

The effects of plant density and irrigation on phenolic content in cauliflower

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Abstract

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This study was conducted to study the influence of plant density and irrigation on the content of phenolic compounds, i.e., phenolic acids and flavonols in cv. ‘Sevilla’ cauliflower curds. Levels of phenolic acids and flavonols were in the range of 3.0–6.2 mg and 25.4–87.8 mg/100 g of dry weight, respectively, depending on plant density and irrigation. Of the phenolic acids, caffeic acid was detected in the highest amount, followed by *p*-coumaric acid, sinapic acid, gallic acid, and ferulic acid. Of the two flavonols detected, the levels of quercetin were higher than those of kaempferol. The content of the detected phenolic acids (with the exception of ferulic acid) and both flavonols increased with increasing plant density. Furthermore, the concentration of phenolic compounds (with the exception of ferulic acid) was significantly higher under irrigation.

Keywords: *Brassica oleracea* L. var. botrytis; flavonols; phenolic acids

Numerous studies have shown that a diet rich in fruit and vegetables offers several health benefits (KRIS-ETHERTON et al. 2002; CHUN et al. 2010). Cauliflower (*Brassica oleracea* L. var. *botrytis*) is a member of the *Brassicaceae* family which is an excellent source of many health-promoting and potentially protective phytochemicals including, among others, phenolic compounds (PODSĘDEK 2007; CARTEA et al. 2011). *Brassicaceae* vegetables are also agriculturally important species that are consumed in high quantities throughout the world (FAHEY et al. 2001).

The content of phytochemicals in *Brassicaceae* vegetables may be influenced by genetics as well

as environmental factors (VALLEJO et al. 2003; GLISZCZYŃSKA-ŚWIGŁO et al. 2007; SCHMIDT et al. 2010; BJÖRKMAN et al. 2011; FALLOVO et al. 2011; PÉK et al. 2013; REILLY et al. 2014). Agronomic practices can also significantly affect the levels of these compounds (VALLEJO et al. 2003; ROBBINS et al. 2005; BJÖRKMAN et al. 2011; FALLOVO et al. 2011; PÉK et al. 2013; REILLY et al. 2014). Several studies have demonstrated that the levels of active compounds in *Brassicaceae* can be increased by the use of appropriate crop management strategies (SCHREINER 2005; KRUMBEIN et al. 2010).

A number of biotic and abiotic stresses such as intense light, UV light, water stress, extreme tem-

peratures and nutrient stress can also affect phytochemical content in plants (RAJASHEKAR et al. 2009; FORTIER et al. 2010; COGO et al. 2011; CHEYNIER et al. 2013). These factors largely affect the primary and secondary metabolism of brassica plants, resulting in the enhanced production of certain metabolites, e.g., amino acids, sugars, indoles, phenolic compounds and glucosinolates (JACOBO-VELÁZQUEZ, CISNEROS-ZEVALLOS 2012). Phenolic compounds are produced in plants as secondary metabolites (CARTEA et al. 2011). CHEYNIER et al. (2013) reported that plants produce an enormous number of phenolic secondary metabolites, which are of vital importance for their interaction with the environment.

Phenolic compounds, depending on their structure, can be classified into simple phenols, phenolic acids, hydroxycinnamic acid derivatives and flavonoids (CARTEA et al. 2011). Brassicaceae are known to contain flavonoids (SOENGAS et al. 2012), and especially flavonols (POLLASTRI, TATTINI 2011; AGATI et al. 2012). Quercetin and kaempferol are the main representatives of the flavonols (MANACH et al. 2004).

Many researchers have observed a correlation between climatic conditions (soil moisture and radiation) and the physiological parameters as well as yield of cauliflower plants (HNILIČKOVÁ, DUFFEK 2004; HNILIČKA et al. 2010; SARKAR et al. 2010; BOZKURT et al. 2011; KASHYAP 2013; YANGLEM, TUMBARE 2014). However, reports on the effects of climatic conditions and cultivation practices on phytochemical content in the cauliflower are scarce in the literature (SCHREINER 2005; KOUDELA et al. 2011). Therefore, the aim of the study was to evaluate the influence of plant density and irrigation on the content of phenolic compounds, i.e., phenolic acids and flavonols in cauliflower curds.

MATERIALS AND METHODS

The study was carried out during the 2011, 2012 and 2013 seasons at the 'Marcelin' research station, Poznań University of Life Sciences, Poland. A two-factor experiment was carried out in a randomised block design with four replications. Plants were grown at four different densities (2, 4, 6 and 8 per m²) and under two water regimes (irrigated and non-irrigated).

Plant material. Cauliflower cv. 'Sevilla' (Bejo Zaden) seeds were germinated in pots (90 cm³)

containing peat substrate for brassica vegetables (Kronen-Klasmann). Seedlings were transplanted to the field on June 29 2011, on the same date in 2012 and on July 3 2013. Each experimental plot contained 30 plants. Depending on plant density, plots were 15, 7.5, 5, or 3.75 m² in size. Cauliflower was irrigated using an on-surface system with drip lines (Aqua-traxx), placed next to plant rows. Irrigation was applied when the value of soil water potential at a depth of 25–30 cm was equal to or less than –20 kPa. The value of water potential in the soil was measured using a tensiometer (Irrometer, USA). Each dose of water consisted of 15 mm. The total amount of irrigation water during growth at various plant densities is shown in Table 1. The maximum, minimum and diurnal mean temperatures and the amount of precipitation during the experiment are presented in Table 2. Transplant and harvest dates are shown in Table 3.

Content of phenolic acids and flavonols. The extraction of the phenolic compounds from frozen and homogenated cauliflower curds was carried out in 80% methanol. The content of phenolic compounds was estimated by means of the Folin-Ciocalteu method with some modifications (DONG et al. 2012), using gallic acid as a standard. The quantification of phenolic compounds was determined after alkaline and acid hydrolysis. The methanolic extracts were treated with 2 M NaOH and boiled for 30 minutes. After acidification, phenolic compounds were extracted with diethyl ether. The diethyl fractions were then transferred into vials. Subsequently, extracts were treated with 6 M HCl, boiled for 30 min. and extracted with diethyl ether again. Both diethyl fractions were mixed, dried and redissolved in 1 ml of 80% ethanol before injection into the HPLC column.

The HPLC analysis was performed with a Waters Alliance 2695 Chromatograph with a Waters 2996 Photodiode Array Detector and an RP C-18 column with dimensions of 250 × 4 mm × 5 µm and with

Table 1. Total amount of irrigation water for plant growth at various densities

| Plant density (pcs/m ²) | Amount of irrigation water (l/m ²) | | |
|--|--|------|------|
| | 2011 | 2012 | 2013 |
| 2 | 25 | 53 | 63 |
| 4 | 83 | 104 | 104 |
| 6 | 75 | 100 | 109 |
| 8 | 96 | 119 | 118 |

Table 2. Climatic conditions during the experiment

| Year | Mean temperature (°C) | | | Precipitation (mm) |
|------|-----------------------|-----------------|-----------------|--------------------|
| | average maximum | average minimum | average diurnal | |
| 2011 | 23.3 | 13.5 | 17.7 | 214 |
| 2012 | 24.5 | 13.9 | 19.0 | 161 |
| 2013 | 21.1 | 11.1 | 16.1 | 151 |

Table 3. Transplant and harvest dates of cauliflower

| Year | Transplant date | Harvest | |
|------|-----------------|--------------|--------------|
| | | first | last |
| 2011 | June 29 | September 1 | September 13 |
| 2012 | June 29 | August 27 | September 3 |
| 2013 | July 3 | September 11 | October 19 |

an acetonitrile: 2% aqueous acetic acid mixture (pH = 2) used as an elution phase (gradient). The concentrations of phenolic compounds were determined by means of an internal standard at wavelengths of 280 nm (gallic, caffeic, *p*-coumaric, sinapic acids) and 320 nm (ferulic acid, quercetin and kaempferol). Compounds were identified by comparison of the retention time of the peak under analysis with the retention time of the standard, and by adding a specific amount of the standard to the analysed samples and repeating the analysis. The limit of detection was 1 µg/g. Gallic, caffeic, *p*-coumaric, ferulic and sinapic acids, quercetin, kaempferol, Folin-Ciocalteu's phenol reagent, sodium carbonate, NaOH and methanol were all purchased from Sigma-Aldrich (St. Louis, USA). Diethyl ether was purchased from Honeywell (Germany). Results were expressed in milligrams per 100 gram of dry weight (mg/100 g d.w.).

Statistical analysis. Statistical analyses of data were carried out using the Stat program. The phenolic content data based on plant density and irrigation were analysed using the *F*-test. Differences between the mean values were estimated with Duncan's test. Significance level was $P = 0.05$.

RESULTS AND DISCUSSION

The results of the present study on the effects of plant density and irrigation on the content of phenolic compounds, i.e., phenolic acids (gallic, caffeic, *p*-coumaric, ferulic, and sinapic) and flavonols (quercetin and kaempferol) in cauliflower curds are

shown in Tables 4 and 5. Many researchers have shown that environmental factors and agronomic conditions may influence the content of phytochemicals in cruciferous vegetables (VALLEJO et al. 2003; GLISZCZYŃSKA-ŚWIGŁO et al. 2007; SCHMIDT et al. 2010; BJÖRKMAN et al. 2011; FALLOVO et al. 2011; PÉK et al. 2013; REILLY et al. 2014). Our results showed that plant density and irrigation had a significant effect on both phenolic acid and flavonol content in cauliflower curds. Many results suggest that the content of phenolic compounds and flavonoids vary considerably in vegetables (LIN, TANG 2007), even within the same species (SULTANA, ANWAR 2008; SCHMIDT et al. 2010).

Phenolic compounds

Phenolic acids. In the present study, the most abundant phenolic acid in cauliflower curds was caffeic acid, followed by *p*-coumaric acid, sinapic acid, gallic acid and ferulic acid (Table 4). These results are in agreement with studies conducted by PELLEGRINI et al. (2010) and MAZZEO et al. (2011), but not with the study of SIKORA et al. (2012). These authors reported *p*-coumaric acid to be most abundant, followed by sinapic acid, caffeic acid and ferulic acid. In a study conducted by AHMED and ALI (2013) in cauliflower curds, gallic acid was found to be most abundant, followed by *p*-coumaric acid and caffeic acid.

Several publications have reported the phenolic acid contents of cauliflower. The results obtained by the different researchers often vary consider-

Table 4. Phenolic acid contents in cauliflower curds depending on irrigation and plant density

| Irrigation | Plant density (pcs/m ²) | | | | Mean for irrigation |
|---------------------------------|-------------------------------------|-------------------------|-------------------------|-------------------------|------------------------|
| | 2 | 4 | 6 | 8 | |
| Gallic acid (mg/100 g d.w.) | | | | | |
| With irrigation | 3.7 ^b ± 0.2 | 3.7 ^b ± 0.3 | 4.0 ^{ab} ± 0.5 | 4.4 ^a ± 0.7 | 3.9 ^A ± 0.5 |
| Without irrigation | 3.3 ^b ± 0.2 | 3.6 ^b ± 0.2 | 3.6 ^b ± 0.3 | 3.6 ^b ± 0.2 | 3.5 ^B ± 0.2 |
| Mean for plant density | 3.5 ^B ± 0.3 | 3.6 ^{AB} ± 0.3 | 3.8 ^{AB} ± 0.4 | 4.0 ^A ± 0.7 | |
| Caffeic acid (mg/100 g d.w.) | | | | | |
| With irrigation | 4.8 ^d ± 0.3 | 5.0 ^{cd} ± 0.6 | 5.5 ^{bc} ± 0.2 | 6.2 ^a ± 0.3 | 5.4 ^A ± 0.6 |
| Without irrigation | 4.5 ^d ± 0.2 | 4.8 ^d ± 0.2 | 5.1 ^{cd} ± 0.4 | 5.8 ^{ab} ± 0.2 | 5.1 ^B ± 0.6 |
| Mean for plant density | 4.6 ^C ± 0.3 | 4.9 ^C ± 0.4 | 5.3 ^B ± 0.4 | 6.0 ^A ± 0.3 | |
| P-coumaric acid (mg/100 g d.w.) | | | | | |
| With irrigation | 4.5 ^{ab} ± 0.3 | 4.5 ^{ab} ± 0.4 | 4.3 ^{ab} ± 0.4 | 4.9 ^a ± 0.5 | 4.6 ^A ± 0.4 |
| Without irrigation | 3.8 ^b ± 0.4 | 4.0 ^b ± 0.3 | 4.4 ^{ab} ± 0.2 | 4.6 ^{ab} ± 0.2 | 4.2 ^B ± 0.4 |
| Mean for plant density | 4.2 ^B ± 0.5 | 4.2 ^B ± 0.4 | 4.4 ^{AB} ± 0.3 | 4.8 ^A ± 0.4 | |
| Ferulic acid (mg/100 g d.w.) | | | | | |
| With irrigation | 3.4 ^{ab} ± 0.5 | 3.4 ^{ab} ± 0.1 | 3.2 ^{ab} ± 0.4 | 3.8 ^a ± 0.3 | 3.4 ^A ± 0.4 |
| Without irrigation | 3.0 ^b ± 0.3 | 3.3 ^{ab} ± 0.4 | 3.5 ^{ab} ± 0.2 | 3.3 ^{ab} ± 0.4 | 3.3 ^A ± 0.4 |
| Mean for plant density | 3.2 ^A ± 0.4 | 3.4 ^A ± 0.3 | 3.3 ^A ± 0.4 | 3.5 ^A ± 0.4 | |
| Sinapic acid (mg/100 g d.w.) | | | | | |
| With irrigation | 3.9 ^{bc} ± 0.4 | 4.1 ^{bc} ± 0.4 | 4.4 ^{ab} ± 0.3 | 4.6 ^a ± 0.4 | 4.3 ^A ± 0.4 |
| Without irrigation | 3.5 ^c ± 0.4 | 3.6 ^c ± 0.3 | 3.7 ^c ± 0.4 | 3.9 ^{bc} ± 0.3 | 3.7 ^B ± 0.4 |
| Mean for plant density | 3.7 ^B ± 0.4 | 3.8 ^B ± 0.4 | 4.1 ^{AB} ± 0.5 | 4.3 ^A ± 0.5 | |

*mean values and standard deviations, ($n = 4$); values with different letters are significantly different at $P = 0.05$; capital letters denote the effect of investigated factors; small letters denote the effect of the interaction of factors

ably. In this study, the content of **gallic acid** ranged from 3.3 to 4.4 mg/100 g of dry weight. Higher values of gallic acid in cauliflower curds were reported by AHMED and ALI (2013). Levels of **caffeic acid** varied between 4.5 and 6.2 mg/100 g d.w. These data are in agreement with SIKORA et al. (2012). In the studies conducted by MAZZEO et al. (2011) and PELLEGRINI et al. (2010) caffeic acid content was almost 4-fold higher. On the other hand, AHMED and ALI (2013) found 8-fold lower caffeic acid content. The differences reported by these researchers could be due to the extraction methods used (JAHANGIRI et al. 2011). The **p-coumaric acid** level (3.8–4.9 mg/100 g d.w.) was close to the value observed by PELLEGRINI et al. (2010) and approximately 2-fold lower than those detected by AHMED and ALI (2013), SIKORA et al. (2012) and MAZZEO et al. (2011). The **ferulic acid** content (3.0–3.8 mg/100 g d.w.) was comparable to the value reported by SIKORA et al. (2012). A lower content of ferulic acid in cauliflower was shown by PELLEGRINI et al. (2010) and MAZZEO et

al. (2011). **Sinapic acid** was present at a concentration of 3.5–4.6 mg/100 g d.w. A similar observation was made by PELLEGRINI et al. (2010). The amount of sinapic acid was relatively low compared with that reported by MAZZEO et al. (2011) and SIKORA et al. (2012).

Quercetin and kaempferol. In the review of PODSĘDEK (2007), it is pointed out that quercetin is the predominant flavonol in *Brassica* vegetables. However, data in the literature regarding the content of flavonols in cauliflower are often contradictory. In the present study, quercetin was the predominant flavonol in cauliflower curds (Table 5). This is in agreement with data reported by PUUPONEN-PIMIÄ et al. (2003), BAHORUN et al. (2004), AHMED and ALI (2013) and DOS REIS et al. (2015). Other authors obtained contradictory results (PELLEGRINI et al. 2010; MAZZEO et al. 2011; SIKORA et al. 2012). In a study conducted by SULTANA and ANWAR (2008) quercetin was not detected at all.

The quercetin levels in cauliflower curds ranged between 28.6 and 87.8 mg/100 g of d.w. Much low-

Table 5. The contents of quercetin and kaempferol in cauliflower curds depending on irrigation and plant density

| Irrigation | Plant density (pcs/m ²) | | | | Mean for irrigation |
|----------------------------|-------------------------------------|--------------------------|--------------------------|-------------------------|--------------------------|
| | 2 | 4 | 6 | 8 | |
| Quercetin (mg/100 g d.w.) | | | | | |
| With irrigation | 39.2 ^{d*} ± 3.7 | 66.1 ^c ± 5.5 | 76.3 ^b ± 8.0 | 87.8 ^a ± 5.4 | 67.4 ^A ± 19.3 |
| Without irrigation | 28.6 ^e ± 3.2 | 38.4 ^d ± 3.9 | 39.6 ^d ± 4.7 | 78.4 ^b ± 8.6 | 46.2 ^B ± 20.3 |
| Mean for plant density | 33.9 ^C ± 6.5 | 52.2 ^B ± 15.5 | 58.0 ^B ± 20.6 | 83.1 ^A ± 8.3 | |
| Kaempferol (mg/100 g d.w.) | | | | | |
| With irrigation | 26.1 ^e ± 2.3 | 31.6 ^e ± 2.3 | 43.6 ^c ± 1.4 | 71.4 ^a ± 6.7 | 43.2 ^A ± 18.4 |
| Without irrigation | 25.4 ^e ± 3.8 | 31.2 ^e ± 3.2 | 37.8 ^d ± 5 | 61.9 ^b ± 5.9 | 39.1 ^B ± 14.9 |
| Mean for plant density | 25.8 ^D ± 2.9 | 31.4 ^C ± 2.6 | 40.7 ^B ± 4.6 | 66.7 ^A ± 7.7 | |

*mean values and standard deviations, ($n = 4$); values with different letters are significantly different at $P = 0.05$; capital letters denote the effect of investigated factors; small letters denote the effect of the interaction of factors

er concentrations of this flavonol were confirmed in other experiments (BAHORUN et al. 2004; PELLEGRINI et al. 2010; MAZZEO et al. 2011; SIKORA et al. 2012). In contrast, AHMED and ALI (2013) reported very high levels of quercetin.

Levels of kaempferol were in the range of 25.4–71.4 mg/g d.w. The values obtained were similar to those measured by AHMED and ALI (2013). However, other researchers observed significantly lower kaempferol content (BAHORUN et al. 2004; PELLEGRINI et al. 2010; MAZZEO et al. 2011; SIKORA et al. 2012). According to KAUR et al. (2007) and LUTHRIA (2009), the differences reported in the levels of phenolic compounds could be due to the methods used.

Effects of plant density and irrigation on phenolic compounds

Studies on plant density and irrigation in cauliflower cultivation are usually concerned with the impact on yield quantity and quality (STIRLING, LANCASTER 2005; RAHMAN et al. 2007; SARKAR et al. 2010; BOZKURT et al. 2011; YANGLEM, TUMBARE 2014). Reports on the relationship between cultivation practices and phytochemical content in cauliflower are scarce in the literature (SCHREINER 2005; KOUDELA et al. 2011).

The effects of plant density on secondary compounds are the result of a combined effect of all factors involved in plant competition, such as decreased availability of light, nutrients and water (BJÖRKMAN et al. 2011). Plants densities of 16,000 to 40,000 per hectare are generally recommended for

cauliflower. In this study, density ranged from 2 to 8 plants per square meter (i.e., 20,000–80,000 per hectare). Levels of phenolic acids and flavonols were in the range of 3.0–6.2 mg and 25.4–87.8 mg/100 g d.w., respectively, depending on plant density and irrigation. The content of phenolic compounds (with the exception of ferulic acid) increased with increasing plant density. Furthermore, the concentration of these compounds (with the exception of ferulic acid) was significantly higher under irrigation.

In the present study, plant density influenced the content of phenolic acids and flavonols in cauliflower curds. According to GHASEMZADEH et al. (2010), phenolic content in shaded plants can be affected by the lower temperatures under these conditions. An increase of total phenolic content with increasing plant density was observed by LOMBARDO et al. (2009) in globe artichokes and by DANESI et al. (2014) in palm tree kale. In the study conducted by RIAD et al. (2009) planting density had no significant effect on the content of phenolic compounds in cabbage. The same results were obtained by REILLY et al. (2014) in broccoli.

Many studies have proven that environmental factors can profoundly influence phenolic content in plants (RAJASHEKAR et al. 2009). However, the results are often conflicting. To date, no studies on the climatic or agronomic basis of the content of phenolic compounds have been reported for cauliflower plants.

Drought is likely to contribute to the accumulation of phenolic compounds in plants. A positive correlation between the total phenolic content and water deficit was observed in lettuce (OH et al. 2010) and basil (KHAN et al. 2012). In studies

conducted by PÉK et al. (2014) and HELYES et al. (2014) irrigation decreased polyphenol content in the tomato. However, SÁNCHEZ-RODRÍGUEZ et al. (2012) obtained contradictory results. In the present study, cauliflower under irrigation contained more phenolic compounds in comparison to non-irrigated plants.

Studies on broccoli have shown that drought stress can lead to decreased levels of flavonoids (FORTIER et al. 2010) and phenolic compounds (ROBBINS et al. 2005, COGO et al. 2011). MAO et al. (2004) found that drought stress reduced the content of caffeic acid in sweet potato. The work of KHOSH-KHUI et al. (2012) showed that long-term drought caused a reduction in total phenolic content in thyme. On the other hand, PÉK et al. (2013) did not observed any detectable pattern of the effects of irrigation on total phenolic production in broccoli. Similarly, RAJABBEIGI et al. (2013) found that quercetin content in lettuce was not significantly affected by drought stress.

In addition, LIN et al. (2006) reported that flooding and drought stresses increased polyphenol and flavonoid content in sweet potato leaves, while KHAN et al. (2011) observed increased kaempferol content in broccoli under flooding and drought stresses.

Our results revealed that phenolic content in cauliflower curds changed depending on varying plant density. Higher plant density led to increased concentrations of phenolic compounds. The present study also demonstrates that irrigation can have a positive effect on phenolic content in cauliflower curds.

References

- Agati G., Azzarello E., Pollastri S., Tattini M. (2012): Flavonoids as antioxidants in plants: Location and functional significance. *Plant Science*, 196: 67–76.
- Ahmed F.A., Ali R.F.M. (2013): Bioactive compounds and antioxidant activity of fresh and processed white cauliflower. *BioMed Research International*, Article ID 367819.
- Bahorun T., Luximon-Ramma A., Crozier A., Aruoma O.I. (2004): Total phenol, flavonoid, proanthocyanidin and vitamin C levels and antioxidant activities of Mauritian vegetables. *Journal of the Science of Food and Agriculture*, 84: 1553–1561.
- Björkman M., Klingen I., Birch A.N.E., Bones A.M., Bruce T.J.A., Johansen T.J., Meadow R., Mølmann J., Seljåsen R., Smart L.E., Stewart D. (2011): Phytochemicals of Brassicaceae in plant protection and human health – Influences of climate, environment and agronomic practice. *Phytochemistry*, 72: 538–556.
- Bozkurt S., Uygur V., Agca N., Yalcin M. (2011): Yield responses of cauliflower (*Brassica oleracea* L. var. Botrytis) to different water and nitrogen levels in a Mediterranean coastal area. *Acta Agriculturae Scandinavica Section B – Soil and Plant Science*, 61: 183–194.
- Cartea M.E., Francisco M., Soengas P., Velasco P. (2011): Phenolic compounds in *Brassica* vegetables. *Molecules*, 16: 251–280.
- Cheynier V., Comte G., Davies K.M., Lattanzio V. (2013): Plant phenolics: Recent advances on their biosynthesis, genetics, and ecophysiology. *Plant Physiology and Biochemistry*, 72: 1–20.
- Chun O.K., Floegel A., Chung S.J., Chung C.E., Song W.O., Sung I., Koo S.I. (2010): Estimation of antioxidant intakes from diet and supplements in U.S. adults. *The Journal of Nutrition*, 140: 317–324.
- Cogo S.L.P., Chaves F.C., Schirmer M.A., Zambiasi R.C., Nora L. (2011): Low soil water content during growth contributes to preservation of green colour and bioactive compounds of cold-stored broccoli (*Brassica oleracea* L.) florets. *Postharvest Biology and Technology*, 60: 158–163.
- Danesi F., Valli V., Elementi S., D'Antuono L.F. (2014): The agronomic techniques as determinants of the phenolic content and the biological antioxidant effect of palm-tree kale. *Food and Nutrition Sciences*, 5: 1–7.
- Dong J., Zhang M., Lu L., Sun L., Xu M. (2012): Nitric oxide fumigation stimulates flavonoid and phenolic accumulation and enhances antioxidant activity of mushroom. *Food Chemistry*, 135: 1220–1225.
- Dos Reis L.C.R., Oliveira V.R., Hagen M.E.K., Jablonski A., Flôres S.H., Rios A.O. (2015): Effect of cooking on the concentration of bioactive compounds in broccoli (*Brassica oleracea* var. Avenger) and cauliflower (*Brassica oleracea* var. Alphina F₁) grown in an organic system. *Food Chemistry*, 172: 770–777.
- Fahey J.W., Zalcmann A.T., Talalay P. (2001): The chemical diversity and distribution of glucosinolates and isothiocyanates among plants. *Phytochemistry*, 56: 5–51.
- Falovo C., Schreiner M., Schwarz D., Colla G., Krumbein A. (2011): Phytochemical changes induced by different nitrogen supply forms and radiation levels in two leafy *Brassica* species. *Journal of Agricultural and Food Chemistry*, 59: 4198–4207.
- Fortier E., Desjardins Y., Tremblay N., Bélec C. (2010): Influence of irrigation and nitrogen fertilization on broccoli polyphenolics concentration. *Acta Horticulturae (ISHS)*, 856: 55–62.
- Ghasemzadeh A., Jaafar H.Z.E., Rahmat A., Wahab P.E.M., Halim M.R.A. (2010): Effect of different light intensities on

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- total phenolics and flavonoids synthesis and anti-oxidant activities in young ginger varieties (*Zingiber officinale* Roscoe). *International Journal of Molecular Sciences*, 11: 3885–3897.
- Gliszczyńska-Świąło A., Kałużewicz A., Lemańska K., Knaflowski M., Tyrakowska B. (2007): The effect of solar radiation on the flavonol content in broccoli inflorescence. *Food Chemistry*, 100: 241–245.
- Helyes L., Lugasi A., Daood H.G., Pék Z. (2014): The simultaneous effect of water supply and genotype on yield quantity, antioxidants content and composition of processing tomatoes. *Notulae Botanicae Horti Agrobotanici Cluj-Napoca*, 42: 143–149.
- Hnilička F., Koudela M., Martinkova J., Hniličková H., Hejnák V. (2010): Effect of water deficit and application of 24-epibrassinolide on gas exchange in cauliflower plants. *Scientia Agriculturae Bohemica*, 41: 15–20.
- Hniličková H., Duffek J. (2004): Water deficit and its effect on physiological manifestations in selected varieties of cauliflower (*Brassica oleracea* var. *botrytis* L.). *Scientia Agriculturae Bohemica*, 35: 57–63.
- Jacobo-Velázquez D.A., Cisneros-Zevallos L. (2012): An alternative use of horticultural crops: Stressed plants as biofactories of bioactive phenolic compounds. *Agriculture*, 2: 259–271.
- Jahangiri Y., Ghahremani H., Abedini Torghabeh J., Ataye Salehi E. (2011): Effect of temperature and solvent on the total phenolic compounds extraction from leaves of *Ficus carica*. *Journal of Chemical and Pharmaceutical Research*, 3: 253–259.
- Kashyap P.S. (2013): Response of cauliflower growth and development under water scarcity conditions in temperate zone. *HortFlora Research Spectrum*, 2: 8–13.
- Kaur C., Kumar K., Anil D., Kapoor H.C. (2007): Variations in antioxidant activity in broccoli (*Brassica oleracea* L.) cultivars. *Journal of Food Biochemistry*, 31: 621–638.
- Khan M.A.M., Ulrichs C., Mewis I. (2011): Effect of water stress and aphid herbivory on flavonoids in broccoli (*Brassica oleracea* var. *italica* Plenck). *Journal of Applied Botany and Food Quality*, 84: 178–182.
- Khan M.M., Hanif M.A., Abraham A.S. (2012): Variations in basil antioxidant contents in relations to deficit irrigation. *Journal of Medicinal Plants Research*, 6: 2220–2223.
- Khosh-Khui M., Ashiri F., Saharkhiz M.J. (2012): Effects of irrigation regimes on antioxidant activity and total phenolic content of thyme (*Thymus vulgaris* L.). *Medicinal & Aromatic Plants*, 1: 114.
- Koudela M., Hnilička F., Svozilová L., Martinkova J. (2011): Cauliflower qualities in two irrigation levels with the using of hydrophilic agent. *Horticultural Science (Prague)*, 38: 81–85.
- Kris-Etherton P.M., Hecker K.D., Bonanome A., Coval S.M., Binkoski A.E., Hilpert K.F., Griel A.E., Etherton T.D. (2002): Bioactive compounds in foods: Their role in the prevention of cardiovascular disease and cancer. *The American Journal of Medicine*, 113: 71S–88S.
- Krumbein A., Schonhof I., Smetanska I., Scheuner E.Th., Rühlmann J., Schreiner M. (2010): Improving levels of bioactive compounds in *Brassica* vegetables by crop management strategies. *Acta Horticulturae (ISHS)*, 856: 37–47.
- Lin J.Y., Tang C.Y. (2007): Determination of total phenolic and flavonoid contents in selected fruits and vegetables, as well as their stimulatory effects on mouse splenocyte proliferation. *Food Chemistry*, 101: 140–147.
- Lin K.H., Chao P.Y., Yang C.M., Cheng W.C., Lo H.F., Chang T.R. (2006): The effects of flooding and drought stresses on the antioxidant constituents in sweet potato leaves. *Botanical Studies*, 47: 417–426.
- Lombardo S., Pandino G., Mauro R., Mauromicale G. (2009): Variation of phenolic content in globe artichoke in relation to biological, technical and environmental factors. *Italian Journal of Agronomy*, 4: 181–189.
- Luthria D.L. (2009): Phenolic compounds analysis in foods and dietary supplements is not the same using different sample preparation procedures. *Acta Horticulturae*, 841: 381–388.
- Manach C., Scalbert A., Morand C., Jiménez L. (2004): Polyphenols: food sources and bioavailability. *American Journal of Clinical Nutrition*, 79: 727–747.
- Mao L., Jett L.E., Story R.N., Hammond A.M., Peterson J.K., Labonte D.R. (2004): Influence of drought stress on sweetpotato resistance to sweetpotato weevil, *Cylas formicarius* (Coleoptera: Apoinidae), and storage root chemistry. *Florida Entomologist*, 87: 261–267.
- Mazzeo T., N'Dri D., Chiavaro E., Visconti A., Fogliano V., Pellegrini N. (2011): Effect of two cooking procedures on phytochemical compounds, total antioxidant capacity and colour of selected frozen vegetables. *Food Chemistry*, 128: 627–633.
- Oh M.M., Carey E.E., Rajashekar C.B. (2010): Regulated water deficits improve phytochemical concentration in lettuce. *Journal of American Society of Horticultural Science*, 135: 223–229.
- Pék Z., Daood H., Nagyné M.G., Neményi A., Helyes L. (2013): Effect of environmental conditions and water status on the bioactive compounds of broccoli. *Central European Journal of Biology*, 8: 777–787.
- Pék Z., Szuvandzsiev P., Daood H., Neményi A., Helyes L. (2014): Effect of irrigation on yield parameters and antioxidant profiles of processing cherry tomato. *Central European Journal of Biology*, 9: 383–395.
- Pellegrini N., Chiavaro E., Gardana C., Mazzeo T., Contino D., Gallo M., Riso P., Fogliano V., Porrini M. (2010): Effect

- of different cooking methods on color, phytochemical concentration, and antioxidant capacity of raw and frozen *Brassica* vegetables. *Journal of Agricultural and Food Chemistry*, 58: 4310–4321.
- Podsędek A. (2007): Natural antioxidants and antioxidant capacity of Brassica vegetables: A review. *LWT-Food Science and Technology*, 40: 1–11.
- Pollastri S., Tattini M. (2011): Flavonols: old compounds for old roles. *Annals of Botany*, 108: 1225–1233.
- Puupponen-Pimiä R., Häkkinen S.T., Aarni M., Suortti T., Lampi A.M., Eurola M., Piironen V., Nuutila A.M., Oksman-Caldentey K.M. (2003): Blanching and long-term freezing affect various bioactive compounds of vegetables in different ways. *Journal of the Science of Food and Agriculture*, 83: 1389–1402.
- Rahman M., Iqbal M., Jilani M.S., Waseem K. (2007): Effect of different spacing on the production of cauliflower (*Brassica oleracea* var. botrytis) under the agro-climatic conditions of D.I. Khan. *Pakistan Journal of Biological Sciences*, 10: 4531–4537.
- Rajabbeigi E., Eichholz I., Beesk N., Ulrichs C., Kroh L.W., Rohn S., Huyskens-Keil S. (2013): Interaction of drought stress and UV-B radiation – impact on biomass production and flavonoid metabolism in lettuce (*Lactuca sativa* L.). *Journal of Applied Botany and Food Quality*, 86: 190–197.
- Rajashekar C.B., Carey E.E., Zhao X., Oh M.M. (2009): Health-promoting phytochemicals in fruits and vegetables: Impact of abiotic stresses and crop production practices. *Functional Plant Science and Biotechnology*, 3: 30–38.
- Reilly K., Valverde J., Finn L., Rai D.K., Brunton N., Sorensen J.C., Sorensen H., Gaffney M. (2014): Potential of cultivar and crop management to affect phytochemical content in winter-grown sprouting broccoli (*Brassica oleracea* L. var. *italica*). *Journal of the Science of Food and Agriculture*, 94: 322–330.
- Riad G., Ghoname A., Ahmed A., El-Baky M.A., Hegazi A. (2009): Cabbage nutritional quality as influenced by planting density and nitrogen fertilization. *Fruit, Vegetable and Cereal Science and Biotechnology*, 3: 68–74.
- Robbins R.J., Keck A.S., Banuelos G., Finley J.W. (2005): Cultivation conditions and selenium fertilization alter the phenolic profile, glucosinolate, and sulforaphane content of broccoli. *Journal of Medicinal Food*, 8: 204–214.
- Sánchez-Rodríguez E., Ruiz J.M., Ferreres F., Moreno D.A. (2012): Phenolic profiles of cherry tomatoes as influenced by hydric stress and rootstock technique. *Food Chemistry*, 134: 775–782.
- Sarkar S., Biswas M., Goswami S.B., Bandyopadhyay P.K. (2010): Yield and water use efficiency of cauliflower under varying irrigation frequencies and water application methods in Lower Gangetic Plain of India. *Agricultural Water Management*, 97: 1655–1662.
- Schmidt S., Zietz M., Schreiner M., Rohn S., Kroh L.W., Krumbein A. (2010): Genotypic and climatic influences on the concentration and composition of flavonoids in kale (*Brassica oleracea* var. *sabellica*). *Food Chemistry*, 119: 1293–1299.
- Schreiner M. (2005): Vegetable crop management strategies to increase the quantity of phytochemicals. *European Journal of Nutrition*, 44: 85–94.
- Sikora E., Cieřlik E., Filipiak-Florkiewicz A., Leszczyńska T. (2012): Effect of hydrothermal processing on phenolic acids and flavonols contents in selected brassica vegetables. *Acta Scientiarum Polonorum, Technologia Alimentaria*, 1: 45–51.
- Soengas P., Cartea M.E., Francisco M., Sotelo T., Velasco P. (2012): New insights into antioxidant activity of Brassica crops. *Food Chemistry*, 134: 725–733.
- Stirling K., Lancaster R. (2005): Alternative planting configurations influence cauliflower development. *Acta Horticulturae (ISHS)*, 694: 301–305.
- Sultana B., Anwar F. (2008): Flavonols (kaempferol, quercetin, myricetin) contents of selected fruits, vegetables and medicinal plants. *Food Chemistry*, 108: 879–884.
- Vallejo E., Tomás-Barberán F.A., García-Viguera C. (2003): Effect of climatic and sulphur fertilisation conditions, on phenolic compounds and vitamin C, in the inflorescences of eight broccoli cultivars. *European Food Research and Technology*, 216: 395–401.
- Yangle S.D., Tumbare A.D. (2014): Influence of irrigation regimes and fertigation levels on yield and physiological parameters in cauliflower. *The Bioscan, An International Quarterly Journal of Life Sciences*, 9: 589–594.

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