to 58.7 (*Tema 2000*) g of chlorogenic acid equivalent (CAE) per kg of fresh matter (FM). Pandino *et al.* (2010) demonstrated a different qualitative and quantitative profile for both caffeoylquinic acids and flavones occurring amongst the capitula of three botanical varieties. In particular, a high content of caffeoylquinic acid was found in the globe artichoke [on average, 1897 mg per kg of dry matter (DM)] and of apigenin aglycone and its derivatives in the wild and cultivated cardoon (6950 mg per kg of DM). In their study, it also included a Sicilian landrace (*Cimiciusa di Mazzarino*), which seemed closer to the cardoon form than the globe artichoke at least on the basis of phenolic composition, representing a intermediate form between wild and cultivated *C. cardunculus* (Pandino *et al*., 2010). Schütz *et al.* (2004) reported that in the globe artichoke head the most abundant compounds are chlorogenic acid, 1,5-*O*-dicaffeoylquinic acid and apigenin-7-*O*-glucuronide. The latter was the only predominant compound in the capitula of cardoon forms (Pandino *et al*., 2010). Schütz *et al*. (2006) also characterised and quantified the anthocyanins in heads of six artichoke cultivars. In particular, it was reported that the total anthocyanin content ranged from 8.4 to 1705 mg per kg of DM. This genetic variability is reflected on the different parts of *C. cardunculus* plant. Several authors focused on the qualitative and quantitative polyphenol profile of leaves, due to their use for hepatoprotection, as choleretic and diuretic (Kirchhoff *et al*., 1994). Pinelli *et al.* (2007) quantified caffeoylquinic acids and flavonoids in wild and cultivated cardoon leaves, which exhibited a large variation among the analysed accessions. In a study carried out on leaf stalks of cultivated cardoon, Lahoz *et al*. (2010) observed a significant variation in both free and total polyphenols (10.9-90.0 and 63.5–155.5 μmol catechin 100 per g of FM, respectively). Similar results, including the globe artichoke, were reported by other authors (Romani *et al*., 2006; Wang *et al.,* 2003; Pandino *et al*., 2011b). By a comparison of the TPC in 17 globe artichoke cultivars, Lombardo *et al*. (2012) reported a great variability of TPC in the floral stem (from 1.2 to

Table 1. Apigenin and luteolin aglycone contents in food herbs and vegetables.

Plant source	Apigenin	Luteolin	Reference
Herbs			
Mint	18-99*	11-42*	Justensen and Knuthsen, 2001
Oregano	2-4*	0-3*	Justensen and Knuthsen, 2001
Parsley	510-630*	0-4*	Justensen and Knuthsen, 2001
	185*	1.1*	Justensen *et al*., 1998
Sage	-	11°	Karakaya and Nehir, 1999
Vegetables			
Celery leaf	75*	20*	Justensen *et al*., 1998
Celery stalk	1.6*	0.5*	Justensen *et al*., 1998
Sweet green pepper	-	0.5*	Justensen *et al*., 1998
Sweet red pepper	-	0.1*	Justensen *et al*., 1998
Sweet yellow pepper	-	0.2*	Justensen *et al*., 1998
Red bell pepper	-	11#	Hertog *et al*., 1992
White celery stalks	0-104§	0-40§	Crozier *et al*., 1997
Green celery hearts	191§	35§	Crozier *et al*., 1997
White celery hearts	17§	6.6§	Crozier *et al*., 1997
Globe artichoke (receptacle)	257-687^	Trace-34^	Pandino *et al*., 2011c
Cultivated cardoon (leaves)	1300^	900^	Pandino *et al*., 2010

*mg 100 g^{-1} fresh weight; °μg L^{-1}; #mg kg^{-1} of fresh edible part; §μg g^{-1} of fresh weight; ^mg kg^{-1} of dry matter.

17.6 g CAE per kg of FM) and in the receptacle (from 2.4 to 11.3 g CAE per kg of FM). In the receptacle of cultivated cardoon the TPC was ~20 times lower than globe artichoke (Fratianni *et al.,* 2007), highlighting the genetic distance between the globe artichoke and cardoon forms, as reported in the literature (Lanteri *et al*., 2004). According to the HPLC profile, similar conclusions were drawn by Pandino *et al*. (2011b), who found that floral stems of the cardoon forms are richer than the globe artichoke in the total amount of apigenin and its derivatives (on average, 0.33 g per kg of DM). Regards to the receptacle, it is interesting to note this genetic variability, representing an useful tool to define its aptitude for a specific use (fresh market or food processing), and for breeding new varieties. In this respect, Bonasia *et al.* (2010) analysed new seed-propagated globe artichoke cultivars, in order to define their better end-use. These authors reported that the hybrids had in the *hearth* (receptacle and inner bracts) the lowest TPC [on average, 2.5 g of gallic acid equivalent (GAE) per kg of FM] compared to the standard cultivated varietal types (on average, 5.1 g GAE per kg of FM). Similar results were found by Lombardo *et al.* (2012), where the TPC of standard cultivated varietal types in the *hearth* was higher than hybrids (on average, 6.2 and 4.7 g CAE per kg of DM, respectively). The same trend was achieved for both outer and inner bracts (Lombardo *et al*. 2012).

Regardless of genotype, Lombardo *et al.* (2009) demonstrated that the TPC of globe artichoke is affected by plant part. In particular, the floral stem had the highest TPC, followed by the receptacle, while the outer bracts had the lowest (Figure 2). In terms of polyphenol profile, it is interesting to note the massive decrease of caffeoylquinic acids from inner to outer bracts reported by Pandino *et al.* (2011b, 2011c), as well as the wide variation amongst the genotypes in terms of total caffeoylquinic acids, total luteolin and total apigenin content (Figure 3). Lombardo *et al.* (2010, 2012) characterised the polyphenol profile in several globe artichoke cultivars and found that the outer bracts accumulated preferentially apigenin and its derivatives, while inner bracts and receptacle had a good content of both caffeoylquinic acids and flavones. Fratianni *et al*. (2007) have also demonstrated that single polyphenols are localised in specific parts of the heads. Romani *et al.* (2006) estimated the polyphenol composition of the different plant parts and observed that leaves contain the highest amount of flavonoids, while they are completely lacking in the floral stems. Falleh *et al*. (2008) studied a Tunisian cardoon type and recorded the lowest TPC in the flowers compared to leaves and seeds. In another study, Pandino *et al.* (2011a, 2011b) investigated the polyphenol profile in leaf and floral stem of *C. cardunculus* genotypes. In leaves, the flavones were the major compounds, whereas in the floral stem, caffeoylquinic acids were the most abundant, presumably related to their different roles in the plant.

Environmental factors

Besides the role in the plant, the concentration of flavones and caffeoylquinic acids is linked to the environmental conditions, such as light exposure. Pinelli *et al.* (2007) studied the effect of the light on two cultivated cardoons and observed a low amounts of flavones compared to the samples not exposed to the light. The light, mainly ultraviolet (UV), affects the different classes of polyphenols in *C. cardunculus*, as reported by Pandino *et al*. (2011b). These authors found that in the leaves of globe artichoke the luteolin derivatives were the main compounds, whereas in cardoon forms, apigenin derivatives were the most abundant. Moglia *et al*. (2008) observed in the leaves of globe artichoke a significant increase in the content of the main dicaffeoylquinic acids upon UV-C irradiation. The TPC is also affected by meteorological conditions, such as rainfall level and temperatures, as described by Lombardo *et al.* (2009) in a two-year experiment on the whole globe artichoke head. In particular, it was reported that the different weather conditions recorded during the harvest period of the first growing season, represented mainly by the highest average maximum temperatures and the greater quantity of rainfall, are presumably more favourable to polyphenol biosynthesis for most of the genotypes (Figure 4).

Plant age and harvest time factors

Wang *et al.* (2003) showed a significant variation in TPC between young and mature heads (on average, 2.8 and 1.9% of DM, respectively). Fratianni *et al.* (2007) compared the obtained data on the leaf content of caffeoylquinic acids and flavones with those reported by Wang *et al.* (2003) and underlined that the discrepancy among these data were due to different leaf ages. In contrast, Lutz *et al.* (2011) did not observe significant difference in TPC between mature (diameter of 11 cm) and baby (diameter of 4.5 cm) globe artichoke.

Lombardo *et al.* (2010) characterised the polyphenol profile of globe artichoke cultivar (*Romanesco* clone C_3) in relation to harvest time (winter and spring harvest) and plant part. Their results demonstrated that the polyphenol content increased from winter to spring harvest,

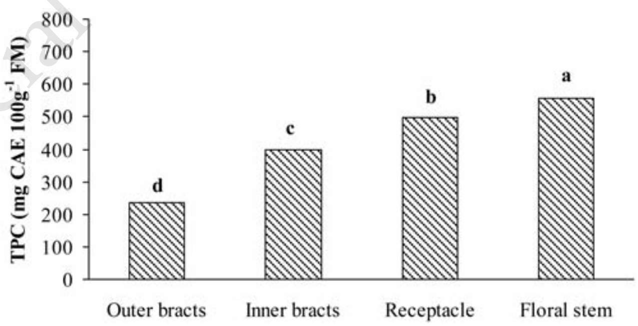

Figure 2. Total polyphenols content (TPC) of globe artichoke as affected by head fraction. CAE, chlorogenic acid equivalent; FM, fresh matter. Different letters indicate statistical significance at P≤0.05 (adapted from Lombardo *et al.*, 2009).

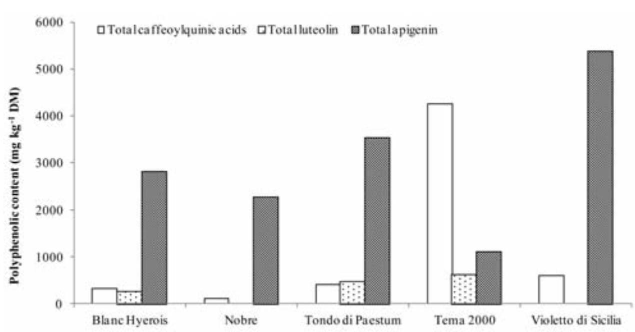

Figure 3. Total caffeoylquinic acids, total luteolin and total apigenin of globe artichoke receptacle as affected by genotype (adapted from Pandino *et al.,* 2011c). DM, dry matter.

particularly in the floral stem for both caffeoylquinic acids and luteolin derivatives and in the receptacle for apigenin derivatives (Figure 5). Todaro *et al.* (2010) also reported a higher TPC in spring than in winter (on average, 8.1 and 1.5 mg of CAE per g of FM, respectively), in a study carried out on heads of three globe artichoke cultivars.

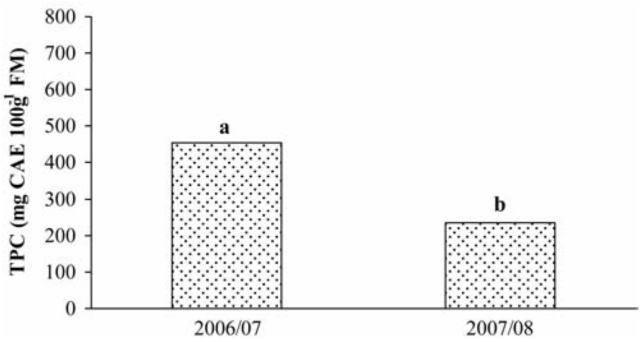

Figure 4. Total polyphenols content (TPC) of the whole globe artichoke head as affected by season conditions. CAE, chlorogenic acid equivalent; FM, fresh matter. Different letters indicate statistical significance at P≤0.05 (adapted from Lombardo *et al.* 2009).

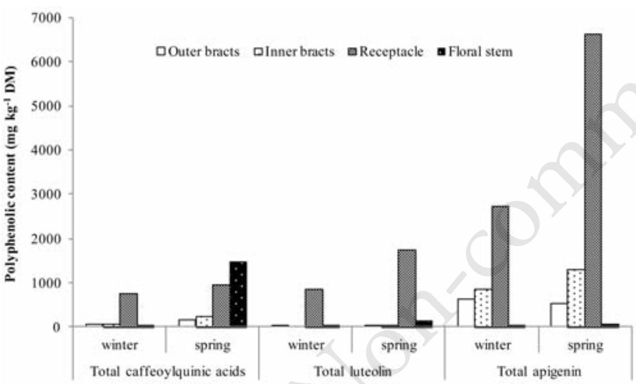

Figure 5. Total caffeoylquinic acids, luteolin and apigenin of globe artichoke in relation harvest time and plant part (adapted from Lombardo *et al.*, 2010). DM, dry matter.

Table 2. Total polyphenols content of the whole globe artichoke head in relation to plant arrangements and planting density (adapted from Lombardo *et al.*, 2009).

Plant arrangement (Pa)	Planting density (Pd) n m^{-2}				Mean
	1.0	1.2	1.4	1.8	
	mg CAE 100 g^{-1} FM				
Single row	482	486	482	553	501
Twin rows	406	501	567	790	566
Mean	444	493	524	671	L***QNS

LSD (P≤0.05); CAE, chlorogenic acid equivalent; Pa, 53; Pd, 75; Pa × Pd interaction, 105; L, linear; Q, quadratic; ***significant at P≤0.001 to regression analysis; NS, not significant to regression analysis.

Crop management factors

With regard to the effect of crop management practices on the content of polyphenols, Lombardo *et al.* (2009) focused on the plant arrangement (single and twin rows) and density (1.0, 1.2, 1.4 and 1.8 plant m^2) and found that the TPC increased from lower to higher plant density, mainly in the twin rows (Table 2). In addition, they observed a significant *planting density* × *head part*s interaction, particularly in the inner bracts, where the TPC increased 108% from the lower to the higher plant density. Sharaf-Eldin *et al.* (2007) studied the possible interaction between gibberellic acid, supplied to the plants during the crop cycle used to shorten time to harvest for globe artichoke field plants, and the content of 2 phenolic acids (chlorogenic acid and 1,5-*O*-dicafeoylquinic acid) in leaves and receptacle of globe artichoke both grown from field transplants and by direct field seeding. They observed an increase of chlorogenic acid in leaves of globe artichoke grown from field transplants, while no significant differences were found for 1,5-*O*-dicafeoylquinic acid, as well for the receptacle in both types of field trials. In contrast, El-Abagy *et al*. (2010) showed significant increment in total polyphenols in the flower heads when the leaves were treated with gibberellic acid and salicylic acid, while the putrescine did not affect the polyphenol content.

Handling and storage factors

As reported by Lattanzio *et al*. (1994), the polyphenol content in the globe artichoke is affected also by post-harvest handling and storage conditions. During postharvest handling the globe artichoke tissue could be subjected to mechanical damages, leading to activation of polyphenol oxidase (PPO). This enzyme oxidizes phenolic acids and, therefore, reduces their amount by producing melanins (brown polymers). These authors also reported that during storage of artichoke heads at 4°C the activity of the enzyme phenylalanine ammonia-lyase (PAL) is stimulated, consequently leading to a biosynthetic increase of phenolic acids, especially chlorogenic acid. On the other hand, this increase becomes a good substrate for PPO (Shahidi, 1997). Since globe artichokes are usually cooked before eating, some authors evaluated the effect of cooking on the content of polyphenol compounds. In this respect, Ferracane *et al*. (2008) achieved an increase of ~2 times for the total caffeoylquinic acids and a decrease of 40% for the total apigenin derivatives from the raw to cooked globe artichoke. Lutz *et al.* (2010) also observed a significant increase of caffeoylquinic acids after cooking, in agreement with the findings of other authors, which estimated the TPC after water blanching (Llorach *et al*., 2002; Schütz *et al*. 2004; Peschel *et al*., 2006). This increase is probably due to the inactivation of the PPO by blanching, preserving the content of phenolic acids.

Conclusions

The studies of polyphenols in *C. cardunculus* that have been conducted to date provide a good indication of their qualitative and quantitative variation. Available evidence suggests that the qualitative and quantitative polyphenol profile appears to be strongly influenced by a high degree of heterozygosity inside of *C. cardunculus*. This has made it possible to conserve genetic variability, but on the other hand, the importance of genetic control on polyphenol content for the industrial processing has led to the development of new cultivars, which have low polyphenol content. Another approach was to work on a breeding programme in order to improve the total polyphenol content for cultivars destined for fresh consumption or decrease it with advantages for food processing (Pandino *et al*., 2011a). Recently, we selected by breeding between artichoke and cardoon forms some genotypes, which have a content of polyphenols about 10 times higher than their parents. However, given the practical difficulties of *ex situ* germplasm conservation in this species, a strategy of clonal selection may be the optimum route for enhancing current landraces, while at the same time conserving them *in situ* (Pandino *et al.,* 2012). In addition to genetic factors, environmental conditions seem also to affect the polyphenol profile. These, combined with breeding programmes, might be a powerful tool to manipulate the polyphenol content in relation to the end-use (fresh consumption, industrial processing, pharmaceutical purposes, *etc*.) of a specific genotype and specific part of plant of *C. cardunculus*. A better knowledge of these correlations will be of great help in investigating the high variability of polyphenols. This review also reports that crop management practices (*e.g.* plant density and harvest time), cooking procedures and storage conditions affect the polyphenol content of *C. cardunculus*. As a general role, the cooking methods increase the qualitative and quantitative polyphenol profile, while concerning the other factors no uniform trend is noticeable, as especially observed for the crop management practices. Overall, this review demonstrates, according to the available data in the literature, the role of *C. cardunculus* as good source of phenolic acids and flavones, encouraging a wider cultivation and consumption of this vegetable not only in the Mediterranean area, but all over the world.

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