Original scientific paper
DOI: /10.5513/JCEA01/19.3.2077
Journal of Central European Agriculture, 2018, 19(3), p.593-606

# Bioactive compounds, pigment content and antioxidant capacity of selected cabbage cultivars

# Bioaktivni spojevi, pigmentni sastav i antioksidacijski kapacitet različitih kultivara kupusa

Sandra VOĆA, Jana ŠIC ŽLABUR*, Nadica DOBRIČEVIĆ, Božidar BENKO, Stjepan PLIESTIĆ, Matea FILIPOVIĆ and Ante GALIĆ

University of Zagreb Faculty of Agriculture, Svetošimunska cesta 25, 10 000 Zagreb, Croatia,
*correspondence: jszlabur@agr.hr

## Abstract

The main aim of this research was to determine the amount of bioactive compounds and antioxidants, as well as differences in chemical composition between six cabbage cultivars. Also, the amount of pigment compounds and relationship between chromaticity parameters between selected cabbage cultivars was determined. The significant differences (P≤0.0001) of all analyzed chemical parameters were determined. According to the obtained results of pigment composition, white cabbage cultivars contained the higher amounts of total chlorophylls (average 3.15 mg*g$^{-1}$ fresh weight), while red cabbage cultivars contained the higher amounts of anthocyanins (average 696.08 mg*kg$^{-1}$ fresh weight). Red cabbage cultivars contained the higher amounts of biologically active compounds. Average values of total phenols, total flavonoids, non-flavonoids and vitamin C were as follows: 172.45 mg GAE*100 g$^{-1}$ fresh weight, 88.88 mg GAE*100 g$^{-1}$ fresh weight, 83.59 mg GAE*100 g$^{-1}$ fresh weight and 28.49 mg*100 g$^{-1}$ fresh weight. Higher antioxidant capacity was determined in red cabbage cultivars. On average, in red cabbage cultivars even 3.9 times higher antioxidant capacity was determined compared to the selected white cabbage cultivars.

**Keywords:** antioxidants, *Brassica oleracea* L. var. *capitata*, chemical composition, pigments, total phenols, vitamin C

## Sažetak

Cilj ovog istraživanja bio je utvrditi količinu bioaktivnih spojeva i antioksidansa, kao i temeljne razlike kemijskog sastava između šest kultivara kupusa. Također, utvrđena je količina pojedinih pigmenata kao i povezanost parametara boje testiranih kultivara kupusa. Analizom nutritivnog sastava istraživanih kultivara kupusa utvrđene su značajne razlike (P≤0,0001) svih analiziranih parametara. Prema rezultatima pigmentnog sastava, kultivari bijelog kupusa sadržavali su veće količine ukupnih

klorofila (prosječno 3,15 mg*g$^{-1}$ svježe tvari), dok su kultivari crvenog kupusa veće količine antocijana (prosječno 696,08 mg*kg$^{-1}$ svježe tvari). Kultivari crvenog kupusa sadržavali su i veće vrijednosti biološki aktivnih spojeva. Prosječne vrijednosti ukupnih fenola, ukupnih flavonoida, neflavnoida i vitamina C iznosile su redom: 172,45 mg GAE*100 g$^{-1}$ svježe tvari, 88,88 mg GAE*100 g$^{-1}$ svježe tvari, 83,59 mg GAE*100 g$^{-1}$ svježe tvari i 28,49 mg*100 g$^{-1}$ svježe tvari. Značajno veća antioksidacijska aktivnost dokazana je u kultivarima crvenog kupusa. U prosjeku, čak 3,9 puta veća vrijednost antioksidacijskog kapaciteta utvrđena je u crvenim kultivarima u usporedbi s bijelim kultivarima kupusa.

**Keywords:** antioksidansi, *Brassica oleracea* L. var. *capitata*, kemijski sastav, pigmenti, ukupni fenoli, vitamin C

## Introduction

Cultivated cabbage cultivars show high variability in morphological characteristics and are divided into two main groups, white (*Brassica oleracea* var. *capitata* f. *alba*), common name for cabbage of green leaves and red cabbage (*Brassica oleracea* var. *capitata* f. *rubra*) (Singh et al., 2006). The characteristic color of fruits and vegetables is result of presence of natural pigments, therefore in white cabbage cultivars dominate chlorophylls (Fernández-León et al., 2010) while in red cabbage cultivars anthocyanins (Arapitsas et al., 2008). Cabbage is widely used for nutrition, primarily due to significant bioactive and antioxidant properties as well as anti-inflammatory and antibacterial action (Cartea et al., 2011; Šamec et al., 2011). Besides polyphenols, main bioactive compound in plants from Brassicaceae family is vitamin C one of the most important micronutrients (Martín-Belloso and Fortuny, 2011). Significant biological activity also express pigment compounds such as chlorophylls, carotenoids and anthocyanins (Hsu et al., 2013). The aim of this study was to determine the amount of bioactive and pigment compounds, antioxidant capacity and differences in basic chemical composition between selected white and red cabbage cultivars. Namely, similar researches of nutritional composition are rarely based on the differences between cultivars which differ by color, shape, texture and in general in the chemical composition. The results of this research can be used as a basis for the future researches of chemical composition and the content of bioactive compounds in cabbage cultivars which is due to the positive impact on human health increasingly popular ingredient in dietary supplements.

## Materials and methods

### Plant material

The research included four white (‘Bravo F1’, ‘Bronco F1’, ‘Slava’, ‘Farao F1’) and two red (‘Maestro F1’, ‘Primero F1’) cabbage cultivars bought at the local market (Zagreb, Croatia). Mentioned cabbage cultivars were bought at the local market. In the laboratory the cabbage samples (n=10 for each cabbage cultivar) with mechanical damage and visible signs of spoilage were separated. Before chemical analysis, the samples of cabbage cultivars were chopped with the laboratory

homogenizer. Prepared samples were stored at 4 °C for one day until intended analysis.

### Determination of chromaticity parameters

The color intensity of outer and inner cabbage leaves was determined with ColorTec PCM+ colorimeter (USA) by CIELAB method. Colorimeter is the three stimulus device, which means that color parameters are described by three numeric values: L, a and b. Value L indicates the intensity of light or darkness and L=0 if there is no reflection which suggesting the presence of black color, while L=100 reflection is the highest which suggesting the presence of white. Value a indicates the intensity of red or green color, so the negative a values (- a) indicate the presence of green color and a positive values (+ a) the presence of red color. Value b indicates the intensity of yellow or blue color, respectively the negative values (- b) indicates the presence of blue color and positive values (+ b) the presence of yellow.

### Determination of chemical composition, pigment and bioactive compounds content and antioxidant capacity

The analysis of basic chemical composition of selected cabbage cultivars were conducted according to the protocol of standard methods (AOAC, 1995; 2002), and included determination of following parameters: dry matter content (%), total soluble solids (%) by refractometer (A. Krüss, Germany), pH-value by pH-meter (Mettler-Toledo, Switzerland), total acids (%) by potentiometric titration, vitamin C content by titration with 2,6-p-dichlorindophenol. Total phenols content (mg GAE 100 $g^{-1}$ fresh weight) were determined by Folin-Ciocalteu colorimeter method (Ough and Amerine, 1988), total chlorophylls content (mg*$g^{-1}$ fresh weight) by spectrophotometer (Shimadzu, UV 1650 PC) according method per Holm (1954) and Wetsttein (1957); total anthocyanins content (mg*$kg^{-1}$ fresh weight) by method of disulfite bleaching (Ough and Amerine, 1988) and antioxidant capacity by spectrophotometer using the ABTS radical cation (2, 2'-azinobis (3-ethylbenzothiazoline-6-sulfonic acid)), (Re et al., 1999).

### Statistical analysis

Statistical analysis was performed using the SAS® version 9.3 (2010). Treatments were arranged in a randomized complete block design with 3 replications. Data were subjected to the one-way analysis of variance (ANOVA) according to the treatment structure. Mean values were compared by t test (LSD), and considered significantly different at P≤0.05. Correlation analysis was performed in order to determine the nature and intensity of relationships between pigment compounds and color parameters in vitro. Correlation value was numerically shown by Pearson's coefficient (r) while the significance of the coefficient was expressed by P value. Correlation coefficients with P≤0.05 were considered significant.

## Results and discussion

### Basic chemical composition

The results of basic chemical composition of selected cabbage cultivars are shown in Table 1. There were significant differences in all analyzed parameters between tested cabbage cultivars. Dry matter content (DM) of selected cultivars was in range from 7.43% ('Bronco F1') to 12.42% ('Slava'). The vegetable crops in average contain 3 to 6.7% DM (Srilakshmi, 2003). Results obtained in this research are in agreement with Salo et al. (2000) which state that cabbage dry matter content varies from 8.1 to 16.3% DM. According to the mentioned average content of cabbage dry matter, results obtained in this study are in agreement with literature data. Relatively high values of DM in selected cabbage cultivars show a high nutritional value of cabbage as vegetable crop. The total acid content (TA) was in range from 0.04 ('Farao F1') to 0.1% ('Maestro F1'; Table 1). According to Hui et al. (2010) the average TA in vegetable crops does not exceed 0.1 do 0.2%. Results of TA in this study show significant differences between white and red cabbage cultivars. The red cabbage cultivars in average contained a higher values of TA compared to the white cabbage cultivars. Namely, red cabbage cultivars also contained a higher amount of vitamin C (ascorbic acid) which significantly contributed to the increase of TA. In accordance with low total acids content, pH values in analyzed cabbage cultivars were in range from 6.05 ('Slava') to 6.42 ('Primero F1') which is in agreement with results obtained in other studies (Kalač et al., 2000; Haque et al., 2006). Total soluble solids (TSS) were in range from 6.23 ('Bronco F1') to 8.5% ('Slava'; Table 1). Obtained results of TSS in this research significantly varied depending on the cabbage cultivar. Obtained values of TSS were higher than results stated by Haque et al. (2006) and Žnidarčič et al. (2007) thus can be concluded that the genetic characteristics of certain cultivars show a significant impact on the TSS content. The ratio between total soluble solids and total acids (TSS/TA) is very important in the flavor formation for consumption of fresh fruits and vegetables. If the TSS/TA ratio is higher, the taste is more acceptable for consumers (Belitz and Grosch, 1999). According to the obtained results, the highest TSS/TA ratio was recorded in cultivar 'Farao F1', while the cultivar 'Maestro F1' stood out with the lowest TSS/TA ratio. In general, in white cabbage cultivars the higher TSS/TA was determined.

Table 1. Basic chemical composition of selected cabbage cultivars

| Cultivar | DM (%) | TA (%) | TSS (%) | TSS/TA | pH |
|---|---|---|---|---|---|
| 'Bravo F1' | $10.02^{b}$±0.21 | $0.08^{b}$±0.01 | $7.5^{bc}$±0.1 | $93.75^{cd}$±2.14 | $6.15^{c}$±0.03 |
| 'Bronco F1' | $7.43^{e}$±0.19 | $0.06^{c}$±0.02 | $6.23^{d}$±0.42 | $103.83^{c}$±4.63 | $6.22^{c}$±0.02 |
| 'Slava' | $12.42^{a}$±0.03 | $0.06^{c}$±0.01 | $8.5^{a}$±0.36 | $141.67^{b}$±3.28 | $6.05^{d}$±0.04 |
| 'Farao F1' | $9.09^{c}$±0.04 | $0.04^{d}$±0.01 | $7.57^{bc}$±0.23 | $189.25^{a}$±10.83 | $6.32^{b}$±.0.04 |
| 'Maestro F1' | $8.07^{d}$±0.02 | $0.1^{a}$±0.55 | $7.3^{c}$±0.1 | $73^{d}$±1.23 | $6.16^{c}$±0.02 |
| 'Primero F1' | $9.54^{bc}$±0.55 | $0.08^{b}$±0.03 | $8.1^{ab}$±0.01 | $101.25^{c}$±1.26 | $6.42^{a}$±0.03 |
| Pr>F | ≤0.0001 | ≤0.0001 | ≤0.0001 | ≤0.0001 | ≤0.0001 |

DM - dry matter content; TA - total acids; TSS - total soluble solids; TSS/TA - ratio of total soluble solids and total acids. Different letters indicate significant differences between mean values within each column.

## Bioactive and pigment compounds

In Table 2 are shown the results of pigment compounds content. Statistically significant differences (P≤0.0001) between cabbage cultivars were determined. The total chlorophyll and carotenoid content was only determined in white cabbage cultivars. Chlorophylls are, with carotenoids and anthocyanins, the most widespread plant pigments in nature. There are two different chemical forms of chlorophyll: blue-green chlorophyll a and yellow-green chlorophyll b (Chen, 2015). Mentioned chlorophyll types can be found in most green vegetables such as broccoli and cabbage (Fernández-León et al., 2010). In this study, in all white cabbage cultivars the total chlorophyll content was in range from 3.83 (Bronco F1) to 15.31 $mg*g^{-1}$ ('Bravo F1'). The chlorophyll content in vegetable crops is strongly influenced by growing conditions, general ecological factors and genetic characteristics (Gross, 1991) which is the main reason for such wide range of total chlorophyll content between different cabbage cultivars. The carotenoids are source of yellow, orange and red pigments in fruits and vegetables (Podsędek, 2005). In this study, carotenoids are determined only in white cabbage cultivars (Table 2). The highest concentrations of carotenoids are contained in plant tissues with higher chlorophylls content (Chen, 2015) which is also confirmed by results of this research. Carotenoids content was in range from 0.15 ('Bronco F1') to 0.42 $mg*g^{-1}$ ('Slava') and obtained results are in agreement with other literature data (Muller, 1997). Anthocyanins are determined in both red cabbage cultivars and cultivar 'Slava' which was expected due to green-purple leaves. Other literature data cited the lower anthocyanins content (Wang et al., 1997) compared to values obtained in this research. Red

cabbage significantly differs according to the anthocyanins content as compared to the other species from Brassicaceae family (Wu et al., 2006).

Table 2. The pigment composition of analyzed cabbage cultivars

| Cultivar | Chlorophyll a ($mg*g^{-1}$) | Chlorophyll b ($mg*g^{-1}$) | Total chlorophylls ($mg*g^{-1}$) | Carotenoids ($mg*g^{-1}$) | Anthocyanins ($mg*kg^{-1}$) |
|---|---|---|---|---|---|
| 'Bravo F1' | $5.21^{a}$±0.03 | $10.1^{a}$±0.05 | $15.31^{a}$±0.08 | $0.16^{c}$±0.01 | $ND^{c}$ |
| 'Bronco F1' | $1.32^{d}$±0.04 | $2.52^{d}$±0.09 | $3.83^{d}$±0.14 | $0.15^{d}$±0.01 | $ND^{c}$ |
| 'Slava' | $4.47^{b}$±0.01 | $8.84^{b}$±0.02 | $13.31^{b}$±0.03 | $0.42^{a}$±0.01 | $4.1^{c}$±1.77 |
| 'Farao F1' | $1.58^{c}$±0.02 | $3.14^{c}$±0.03 | $4.71^{c}$±0.05 | $0.29^{b}$±0.01 | $ND^{c}$ |
| 'Maestro F1' | $ND^{e}$ | $ND^{e}$ | $ND^{e}$ | $ND^{e}$ | $641.45^{b}$±3.16 |
| 'Primero F1' | $ND^{e}$ | $ND^{e}$ | $ND^{e}$ | $ND^{e}$ | $750.71^{a}$±4.09 |
| Pr>F | ≤0.0001 | ≤0.0001 | ≤0.0001 | ≤0.0001 | ≤0.0001 |

ND – not determined. Different letters indicate significant differences between mean values within each column.

The results of studied bioactive compounds in selected cabbage cultivars are shown in the Table 3. High significant statistical difference (P≤0.0001) between analyzed cabbage cultivars was determined. The vitamin C content was in range from 7.02 ('Bronco F1') to 29.46 $mg*100\ g^{-1}$ of fw ('Maestro F1'). In red cabbage cultivars significantly higher values of vitamin C content were determined compared to the white cabbage cultivars, except cultivar 'Slava'. Other literature data cites contrary values of vitamin C content in different cabbage cultivars (Singh et al., 2006; Park et al., 2014) mainly due to the differences in the cabbage genetic characteristics and different ecological factors during cultivation. Phenol compounds are, with vitamin C, the most important antioxidants in species of Brassica genus (Podsędek, 2005). Plant phenols are multipurpose, have different biological activities besides acting as reducing agents (Rice-Evans et al., 1997; Hui et al., 2006; Ignat et al., 2011). Total phenols in selected cabbage cultivars were in range from 24.76 ('Bronco F1') to 174.38 mg GAE$*100\ g^{-1}$ of fresh weight ('Maestro F1') with determined high statistical difference (P≤0.0001) between cultivars. On average, in red cabbage cultivars even 4.4 times higher values of total phenols and 2.8 times higher values of vitamin C were determined compared to the white cultivars. According to Leja et al. (2010) red cabbage cultivars contain more total phenols than white cultivars. From the white cabbage cultivars, cultivar 'Slava' emphasizes with the highest total phenol content. Considering to the highest total phenol value the highest value of non-flavonoid and flavonoid was determined in cultivar 'Maestro F1'. The lowest non-flavonoid value

was recorded in cultivar 'Bronco F1' while flavonoid in cultivar 'Farao F1'. Leja et al. (2010) determined the flavonoid content in the range from 8.3 to 8.8 mg*100 $g^{-1}$ fw for white cabbage cultivars and 23.3 to 55 mg*100 $g^{-1}$ fw for red cultivars. In this research, significantly higher values of flavonoid were determined. The total phenol, non-flavonoid and flavonoid content showed that analyzed cabbage cultivars, especially red cultivars have high nutritional value. The antioxidant activity within Brassicaceae family is in correlation to the content of vitamin C, total phenols, anthocyanins and carotenoids (Hounsome et al., 2009). Variation in antioxidant activity within Brassicaceae family can be caused by many factors: differences in cultivars, the maturity state, cultivation methods, the substrate condition and the storage conditions (Kurilich et al., 1999; Jeffery et al., 2003). Tested cabbage cultivars differed significantly (P≤0.0001) in the antioxidant capacity. The lowest antioxidant capacity was determined for cultivar 'Bronco F1', while cultivars 'Maestro F1' and 'Primero F1' had the highest determined values. In general, the red cabbage cultivars on average had 3.9 times higher antioxidant capacity compared to the white cultivars. From white cabbage cultivars, 'Slava' stood out with the highest determined antioxidant capacity. The difference between white and red cabbage cultivars in antioxidant capacity is expected due to higher content of vitamin C and total phenols in red cabbage cultivars. Also, red cabbage cultivars contain a higher anthocyanin content which are a very important antioxidants. The results of this study are similar with the results of other researches (Kusznierewicz et al., 2008; Šamec et al., 2011).

Table 3. The content of vitamin C, total phenols, non-flavonoids and flavonoids and antioxidant capacity in selected cabbage cultivars

| Cultivar | Vitamin C (mg*100 $g^{-1}$ fw) | Total phenols (mg GAE*100 $g^{-1}$ fw) | Non-flavonoids (mg GAE*100 $g^{-1}$ fw) | Flavonoids (mg GAE*100 $g^{-1}$ fw) | Antioxidant capacity (mM TE*$kg^{-1}$) |
|---|---|---|---|---|---|
| 'Bravo F1' | $7.85^{c}$±0.19 | $45.45^{d}$±0.29 | $15.34^{d}$±1.21 | $30.11^{c}$±0.75 | $0.54^{c}$±0.06 |
| 'Bronco F1' | $7.02^{c}$±0.41 | $24.76^{e}$±0.46 | $4.08^{f}$±0.39 | $20.77^{d}$±0.38 | $0.14^{e}$±0.02 |
| 'Slava' | $18.36^{b}$±0.87 | $60.36^{c}$±0.41 | $25.28^{c}$±0.1 | $35.12^{b}$±2.21 | $1.15^{b}$±0.08 |
| 'Farao F1' | $7.76^{c}$±0.49 | $24.83^{e}$±0.7 | $9.21^{e}$±0.26 | $15.62^{e}$±0.16 | $0.36^{d}$±0.01 |
| 'Maestro F1' | $29.46^{a}$±2.41 | $174.38^{a}$±2.12 | $85.16^{a}$±0.18 | $89.23^{a}$±0.75 | $2.15^{a}$±0.01 |
| 'Primero F1' | $27.53^{a}$±2.18 | $170.53^{b}$±0.38 | $82.01^{b}$±0.42 | $88.52^{a}$±1.13 | $2.14^{a}$±0.03 |
| Pr>F | ≤0.0001 | ≤0.0001 | ≤0.0001 | ≤0.0001 | ≤0.0001 |

Different letters indicate significant differences between mean values within each column.

## Chromaticity parameters

In Table 4 and Table 5 the chromaticity parameters of cabbage leaves (outer and inner) are shown. According to the results, a high statistical difference (P≤0.0001) of chromaticity parameters (L, a, b) between cultivars are determined. In white cabbage cultivars the presence of green and yellow color was determined. According to the obtained chromaticity parameters, cultivar 'Bronco F1' had the brightest and most uniformly colored outer and inner leaves of head. The darker green color of outer leaves, compared to the cultivar 'Bronco F1', had cultivar 'Farao F1', followed by 'Slava' and 'Bravo F1'. According to the results of L values of outer leaves color (Table 4), cultivar 'Bronco F1' shows the lightest coloring shade, while 'Bravo F1', the darkest shade. It was determined that there is no strong connection between color of outer and inner head leaves. The darkest green color of inner head leaves was determined for cultivar 'Slava'. Cultivars 'Maestro F1' and 'Primero F1' had the lowest L values, the positive a values and negative b values of the outer and inner head leaves. The obtained results are in agreement with its specific red coloration. Obtained results of chromaticity parameters (L, a, b) completely correspond to the visual characteristics of cultivars.

Table 4. Chromaticity parameters (L, a, b) of outer leaves of cabbage cultivars

| Cultivar | Color (visual characteristics) | Outer leaves L P≤0.0001 | a P≤0.001 | b P≤0.0001 |
|---|---|---|---|---|
| 'Bravo F1' | Green | $40.35^{cd}$±0.03 | $-4.89^{ab}$±1.12 | $11.09^{b}$±2.06 |
| 'Bronco F1' | Light green | $74.53^{a}$±1.25 | $-3.59^{ab}$±0.03 | $13.16^{b}$±0.03 |
| 'Slava' | Dark green | $45.41^{bc}$±0.06 | $-4.76^{ab}$±0.02 | $8.95^{b}$±0.01 |
| 'Farao F1' | Green | $56.23^{b}$±0.01 | $-6.96^{b}$±0.06 | $24.06^{a}$±0.01 |
| 'Maestro F1' | Dark purple | $26.69^{d}$±0.25 | $4.22^{ab}$±1.04 | $-0.03^{c}$±0.06 |
| 'Primero F1' | Purple (waxy coating) | $25.21^{e}$±0.09 | $9.63^{a}$±0.25 | $-2.13^{c}$±0.4 |

Different letters indicate significant differences between mean values within each column.

Table 5. Chromaticity parameters (L, a, b) of inner leaves of cabbage cultivars

| Cultivar | Color (visual characteristics) | Inner leaves L P≤0.02 | a P≤0.001 | b P≤0.001 |
|---|---|---|---|---|
| 'Bravo F1' | Light green | 75.86$^{a}$±0.72 | -4.7$^{d}$±0.01 | 24.39$^{a}$±0.01 |
| 'Bronco F1' | Light green | 77.37$^{a}$±0.01 | -2.45$^{c}$±0.92 | 12.43$^{b}$±0.36 |
| 'Slava' | Dark green | 62.99$^{a}$±0.04 | -4.12$^{cd}$±0.56 | 10.95$^{b}$±0.05 |
| 'Farao F1' | Green | 75.33$^{a}$±1.12 | -2.7$^{c}$±0.02 | 23.19$^{a}$±0.01 |
| 'Maestro F1' | Dark purple | 26.28$^{b}$±0.72 | 12.35$^{a}$±0.06 | -4.09$^{c}$±0.02 |
| 'Primero F1' | Dark purple | 25.71$^{b}$±0.01 | 6.19$^{b}$±1.12 | -0.64$^{c}$±0.03 |

Different letters indicate significant differences between mean values within each column.

In Tables 6, 7 and 8 are shown correlation coefficients (r) between chromaticity parameters L, a, b and pigment compounds content (total chlorophylls, total carotenoids and anthocyanins) in cabbage cultivars. Depending on the color parameter and cabbage cultivar, mainly significant differences in the relationship between outer and inner color leaves of cabbage heads were not determined. Also, significant relationships were not determined between the color of outer and inner cabbage leaves and the content of anthocyanins, chlorophylls and carotenoids with a few exceptions. For cultivar 'Bronco F1' the significant relationship between color parameters (L, a, b) of inner leaves and anthocyanin content was determined, respectively the negative correlation coefficients confirms that cultivars with higher L values, negative a values and positive b values had a lower anthocyanins concentrations. Also, for cultivar 'Maestro F1' significant correlation between total chlorophyll and carotenoid content and color parameters of outer and inner leaves was determined. The negative correlation coefficients confirm that red cabbage cultivars with determined lower L values, positive a values and negative b values did not contained the significant amounts of chlorophylls and carotenoids.

Table 6. Correlation coefficients (r) between anthocyanins content and chromaticity parameters L, a, b of outer and inner leaves in selected cabbage cultivars

| Cultivar | Outer leaves | | | Inner leaves | | |
|---|---|---|---|---|---|---|
| 'Bravo F1' | 0.17NS | -0.46NS | 0.17NS | -0.63NS | 1*** | -0.63NS |
| 'Bronco F1' | -0.25NS | 1*** | -0.25NS | -1*** | -0.77** | -1*** |
| 'Slava' | -0.05NS | 0.13 NS | 0.48NS | -0.20NS | 0.29NS | -0.2NS |
| 'Farao F1' | 0.46NS | -0.46NS | 0.5NS | -0.46NS | -0.01NS | 0.01NS |
| 'Maestro F1' | -0.23NS | 0.23NS | 0.08NS | -0.04NS | 0.01NS | -0.93** |
| 'Primero F1' | 0.01NS | 0.01NS | 0.01NS | 0.58NS | 0.12NS | -0.57NS |

* 0.01≤P≤0.05; ** P≤0.001; *** P≤0.0001; NS - not significant

Table 7. Correlation coefficients (r) between total chlorophylls content and chromaticity parameters L, a, b of outer and inner leaves in selected cabbage cultivars

| Cultivar | Outer leaves | | | Inner leaves | | |
|---|---|---|---|---|---|---|
| 'Bravo F1' | NS | 0.81* | 0.37NS | 0.84* | -0.89* | 0.28NS |
| 'Bronco F1' | 0.92*** | 0.01NS | 0.01NS | 0.39NS | 0.5NS | 0.38NS |
| 'Slava' | 0.57NS | 0.42NS | 0.62NS | -0.06NS | 0.81* | -0.05NS |
| 'Farao F1' | -0.24NS | 0.25NS | -0.44NS | -0.73NS | 0.22NS | -0.24NS |
| 'Maestro F1' | -0.93** | -0.94** | 0.86* | -0.94** | -0.88** | 1.16NS |
| 'Primero F1' | 0.61NS | 0.5NS | 0.93** | -0.88* | 0.25NS | 0.01NS |

* 0.01≤P≤0.05; ** P≤0.001; *** P≤0.0001; NS - not significant

Table 8. Correlation coefficients (r) between total carotenoids and chromaticity parameters L, a, b of outer and inner leaves in selected cabbage cultivars

| Cultivar | Outer leaves | | | Inner leaves | | |
|---|---|---|---|---|---|---|
| 'Bravo F1' | -0.17NS | 0.23NS | 0.34NS | 0.25NS | -0.63NS | -0.13NS |
| 'Bronco F1' | -0.17NS | 0.69NS | -0.68NS | -0.76NS | -0.42NS | -0.75NS |
| 'Slava' | 0.44NS | -0.25NS | 0.48NS | -0.63NS | 0.01NS | 0.62NS |
| 'Farao F1' | -0.29NS | 0.28NS | -0.63NS | 0.58NS | 0.38NS | 0.59NS |
| 'Maestro F1' | -0.93** | -0.92** | 0.86* | -0.94** | -0.88* | 0.16NS |
| 'Primero F1' | 0.61NS | 0.5NS | 0.93** | -0.88* | 0.25NS | 0.01NS |

* 0.01≤P≤0.05; ** P≤0.001; *** P≤0.0001; NS - not significant

## Conclusions

The results of study show a significant differences in cabbage cultivars. White cabbage cultivars had a significantly higher values of total chlorophylls (chlorophyll a and b) and carotenoids while in red cabbage cultivars mentioned pigments were not determined. The anthocyanins were dominant in red cabbage cultivars but presence of red pigments were also determined in white cultivar 'Slava'. The obtained results of researched plant pigments in selected cabbage cultivars are in agreement with the results of the chromaticity parameters. According to the bioactive compounds content, in red cabbage cultivars significantly higher values of vitamin C and total polyphenols was recorded and based on the higher content of bioactive compounds red cabbage cultivars show a significantly higher antioxidant capacity.

## References

AOAC (1995) Official methods of analysis. 16th edition. Washington: Association of Official Analytical Chemists.

AOAC (2002) Official methods of analysis. 17th edition. Washington: Association of Official Analytical Chemists.

Arapitsas, P., Shöberg, J. R., Turner, C. (2008) Characterisation of anthocyanins in red cabbage using high resolution liquid chromatography coupled with photodiode array detection and electrospray ionization-linear ion trap mass spectrometry. Food Chemistry, 109 (1), 219-226. DOI: https://doi.org/10.1016/j.foodchem.2007.12.030

Belitz, H. D., Grosch, W. (1999) Food chemistry. 2nd edition. Berlin: Springer.

Cartea, M. E., Francisco, M., Soengas, P., Velasco, P. (2011) Phenolic compounds in Brassica vegetables. Molecules, 16 (1), 251-280. DOI: https://doi.org/10.3390/molecules16010251

Chen, C. (2015) Pigments in fruits and vegetables: Genomics and dietetics. New York: Springer.

Fernández-León, M. F., Lazano, M., Ayuso, M. C., Fernández-León, A. M., González-Gómez, D. (2010) Fast and accurate alternative UV-chemometric method for the determination of chlorophyll A and B in broccoli (*Brassica oleracea Italica*) and cabbage (*Brassica oleracea Sabauda*) plants. Journal of Food Composition and Analysis, 23 (8), 809-813. DOI: https://doi.org/10.1016/j.jfca.2010.03.024

Gross, J. (1991) Pigments in vegetables: chlorophylls and carotenoids. New York: Van Nostrand Renhold.

Haque, K. M. F., Jahangir, A. A., Haque, M. E., Mondal, R. K., Jahanb, M. A. A, Sarkerb, M. A. M. (2006) Yield and nutritional quality of cabbage as affected by nitrogen and phosphorus fertilization. Bangladesh Journal of Scientific and Industrial Research, 41 (1), 41-46.

Holm, G. (1954) Chlorophyll mutations in barley. Acta Agriculturae Scandinavica, 4 (1), 457-471. DOI: https://doi.org/10.1080/00015125409439955

Hounsome, N., Hounsome, B., Tomos, D., Edwards-Jones, G. (2009) Changes in antioxidant compounds in white cabbage during winter storage. Postharvest Biology and Technology, 52 (2), 173-179. DOI: https://doi.org/10.1016/j.postharvbio.2008.11.004

Hsu, C. Y., Chao, P. Y., Hu, S. P., Yang, C. M. (2013) The antioxidant and free radical scavenging activities of chlorophylls and pheophytins. Food and Nutrition Sciences, 4 (8A), 1-8. DOI: http://dx.doi.org/10.4236/fns.2013.48A001

Hui, Y. H., Castell-Perez, E., Cunha, L. M., Guerro-Legarreta, I., Liang, H. H., Lo, Y. M., Marshall, D. L., Nip, W. K., Shahidi, F., Sherkat, F., Winger, R. J., Yam, K. L. (2006) Handbook of food science, technology and engineering. Boca Raton: CRC press.

Hui, Y. H., Chen, F., Nollet, L. M. L. (2010) Handbook of fruit and vegetable flavors. New Jersey: John Wiley & Sons.

Ignat, I., Volf, I., Popa, V. I. (2011) A cricital review of methods for characterisation of polyphenolic compounds in fruits and vegetables. Food Chemistry, 126 (4), 1821-1835. DOI: https://doi.org/10.1016/j.foodchem.2010.12.026

Jeffery, E. H., Brown, A. F., Kurilich, A. C., Keek, A. S., Natushenski, N., Klein, B. P. (2003) Variation in content of bioactive components in brocolli–study review. Journal of Food Composition and Analysis, 16, 323-330. DOI: https://doi.org/10.1016/S0889-1575(03)00045-0

Kalač, P., Špička, J., Križek, M., Pelikanova, T. (2000) Changes in biogenic amine concentrations during sauerkraut storage. Food Chemistry, 69 (3), 309-314. DOI: https://doi.org/10.1016/S0308-8146(99)00273-3

Kurilich, A. C., Tsau, G. J., Brown, A., Howard, L., Klein, B. P., Jeffery, E. H., Kushad, M., Wallig, M. A., Juvik, J. A. (1999) Carotene, tocopherol and ascorbate contents in subspecies of *Brassica oleracea*. Journal of Agricultural and Food Chemistry, 47 (4), 1576-1581. DOI: https://pubs.acs.org/doi/abs/10.1021/jf9810158

Kusznierewicz, B., Bartoszek, A., Wolska, L., Drzewiecki, J., Gorinstein, S., Namiesnik, J. (2008) Partial characterization of white cabbages (*Brassica oleracea* var. *capitata* f. *alba*) from different regions by glucosinolates, bioactive compounds, total antioxidant activities and proteins. LWT- Food Science and Technology, 41 (1), 1-9. DOI: https://doi.org/10.1016/j.lwt.2007.02.007

Leja, M., Karaminska, I., Kolton, A. (2010) Phenolic compounds as the major antioxidants in red cabbage. Folia Horticulturae, 22 (1), 19-24. DOI: https://doi.org/10.2478/fhort-2013-0146

Martín-Belloso, O., Fortuny, R. S. (2011) Advances in fresh-cut fruits and vegetables processing. Boca Raton: CRC Press.

Muller, H. (1997) Determination of the carotenoid content in selected vegetables and fruit by HPLC and photodoide array detection. Zeitschrift für Lebensmittel-Untersuchung und -Forschung. A, Food research and technology, 204 (2), 88-94. DOI: https://doi.org/10.1007/s002170050042

Ough, C. S., Amerine, M. A. (1988) Methods for analysis of musts and wines. New York: John Wiley & Sons.

Park, S., Valan Arasu, M., Lee, M. K., Chun, J. H., Min Seo, J., Lee, S. W., Abdulah Al-Dhabi, N., Kim, S. J. (2014) Quantification of glucosinolates, anthocyanins, free amino acids, and vitamin C in inbred lines of cabbage (*Brassica oleracea* L.). Food Chemistry, 145, 77-85. DOI: https://doi.org/10.1016/j.foodchem.2013.08.010

Podsędek, A. (2005) Natural antioxidants and antioxidant capacity of Brassica vegetables. LWT- Food Science and Technology, 40 (1), 1-11. DOI: https://doi.org/10.1016/j.lwt.2005.07.023

Re, R., Pellegrini, N., Proteggente, A., Pannala, A., Yang, M., Rice-Evans, C. A. (1999) Antioxidant activity applying an improved ABTS radical cation decolorization assay. Free Radical Biology & Medicine, 26 (9-10), 1231-1237. DOI: https://doi.org/10.1016/S0891-5849(98)00315-3

Rice-Evans, C., Miller, N., Paganga, G. (1997) Antioxidant properties of phenolic compounds. Trends in Plant Science, 2 (4), 152-159. DOI: https://doi.org/10.1016/S1360-1385(97)01018-2

Salo, T., Suojala, T., Kallela, M. (2000) The effect of fertigation on yield and nutrient uptake of cabbage, carrot and onion. Acta Horticulturae, 571, 235-241. DOI: https://dx.doi.org/10.17660/ActaHortic.2002.571.28

SAS (2010) Version 9.3. SAS Institute Inc.

Singh, J., Upadhyay, A. K., Bahadur, A., Singh, B., Singh, K. P., Rai, M. (2006) Antioxidant phytochemicals in cabbage (*Brassica oleracea* L. var. *capitata*). Scientia Horticulturae, 108 (3), 233-237. DOI: https://doi.org/10.1016/j.scienta.2006.01.017

Srilakshmi, B. (2003) Food science. 3rd edition. New Delhi: New Age International Ltd.

Šamec, S., Piljac-Žegarac, J., Bogović, M., Habjanič, K., Grúz, J. (2011) Antioxidant potency of white (*Brassica oleracea* L. var. *capitata*) and chinese (*Brassica rapa* L. var. *pekinensis* (Lour.)) cabbage: the influence of development stage, cultivar choice and seed selection. Scientia Horticulturae, 128 (2), 78-83. DOI: https://doi.org/10.1016/j.scienta.2011.01.009

Wang, H., Cao, G., Prior, R. L. (1997) Oxygen radical absorbing capacity of anthocyanins. Journal of Agricultural and Food Chemistry, 45 (2), 304-309. DOI: https://pubs.acs.org/doi/abs/10.1021/jf960421t

Wettstein, D. (1957) Chlorophyll letale und der submikroskopische Formwechsel der Plastiden. Experimental Cell Research, 12 (3), 427–434. DOI: https://doi.org/10.1016/0014-4827(57)90165-9

Wu, X., Beecher, G. R., Holden, J. M., Haytowitz, D. B., Gebhardt, S. E., Prior, R. L. (2006) Concentrations of anthocyanins in common foods in United States and estimation of normal consumption. Journal of Agricultural and Food Chemistry, 54 (11), 4069-4075. DOI: https://pubs.acs.org/doi/abs/10.1021/jf060300l

Žnidarčič, D., Kacjan-Maršić, N., Osvald, J., Požrl, T., Trdan, S. (2007) Yield and quality of early cabbage (*Brassica oleracea* L. var. *capitata*) in response to within-row plant spacing. Acta Biologica Slovenica, 89 (1), 15-23.