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## EFFECT OF COOKING ON THE CONTENT OF CAROTENOIDS AND TOCOPHEROLS IN SWEET CORN

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**Abstract:** Taste and nutritional value make sweet corn a valued plant and an important component of the human diet worldwide. Kernel nutritive composition of sweet corn has been reported in various papers, but a description of carotenoid and tocopherols profile, especially after cooking is scarce. Therefore, the present study was carried out to compare the carotenoid and tocopherol content in sweet corn before and after cooking. Contents of  $\beta$ -carotene, lutein+zeaxanthin and tocopherols ( $\delta$ -T,  $\beta$ + $\gamma$ -T,  $\alpha$ -T) in the kernels of twelve sweet corn hybrids were determined by High-Performance Liquid Chromatography (HPLC) and were expressed as the mean value of three independent measurements. Both genotype and cooking affected the content of the carotenoids and tocopherols in the kernel. The highest content of total carotenoids before and after cooking was found in hybrid ZP486/1su (27.77/45.28  $\mu$ g/g) whereas the lowest content was in hybrid ZP 355su (10.27  $\mu$ g/g) before cooking i.e. in hybrid ZP 347su (24.55  $\mu$ g/g) after cooking. The cooking resulted in a significant increase in the content of total carotenoids and tocopherols, lutein+zeaxanthin, and  $\beta$ -carotene in all hybrids, except the ZP504su in which the  $\beta$ -carotene content decreased. An increase in  $\alpha$ -tocopherol after cooking was observed in hybrids ZP485/1su and ZP484/1su, while a decrease was in hybrids ZP481/1su, ZP486/1su and ZP477/2su. The results showed that increasing micronutrient content is genotype-dependent. This study confirmed that cooking increases the nutritional value of sweet corn and gives it additional value in terms of functional food.

**Key words:** *thermal treatment, lutein, zeaxanthin, carotene, tocopherol isomers, HPLC*

## INTRODUCTION

The main factors influencing the human diet in the 21st century are nutrition and health. Besides the production of enough food for a growing population, the world has a new challenge- the improvement of foods' nutritional quality. Sweet corn is a highly consumed fresh vegetable in many parts of the world and can

be used for nutrition and as a source of phytochemical compounds.

Sweet corn is a mutation of corn at the sugary (*Su*) locus on chromosome 4 that prevents the conversion of sugar to starch (Shin, Kwon, Lee, Mi, & Kim, 2006; Hossain et al., 2015).

This mutation causes the accumulation of twice as much sugar and eight to ten times more water-soluble polysaccharides than the field corn at the milky stage of endosperm development resulting in specific sugary texture and flavour (Srdic, Pajic, Filipovic, Babic & Secanski, 2011).

The nutritional value of sweet corn kernels is related to the content of water (72.7%) and to the total content of solid parts (27.3%), which include carbohydrates (81%), proteins (13%), lipids (3.5%) and others (2.5%), (Swapna, Jadesha, & Mahadevu, 2020). Sweet corn is a relatively abundant dietary source of carotenoids and tocopherols, phytochemicals that have the antioxidant capacity to protect cells against oxidative stress and from the occurrence of other degenerative diseases. Carotenoid consumption is associated with many potential health benefits, such as cancer chemo-protection (Tanaka, Shnimizu & Moriwaki, 2012), prevention of cardiovascular disease (Agarwal, Parameswari, Vasanthi & Das, 2012), prevention of cataracts and age-related macular degeneration (Bone, Landrum, Dixon, Chen & Llerena, 2000; More, Thakre & Khodke, 2018; Ozata, 2019), decreased risk of several degenerative diseases (Obulesu, Dowlathabad & Bramhachari, 2011; Wegner & Khoramnia, 2011), protecting cells from the destructive effects of free radicals (Santocono, Zurria, Berttini, Fedeli & Falcion, 2007). Vitamin E is known as a powerful antioxidant and has anti-cancer (Saini & Keum, 2016), antihypertensive (Kizhakekuttu & Widlansky, 2010), nephroprotective (Tsuduki, Kuriyama, Nakagawa and Miyazawa, 2013), neuroprotective (Rashid, Ahsan, Siddiqui & Siddiqui, 2015), anti-inflammatory activity (Mocchegiani et al., 2014). One hundred grams of kernels, one medium to the large ear of sweet corn, provide 187 IU or 6% of the daily requirement of vitamin-A and about 2.2% of the recommended daily allowance of vitamin E level (Xie et al., 2017).

Sweet corn is directly consumed in form of fresh ears and food processing industry as frozen and canned. Fresh ears are used as food at the milky stage of endosperm development when the kernel is soft, succulent, and sweet (Pajic, Radosavljevic & Eric, 2004). Kernels are rich in sugars that are in good balance with proteins, minerals, and vitamins, and are a good source of fibres. According to Siyuan,

Tong & Li (2018), sweet corn has unique profiles of nutrients and phytochemicals, vitamins (A, B, E, and K), minerals (Mg, P, and K), phenolic acids (ferulic acid, coumaric acid, and syringic acid), flavonoids (anthocyanins), and dietary fibre when compared with other whole grains. Carotenoids and tocopherols can be found in sweet corn kernels (Ibrahim & Juvik, 2009; Das & Singh, 2016; Xiao et al., 2020). Vitamins are found in all major parts of the kernel, including the endosperm (carotenoids), germ (vitamin E), and aleurone water-soluble vitamins (Grams, Blessin & Inglett, 1970). Maize kernels have five kinds of natural carotenoid components including  $\alpha$ -carotene,  $\beta$ -carotene,  $\beta$ -cryptoxanthin, lutein and zeaxanthin and four types of tocopherols ( $\alpha$ -tocopherol,  $\beta$ -tocopherol,  $\gamma$ -tocopherol and  $\delta$ -tocopherol). The content of those phytochemicals is highly influenced by the genotype and by applied agricultural practice (Mesarović et al., 2018; Mesarović et al., 2019). Considerable genetic diversity for carotenoids and tocopherols contents have been observed among sweet corn inbred lines (Kurilich & Juvik, 1999; Ibrahim & Juvik, 2009; Feng, Wang, Zhang, Yang & Li, 2015; Drinic et al., 2019).

Sweet corn is more often available in a canned or frozen product than in fresh form, due to the rapid conversion of free sugars into starch, which results in the loss of sensory characteristics such as sweetness. The frozen product enables an extended shelf life as well as the availability of sweet corn throughout the year. Before consumption, the sweet corn is thermally processed, whether in fresh or frozen form. Many studies indicate that thermal processes affect the nutritional quality (Dewanto, Wu, & Liu, 2002; Miglio, Chiavaro, Visconti, Fogliano & Pellegrini, 2008; Song, Liu, Li & Meng, 2013; Junpatiw, Lertrat, Lomthaisong & Tangwongch, 2013; Knecht, Sandfuchs, Kulling & Bunzel, 2015). Accordingly, in our study, the effect of cooking on the content of antioxidants in the grain of twelve sweet corn hybrids was examined.

## MATERIALS AND METHODS

### Plant material and growing conditions

Twelve sweet corn hybrids of different maturity groups, three commercial ZP504su (FAO 500), ZP 355su (300), ZP 347su (400), and nine experimental ZP 471/2su (500), ZP

475/2su (500), ZP477/2su (600), ZP481/1su (500), ZP482/1su (600), ZP483/1su (400), ZP484/1su (500), ZP485/1su (400), ZP486/1su (600) were investigated. The hybrids were field grown in 2018 using conventional growing practice. Hybrids were sown according to the RCBD design in three replicates. The size of the elementary plot was 7 m<sup>2</sup>, with the final stand of 40 plants per plot in two rows. Each hybrid was hand harvested at 23 day after pollination (DAP), hand husked, de-silked, and graded for uniformity and well-filled kernels.

The corn tips were cut off and only the full kernel parts were blanched and stored at -20±1 °C before cooking. Ten ears of each sweet corn hybrids were cooked in 10 L tap water in a stainless-steel pot with a covered lid. The cooking time was 15 min. The heating water was kept boiling over the cooking period. After the cooking processes, the samples were all drained off, dried at 40 °C and ground to fine powder (particle size <500 µm) in a Perten 120 lab mill (Perten, Sweden). The prepared samples were used for subsequent analysis by HPLC. The content of carotenoids and tocopherols was determined by using HPLC equipped with diode array (DAD) and fluorescence (FLD) detection. The content was presented as the mean value from three independent measurements and expressed as the µg per g of dry mass (µg/g d.m.). The obtained value for DW was achieved by drying the fresh and cooked maize kernel to constant weight in the ventilation dryer (105 °C, 4 h).

#### Determination of carotenoids

Extraction, identification and quantification of carotenoids (lutein + zeaxanthin (L + Z) and  $\beta$ -carotene) were similar as proposed by Mesarović et al. (2019). Approximately 0.5 g of milled and dried grain (fresh and cooked) was extracted with 15 mL of the mixture of methanol and ethyl acetate (6:4, v/v). After homogenization in the ultrasonic bath (30 min at 25 °C), the extracts were evaporated to the dryness under a stream of nitrogen and redissolved in the mobile phase and filtered through 0.45µm nylon filter. Chromatographic separation was performed on a Hypersil GOLD<sup>®</sup> C18 column (150 × 4.6 mm, 3 µm). The content of used mobile phase, isocratic program as well as the column temperature was the same as in Mesarović et al. (2019). Detection of

carotenoids was accomplished on a DAD detector at 450 nm and 470 nm.

#### Determination of tocopherols

Extraction, identification, and quantification of tocopherols ( $\alpha$ -T,  $\beta$ + $\gamma$ -T and  $\delta$ -T) were similar as proposed by Mesarović et al. (2019) with minor modification. Approximately 0.5 g of milled and dried grain (fresh and cooked) was extracted with 10 mL of 2-propanol. After homogenization in the ultrasonic bath (30 min at 25 °C), and filtration through 0.45µm nylon filter the extracts were directly injected into the HPLC system. Chromatographic separation was performed on a Hypersil GOLD aQ<sup>®</sup> C18 column (150 × 4.6 mm, 3 µm). The content of used mobile phase, isocratic program as well as the column temperature was the same as in the Mesarović et al. (2019). Detection of tocopherols was achieved on FLD detector at  $\lambda_{ex}$  290 nm and  $\lambda_{em}$  325 nm.

#### Statistical analysis

Analyses were carried out in triplicate for each sample and the results were presented as mean ± SD. Obtained data were subjected to the two-factorial analysis of variance (ANOVA) by using M-STAT-C software where the factor A was genotype and the factor B was treatment. The differences between means were tested with Fisher's Least Significant Difference (LSD) test at 0.95 confidence level ( $p \leq 0.05$ ).

## RESULTS

#### Effect of cooking on carotenoid content

Kernels from 12 hybrids were analysed using HPLC to determine the presence of carotenoids before cooking. Analysis of variance showed that genotype and cooking treatment, as well as their interaction significantly influenced the content of carotenoids (lutein+zeaxanthin and  $\beta$ -carotene).

The highest content of total carotenoids (lutein+zeaxanthin+ $\beta$  carotene) in the kernel before and after cooking had hybrid ZP486/1su (27.77 µg/g and 45.28 µg/g d.m., respectively). The lowest content of total carotenoids was found in hybrid ZP 355su (10.27 µg/g d.m.) before cooking and in hybrid ZP347su (24.55 µg/g d.m.), after cooking (Fig. 1). After cooking, an increase in the total carotenoid content was observed in all hybrids. The highest increment in the total carotenoids was in ZP 355su and ZP485/1su hybrids (Tab. 3).

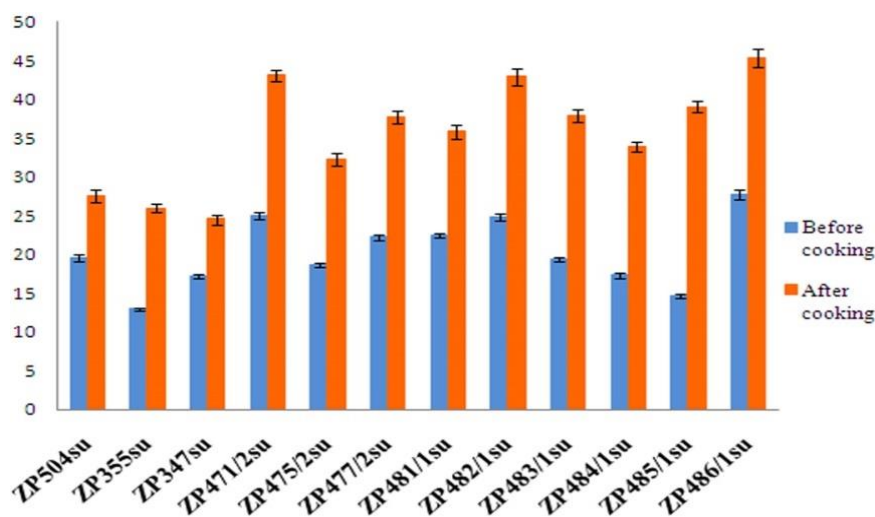


Fig 1. Effect of cooking on total carotenoids content (µg/g d.m.)

**Table 1.**

Content of lutein+zeaxanthin and β-carotene before and after cooking sweet corn kernels (µg/g d.m.)

Hybrids	lutein+zeaxanthin		β-carotene	
	before cooking	after cooking	before cooking	after cooking
ZP504su	19.14±0.46 <sup>l</sup>	27.23±0.73 <sup>h</sup>	0.44±0.01 <sup>k</sup>	0.34±0.01 <sup>m</sup>
ZP355su	12.72±0.20 <sup>o</sup>	25.71±0.54 <sup>i</sup>	0.25±0.01 <sup>o</sup>	0.28±0.01 <sup>o</sup>
ZP347su	16.95±0.24 <sup>m</sup>	24.24±0.64 <sup>j</sup>	0.26±0.01 <sup>o</sup>	0.31±0.01 <sup>n</sup>
ZP471/2su	23.88±0.47 <sup>j</sup>	41.46±0.69 <sup>b</sup>	1.12±0.03 <sup>c</sup>	1.58±0.05 <sup>a</sup>
ZP475/2su	17.95±0.32 <sup>lm</sup>	31.22±0.72 <sup>g</sup>	0.76±0.02 <sup>g</sup>	1.09±0.04 <sup>d</sup>
ZP477/2su	21.35±0.41 <sup>k</sup>	36.74±0.84 <sup>d</sup>	0.87±0.03 <sup>f</sup>	1.01±0.04 <sup>e</sup>
ZP481/1su	21.96±0.32 <sup>k</sup>	35.28±0.85 <sup>e</sup>	0.48±0.01 <sup>j</sup>	0.60±0.02 <sup>i</sup>
ZP482/1su	23.75±0.44 <sup>l</sup>	41.35±1.02 <sup>b</sup>	1.13±0.03 <sup>c</sup>	1.59±0.06 <sup>a</sup>
ZP483/1su	19.12±0.27 <sup>l</sup>	37.24±0.80 <sup>cd</sup>	0.34±0.01 <sup>m</sup>	0.67±0.02 <sup>h</sup>
ZP484/1su	16.93±0.32 <sup>m</sup>	33.24±0.62 <sup>f</sup>	0.40±0.01 <sup>l</sup>	0.61±0.02 <sup>i</sup>
ZP485/1su	14.31±0.26 <sup>n</sup>	38.42±0.72 <sup>c</sup>	0.38±0.01 <sup>l</sup>	0.62±0.02 <sup>i</sup>
ZP486/1su	27.02±0.64 <sup>h</sup>	44.09±1.13 <sup>a</sup>	0.75±0.04 <sup>g</sup>	1.19±0.05 <sup>b</sup>

LSD<sub>0.05</sub> (lutein+zeaxanthin)= 1.24; LSD<sub>0.05</sub> (β carotene)= 0.02. Different superscript letters indicate sign. difference (p<0.05)

In all analysed hybrids major carotenoids detected were lutein (L) and zeaxanthin (Z). The content of L+Z varied in the raw kernel from 12.72 µg/g d.m. (ZP355su) to 27.02 µg/g d.m. (ZP486/1su), with average figure of 19.59 µg/g d.m. Beta-carotene ranged from 0.25 µg/g d.m. (ZP355su) to 1.13 µg/g d.m. (ZP482/1su), average 0.60 µg/g d.m. (Tab. 1).

Hybrids ZP471/2su and ZP482/1su had a high content of L+Z (23.88 µg/g d.m. and 23.75 µg/g d.m., respectively) in the raw kernel. Hybrid ZP471/2su was high in β-carotene content (1.12 µg/g d.m.). After cooking, content of L+Z was in the range from 24.24 µg/g d.m. (ZP 347su) to 44.09 µg/g d.m. (ZP486/1su), average 34.69 µg/g d.m. and hybrids ZP471/2su and ZP482/1su had a high content of L+Z, 41.46 µg/g and 41.35 µg/g d.m.,

respectively. Hybrid ZP482/1su (1.59 µg/g d.m.) had the highest content of β-carotene after cooking, followed by ZP471/2su (1.58 µg/g d.m.) whereas ZP355su was the lowest (0.28 µg/g d.m.) with average figure of 0.83 µg/g d.m. The cooking resulted in a significant increase in the concentration of L+Z (42.26-168.48%), β-carotene (11.76-63.16%) for all examined hybrids, except the ZP504su in which the β-carotene content decreased (22.73%) (Tab. 3).

Similarly, in ZP355su and ZP347su hybrids, the increase in β-carotene content was small.

#### Effect of cooking on tocopherols content

Generally, maize kernels are rich in total tocopherols consisting of α-, β-, γ- and δ- isoforms, mainly present in the germ fraction. As

ANOVA revealed, the factors (genotype, cooking treatment) and their interaction had a significant influence on the content of  $\alpha$ -,  $\gamma$ -, and  $\delta$ -tocopherols. Before cooking, total tocopherols content ( $\delta$ -T,  $\beta+\gamma$ -T and  $\alpha$ -T) was highest in hybrid ZP484/1su (26.40  $\mu\text{g/g}$  d.m.) and lowest in hybrid ZP482/1su (10.27  $\mu\text{g/g}$  d.m.).

After cooking, the highest content of total tocopherols was found in hybrid ZP504su (43.90  $\mu\text{g/g}$  d.m.), whereas hybrid ZP481/1su was the lowest (20.19  $\mu\text{g/g}$  d.m.). The results indicated an increasing trend of total tocopherols content in all hybrids following cooking (Fig. 2). The highest increase was in ZP482/1su and ZP483/1su hybrids (Table 3).

Content of  $\delta$ -tocopherols was 0,27-1,0  $\mu\text{g/g}$  D.M.,  $\beta+\gamma$ - tocopherols 7.98-21.09  $\mu\text{g/g}$  d.m. and  $\alpha$ -tocopherols 2.16-6.89  $\mu\text{g/g}$  d.m. in kernels before cooking (Tab. 2).

The mean value of  $\delta$ -tocopherols,  $\beta+\gamma$ -tocopherols and  $\alpha$ -tocopherol was 0.62  $\mu\text{g/g}$  D.M., 13.97 and 3.87  $\mu\text{g/g}$  d.m., respectively. After cooking all mean values were higher for  $\delta$ -tocopherols 0.78  $\mu\text{g/g}$  d.m.,  $\beta+\gamma$ - tocopherols 24.99  $\mu\text{g/g}$  d.m. and  $\alpha$ -tocopherol 4.59  $\mu\text{g/g}$  d.m. Hybrid ZP347su (3.11  $\mu\text{g/g}$  d.m.) had the lowest, hybrid ZP486/1su (6.55  $\mu\text{g/g}$  d.m.) the highest content, and hybrids ZP477/2su and ZP484/1su had high content of  $\alpha$ -tocopherol. After cooking same hybrids kept high content of  $\alpha$ -tocopherol.

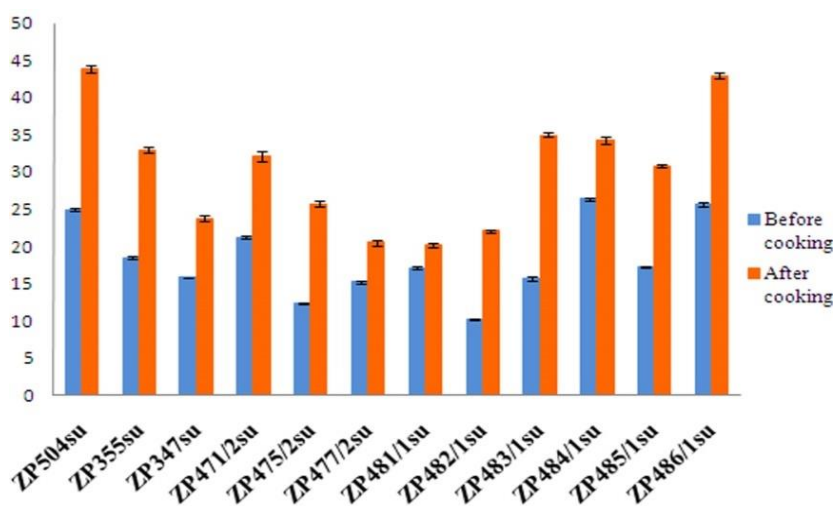


Fig 2. Effect of cooking on total tocopherols content in sweet corn ( $\mu\text{g/g}$  d.m.)

**Table 2.**

Content of  $\alpha$ -,  $\beta+\gamma$ -, and  $\delta$ -tocopherols ( $\alpha$ -T,  $\beta+\gamma$ -T, and  $\delta$ -T) in sweet corn kernel before and after cooking ( $\mu\text{g/g}$  d.m.)

Hybrids	$\alpha$ -T		$\beta+\gamma$ -T		$\delta$ -T	
	before cooking	after cooking	before cooking	after cooking	before cooking	after cooking
ZP504su	3.29±0.03 <sup>n</sup>	4.11±0.05 <sup>l</sup>	21.09±0.16 <sup>h</sup>	38.83±0.49 <sup>a</sup>	0.55±0.04 <sup>ghijk</sup>	0.96±0.04 <sup>abcd</sup>
ZP355su	3.34±0.04 <sup>m</sup>	3.50±0.04 <sup>l</sup>	14.16±0.18 <sup>p</sup>	28.38±0.36 <sup>d</sup>	1.00±0.01 <sup>abc</sup>	1.15±0.05 <sup>a</sup>
ZP347su	2.74±0.01 <sup>q</sup>	3.11±0.05 <sup>o</sup>	12.54±0.05 <sup>q</sup>	19.82±0.31 <sup>j</sup>	0.53±0.02 <sup>hijk</sup>	0.80±0.01 <sup>cdef</sup>
ZP471/2su	4.55±0.03 <sup>h</sup>	5.19±0.08 <sup>f</sup>	15.95±0.11 <sup>m</sup>	26.02±0.60 <sup>f</sup>	0.76±0.01 <sup>defg</sup>	0.95±0.02 <sup>abcd</sup>
ZP475/2su	2.16±0.01 <sup>r</sup>	3.96±0.06 <sup>j</sup>	10.30±0.07 <sup>s</sup>	21.14±0.34 <sup>h</sup>	0.95±0.03 <sup>abcd</sup>	0.64±0.01 <sup>fghij</sup>
ZP477/2su	5.52±0.06 <sup>d</sup>	5.40±0.03 <sup>e</sup>	9.31±0.10 <sup>t</sup>	14.69±0.28 <sup>o</sup>	0.37±0.02 <sup>kl</sup>	0.41±0.02 <sup>kl</sup>
ZP481/1su	4.57±0.05 <sup>h</sup>	4.12±0.07 <sup>i</sup>	11.77±0.14 <sup>r</sup>	15.57±0.27 <sup>n</sup>	0.76±0.01 <sup>def</sup>	0.49±0.02 <sup>ijk</sup>
ZP482/1su	2.03±0.01 <sup>s</sup>	3.63±0.04 <sup>k</sup>	7.98±0.05 <sup>u</sup>	17.84±0.18 <sup>l</sup>	0.27±0.03 <sup>l</sup>	0.66±0.02 <sup>fghi</sup>
ZP483/1su	3.27±0.05 <sup>n</sup>	5.01±0.04 <sup>g</sup>	11.59±0.17 <sup>r</sup>	29.08±0.26 <sup>c</sup>	0.78±0.01 <sup>def</sup>	0.88±0.03 <sup>bcd</sup>
ZP484/1su	5.18±0.03 <sup>f</sup>	5.95±0.09 <sup>c</sup>	20.78±0.12 <sup>i</sup>	27.60±0.46 <sup>e</sup>	0.44±0.04 <sup>ijkl</sup>	0.73±0.01 <sup>efgh</sup>
ZP485/1su	2.85±0.03 <sup>p</sup>	4.55±0.03 <sup>h</sup>	14.04±0.14 <sup>p</sup>	25.54±0.19 <sup>g</sup>	0.37±0.03 <sup>kl</sup>	0.67±0.04 <sup>fghi</sup>
ZP486/1su	6.89±0.07 <sup>a</sup>	6.55±0.04 <sup>b</sup>	18.19±0.20 <sup>k</sup>	35.38±0.20 <sup>b</sup>	0.64±0.01 <sup>fghij</sup>	1.06±0.09 <sup>ab</sup>

$LSD_{0.05}$  ( $\alpha$ -tocopherol) = 0.02;  $LSD_{0.05}$  ( $\gamma$ -tocopherol) = 0.29;  $LSD_{0.05}$  ( $\delta$ -tocopherol) = 0.21. Different superscript letters indicate sign. difference ( $p < 0.05$ )

**Table 3.**  
Increase (%) in carotenoids and tocopherols after cooking of sweet corn kernels

Hybrids	Total carotenoids	L + Z	$\beta$ -carotene	Total tocopherols	$\alpha$ -T	$\beta$ + $\gamma$ -T	$\delta$ -T
ZP504su	40.79	42.27	-22.72	76.10	24.92	84.11	74.55
ZP355su	10.30	102.12	12.00	78.45	4.79	100.42	15.00
ZP347su	42.69	43.00	19.23	50.13	13.5	58.05	50.94
ZP471/2su	72.18	73.62	41.07	51.33	14.06	63.13	25.00
ZP475/2su	72.71	73.92	43.42	107.5	83.33	105.24	-32.63
ZP477/2su	69.85	72.08	16.09	32.75	-2.17	57.78	10.81
ZP481/1su	59.94	60.66	25.00	18.06	-9.84	32.28	-35.52
ZP482/1su	72.60	74.10	40.71	115.42	78.81	123.55	144.44
ZP483/1su	94.77	94.77	97.05	123.55	53.21	150.91	12.82
ZP484/1su	95.43	96.33	52.50	29.85	14.86	32.82	65.90
ZP485/1su	165.74	168.48	63.16	78.22	59.64	81.90	81.08
ZP486/1su	63.06	63.17	58.67	67.09	-4.94	95.6	65.62

L+Z: lutein+zeaxanthin

An increase in  $\alpha$ -tocopherol after cooking was noticed in hybrids ZP485/1su and ZP484/1su but a decrease was found in hybrids ZP481/1su, ZP486/1su and ZP477/2su (Tab. 3).

The highest content of  $\beta$ + $\gamma$ -tocopherols was recorded in ZP504su both before and after cooking. In all hybrids content of  $\beta$ + $\gamma$ -tocopherols increased, but the content of  $\delta$ -tocopherol in two hybrids ZP481/1su and ZP475/2su decreased after cooking.

## DISCUSSION

Many studies have shown that maize nutritive composition is modulated by genetic factors (Ibrahim & Juvik, 2009; Nikolic et al., 2019), stages of maturation (Hu & Xu, 2011; Feng, Wang, Zhang, Yang & Li, 2013; Song, Li, He, Chen & Liu, 2016), the influence of herbicide (Mesarović et al., 2018; Mesarović et al., 2019) and processing (Scott & Eldridge, 2005; Li, Tayie, Young, Rocheford & White, 2007). Moreover, the levels of phytonutrients differ significantly in different maize genotypes (Hu & Xu, 2011; Žilić, Serpen, Akilloğlu, Gökmen & Vančetović, 2012; Drinic et al., 2017).

In this study, both genotypes and treatment affected the contents of the carotenoids and tocopherols. Genetic variation for the carotenoids viz. lutein+zeaxanthin and  $\beta$ -carotene in the kernel of 12 sweet corn hybrids was revealed. The content of lutein+zeaxanthin varied from 12.72  $\mu$ g/g D.M. to 27.02  $\mu$ g/g D.M. and  $\beta$  carotene from 0.25  $\mu$ g/g D.M. to 1.13  $\mu$ g/g D.M. In all hybrids major carotenoids detected were lutein and zeaxanthin. That was in line with findings obtained for sweet corn as well standard kernel type maize (Chander,

Meng, Zhang, Yan & Li, 2008; Safawo et al., 2010; Muthusamy et al., 2014). Feng et al. (2014) showed that the contents of carotenoid components from high to low were zeaxanthin, lutein,  $\beta$ -cryptoxanthin,  $\beta$ -carotene and  $\alpha$ -carotene in 10 sweet corn inbred lines. Ninety-seven inbred lines with different kernel types (standard, sweet corn, popcorn) were analyzed for carotenoid content (Drinic et al., 2019).

Average levels of lutein+zeaxanthin in standard inbred lines was 32.44  $\mu$ g/g, in sweet corn inbred lines 28.27  $\mu$ g/g and in popcorn 29.67  $\mu$ g/g, while  $\beta$ -carotene levels reached 10.55  $\mu$ g/g, 3.82  $\mu$ g/g and 6.28  $\mu$ g/g, respectively.

Generally, wide genetic variation in tocopherol components has been observed in maize (Rocheford, Wong, Egesel & Lambert, 2002; Wong, Lambert, Tad.m.or & Rocheford, 2003). According to Ibrahim & Juvick (2009),  $\gamma$ -tocopherol was the primary compound in sweet corn.

In our study, the content of tocopherol components from the highest to the lowest were  $\beta$ + $\gamma$ -tocopherol,  $\alpha$ -tocopherol and  $\delta$ -tocopherol. These results were consistent with the previous studies about dent maize (Goffman & Boehme, 2001; Egesel, Wong, Lambert & Rocheford, 2003; Chander et al., 2008) and sweet corn (Feng et al., 2013). Drinic et al. (2019) analysed tocopherol content in maize inbred lines with different kernel types and colours and found out that sweet corn inbred lines had the highest average value of  $\beta$ + $\gamma$  tocopherols (59.61  $\mu$ g/g) followed by orange kernel inbred lines (48.26  $\mu$ g/g), popcorn (41.75  $\mu$ g/g), white kernel inbred lines (40.38  $\mu$ g/g) and yellow kernel inbred lines (39.18  $\mu$ g/g).

Sweet corn is harvested 75-80 days after planting, 21 to 24 days after pollination, and eaten as a vegetable. Most vegetables are thermally cooked before consumption. Cooking methods affect both physical and chemical changes resulting in an increase or decrease in phytochemical contents, particularly antioxidants present in vegetables (Lessin, Catigani & Schwartz, 1997; Dewanto et al., 2002; Zhang & Hamauzu, 2004; Turkmen, Sari & Velioglu, 2005; Moreira, de Carvalho, Cardoso, Ortiz, Finco & de Carvalho, 2020). Lee, Choi, Jeong, Lee & Sung (2018) showed that cooked vegetables occasionally have higher fat-soluble vitamin content including  $\alpha$ -tocopherol and  $\beta$ -carotene, than those of their fresh counterparts but it depends on the type of vegetables. Bernhardt & Schlich (2006) reported a significant increase in the release of  $\beta$ -carotene and tocopherol in broccoli upon cooking. An increase in carotenoids and tocopherols content after cooking in this study could be explained by the hydrolysis of bound molecules since the extraction of carotenoids and tocopherols was done without the saponification step.

Among vegetables, sweet corn and broccoli are important sources of dietary carotenoids and tocopherols (Ibrahim & Juvik, 2009). The sweet corn ear is used immediately or frozen for later use since its sugar turns quickly into starch. Before consumption, sweet corn is usually cooked using heat treatments such as blanching, steaming, boiling, and microwaving. In our study ears were blanched and frozen at  $-20^{\circ}\text{C}$  after harvest. Several researchers analysed nutrient content in fresh and frozen sweet corns and found that freezing produced a slight reduction of trans- $\beta$ -carotene (Gebczynski & Lisiewska, 2006; Hunter & Fletcher, 2012), but blanching before freezing improved carotenoid retention by inactivation of enzymes, such as peroxidase and lipoxygenase, that are involved in carotenoid destruction (Baloch, Buckle & Edwards, 1977; Rickman, Bruhn & Barrett, 2007). Frozen sweet corn kernels contained a higher total amount of phenolic and total carotenoids versus the fresh ones (Song et al., 2013). Scott & Eldridge (2005) investigate the levels of carotenoid content in frozen and canned corn compared to fresh corn from the same growing area and found that frozen samples contained a comparable or greater amount of carotenoids.

Thermal processing increases the bioactive contents and total antioxidant activity of sweet corn (Dewanto, Wu & Liu, 2002), resulting in a higher nutritional value compared to fresh produces. Alpha-tocopherol content in vegetables benefited the most from blanching and frozen storage, as compared to fresh storage. When stored fresh, peas, carrots, and corn showed significant decreases in  $\alpha$ -tocopherol content (Bouzari, Holstege & Barrett, 2014).

In our study cooking resulted in a significant increase in the concentration of total carotenoids, lutein+ zeaxanthin (42.26-168.48%),  $\beta$ -carotene (11.76-63.16%) for all hybrids, except ZP504su in which the  $\beta$ -carotene content decreased (22.73%). This increase has been attributed to higher extraction efficiency since the heat treatment can inactivate oxidative enzymes and denature the complex between carotenoid and protein that exists in plant cells (Moreira et al., 2020). Junpatiw et al. (2013) studied the effects of steaming, boiling and frozen storage on carotenoid contents of various sweet corn cultivars and showed that the increase in carotenoids following thermal treatments was cultivar-dependent whereas loss of  $\beta$ -carotene after boiling occurred in one hybrid but not in the others. In all sweet corn hybrids content of total and  $\beta$ + $\gamma$ -tocopherols increased after cooking, but the content of  $\delta$ -tocopherols decreased in two hybrids (ZP481/1su and ZP 475/2su). An increase in  $\alpha$ -tocopherol after cooking was noticed in hybrids ZP485/1su and ZP484/1su but there was a decrease as well in hybrids ZP481/1su, ZP486/1su and ZP477/2su.

Heat treatment during cooking may cause softening of the tissue by cell disruption that consequently results in the release of vitamin E from the lipids, making it more available for extraction; moreover, heat may also abolish the activity of tocopherol oxidase. (Choi, Lee, Chun & Lee, 2006; Knecht et al., 2015). Hybrids ZP482/1su, ZP486/1su, and ZP471su had high content of total carotenoids, lutein+zeaxanthin and  $\beta$ -carotene whereas hybrids ZP484su and ZP486/1su had a high content of total tocopherols,  $\alpha$ - and  $\gamma$ -tocopherols.

## CONCLUSIONS

In sweet corn hybrids, high natural variation in carotenoids and tocopherols exists. Carotenoid and tocopherol contents significantly depended on the genotype of sweet corn. High lutein and



zeaxanthin levels as well as  $\beta$ + $\gamma$ -tocopherol levels were found in the sweet corn hybrids, which might promote health benefits in humans. Hybrid ZP486su had a high content of carotenoids and tocopherols. Due to the high content of compounds with health-promoting properties, this hybrid is suitable for use in functional food. The results obtained in this study demonstrated that cooking significantly improved the contents of available carotenoids in hybrids ZP484/1su, ZP485/1su and ZP486/1su. Generally, cooking increased available tocopherols in all hybrids, except for  $\alpha$ -tocopherols in three, and  $\delta$ -tocopherols in two hybrids. ZP482/1su hybrid showed a significant increase in the content of all examined tocopherols following cooking. Considering the general trends regarding the effects of processing on the micronutrient content of corn products, this research provides a good guideline for food producers and dietary nutrient evaluations.

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## UTICAJ KUVANJA NA SADRŽAJ KAROTENOIDA I TOKOFEROLA KOD KUKURUZA ŠEĆERCA

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**Sažetak:** Ukus i hranljiva vrednost čine kukuruz šećerac cenjenom biljkom i važnom komponentom ljudske ishrane širom sveta. Hranljivi sastav zrna kukuruza šećerca zabeležen je u raznim radovima, ali opis profila karotenoida i tokoferola, naročito posle kuvanja, je oskudan. Stoga je ovo istraživanje sprovedeno radi upoređivanja sadržaja karotenoida i tokoferola u kukuruzu šećercu pre i posle kuvanja. Sadržaj  $\beta$ -karotena, luteina + zeaksantina i tokoferola ( $\delta$ -T,  $\beta$ + $\gamma$ -T,  $\alpha$ -T) u zrnu dvanaest hibrida kukuruza šećerca određen je tačnom hromatografijom visokih performansi (HPLC) i izražen kao srednja vrednost iz tri nezavisna merenja. I genotip i kuvanje uticali su na sadržaj karotenoida i tokoferola u zrnu. Najveći sadržaj ukupnih karotenoida pre i posle kuvanja imao je hibrid ZP 486/1su (27,77 / 45,28  $\mu$ g/g), dok je najmanji sadržaj pre kuvanja imao hibrid ZP 355su (10,27  $\mu$ g/g) i hibrid ZP 347su (24,55  $\mu$ g/g) posle kuvanja. Kuvanje je rezultiralo značajnim povećanjem sadržaja ukupnih karotenoida i tokoferola, luteina + zeaksantina i  $\beta$ -karotena u svim hibridima, osim u ZP 504su u kojima se sadržaj  $\beta$ -karotena smanjio. Povećanje  $\alpha$ -tokoferola nakon kuvanja primećeno je kod hibrida ZP 485/1su i ZP 484/1su, dok je smanjenje bilo kod hibrida ZP 481/1su, ZP 486/1su i ZP 477/2su. Rezultati su pokazali da povećanje sadržaja mikrohranljivih sastojaka zavisi od genotipa. Ova studija je potvrdila da kuvanje povećava nutritivnu vrednost kukuruza šećerca i daje mu dodatnu vrednost u pogledu funkcionalne hrane. vrednost kukuruza šećerca i daje mu dodatnu vrednost u pogledu funkcionalne hrane.

**Ključne reči:** termički tretman, lutein, zeaksantin, karoten, izomeri tokoferola, HPLC

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