

Polyphenol content in cultivated cardoon (*Cynara cardunculus* L. var. *altilis* DC.) leaves as affected by intraspecific plant competition

G. Pandino¹, F. Gattesco², E. De Combarieu³, A. Scavo¹, S. Lombardo^{1,a} and G. Mauromicale¹

¹Dipartimento di Agricoltura, Alimentazione e Ambiente Università degli Studi di Catania (Di3A), via Valdisavoia 5, 95123 Catania, Italy; ²Indena S.p.A., Botanical Research, Settala (Milan), Italy; ³Indena S.p.A., QC/R&D Laboratories, Settala (Milan), Italy.

Abstract

Polyphenols, a large group of secondary metabolites widely distributed in plants, have received considerable attention, as they act as powerful scavengers of harmful radicals and, thus, can be protective against chronic diseases such as cancer and cardiovascular malfunction. Their content is influenced by several biotic and abiotic factors. In this light, this study aimed to evaluate the influence of intraspecific plant competition, determined by plant density, on the total caffeoylquinic acids (CCs), chlorogenic acid (CGA), flavonoids (Fs), and cynaropicrin (Cp) content of cultivated cardoon leaf blades over two cutting times. The leaf blade yield was also considered. The polyphenols profile was determined by HPLC analysis. Effects of intraspecific plant competition were shown in both cutting times (early May and late June). In particular, the total content of CCs and Fs decreased, respectively, by about 16 and 15% passing from high to low intraspecific plant competition, while both CGA and Cp reported a decrease of about 10%. The phenolic acids had the greatest value during the second cutting time, whereas Fs and Cp in the first. In conclusion, the intraspecific plant competition could have a key role in the polyphenol content although the effect was also time-dependent.

Keywords: *Cynara cardunculus* var. *altilis*, intraspecific competition, flavonoids, caffeoylquinic acids, cynaropicrin

INTRODUCTION

Polyphenols are the most important secondary metabolites synthesized by plant tissues. These compounds play an important role in the mechanisms of chemical defense against abiotic and biotic stresses in plants (Samec et al., 2021; Singh et al., 2021). They have also been associated with the organoleptic and nutritional properties of foods and their shelf life (Manach et al., 2005; Muratore et al., 2015). When introduced to the diet, they provide several beneficial effects on human health, due to their anticarcinogenic, antimutagenic, antibacterial, antiviral, anti-inflammatory, and anti-atherosclerotic properties (Chojnacka et al., 2021; Afnan et al., 2022; Ziólkiewicz et al., 2023). Some studies also demonstrated the allelopathic activity of polyphenols and sesquiterpene lactones on some weeds (Scavo et al., 2019a, 2020a). Our days, the perceived inferiority of synthetic antioxidants, widely added to foodstuffs, led to an increased interest in the recovery and exploitation of natural antioxidants, among which phenolic compounds and flavonoids, from plant sources (Tlais et al., 2020).

Among plant sources, the leaves of cultivated cardoon (*Cynara cardunculus* L. var. *altilis* DC.) achieved the attention of both the scientific community and stakeholders, because of its high content of phenolic acids, flavonoids, and sesquiterpene lactones (Pandino et al., 2012a, 2013; Scavo et al., 2020b), making it suitable for the recovery of natural antioxidants (Pandino and Mauromicale, 2020a). Among sesquiterpene lactones, in *C. cardunculus* the predominant is the cinaropicrin (Pandino et al., 2020b; Scavo et al., 2020b). The content of these compounds is affected by a large number of factors such as genotype, climatic conditions,

^aE-mail: saralomb@unict.it



plant tissue, storage time, and agro-technical processes (Pandino et al., 2012b, 2017a, b, 2022; Lombardo et al., 2015a, 2018, 2022; Salata et al., 2022, 2023). To our knowledge, some studies investigated the influence of plant density on polyphenol compounds and morphological characteristics of globe artichoke (Honermeier and Goettmann, 2010; Lombardo et al., 2009; Mauro et al., 2011; Pandino et al., 2020b), while no data on how these compounds may vary in cultivated cardoon is available in the literature.

In this respect, the objective of the present study was to investigate the variation of the content of the total caffeoylquinic acids (CCs), chlorogenic acid (CGA), flavonoids (Fs), and cynaropicrin (Cp) in leaf blades of cultivated cardoon about intraspecific plant competition over two cutting times.

MATERIALS AND METHODS

Plant material, experimental design, and sample preparation

The field experiments were conducted during the growing season of 2014-15 on the Catania Plain (Sicily, Italy). The soil characteristics were as follows: 45% clay, 37% silt, and 18% sand. The chemical analysis of trial soil shows that it has 0.8 g kg⁻¹ of total nitrogen (N), 10 mg kg⁻¹ of assimilable phosphorous (P₂O₅), and 347 mg kg⁻¹ of exchangeable potassium (K₂O). The local climate is semi-arid Mediterranean with mild winters and hot, rainless summers. A split-plot experimental design with four replications, 40 plants per plot, was adopted to evaluate the effects of two levels of intraspecific competition, determined by two planting densities (2.0 vs. 8.0 plant m⁻², referred to as low and high intraspecific plant competition, respectively) (Figure 1), and two cutting times (early May and late June referred to as first and second cutting time, respectively) as sub-plot. Planting was done manually using plantlets with 3-4 leaves in August 2014. Before planting, the field was plowed to a depth of 30 cm, harrowed, and a fertilizer rate of 50 kg N ha⁻¹ (as urea), 80 kg P₂O₅ ha⁻¹ (as double perphosphate), and 80 kg K₂O ha⁻¹ (as potassium sulfate) was applied. Manual weeding was conducted two times. At least 0,5 kg of leaves of seed propagated genotype ('Bianco Gigante Inerme') per replicate and plant density were harvested from disease-free plants. Seeds were provided by the Suba Seeds Company (Longiano, Italy). The leaves were cleaned with flowing tap water and the leaf midribs were removed. Then, the leaf blades were oven-dried at 45°C (Binder Drying chamber, Tuttlingen, Germany) until a constant weight was reached and submitted to the HPLC analysis. Moreover, the leaf blade yield was evaluated and expressed as t ha⁻¹ of dry matter (DM) and the ratio CCs/CGA was calculated. The latter indicates the amount of CGA, the most important caffeoylquinic acid among the total content of CCs.



Figure 1. Leaves of cultivated cardoon 'Bianco Gigante Inerme' under low (A) and high intraspecific plant competition (B).

Reagents and solvents

Reagents and solvents were purchased from VWR (Leighton Buzzard, UK) and were of analytical or HPLC grade. Apigenin-7-*O*-glucoside, apigenin, luteolin-7-*O*-glucoside, luteolin, 5-*O*-caffeoylquinic acid (chlorogenic acid) cynaropicrin, and hesperetin were obtained from Extrasynthese (Lyon, France), cynarin (1,3-di-*O*-caffeoylquinic acid) was from Roth (Karlsruhe, Germany), and BHT (butylated hydroxytoluene) was purchased from Sigma Chemicals Co (St. Louis, MO). Milli-Q system (Millipore Corp., Bedford, MA) ultrapure water was used throughout this research.

HPLC analysis

The extraction method and HPLC analysis were carried out as described previously by Pandino et al. (2017c). The mobile phase consisted of 1% (v/v) formic acid in water (solvent A) and 1% (v/v) formic acid in acetonitrile (solvent B). The gradient started with 5% B to reach 10% B at 10 min, 40% B at 30 min, 90% B at 50 min, and 90% B at 58 min.

For the cynaropicrin, it was adapted the method proposed by Pandino et al. (2020c). The mobile phase was 0.1% formic acid in water (solvent A) and in acetonitrile (solvent B) at a flow rate of 0.3 mL min⁻¹. The gradient started with 5% B to reach 10% B at 10 min, 30% B at 25 min, and 40% at 30 min.

Chromatograms were recorded at 280 (Cp), 310 (CCs and apigenin derivatives) and 350 (luteolin derivatives) nm. Spectra were obtained between 200 and 600 nm. Total CCs content was calculated as the sum of mono and di-caffeoylquinic acids, whereas total Fs was obtained by summing apigenin and luteolin derivatives. All samples were assayed in triplicate and expressed as g 100 g⁻¹ of dry matter (DM).

Statistical analysis

All data were subjected to a two-way ('intraspecific plant competition × cutting time') analysis of variance (ANOVA), and the means were separated by a least significance difference (*LSD*) test when the *F*-test was significant. All calculations and analyses were performed using CoStat® version 6.003 (CoHort Software, Monterey, CA, USA).

RESULTS

Except for the leaf blade yield, the contents of all considered polyphenols and Cp were affected by intraspecific plant competition, cutting time, and their interaction.

About the intraspecific plant competition, all polyphenol compounds under study and Cp had the highest levels under low intraspecific plant competition (Figures 2 and 3). In particular, the total content of CCs and Fs decreased by about 16 and 15%, respectively, passing from high to low intraspecific plant competition. For CGA and Cp the decrease was less marked (about 10%).

Independently of intraspecific plant competition, each phytochemical group had a different behavior about the cutting time. Phenolic acids (CCs, CGA, and ratio CCs/CGA) had the greatest value during the second cutting time, while both Fs and Cp were in the first cutting time (Figures 3 and 4). In detail, it was observed an increase of about 17% for both the total content of Fs and Cp at the first cutting time. On the contrary, in the second cutting time, the leaf blades reached the highest values of both CCs and CGA (3.90 and 1.72 g 100 g⁻¹ DM, respectively).

A key role was observed also in the interaction 'intraspecific plant competition × cutting time' (Table 1). In particular, low intraspecific plant competition plots ensured higher values for both CCs and Fs in the second and first cutting time, respectively. The Cp and ratio CCs/CGA recorded a trend similar to the Fs, while CGA achieved the lowest content in the second cutting time at high intraspecific plant competition plots.

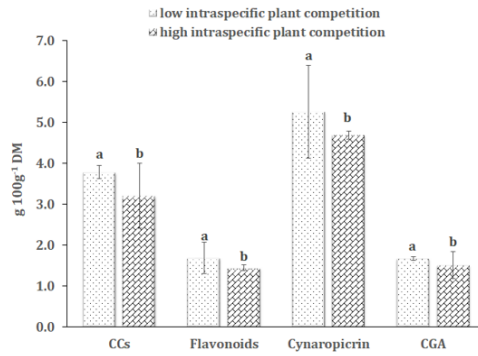


Figure 2. Total caffeoylquinic acids (CCs), total flavonoids, cynaropicrin, and chlorogenic acid (CGA) content as affected by intraspecific plant completion in leaf blades of cultivated cardoon 'Bianco Gigante Inerme'. Different letters within each parameter under study indicate significance at Fisher's protected LSD (least significant difference) test ($P \leq 0.05$). Vertical bars indicate mean \pm standard deviation.

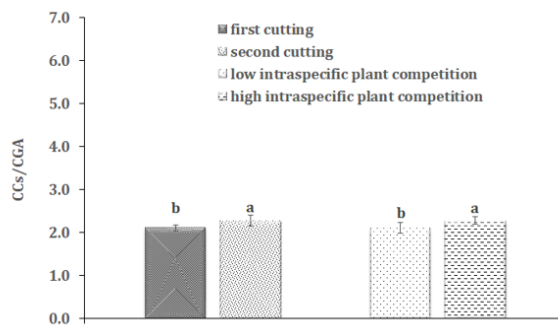


Figure 3. Ratio CCs/CGA as affected by intraspecific plant completion and cutting time in leaf blades cultivated cardoon 'Bianco Gigante Inerme'. Different letters within each factor under study indicate significance at Fisher's protected LSD (least significant difference) test ($P \leq 0.05$). Vertical bars indicate mean \pm standard deviation.

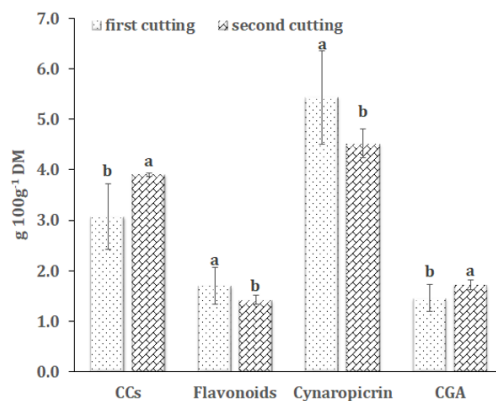


Figure 4. Total caffeoylquinic acids (CCs), total flavonoids, cynaropicrin, and chlorogenic acid (CGA) content as affected by intraspecific plant completion in leaf blades of cultivated cardoon 'Bianco Gigante Inerme'. Different letters within each parameter under study indicate significance at Fisher's protected LSD (least significant difference) test ($P \leq 0.05$). Vertical bars indicate mean \pm standard deviation.

Table 1. Total caffeoylquinic acids (CCs), total flavonoids (Fs), cynaropicrin (Cp), and chlorogenic acid (CGA) content (g 100 g⁻¹ dry matter), ratio CCs/CGA and leaf blades yield (t ha⁻¹ DM) as affected by 'intraspecific plant completion × cutting time' interaction in leaf blades of cultivated cardoon 'Bianco Gigante Inerme'.

Parameter	Low intraspecific plant competition		High intraspecific plant competition	
	First cutting	Second cutting	First cutting	Second cutting
CCs	2.52±0.04 d	3.88±0.04 b	3.64±0.03 c	3.92±0.04 a
Fs	2.01±0.04 a	1.35±0.06 b	1.39±0.06 b	1.48±0.06 b
Cp	6.23±0.08 a	4.28±0.04 c	4.62±0.06 b	4.76±0.07 b
CGA	1.65±0.07 a	1.68±0.03 a	1.79±0.04 a	1.23±0.06 b
Ratio CCs/CGA	2.38±0.04 a	2.17±0.03 b	2.17±0.05 b	2.05±0.02 b
Leaf blades yield	3.04±0.34 a	2.23±0.32 a	2.38±0.08 a	2.33±0.22 a

Different letters within each parameter indicate significance at Fisher's protected LSD (least significant difference) test ($P \leq 0.05$). Values are mean±standard deviation.

DISCUSSION

Here, for the first time, on cultivated cardoon, the variation of the above parameters about intraspecific plant competition and cutting time was reported. Overall, the CCs were the predominant compounds, as observed by Pinelli et al. (2007). According to our data, the phytochemicals were intraspecific plant competition-dependent. The low intraspecific plant competition appears to increase the level of phytochemical compounds in leaf blades. Our data are in agreement with our previous work on leaves of globe artichoke, where the highest plant density was characterized by the lower content of CCs (Pandino et al., 2020b). As expected, the CGA reflected the trend observed in CCs, as well as the ratio of CCs/CGA. The CGA can exert a wide range of potential health benefits of CGA, including its anti-diabetic, anti-carcinogenic, anti-inflammatory, and anti-obesity impacts, (Tajik et al., 2017). Also the level of Cp, a compound with several pharmacological properties, antimicrobial activity, and allelopathic effects (Scavo et al., 2019a, b, 2020a, b; Rotondo et al., 2022) presented the highest values at low levels of intraspecific plant competition. In this view, the pre-harvest factors highlight their pivotal role in the amount of these compounds. Nevertheless, also the cutting time significantly affects the amount of phytochemical compounds. To our knowledge, in literature data on the variation of phytochemical compounds about the cutting time is missing and, therefore, it's hard to compare our results with previous findings. Some works focus on the impact of harvest time and/or plant growth stage on the chemical composition of cultivated cardoon blades and globe artichoke (Mandim et al., 2021, 2022; Lombardo et al., 2015b). In conclusion, the proper control/regulation of the factors, here under study, could have a key role in the polyphenol content of cultivated cardoon, without significantly affecting the leaf blade yield.

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