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Organic versus conventional globe artichoke: Influence of cropping system and harvest date on physiological activity, physicochemical parameters, and bioactive compounds

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ABSTRACT

The aim of this study was to compare the impact of an organic cropping system (ORG) and a conventional one (CONV) on 'Spinoso Sardo' artichoke heads quality over the whole crop cycle. Respiratory activity, texture properties, fibres content, sucrose, glucose, fructose, bioactive compounds, total phenols, and antioxidant activity were measured. The results showed that respiratory activity determined at 5 °C or at 20 °C was similar in artichoke heads of both cropping systems, but changed as the harvesting season progressed, with higher rates in samples collected in November and April and lower ones in those collected in January and February. Similarly, the textural parameters and sugar content of the two cropping systems were quite similar, but both parameters changed significantly over the harvesting season. In contrast, phenolic profile, total phenolics and antioxidant activity were significantly affected by the two cropping systems as well as by harvest time. Artichoke heads from ORG had higher levels of chlorogenic acid and total phenols alongside with a higher antioxidant capacity compared to CONV heads. It can be concluded that while the postharvest behaviour and several quality traits of ORG and CONV samples did not differ significantly, others such as the phenolic compounds and the antioxidant capacity, were higher in ORG artichokes. As a result, the consumption of ORG artichokes may be more beneficial for human health than CONV one.

1. Intoduction

Organic farming is an alternative method of food production, which differs from conventional ones for the non-use of synthetic chemicals (pesticides and fertilizers), to prevent food contamination, and soil pollution and fertility. Many people choose organic food, associating organic-based dietary models with a healthier and more environmentally friendly lifestyle. For this reason, consumers are willing to pay a higher price for organic products, although the real nutritional benefits and advantages linked to biodiversity and environmental sustainability of organic farming are controversial (Baranski et al., 2017; Hurtado-Barroso et al., 2019).

Although most studies report differences between organic and conventional food, there is no common agreement on which are nutritionally better (Hurtado-Barroso et al., 2019). Many reports have shown that organic food can offer better nutritional and nutraceutical properties containing more macronutrients, phytochemicals, and antioxidant properties (Olivera et al., 2013; Aina et al., 2019; Hurtado-Barroso et al., 2019; Ren et al., 2017). In contrast, other studies have shown no meaningful difference in nutrient and nutraceutical components between organic and conventional horticultural products (Lombardo et al., 2012; Bach et al., 2015; Mazzoncini et al., 2015; Suciu et al., 2019).

The contrasting results found in literature may depend mainly on genotype–environment interactions (Lombardi-Boccia et al., 2004; Faller and Fialho, 2010). The genotype and the environmental factors (e.g., cultivar, culture in greenhouses or fields, organic practice, hydroponic culture) have a major effect on the concentrations and proportions of different nutritional and nutraceutical compounds such as polyphenols (Lombardi-Boccia et al., 2004; Fess and Benedito 2018). For example, some studies of organic carrots and tomatoes have shown

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higher levels of secondary metabolites than conventional ones, while other have reported opposite results (Sikora et al., 2009; Pieper et al., 2009; Rossi et al., 2008; Krejčová et al., 2016). In conventional plums, total polyphenol content was higher than in organic ones whereas ascorbic acid, alpha-tocopherol, and beta-carotene were higher in organic samples. On the other hand, phenolic acid content was similar in organic and conventional eggplant (Chassy et al., 2006; D'Evoli et al., 2010; Luthria et al., 2010).

Yet, data from the literature report that there has not been a clear tendency in favour of organic or conventional agriculture regarding the antioxidant capacity, as the antioxidant capacity is related to the concentration and type of phenolic compounds, which are strongly dependent on the interaction between the genotype and the cultivation system (Rice-Evans et al., 1997; Faller and Fialho, 2010). Antioxidant capacities of organic and conventional peaches and pears were similar, although the specific antioxidant compounds varied between the fruits and agricultural types (Carbonaro et al., 2002). Considering the scientific literature related to nutritional properties and in particularly to secondary metabolites of organic products versus conventional ones, it is not possible to conclude that an organic production system is better than a conventional system (Hurtado-Barroso et al., 2019; Chausali and Saxena, 2021).

Overall results are contradictory and difficult to interpret because besides differences due to environmental conditions, farming practices, and cultivar an important role is also played by sampling and analytical methods; thus, additional studies are necessary (Fess and Benedito, 2018).

Specifically, to artichoke, to our knowledge, just a few research projects compared the chemical composition of organic artichoke heads versus conventional ones. Additionally, there is no study regarding the comparison of the respiratory activity, texture properties, fibre and sugar content of the heads (Spanu et al., 2018; Leskovar and Othman, 2018; Othman and Leskovar, 2018; Yildirim et al., 2020). Yet, results related to comparison between organic and conventional grown artichoke are contrasting according to the cultivar taken into consideration. In 'Bayrampaşa' artichoke, Yildirim et al. (2020) found enhanced cynarin (the most abundant compound), chlorogenic acid, luteolin, flavonoids amounts and an augmented antioxidant capacity in organic grown samples than in the conventional ones, but there was no difference in total phenolic content.

Spanu et al. (2018) in heads of 'Spinoso sardo' found higher total polyphenol compounds content in non-conventional growing system than conventional one, but several individual phenolics were either higher in conventional cropping system or showed contrasting trends in the two years of experimentation. For example, the content of apigenin-7-O-glucuronide was higher in conventional (CONV) management system than organic (ORG), whereas the concentration of the dihydroxycinnamic acids, dicaffeoylquinic acids and flavonoids differed with the harvesting dates between January and March. Yet, while chlorogenic acid was the most abundant phenol compound found in artichoke heads, cynarin was absent.

In a comparative study between an organic system and a conventional one, of different artichoke cultivars, Leskovar and Othman (2018) found that conventional management improved chlorophyll content index, leaf area index, stomatal conductance, photosynthesis and marketable yield. Furthermore, they also found that the chlorogenic acid and cynarin content in artichoke heads was affected by cultivars rather than management systems.

Globe artichoke represents an important source of bioactive and nutraceutical compounds with protective potentials for human health (hepatoprotective action, antitumor and hypocholesterolemic activity) (Fratianni et al., 2007; Lattanzio et al., 2009; De Falco et al., 2015). The consumption of artichokes has been linked to a reduction in cholesterol levels and improved heart health. This may be due to the ability of artichoke extract to inhibit the enzyme HMG-CoA reductase, which is involved in cholesterol synthesis (Gebhardt, 1998). Artichokes are also a good source of inulin, a type of dietary fiber that can help to regulate blood sugar levels. Inulin helps slow down the digestion of carbohydrates, preventing rapid spikes in blood sugar levels, which can be beneficial for those with diabetes (Lattanzio et al., 2009). Artichokes are rich in antioxidants, which can help to protect the body against damage from free radicals. This may help to reduce the risk of certain chronic diseases, such as cancer and heart disease (Ceccarelli et al., 2010).

Caffeic acid derivatives are the main phenolic compounds in artichoke heads such as caffeoylquinic acid derivatives. Among these, chlorogenic acid represents one of the most important compounds (Lattanzio et al., 2009; Lombardo et al., 2010; Pandino et al., 2011). Other phenolics which contribute to the potential health-promoting effects of globe artichoke are apigenin and luteolin flavonoids (Schütz et al., 2004; Gouveia and Castilho, 2012).

Thanks to the concomitant high content of nutritional and phytochemical compounds, globe artichoke has been used both as a food and as a medicine since ancient time and the nutritional and nutraceutical composition and properties has been extensively studied (Chevallier 1996).

The phenolic composition and concentration can be affected by environmental and genetic factors, growing stage, horticultural practices, and part of plant analysed (Pandino et al., 2011; Negro et al., 2016; Palermo et al., 2013; Allahdadi et al., 2020).

In Southern Italian regions, artichoke is mainly cultivated as an annual crop with a summer implantation of dormant offshoots subjected to a forcing production technique which anticipates the harvesting time to October-November and a harvesting window that ends in April. As a result, physical and nutritional quality change markedly with the succession of cuts over the production cycle (Pisanu et al., 2009). This agronomic technique, that aims to attain an early fresh product that ensures good economic returns for farmers, is based on a large use of mineral fertilizers with a surplus of nitrogen (Deligios et al., 2019). The conversion of the artichoke crop system towards a more sustainable application of conventional fertilizer or organic practices is desirable as it can contribute to a significant reduction of fertilizers input while preserving the environment. However, due to the lack of information, it is not clear how the adoption of an alternative organic cultivation system to the conventional one can affect the physiology and quality of the artichoke head. The only study where a comparison of the nutritional properties of organic versus conventional artichokes was carried out, considered different cuts but only concentrated in the central phase of the production cycle (Spanu et al., 2018).

Therefore, the objective of this study was to evaluate the effects of an organic system versus a conventional one on the physiological, physicochemical properties, content of bioactive compounds and antioxidant activity of globe artichoke cv. Spinoso Sardo (which at present is produced almost exclusively using conventional cropping systems) during the entire production cycle (November–April).

2. Materials and methods

2.1. Site description and crop management

The experiment was carried out at a private farm located in Uri, Sardinia (Italy, 40° N, 8° E, 128 m a. s. l.) during three consecutive growing seasons from the summer of 2018 to 2021.

The climate condition of the experimental site is Mediterranean, characterized by temperate and rainy winters followed by warm summers with a 4-month drought period from May to August, coinciding with the highest temperatures (Seager et al., 2019).

The average 30-year annual precipitation is around 715 mm mostly concentrated in the autumn and winter seasons (October to January). During the studied period, the mean minimum and maximum temperatures, recorded by a weather station located on site, were 9 °C in January and 28 °C in August, respectively.

The soil is of alluvial origin (Haplic Luvisols and Gleyic Luvisols) characterized by a clay-loam texture, pH 8.1, total nitrogen content 1.20 g kg^{-1} and soil organic matter content 1.6%.

Globe artichoke (*Cynara cardunculus* L. var. *scolymus* L.) cv. Spinoso sardo subjected to the traditional forcing technique (De Menna et al., 2016, 2018) was grown under two different management systems: the ordinary practice of local farmers, here indicated as conventional management (CONV), and an organic management system (ORG).

Conventional and organic managements were applied in separate sectors of the same farm with an experimental unit sector size of 2500 m^2. Indeed, as explained by Gomez and Gomez (1984) and done by other authors in previous studies (Archontoulis et al., 2011; Deligios et al., 2019), it was not feasible to include the two managements in a single experimental layout due to practical considerations such as interplot interference and cross-contamination.

Planting of semi-dormant offshoots occurred each year at the beginning of July with a farmer-modified transplanter (Wolf Pro Smartwolf, Checchi & Magli, Italy), in both managements. Globe artichoke plants were spaced 70 cm apart within each row, resulting in a total density of about 9500 plants per hectare. Irrigation was supplied by a mini-sprinkler irrigation system distributing about 6300–6500 m^3 ha^{-1} for each growing season. Daily irrigation was applied from the time of planting to the first rainfall, and it was triggered by accumulated daily evaporation reaching 35 mm (100% of maximum evapotranspiration).

The CONV management was based on a continuous globe artichoke monoculture where the crop dried residues were incorporated into the soil at the end of the growing cycle (Deligios et al., 2017, 2021). Synthetic fertilizers were supplied by taking into account soil characteristics, and crop nutrient requirements (Piras, 2013). Phosphorous (diammonium phosphate) and potassium (potassium sulphate) were supplied before planting at a rate of 170 kg ha^{-1} and 250 kg ha^{-1}, respectively. Nitrogen (urea and diammonium phosphate) fertilization (190 kg ha^{-1}) was split into two events [31 and 59 BBCH scale, Archontoulis et al. 2010]. Pest and disease controls followed the regional recommendations and weed control was achieved by mechanical means.

In the ORG system no synthetic fertilizer was used, and nutrition management was entirely based on the sowing of a legume cover crop (*Pisum sativum* L. var. Enduro, provided by ADAGLIO Sementi S.r.l., Oviglio, AL, Italy) in the globe artichoke inter-row spaces. Pea was sown at a rate of 200 kg ha^{-1} between mid-September and the first ten days of October. After the primary crop's marketable harvest period and during pea full flowering (end of April), all residues from artichoke and pea were incorporated into the soil. Pest and disease management was based on the use of microorganisms with mycoparasite activity (e.g. genus *Trichoderma*, and *Bacillus*).

Globe artichoke heads harvest started in November for each management (ORG and CONV) and growing season and lasted until the end of April.

2.2. Plant material and sample preparation

Artichoke heads were collected six times starting from November until the end of April, distancing one collection from the next one by about a month. At each sampling time, 30 commercial heads weighing about 150 g each and disease-free were selected following for each treatment. From each experimental plot (CONV and ORG), artichoke heads were sampled along the main diagonal of each plot. Artichoke heads were used for analyses after removing the first two layers of external bracts and the apical portion containing the thorns.

2.3. Chemicals

Acetonitrile, trifluoroacetic acid and methanol of HPLC-gradient grade, neochlorogenic acid, chlorogenic acid, apigenin-glucoside, glucose, fructose, and sucrose were purchased from Sigma-Aldrich Co. (Milan, Italy). Other reagents were of analytical grade. Sodium carbonate was from Merck; 2,2-diphenyl-1-picrydazyl (DPPH), Trolox (6-hydroxy-2,5,7,8-tetramethylchroman-2-carboxylic acid), and Folin–Ciocalteu phenol reagent were from Fluka (Buchs, Switzerland). Neutral detergent fiber (NDF), acid detergent fiber (ADF) and sulfuric acid were purchased from Carlo Erba Reagents (Milan Italy).

2.4. Respiratory activity

At each sampling time, respiratory activity of 6 heads of each treatment was determined after 24 h conditioning at 5 °C or 20 °C following harvest. Afterwards, determinations were done at day intervals for the next 7 d Individual heads were placed in 1 L jars, whose lids were fitted with two silicon septa and closed for 4 h for heads stored at 5 °C or 2 h for those stored at 20 °C. At the end of incubation, the headspace air was mixed for 1 min by an electrical fan fixed inside the jar. CO_2 concentrations were determined by a combined CO_2/O_2 analyser (F-940, Felix Instruments, Camas, WA USA) connected with each jar by two tubes, each one ending with a needle inserted in one of the two septa, to form a closed system. An incorporated pump in the CO_2/O_2 analyser, continually pumped headspace air through the inlet tube and reinjected, after reading, the same air into the jars through the outlet tube. The analysis lasted until the reading values of CO_2 was constant, and this took about 60 s. Respiration activity, as release of CO_2, was expressed as μg CO_2 Kg^{-1} s^{-1}.

2.5. Determination of texture properties and fibres content

The texture properties were determined on individual bracts. A testing machine (model DO-FB 0.5 TS, Zwick-Roell, Ulm, Germany) was used to simultaneously determine bracts resistance (F Max) to penetration of a 1.2 mm diameter cylindrical plunger with flat face, moving at a speed of 3.3 mm s^{-1}, and surface deformation of the bracts measured before penetration of the plunger (L at F max). The two parameters, F Max, and L at F Max were expressed as newton (N) and mm respectively. For each treatment the first external bracts were discarded and the next 30 bracts from 12 artichoke heads were used for measurements. The test was performed in the central area of each bract at the point of transition of the colour from yellow to green.

A Ankom fibre Analyzer (model A200IAnkom Technology, NY, USA) was employed to determine fibers content. Neutral and acid detergent fibres (NDF and ADF) and acid detergent lignin (ADL) were determined according to Van Soest et al. (1991) procedure. The cellulose content was calculated as ADF minus ADL, hemicellulose as the difference between NDF and ADF, and lignin as the ADL value.

2.6. Sample preparation

25 g of sample, obtained by taking thin slices cut lengthwise from 12 artichoke heads, were mixed using an immersion blender (model RCSM-350-400P, Royal Catering, Italy) with 50 ml of methanol/water (80/20 v/v) extracting solution until a fine suspension is obtained. After 30 min in agitation at room temperature and in the dark, the suspension was centrifuged for 15 min at 13,000 g (Centurion Scientific Ltd, West Sussex, England) and the supernatant, filtered through a 0.45 mm acetate cellulose filter, was employed for the analyses of carbohydrates, phenolic compounds, total phenols content, and antioxidant activity. Each analysis was accomplished in triplicates.

2.7. Carbohydrates, phenolic compounds, total phenol content, and antioxidant activity analysis

Carbohydrates analysis and polyphenolics profile characterization was carried out by a HPLC system (LaChrom Merck-Hitachi liquid chromatograph, Hitachi Ltd., Tokyo, Japan) consisting of a D-7000 system manager, L-7100 pump, L-7200 autosampler was employed. For carbohydrates analysis the HPLC system was coupled with an evaporative light scattering detector (ELSD SEDEX 60LT, France), and a BIO-Rad

Aminex fast carbohydrate lead resin ionic form column (100 × 7.8 i.d.) with a BIO-Rad Carbo-P micro-guard cartridge thermostated at 80 °C according to the procedure described by Palma et al. (2018). Stock standard solutions of each carbohydrate were prepared in ultrapure water and their quantifications was carried out by external standard calibration. The calibration curves of standards were in the range 0.16–0.042 g 100 mL^{-1}, 0.17–0.042 g 100 mL^{-1}, and 0.08–0.020 g 100 mL^{-1} with a regression equation of $y = -7E\text{-}16\times^2 + 7E\text{-}09X + 0{,}0022$ ($R^2 = 0.9998$), $y = -4E\text{-}16\times^2 + 6E\text{-}09X + 0{,}0024$ ($R^2 = 0.9995$), and $y = -4E\text{-}16\times^2 + 6E\text{-}09X + 0{,}003$ ($R^2 = 0.9999$) for sucrose, glucose, and fructose respectively (Y = analytical signal mV, X = concentration of compounds). The inter-day and intra-day precision was evaluated considering its relative standard deviation for 10 analyses of sample. Relative standard deviation ranged between 3.11–3.22%, 3.02–3.14%, and 2.68–2.98%, respectively for sucrose, glucose, and fructose. Detection limits were 0.006 for sucrose, 0.008 for glucose, and 0.005 gL^{-1} for fructose.

For phenolics compounds quantification and profile identification, the HPLC system was coupled with L-7455 photodiode detector (DAD) and a C18 Prevail column (250 mm x.4.6 mm, 5 μ, Alltech, Milan, Italy), with a Alltech C18 precolumn (7.5 mm x 4.6 mm I.D.). HPLC elution was carried out at 30 °C. The solvent gradient was performed by varying the proportion of solvent A (H_2O with 0.1% trifluoroacetic acid) and solvent B (CH3CN with 0.1% trifluoroacetic acid) as follows: initial condition 5% B; at 60 min, 25% B; at 70 min, 5% B; with a flow rate of 1 mL/min. The chromatogram was monitored simultaneously at 280 and 330 nm. Calculation of concentrations for neochlorogenic acid, chlorogenic acid and apigenin-glucoside, was based on external standards while the concentration of the other compounds detected was expressed as chlorogenic acid equivalent (g kg^{-1}).

The calibration curves of standard compounds were linear in the range of 10–100 μg mL^{-1}. The regression equation of neochlorogenic acid, chlorogenic acid and apigenin-glucoside, were $y = 10626X – 3696$ ($R^2 = 0.9995$), $y = 14574X + 7047{,}6$ ($R^2 = 0.9996$), $y = 8304{,}7X - 2360{,}4$ ($R^2 = 0.9994$).

The inter-day and intra-day precision results fall within the acceptance criteria of 15% of the theoretical value. The lowest concentration of neochlorogenic acid, chlorogenic acid and apigenin-glucoside in a simple that could be detected and the lowest concentration in a sample that could be accurately quantitated was 2.02, 1.12, 2.23 μg mL^{-1} and 5.92, 3.26, 6.31 μg mL^{-1}, respectively.

Phenolics compounds were identified by LC-electrospray ionization (ESI) MS analysis using an Agilent Technologies (Palo Alto, CA, USA) 1100 series LC/MSD equipped with a diode-array detector (DAD). A chemstation HP A.10.02 was used for data analysis.

Total phenolic content was determined according to the Folin-Ciocalteu colorimetric method (Singleton and Rossi, 1965). The absorbance was achieved at 760 nm by a UV–vis spectrophotometer (Varian Cary 50, Netherlands). Total phenolic content was expressed as mg kg^{-1} of gallic acid equivalents. Antioxidant activity was assessed using the free radical DPPH (2,2-diphenyl-1-picrylhydrazyl). The mixture containing 3 mL of a methanol solution of 0.16 mM DPPH and 100 mL of sample, was allowed to react for 15 min in a cuvette. The absorbance of the DPPH solution was determined at 515 nm by a UV–vis spectrophotometer. Antioxidant activity was expressed as mmol Kg^{-1} of Trolox equivalent antioxidant capacity (TEAC).

2.8. Statistical analysis

Statistical analysis was performed using Statgraphics Centurion software (Herndon, VA, USA), version XV Professional statistical program. The experiment was considered as a 6 × 2 randomized factorial design in ANOVA, where harvest time (S) had six levels and treatments had two levels (Conventional and Organic). The number of replications was six for respiration, 30 for resistance to penetration and deformation, and 3 for all the other parameters. When the number of means to compare was higher than two, the Tukey's multiple range test at $P<0.05$ was used.

The Pearson correlation coefficient (r) and P-Value were used to evaluate the correlation between texture properties and fibres content. Probability values of $p < 0.05$ were considered statistically significant.

3. Results and discussion

3.1. Respiratory activity

Respiratory activity was significantly affected by harvest time, but not by treatments (Table 1).

It was higher in samples collected in November and April and lower in January and February (Fig. 1A and B). Detected differences can be attributed to weather conditions, particularly the ambient temperature, and the phenological stage of the crop. The average respiratory rate measured at 5 °C was about 13 and 14.5 μg CO_2 kg^{-1} s^{-1} in November and April respectively and about 11 μg CO_2 kg^{-1} s^{-1} in January-February, while at 20 °C it averaged 42 and 37–40 μg CO_2 kg^{-1} s^{-1} in November-April and January-February, respectively (Fig. 1A and B). Similar results were found by Gimenez et al. (2022) in 'Blanca de Tudela' artichoke, where the respiratory activity at harvest was higher in spring compared to winter. Respiration rate detected in 'Spinoso sardo' artichokes was similar to that of 'Blanca de Tudela' artichokes (Gil-Izquierdo et al., 2002; Gimenez et al.; 2022), but higher than values reported by Kader (2002). At 5 °C, during the 7 d of observation, a constant decrease in respiratory activity occurred in both cropping systems over the whole collecting period, with values ranging from 5.1 to 7 μg CO_2 kg^{-1} s^{-1}, while at 20 °C respiration changed slightly (data not shown). To our knowledge, no data are reported about the respiratory activity of the cv. Spinoso Sardo artichoke. The respiratory activity detected in our research fell in the range reported for other cultivars (Suslow and Cantwell 1997; García-Martínez et al., 2017).

Although no information is available on the comparison between respiratory activity of organic vs conventional artichoke heads, the little information available for other fruit and vegetables is contrasting. Peck et al. (2006) did not observe significant effects in respiration rates and ethylene production in apples grown with different cropping systems (organic, conventional or, integrated). Similarly, Amodio et al. (2007), did not detect significant differences neither after 35 d cold storage nor during the following 7 d of shelf-life at 20 °C between conventional and organic kiwifruits; however, after 3 months of cold storage the respiration rate of organically grown kiwifruits kept for an additional week at 20 °C was significantly lower than that of the conventional ones. In contrast, Amodio and Colelli (2020) found higher respiration rates in organic grown grapes than in conventional ones.

Respiration is considered an important indicator of cellular metabolic activity and in general low values are positively correlated with the extension of post-harvest life of horticultural products while faster respiration rates will result in a faster depletion of nutritional compound, loss of saleable weight, poorer flavour, and thus reduced product quality (Fonseca et al., 2002; Kader 2002).

Thus, our overall results indicate no significant difference between the metabolic activity of e organic and conventional artichoke heads.

3.2. Textural properties and fibre content

Texture is a critical quality attribute in artichoke as tissue consistency represents an important parameter that consumers consider when choosing a product. It changed significantly over the harvesting period but was not affected by the treatments (Table 1). The results for the texture parameters are reported in Fig. 2A and B

In fact, as shown in Fig. 2A and B, the maximum force required for penetration (Fmax) as well as the deformation of the bracts before penetration (L at F max), did not differ significantly between the two cropping systems. However, both parameters changed significantly over

Table 1
. Multifactor ANOVA analysis of detected parameters of 'Spinoso Sardo' artichoke heads as affected by harvest time (S) and agronomic management (T) (conventional vs organic).

SOURCE	ANOVA SUMMARY Harvest time (S)		Treatments (T)		S x R	
	Df	F value	Df	F value	Df	F value
Respiration at 5°C	5	17.31***	1	1.31ns	5	0.75ns
						757
Respiration at 20°C	5	18.44***	1	0.44ns	5	1.29ns
Resistance to penetration	5	43.09***	1	0.18ns	5	0.49ns
Deformation	5	109.8***	1	0.47ns	5	1.12ns
Neutral detergent fiber (NDF)	5	25.31***	1	0.481ns	5	0.17ns
Acid detergent fiber (ADF)	5	11.16***	1	0.25ns	5	0.62ns
Acid detergent lignin (ADL)	5	23.38***	1	0.50ns	5	0.24ns
Hemicellulose	5	5.28**	1	0.93ns	5	0.12ns
Cellulose	5	3.83*	1	0.64ns	5	0.30ns
Sucrose	5	55.55***	1	1.49ns	5	0.53ns
Glucose	5	12.96***	1	1.36ns	5	0.52ns
Fructose	5	5.97**	1	0.01ns	5	1.91ns
Total sugars	5	27.90***	1	2.15ns	5	0.65ns
Antioxidant activity (TEAC)	5	261.25***	1	33.60***	5	0.84ns
Total phenolics content	5	116.40***	1	46.63***	5	0.72ns
Neochlorogenic	5	45.10***	1	11.20**	5	1.56ns
Chlorogenic	5	141.08***	1	93.55***	5	2.80*
1-O-caffeoylquinic	5	7.87***	1	24.77***	5	2.13ns
3,5-O-dicaffeoylquinic	5	40.13***	1	0.04ns	5	0.40ns
		30.12***				
1,5-O-dicaffeoylquinic	5	18.24***	1	0.26ns	5	0.46ns
Apigenin 7-O-glucoside	5	26.42***	1	0.89ns	5	1.40ns

Significant at: * P<0.05, ** P<0.01, *** P<0.001.
ns non-significant.
Df = degrees of freedom.

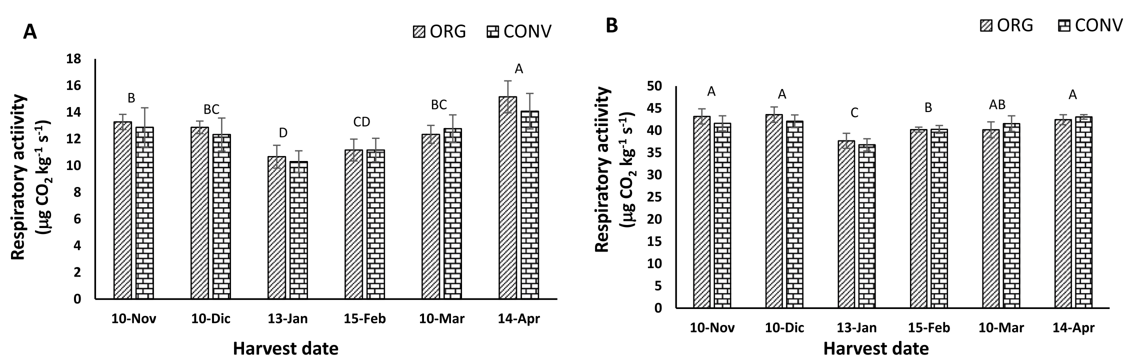

Fig. 1. Respiration at 5° (A) or 20 °C (B) of organic (ORG) and conventional (CONV) artichokes at different harvest dates. Vertical bars represent the standard deviation (n= 6). For each storage time means followed by unlike lowercases denote a significant difference between BIO and CONV treatments at P<0.05; those not followed by any letter are not significantly different at P<0.05. Unlike uppercases letters denote differences among harvest time of the averages between CON and ORG at P<0.05; means separation was accomplished by the Tukey test.

the sampling period; in January and February, penetration test as well as deformation test reached the lowest values (about 14.5 N and 3 mm), while in November and April they showed the highest values, accounting about 20 N and 3.5 and 3.9 mm, respectively, confirming that bracts tended to be leatherier. Similarly, Di Salvo et al. (2014) in a cutting test, found the lowest values in January/February and the highest in April.

Dietary fibres, which represent the non-digestible fraction by humans of the edible portion of horticultural products, include cellulose, hemicellulose, and lignin: their content is influenced by several factors such as pedoclimatic conditions and cropping systems (Dhingra et al., 2012; Pandino et al., 2020). The content and type of fibre in food is important as it can influence the textural properties, rheological behaviour, and sensory attributes.

Artichokes are among the horticultural products with the highest fibre content; nevertheless, changes associated with different with cropping systems or harvest time have only partially been explored (Fateh et al., 2009; Morsy 2019).

Tables 1 and 2, and Fig. 3 report the effect of conventional and organic cropping systems over a harvesting window of five months on globe artichoke fibres content (i.e., NDF, ADF, ADL hemicellulose and cellulose). As it is shown, the dietary fibre content was not affected by the two cropping systems but significantly changed over the harvest time.

The bracts NDF values were in good agreement with those mentioned by Attia et al. (2016) and Salman et al. (2014), while ADF, ADL, hemicellulose and cellulose showed lower concentrations than in previous studies (Allahdadi et al., 2020).

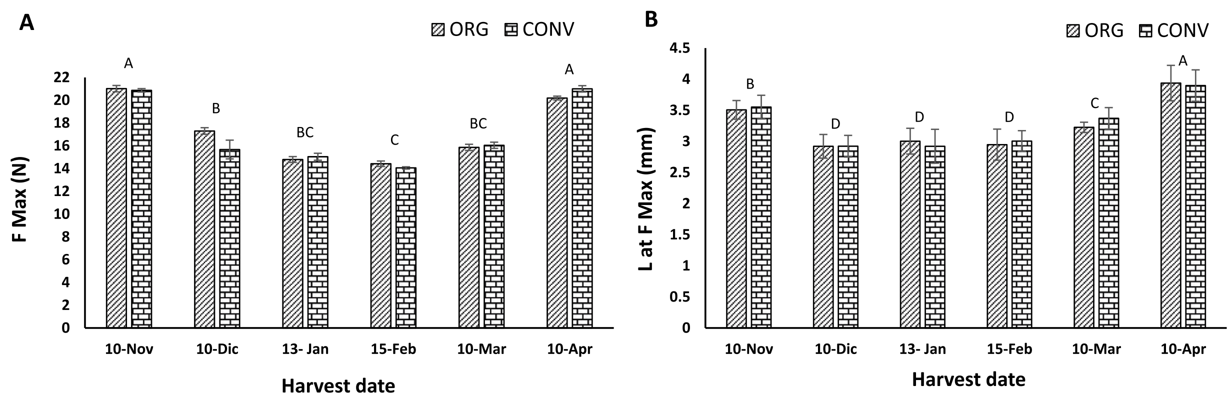

Fig. 2. . Resistance to penetration (A) and deformation (B) in organic (ORG) and conventional (CONV) artichoke bracts at different harvest dates. Vertical bars represent the standard deviation (n=30). For each storage time, means followed by unlike lowercases denote a significant difference between BIO and CONV treatments at P<0.05; those not followed by any letter are not significantly different at P<0.05. Unlike uppercases letters denote differences among harvest time of the averages between CON and ORG at P<0.05; means separation was accomplished by the Tukey test.

Table 2
. Changes in hemicellulose and cellulose in organic (ORG) and conventional (CONV) artichoke heads in different harvest date.

Harvest date	Hemicellulose	Cellulose
10 November	6.81 ± 0.94 a	8.73 ± 0.83 c
10 December	6.06 ± 1.45 a	10.53 ± 0.96 ab
13 January	4.60 ± 1.44 bc	9.56 ± 1.01 bc
5 February	4.00 ± 0.38 c	10.01 ± 0.78 bc
15 March	5.68 ± 0.49 ab	10.96 ± 0.60 a
15 April	6.39 ± 1.40 a	10.33 ± 1.23 ab

Values in a column not followed by the same letter are significantly different at P ≤0.05 according to Tukey's multiple range test; '±' stands for standard deviation of the mean (n=30).

Regarding the harvest time, the value of NDF found in our study was higher in the first and last sampling time (November and April), accounting for about 24% of total fibres, and lower in January and February, with values of about 19% for both cropping systems. Similarly, ADL content was higher in November (7.9%) and April (7.2%) and lower in January and February (about 5%) (Fig. 3C). A similar trend was observed for hemicellulose content (Table 2) and ADF (Fig. 3B). In contrast, cellulose content did not show appreciable changes, apart the samples of November, which were the lowest (Table 1).

The values of textural parameters of the bracts of both cropping systems were positively correlate with hemicellulose and lignin contents.

Pearson's correlation, tested in both cropping systems, confirmed that the bracts more resistant to penetration were richer in hemicellulose and lignin. In fact, a good correlation between the hemicellulose content and F max was detected both in ORG (r= 0.73) and in CONV (r= 0.60), whereas the r value (0.84) between Fmax and ADL content was similar in samples of both Systems (Table 3).

Although hemicellulose and lignin contents did not allow a distinction between organic and conventional artichokes, their content permitted to discriminate the artichokes collected at the beginning from those collected at the end of the harvesting season or from those harvested in the winter period.

In globe artichoke high content of dietary fibre, in particular lignin, is not appreciated by consumers because makes tissues less tender and increases the toughness of bracts (Lattanzio, 2003). Nevertheless, a diet rich in foods with high fibre levels, such as fruits and vegetables, may have a positive effect on health, preventing important pathologies such as coronary heart disease, glycaemic levels, diverticular disease, and decreasing the intestinal transit time thus favouring proliferation of the healthy gut microbiota (Dhingra et al., 2012; Dreher, 2018).

3.3. Carbohydrates, phenolic compounds, total phenol content, and antioxidant activity analysis

In Fig. 4 the content of the free sugars, sucrose, glucose, and fructose and of total sugars is reported.

Their level was not affected by the two studied cropping systems; in contrast, it significantly changed with harvest time (Table 1).

Glucose was the most representative free sugar, reaching values of about 1.0 g 100 g^{-1} (Fig. 4B); fructose and sucrose were present in similar concentrations (0.6 g 100 g^{-1}) (Fig. 4A and C).

In other species, a great variability and contrasting results have been detected between organic and conventional fruits and vegetables. Suja et al. (2017) and Hallmann (2012) found higher total sugars in organically produced taro and tomatoes over conventional crop, whereas Lombardo et al. (2012) showed opposite results, detecting higher sugars content in conventionally grown tomatoes. In contrast, Lester et al. (2007), Çandır et al. (2013) and Bach et al. (2015), found no significant difference between organic and conventional grapefruits, oranges, and carrots.

No research experiment reported in the literature has so far compared the heads' sugars content of artichokes grown organically and artichokes grown conventionally. Several studies linked the nitrates, organic ammonium, and nitrogen content to the sugar content of plant tissues (Heeb et al., 2005). Our results did not show significant differences between the two cropping systems, suggesting that the two different agronomic practices can provide the crop a similar availability of nitrogenous compounds.

Although significant changes occurred in all free sugars over the harvesting season, only in sucrose and glucose changes were remarkable (Fig. 4A–C). Sucrose peaked in January and February (about 0.6 g 100 g^{-1}), whereas was lowest in November (about 0.5 g 100 g^{-1}). Similar results were found for glucose, which reached its highest values in February and minimum in November and April. In contrast with our results, Pandino et al. (2017) found a significantly higher carbohydrate content in globe artichoke harvested in April, compared to samples collected in March. These differences besides to genetic diversity, might be due to agronomic and environmental factors (Mandim et al., 2020). Probably the lower solar radiation associated with the lower temperature of wintertime, may have stimulated sugar accumulation (Pandino et al., 2013).

Globe artichokes are rich in phenolic compounds such as caffeic acid and caffeoylquinic acid derivatives (chlorogenic acid is the most important), and flavonol glycosides. Their content can be affected by several factors, such as cropping system, environmental conditions, cultivar, and different parts of the plant (Lattanzio et al., 2009; Pandino et al., 2011). In this study, the phenolic profile in general was responsive

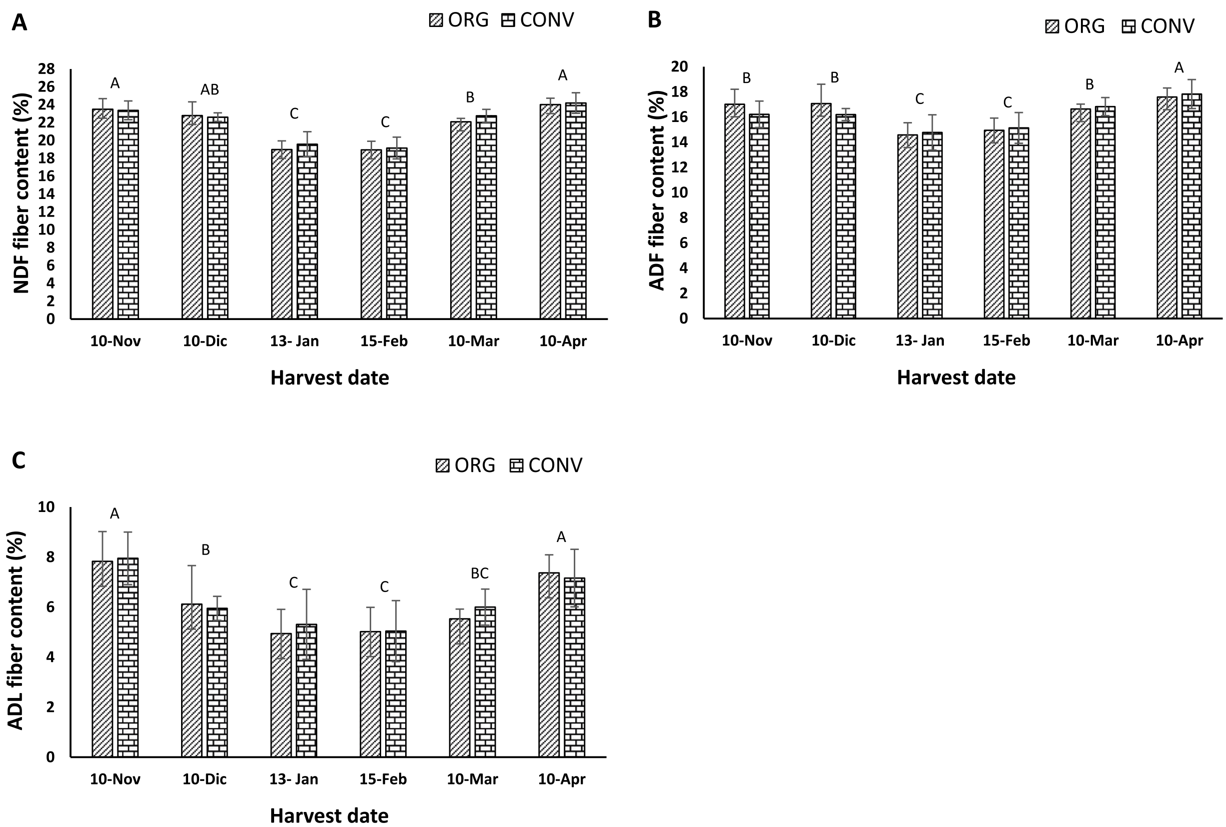

Fig. 3. . Neutral detergent fiber (NDF) (A), acid detergent fiber (ADF) (B) and acid detergent lignin (ADL) (C) in organic (ORG) and conventional (CONV) artichoke heads. Vertical bars represent the standard deviation (n=3). For each storage time, means followed by unlike lowercases denote a significant difference between BIO and CONV treatments at P<0.05; those not followed by any letter are not significantly different at P<0.05. Unlike uppercases letters denote differences among harvest time of the averages between CON and ORG at P<0.05; means separation was accomplished by the Tukey test.

Table 3
. Pearson correlation coefficient between hemicellulose or acid detergent lignin (ADL) and textural properties (Fmax and L at Fmax) in organic (ORG) or conventional (CONV) artichoke heads.

		F max	P-Value	L at F max	P-Value
ORG	Hemicellulose	0.7300	0.0006	0.5412	0.0204
CONV	Hemicellulose	0.6071	0.0075	0.3614^{ns}	0.1406
ORG	ADL	0.8378	0.0001	0.7159	0.0008
CONV	ADL	0.8379	0.0001	0.7759	0.0002

Results were expressed as statistically significant (P<0.05); ns: non-significant.

to the different cropping systems as well as to harvest time, both quantitatively and qualitatively (Table 1). The identified compounds were neochlorogenic acid (Fig. 5A), chlorogenic acid (5-O-caffeoylquinic acid) (Fig. 5B), 1-O-caffeoylquinic acid (Fig. 5C), 3,5-O-dicaffeoylquinic acid (Fig. 5D), 1,5-O-Dicaffeoylquinic acid (Fig. 5E), and Apigenin 7-O-glucoside (Fig. 5F). In accordance with results reported by Lattanzio et al. (2009), Christaki et al. (2012) and Spanu et al. (2018), chlorogenic acid (Fig. 5B), followed by 1,5-O-dicaffeoylquinic acid (Fig. 5E) and 3,5-O-dicaffeoylquinic acid (Fig. 5D) were the main compounds.

Cropping systems and harvest time can significantly affect phenolics content (Table 1). In this study, ORG samples had higher chlorogenic acid levels at all harvesting times (except April) accounting for 5–23% of total phenols. Similarly, Leskovar and Othman (2018) found higher chlorogenic acid and cynarin content in organic soil than in conventional managed one. Also, Spanu et al. (2018) found higher content of chlorogenic acid and 1-O-caffeoylquinic acid in organic cropping systems than in conventional ones, while for the other polyphenols compounds a contrasting trend emerged over the two year-lasting experiment.

For the other phenolic compounds, differences due to cropping systems were minimal and generally not significant (Table 1). Similarly, Leskovar and Othman (2018) found higher chlorogenic acid and cynarin content in organic soil than in conventional managed one.

The phenolic compounds increased as the harvesting season progressed, reaching the highest values in April, except for 1-O-caffeoylquinic acid (Fig. 5C), which underwent only slight variations. Chlorogenic acid content increased from November to April by 47% and 42%, while 1,5-O-dicaffeoylquinic acid increased by 22% and 24%, in the conventional and organic cropping system, respectively. Pandino et al. (2013) found the highest receptacle polyphenol contents in April, with chlorogenic acid and apigenin-7-O-glucuronide as predominant compounds, but, in bracts, the same authors found the highest polyphenol contents in February. Spanu et al. (2018) reported contradictory results over a two-year lasting trial detecting as a general trend a decrease in total polyphenols over the harvesting seasons, while an overall higher content was detected in unconventional system compared to the conventional one.

In this study, total phenols reflected the trend shown by individual compounds detected by chromatography (Table 1, Fig. 6): their level was significantly higher in ORG samples from January to April. Yet, as the season progressed, their content increased in both treatments peaking in April, with value of 3408 mg kg^{-1} and 3170 mg kg^{-1} in ORG and CONV, respectively.

Similarly, the antioxidant activity in ORG was affected by harvest time and treatments (Table 1) and was generally higher than in ORG (Fig. 7), apart in samples collected in November and March, when differences between the two cropping systems were smaller. Similar results are reported for organic beetroot compared to conventional one (Carillo et al. 2019). Faller and Fialho (2010) detected a greater antioxidant

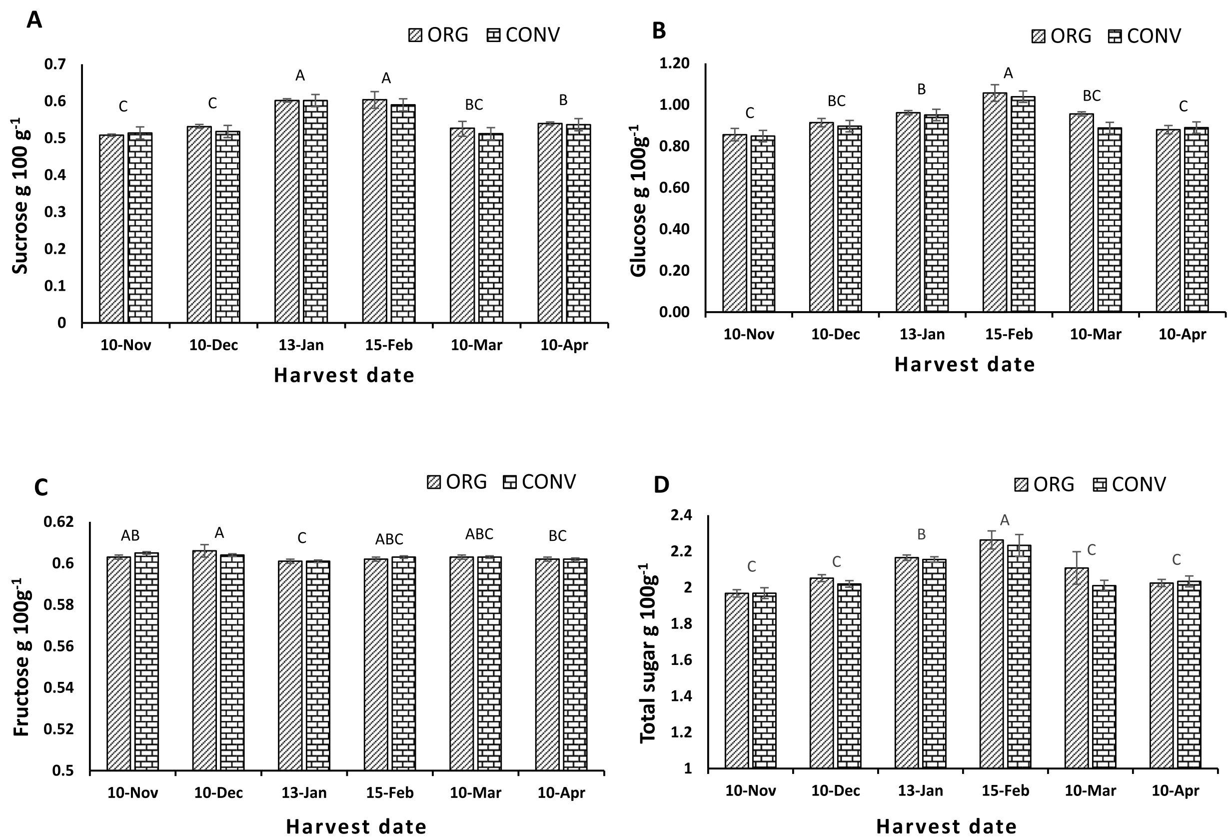

Fig. 4. Sucrose (A), glucose (B), fructose (C) and total sugar (D) content in organic (ORG) and conventional (CONV) artichoke heads as affected by harvest date and agronomic managment. For each storage time, means followed by unlike lowercases denote a significant difference between BIO and CONV treatments at P<0.05; those not followed by any letter are not significantly different at P<0.05. Unlike uppercases letters denote differences among harvest time of the averages between CON and ORG at P<0.05; means separation was accomplished by the Tukey test. Vertical bars represent the standard deviation (n=3).

activity in broccoli cultivated with conventional agronomic practices, while for potatoes and onions the higher antioxidant activity was found in organic samples: they concluded that the antioxidant activity was affected not only by the cropping system but also by the genotype.

Antioxidant activity of artichoke relies in part on phenolics content, as previously reported by several authors. Lombardo et al. (2010) and Salata et al. (2022) found a positive relationship between artichoke phenolic compounds and the antioxidant activity, which was mainly attributed to chlorogenic acid. Similarly, Leskovar and Othman (2018) detected a higher concentration of chlorogenic acid and cynarin in artichoke heads from an organic site compared to samples from a conventional one.

Results of this study show that artichoke heads of ORG synthetized higher level of phenolics and that the concentrations of individual compounds were selectively influenced by the cropping systems over the crop cycle (Table 3).

Many reports suggest that organic farming can induce, for various reasons, the production of a greater quantity of polyphenol compounds. For example, the absence of synthetic pesticides to control plant pests, by exposing the plant to stressful situations could result in an augmentation of synthesis of natural defence substances, by modulation of phenylalanine ammonia lyase activity (Woese et al., 1997; Winter and Davis, 2006; Reyes et al., 2007; Faller and Filho; 2010; Letaief et al., 2016). Furthermore, the intensive use of synthetic fertilizers capable of making nitrogen more available for the plant and in higher quantities than needed, may lead to a decrease in the production of plant secondary metabolites in conventional cropping systems (Winter and Davis 2006).

Several studies have also shown that, compared to conventional agriculture, an organic system can improve the soil physical, chemical, and microbiological properties and, consequently, enhancing water retention capacity, nutrients availability and microorganisms' activity; all these factors may positively affect total phenolics, flavonoids, and ascorbic acid content. Leskovar and Othman (2018) and Ibrahim et al. (2013) found that organic fertilizer significantly increased phenolic compounds and antioxidant activity in artichoke, *Labisia pumila* and *Ziziphus jujube*, compared to chemical fertilizer.

Regarding harvest time, the variation in polyphenol content and antioxidant activity can be explained as dependent on environmental conditions such as temperature, level of solar radiation, and hygrometric conditions. Pandino et al. (2013) found that air temperature and solar radiation were among the main parameters affecting the polyphenol content and their profile in globe artichoke heads, reaching the highest values in the bracts in February and in the receptacle in April. The same authors suggested as best harvesting window February-April for fresh consumption when the antioxidants compounds of in artichoke heads peak.

4. Conclusions

The main goal of organic farming systems is the sustainable exploitation of natural resources, while banning the use of synthetic chemicals, to obtain high quality eco-friendly food.

The effect of organic practices regarding the nutrient composition and antioxidant capacity can be different according to the plant species analysed. In general, studies dealing with organic and conventional foods have been inconclusive in highlighting any possible difference on nutritional quality, health and safety aspects, especially on nutritional value. As a result, the potential advantages of eating organic over conventional produce are unclear.

In our study two different cropping systems, organic and

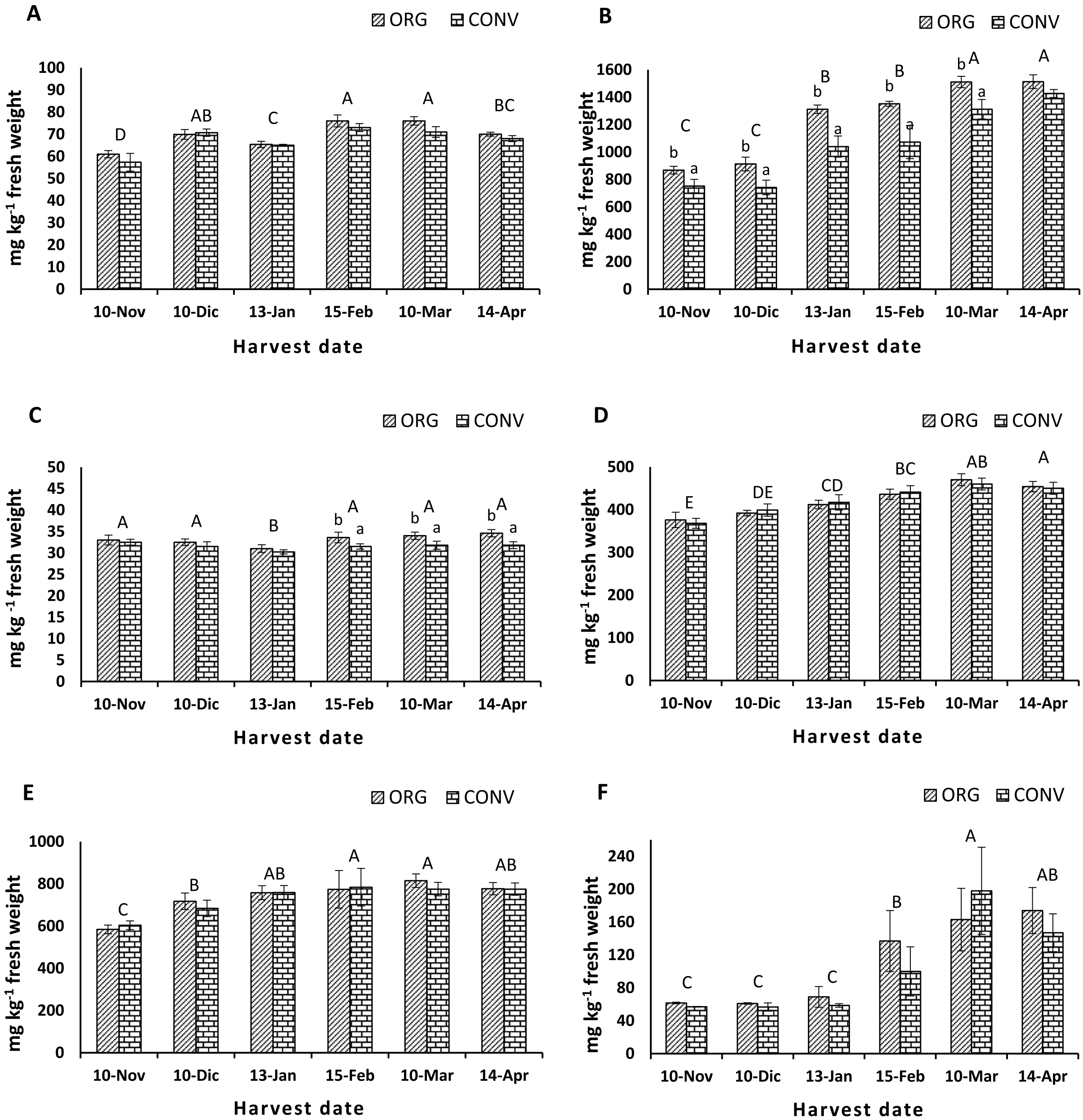

Fig. 5. . Neochlorogenic acid (A), chlorogenic acid (B), 1-O-caffeoylquinic acid (C), 3,5-O-dicaffeoylquinic (D), 1,5-O-dicaffeoylquinic (E) and apigenin-glucoside (F), in organic (ORG) and conventional (CONV) artichoke heads as affected by harvest date. For each storage time, means followed by unlike lowercases denote a significant difference between BIO and CONV treatments at $P<0.05$; those not followed by any letter are not significantly different at $P<0.05$. Unlike uppercases letters denote differences among harvest time of the averages between CON and ORG at $P<0.05$; means separation was accomplished by the Tukey test. Vertical bars represent the standard deviation (n=3).

conventional, were compared to evaluate the effect on physiology, physical properties, and chemical composition of 'Spinoso Sardo' artichoke.

Our study revealed that the two cropping systems had no significant effect on respiratory activity, textural properties, fibre content and free sugars. Conversely, artichoke heads from ORG had generally higher phenols content and antioxidant activity than those of CONV ones. The results complement the existing knowledge and highlight confirming that organic cropping systems may enhance the nutritional and nutraceutical value of artichoke heads.

CRediT authorship contribution statement

A. Palma: Conceptualization, Data curation, Validation, Methodology, Formal analysis, Writing – original draft, Writing – review & editing. **M. Cossu:** Methodology, Conceptualization, Writing – review & editing. **P.A. Deligios:** Methodology, Conceptualization, Writing – review & editing. **L. Ledda:** Methodology, Conceptualization, Writing – review & editing. **M.T. Tiloca:** Methodology, Conceptualization, Writing – review & editing. **M.M. Sassu:** Methodology. **S. D'Aquino:** Conceptualization, Data curation, Validation, Methodology, Formal analysis, Writing – original draft, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

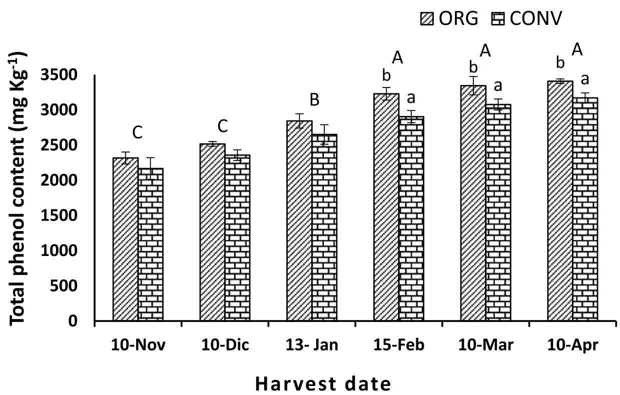

Fig. 6. Total phenolics content in organic (ORG) and conventional (CONV) artichoke heads as affected by harvest date. For each storage time, means followed by unlike lowercases denote a significant difference between BIO and CONV treatments at P<0.05; those not followed by any letter are not significantly different at P<0.05. Unlike uppercases letters denote differences among harvest time of the averages between CON and ORG at P<0.05; means separation was accomplished by the Tukey test. Vertical bars represent the standard deviation (n=3).

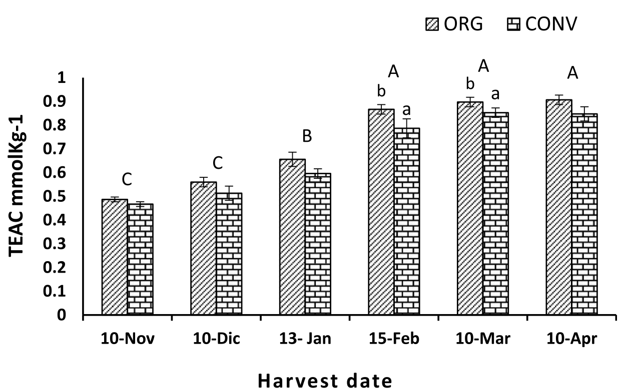

Fig. 7. Antioxidant activity (TEAC) in organic (ORG) and conventional (CONV) artichoke heads as affected by harvest date. For each storage time, means followed by unlike lowercases denote a significant difference between BIO and CONV treatments at P<0.05; those not followed by any letter are not significantly different at P<0.05. Unlike uppercases letters denote differences among harvest time of the averages between CON and ORG at P<0.05; means separation was accomplished by the Tukey test. Vertical bars represent the standard deviation (n=3).

Data availability

Data will be made available on request.

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