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# *In vitro* bioaccessibility of phenolics and flavonoids in various dried vegetables, and the determination of their antioxidant capacity via different spectrophotometric assays

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**Abstract**

In the present work, the *in vitro* bioaccessibility of total phenolic content (TPC), total flavonoid content (TFC) and total antioxidant capacity (TAC) of 13 dried vegetables were determined. The dried vegetables analysed were eggplant, dill, red pepper, green pepper, celery leaves, parsley, zucchini, tomato, onion, leek, garlic, white cucumber and string beans. Three different TAC determination methods (ABTS, DPPH, CUPRAC) were performed for this purpose. According to the results; prior to *in vitro* digestion, eggplant yielded the highest TAC and TFC values in all assays. In addition, eggplant and red pepper yielded the highest TPC ($p > 0.05$). Following *in vitro* digestion, dill yielded the highest TAC in DPPH assay, while celery leaves yielded the highest TAC in ABTS and CUPRAC assays from IN sample. Dill also yielded the highest TFC, while white cucumber and zucchini yielded the lowest. TPC was found the lowest value in string beans while it was the highest in red pepper. The highest bioaccessibility of both TPC (85%) and TFC (86%) were determined in garlic, while eggplant had the lowest TPC, TFC and TAC (≤ 10%) bioaccessibility. Maximum TAC bioaccessibility (%) of IN samples was determined in garlic in ABTS (30%) and CUPRAC (720%) assays; and zucchini (127%) in DPPH assay. The present work provides valuable data on the effect of *in vitro* gastrointestinal digestion on phenolic content, flavonoid content and antioxidant capacity of 13 types of dried vegetables.



## Introduction

Vegetables are rich sources for bioactive compounds that have important roles in human health (Reddy *et al*., 2010). Previous studies and clinical evidences have claimed that consumption of fruits and vegetables at high levels can provide significant amounts of antioxidants associated with a lower risk of chronic diseases, such as cardiovascular diseases, diabetes and cancer (Reddy *et al*., 2010; Romero-de Soto *et al*., 2013). The protective effects of vegetables are strongly related to their antioxidant contents and levels (Isabelle *et al*., 2010).

Most vegetables are highly perishable due to their high water content. The preservation of vegetables' nutrients is essential through convenient processing techniques (Gupta *et al*., 2013). Dehydration or drying is one of the most widely used technique for vegetables which is a key method to preserve foods in a stable and safe condition (Vega-Galvez *et al*., 2009; Romero-de Soto *et al*., 2013). The primary objective of this method is removing water to the level at which microbial spoilage and deteriorative reactions are minimum since low moisture content prevents the growth of certain microorganisms responsible for the deterioration of fresh products (Vega-Galvez *et al*., 2009; Kamiloglu *et al*., 2015).

During conventional thermal drying of vegetables, there are several changes in physical, structural, chemical and nutritional composition of

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vegetables that affect the total phenolic content (TPC), total flavonoid content (TFC) and total antioxidant capacity (TAC) of the final product. However, drying vegetables rich in micronutrients can provide a concentrated source of health-beneficial antioxidant compounds due to high water loss (Gupta *et al*., 2013), even if heat treatment causes a significant decrease in TPC during drying. As compared to fresh commodities, polyphenol content and TAC of dried vegetables are supposed to be higher due to their low moisture content with increased shelf life (Reddy *et al*., 2010). Furthermore, dried vegetables attract much attention since they can be easily produced and stored, and transported at relatively low cost. Recent studies have shown that a number of dried vegetables such as tomato, carrot, onion and garlic showed high TAC when tested by different biochemical assays (Romero-de Soto *et al*., 2013).

Vegetables are widely produced in Turkey both for local consumption and for exportation. Turkey geographically presents great agro-ecological diversity and a large production of vegetables. However inadequate data is available on antioxidant activity, polyphenol compounds and phenolic content of dried vegetables commonly marketed and consumed in Turkey. Therefore, it was considered favourable to determine the TPC, TFC and TAC of selected vegetables which are most commonly consumed in Turkey.

The bioaccessibility of antioxidants and micronutrients depend on their release from the food matrix during the digestion process, thus the potential availability of those compounds after digestion has importance since many studies have stated that the bioavailability of certain antioxidants is poor due to their solubility and metabolism in digestive tract (Kamiloglu *et al*., 2014). Several techniques have been employed for evaluating the *in vitro* bioaccessability of TAC in order to allow rapid screening of these beneficial substances (Tiveron *et al*., 2012; Kamiloglu *et al*., 2014). 2,2-azinobis-3-ethylbenzothiazoline-6-sulfonic acid (ABTS), 2,2-diphenyl-1-picrylhydrazyl (DPPH), and cupric ion reducing antioxidant capacity (CUPRAC) assays are the most widely used assays in foods (Rodriguez-Amaya, 2010). These methods are simple, cost effective, easily interpreted and be displayed either reduction capacity (CUPRAC) or direct free radical inhibition (DPPH and ABTS). The combination of at least two antioxidant capacity assays was recommended by several authors to provide a reliable result of the TAC of a food product (Karadag at al., 2009; Chen *et al*., 2013; Kamiloglu *et al*., 2014). For this reason, three different antioxidant capacity assays namely ABTS, DPPH and CUPRAC assays were performed to determine the TAC of the selected dried vegetables.

The aim of the present work was to investigate the effect of *in vitro* digestion on TPC, TFC and TAC of 13 dried vegetables (eggplant, dill, red pepper, green pepper, celery leaves, parsley, zucchini, tomato, onion, leek, garlic, white cucumber and string beans) which are commonly available in Turkey. To the best of our knowledge, this is the first attempt to elucidate the TPC, TFC and TAC of dried vegetables during *in vitro* digestion.

## Materials and methods

### *Samples*

Thirteen types of dried vegetables; onion (*Allium cepa*), garlic (*Allium sativum*), leek (*Allium ampeloprasum*), parsley (*Petroselinum crispum*), dill (*Anethum graveolens*), celery (*Apium graveolens*) leaves, white cucumber (*Cucumis sativus*), tomato (*Solanum lycopersicum*), eggplant (*Solanum melongena*), zucchini (*Cucurbita pepo*), red and green pepper (*Capsicum annuum*), and string beans (*Phaseolus vulgaris*) were purchased from a local market in Istanbul, Turkey. Samples were ground to a fine powder under liquid nitrogen using a pre-cooled grinder (IKA A11, Germany), and stored at -80°C before analysis.

### *Chemicals and reagents*

Pepsin, pancreatin, bile salts, dialysis bags (Membra-Cel MD34), sodium bicarbonate, potassium persulfate, copper (II) chloride, neocuproine and ammonium acetate were purchased from Sigma Aldrich Chemie GmbH (Steinheim, Germany). Methanol, hydrochloric acid and Folin–Ciocalteau reagent were purchased from Merck Co (Darmstadt, Germany). All the chemicals and reagents used in the present work were of analytical grade.

### *Preparation of extracts*

Approximately, 10 mL of methanol/water (75:15 v/v) was added to 2 g of dried vegetable samples and mixed for 1 min. Then, the samples were sonicated using a cooled ultrasonic bath (VWR ultrasonic cleaner, US), and centrifuged at 2500 rpm for 10 min at 4°C (Hettich Zentrifugen Universal 32R, UK). Another 5 mL of aqueous-methanol was added to the pellet and this procedure was repeated twice. The supernatants were pooled and stored at -80°C until analyzes.

*In vitro gastrointestinal (GI) digestion*

The *in vitro* GI digestion model was adapted from McDougall *et al*. (2005) and Gultekin-Ozguven *et al*. (2016), and performed in triplicate for each sample. Briefly, 2 g of samples were mixed with 20 mL of distilled water and 1.5 mL of pepsin solution. The pH was adjusted to 1.7 with 5 M HCl. The mixture was incubated for 2 h in a shaking water bath at 37°C at 100 rpm. After 2 h, mL of aliquots from the post-gastric (PG) digestion were collected. Then, 4.5 mL of 4 mg/mL pancreatin solution 25 mg/ml bile salt solution was added. The dialysis bags filled with sodium bicarbonate solution to neutralize the titratable acidity (pH 7) was put in glass beakers and incubated in a shaking water bath at 37°C and 100 rpm for 2 h. The solution in the dialysis tubing was coded as IN sample representing the material that entered the serum, while the solution outside the dialysis bags were coded as OUT sample representing material that remained in the GI tract. PG, IN and OUT samples were stored at -20°C until further analysis. Prior to analysis, samples were centrifuged, and the supernatants were filtered through a 0.45 µm membrane filter and assayed for spectrophotometric measurements (Biotek Instruments Inc., Vinooski, USA).

*Spectrophotometric assays*

*Determination of total phenolic content*

TPC of the extracts was determined according to the Folin–Ciocalteau method. Briefly, 1.5 mL of diluted Folin–Ciocalteau reagent (1:10, v/v) was added to 200 µL extract, then 1.2 mL aqueous 7.5% sodium bicarbonate solution was added and allowed to stand at room temperature in the dark for 90 min. The absorbance was determined at 765 nm. Results were expressed as mg of gallic acid equivalents (GAE) per gram dry weight (dw) of samples.

*Determination of total flavonoid content*

TFC was determined according to the method of Bouayed *et al*. (2011). Briefly, 250 µL extract was diluted with 1.25 mL of distilled water. Then, 75 µL of $NaNO_2$ solution (5% w/v) was added. After 5 min, 150 uL of $AlCl_3$ solution (10% w/v) was added prior to addition of 500 uL of 1 M NaOH solution. The mixture was incubated for 5 min. The volume of the mixture was increased to 2.5 mL with distilled water. The absorbance was measured immediately against blank at 510 nm. The results were expressed as mg catechin equivalent (CAE) per g dw sample.

*Determination of total antioxidant capacity using ABTS assay, DPPH assay and CUPRAC assay*

Three different spectrophotometric assays were performed for the determination of TAC of the samples. ABTS assay was performed according to Miller and Rice-Evans (1993), DPPH radical scavenging assay was performed according to Kumaran and Karunakaran (2006), and CUPRAC assay was performed according to Apak *et al*. (2004). The absorbances were measured at 734 nm, 517 nm and 450 nm for ABTS, DPPH and CUPRAC assays, respectively. Results were expressed in terms of mg of trolox equivalent (TEAC) per 100 g dw of sample in all assays.

*Statistical analysis*

All measurements were performed in triplicate and data were reported as mean ± standard deviation. For multiple comparisons, data were subjected to statistical analysis using IBM SPSS software (version 24.0, Chicago, IL, USA) for the analysis of variance (ANOVA). Tukey's test was used to analyse differences between means ($p < 0.05$). The correlation coefficients ($R^2$) for spectrophotometric assays were calculated by using the Microsoft Office Excel 2011 software (Microsoft Corporation, Redmond, WA).

## Results and discussion

*Total phenolic and total flavonoid content*

The effect of *in vitro* GI digestion on TPC of dried vegetable samples were determined and the results are represented in Table 1. According to the results, prior to *in vitro* digestion, red pepper, eggplant and dill significantly showed the highest TPC value (> 12 mg GAE/g dw). These were followed by green pepper, celery leaves and parsley (≈10 mg GAE/g dw). The TPC in garlic and string beans were lower than other samples (<2 mg GAE/g dw). These findings are almost comparable with the results reported by Hervert-Hernàndez *et al*. (2010) and Naidu *et al*. (2016) who found ≈20 mg/g dw TPC in different dried red pepper varieties and 5-15 mg GAE/g dw in dried dill. In PG samples, a reduction in TPC values was observed except for dried tomato. Although the highest TPC amount was found in green pepper in gastric media, TPC was found the highest in dill in both inner and outer intestine media.

The changes in TFC of selected dried vegetables before and during *in vitro* digestion are shown in Table 2. For the initial samples, eggplant yielded the highest TFC while garlic had the lowest. PG samples

Table 1. Total phenolic compound (TPC) (mg GAE/ gram sample) of dried vegetables before, during and after *in vitro* digestion.

| Sample | Initial | Post Gastric | Post Intestine | |
|---|---|---|---|---|
| | | | IN | OUT |
| Red pepper | 16.09 ± 2.88$^{a}$ | 8.03 ± 0.37$^{a}$ | 2.48 ± 0.05$^{a}$ | 6.91 ± 1.55$^{a}$ |
| Eggplant | 14.57 ± 0.38$^{a}$ | 6.51 ± 0.39$^{b}$ | 1.52 ± 0.08$^{b}$ | 7.70 ± 0.34$^{a}$ |
| Dill | 13.70 ± 0.34$^{a}$ | 8.36 ± 0.68$^{ac}$ | 2.90 ± 0.03$^{c}$ | 11.01 ± 1.67$^{b}$ |
| Green pepper | 10.84 ± 0.09$^{b}$ | 12.44 ± 0.76$^{d}$ | 1.84 ± 0.10$^{d}$ | 4.59 ± 0.13$^{c}$ |
| Celery leaves | 10.71 ± 0.86$^{b}$ | 7.48 ± 1.08$^{ae}$ | 2.42 ± 0.05$^{ae}$ | 8.19 ±0.10$^{d}$ |
| Parsley | 9.83 ± 0.19$^{b}$ | 6.09 ± 0.22$^{bf}$ | 1.56 ± 0.12$^{df}$ | 4.88 ± 0.20$^{f}$ |
| Zucchini | 4.75 ± 0.29$^{c}$ | 2.09 ± 0.08$^{g}$ | 0.58 ± 0.06$^{g}$ | 3.01 ± 0.02$^{g}$ |
| Tomato | 4.73 ± 0.02$^{c}$ | 5.21 ± 0.45$^{bfh}$ | 1.18 ± 0.17$^{h}$ | 2.95 ± 0.39$^{g}$ |
| Onion | 4.32 ± 0.08$^{d}$ | 2.30 ± 0.30$^{gj}$ | 1.13 ± 0.05$^{h}$ | 1.05 ± 0.06$^{h}$ |
| Leek | 4.01 ± 0.01$^{e}$ | 3.43 ± 0.23$^{k}$ | 1.09 ± 0.13$^{h}$ | 1.72 ± 0.03$^{j}$ |
| White cucumber | 3.43 ± 0.46$^{e}$ | 3.18 ± 0.20$^{k}$ | 0.58 ± 0.04$^{j}$ | 3.67 ± 0.15$^{k}$ |
| Garlic | 1.99 ± 0.10$^{f}$ | 1.50 ± 0.55$^{l}$ | 1.70 ± 0.13$^{dfk}$ | 1.30 ± 0.13$^{l}$ |
| String beans | 1.87 ± 0.04$^{g}$ | 1.26 ± 0.28$^{l}$ | 1.02 ± 0.05$^{l}$ | 1.20 ± 0.22$^{l}$ |

Table 2. Total Flavonoid Content (TFC) (mg catechin/gram sample) of dried vegetables before, during and after *in vitro* digestion.

| Sample | Initial | Post Gastric | Post Intestine | |
|---|---|---|---|---|
| | | | IN | OUT |
| Eggplant | 13.78 ± 1.22$^{a}$ | 9.19 ± 0.95$^{a}$ | 1.43 ± 0.01$^{a}$ | 4.51 ± 0.35$^{a}$ |
| Dill | 10.66 ± 2.47$^{b}$ | 7.20 ± 0.19$^{b}$ | 2.66 ± 0.07$^{b}$ | 4.43 ± 0.24$^{a}$ |
| Celery leaves | 5.92 ± 0.40$^{c}$ | 3.35 ± 0.22$^{c}$ | 1.48 ± 0.11$^{c}$ | 4.15 ± 0.24$^{a}$ |
| Parsley | 4.56 ± 0.16$^{d}$ | 4.07 ± 1.24$^{c}$ | 0.56 ± 0.03$^{d}$ | 4.26 ± 0.58$^{a}$ |
| Red pepper | 2.70 ± 0.42$^{e}$ | 2.41 ± 0.20$^{d}$ | 0.45 ± 0.06$^{e}$ | 1.44 ± 0.07$^{b}$ |
| Green pepper | 1.23 ± 0.03$^{f}$ | 1.21 ± 0.17$^{e}$ | 0.35 ± 0.04$^{e}$ | 1.37 ± 0.10$^{b}$ |
| Leek | 0.51 ± 0.05$^{g}$ | 0.49 ± 0.06$^{f}$ | 0.24 ± 0.04$^{f}$ | 1.22 ± 0.17$^{b}$ |
| Tomato | 0.44 ± 0.06$^{g}$ | 0.68 ± 0.04$^{g}$ | 0.32 ± 0.11$^{eg}$ | 0.52 ± 0.05$^{c}$ |
| String beans | 0.38 ± 0.04$^{h}$ | 0.53 ± 0.04$^{fh}$ | 0.30 ± 0.01$^{eg}$ | 0.84 ± 0.10$^{d}$ |
| White cucumber | 0.35 ± 0.05$^{h}$ | 0.42 ± 0.05$^{fh}$ | 0.15 ± 0.01$^{h}$ | 0.86 ± 0.12$^{d}$ |
| Onion | 0.25 ± 0.01$^{j}$ | 0.23 ± 0.04$^{j}$ | 0.17 ± 0.01$^{h}$ | 0.69 ± 0.06$^{e}$ |
| Garlic | 0.21 ± 0.02$^{k}$ | 0.27 ± 0.03$^{j}$ | 0.18 ± 0.04$^{h}$ | 0.17 ± 0.06$^{f}$ |
| Zucchini | 0.21 ± 0.02$^{k}$ | 0.26 ± 0.02$^{j}$ | 0.15 ± 0.01$^{h}$ | 0.69 ± 0.11$^{eg}$ |

showed higher TFC than IN and OUT samples except for OUT samples of white cucumber, eggplant, zucchini, dill and celery leaves. Similarly; TFC of PG samples were higher than both of IN and OUT samples for garlic, tomato, eggplant, red pepper and dill. Moreover, PG samples had higher TFC as compared to initial samples for white cucumber, garlic, tomato, zucchini and string beans. This was probably due to the acidic hydrolysis of the phenolic glycosides to their aglycons during simulated gastric digestion (Kamiloglu *et al*., 2014). The bioaccessibility (%) of samples collected from IN fraction changed between 10-85% of initial samples where the highest TPC bioaccessibility was found for garlic while the lowest was for eggplant. For TFC of IN samples, the bioaccessibility was between 12–86% of initial samples where garlic yielded the highest while parsley the lowest TFC bioaccessibility during *in vitro* GI digestion. An increase in OUT fractions was observed for white cucumber, eggplant, zucchini, dill and celery leaves as compared to PG and IN samples which was attributed to longer extraction time and possible release of phenolics from the complex matrix by the effect of pancreatin as explained by Bouayed *et al*. (2011).

The differences in bioaccessibility among different dried vegetables could be due to several factors such as possible interactions with other food

components; the chemical state of the compound and its release from the food matrix (Barba *et al*., 2017; Cilla *et al*., 2018; Dufour *et al*., 2018). Since selected dried vegetables had different compositions and structures, the bioaccessibility of TPC and TFC showed differences during *in vitro* digestion. It was explained that thermal process applied during drying could damage cell walls thereby releasing more polyphenols during digestion (Barba *et al*., 2017; Cilla *et al*., 2018). At this point, the cell structure and the location of polyphenols in the cell of each vegetable type could determine the TPC and TFC values of dried vegetables. In the present work, some vegetables showed similar TPC value ($p > 0.05$) before and after *in vitro* digestion. This might be related to the families to which the vegetables belong. There was no significant difference ($p > 0.05$) in terms of TPC both in undigested and OUT sample of red pepper and eggplant which belong to family Solananceae. Moreover, in PG sample eggplant and tomato, which is also in family Solananceae, showed same TPC value ($p > 0.05$). Similar pattern was observed in families Apiaceae/Umbelliferae (parsley, dill and celery leaves) and Amaryllidaceae (garlic, onion, leek). Although the results suggest possible association between vegetable family and vegetable polyphenol contents; there are several other important factors that affect the amount of polyphenols.

The correlation coefficients ($R^2$) between TFC and TPC were also calculated. In initial samples, $R^2$ between TFC and TPC was 0.745, while in IN samples 0.726, and in OUT samples 0.823. Poor correlation was found for PG samples.

*Total antioxidant capacity*

TAC of dried vegetables was evaluated by three different assays. Tables 3, 4 and 5 show the TAC of samples determined by ABTS, DPPH and CUPRAC assays, respectively. Before *in vitro* digestion, TAC of samples were in the order of eggplant > celery leaves = red pepper = dill > parsley = tomato > green pepper > onion = leek = white cucumber > string beans > zucchini > garlic by ABTS assay. By DPPH assay, this order changed to eggplant > dill > green pepper > celery leaves > parsley > red pepper > white cucumber > tomato > onion = leek > string beans > garlic > zucchini. By CUPRAC assay, the TAC order was eggplant > celery leaves > red pepper = green pepper > dill = parsley > tomato > white cucumber > leek > onion > zucchini > string beans > garlic. Results indicated that prior to *in vitro* digestion, eggplant showed the highest TAC in all assays. TAC value of the dried vegetables may have been affected by the chemical composition of the vegetables as previously discussed.

The bioaccessibility of IN fractions showed a wide range that were 6-127% of initial values according to DPPH assay, 3-29% for ABTS assay, and 10-720% for CUPRAC assay. According to ABTS assay, the highest TAC bioaccessibility was found in garlic (30%). Eggplant showed the lowest TAC bioaccessibility in all assays; 3%, 6% and 10% by ABTS, DPPH and CUPRAC assays, respectively. Bouayed *et al*. (2011) reported that, possible interaction between polyphenols and other macromolecular compounds restrict the dialysability of related polyphenols. This possible interaction in dried vegetables might be responsible for the low

Table 3. Total antioxidant capacity (TAC) by ABTS assay (mg TEAC/ g sample) of dried vegetables before, during and after *in vitro* digestion.

| Sample | Initial | Post Gastric | Post Intestine | |
|---|---|---|---|---|
| | | | IN | OUT |
| Eggplant | $27.87 \pm 2.43^{a}$ | $7.23 \pm 0.03^{a}$ | $0.86 \pm 0.01^{a}$ | $8.30 \pm 0.56^{a}$ |
| Celery leaves | $22.57 \pm 0.44^{b}$ | $0.86 \pm 0.01^{b}$ | $0.97 \pm 0.04^{b}$ | $5.17 \pm 0.11^{b}$ |
| Red pepper | $21.86 \pm 0.07^{b}$ | $3.55 \pm 0.01^{c}$ | $0.81 \pm 0.01^{c}$ | $3.39 \pm 0.03^{c}$ |
| Dill | $21.19 \pm 0.35^{b}$ | $3.75 \pm 0.02^{d}$ | $0.90 \pm <0.01^{d}$ | $6.18 \pm 0.76^{bd}$ |
| Parsley | $17.26 \pm 0.55^{c}$ | $1.69 \pm 0.04^{f}$ | $0.85 \pm 0.03^{ae}$ | $2.89 \pm 0.02^{e}$ |
| Tomato | $15.04 \pm 1.19^{c}$ | $1.67 \pm < 0.01^{f}$ | $0.70 \pm 0.06^{f}$ | $3.07 \pm 0.03^{f}$ |
| Green pepper | $8.65 \pm 0.02^{d}$ | $3.66 \pm 0.16^{dg}$ | $0.47 \pm <0.01^{g}$ | $1.49 \pm 0.09^{g}$ |
| Onion | $6.92 \pm 0.03^{e}$ | $1.24 \pm 0.03^{h}$ | $0.44 \pm < 0.01^{h}$ | $1.01 \pm 0.02^{h}$ |
| Leek | $6.42 \pm 0.38^{e}$ | $0.95 \pm 0.01^{j}$ | $0.46 \pm 0.01^{j}$ | $1.21 \pm 0.07^{h}$ |
| White cucumber | $6.27 \pm 0.06^{e}$ | $1.34 \pm 0.02^{k}$ | $0.29 \pm 0.03^{k}$ | $2.30 \pm 0.11^{j}$ |
| String beans | $5.52 \pm 0.05^{f}$ | $1.56 \pm 0.01^{l}$ | $0.47 \pm < 0.01^{gl}$ | $1.02 \pm 0.02^{hk}$ |
| Zucchini | $2.78 \pm 0.02^{g}$ | $0.81 \pm 0.11^{m}$ | $0.38 \pm < 0.01^{m}$ | $0.52 \pm 0.03^{l}$ |
| Garlic | $1.60 \pm 0.13^{h}$ | $0.91 \pm 0.10^{n}$ | $0.48 \pm < 0.01^{n}$ | $0.20 \pm 0.01^{m}$ |

Table 4. Total antioxidant capacity (TAC) by DPPH assay (mg TEAC/ g sample) of dried vegetables before, during and after *in vitro* digestion.

| Sample | Initial | Post Gastric | Post Intestine | |
|---|---|---|---|---|
| | | | IN | OUT |
| Eggplant | 23.43 ± 4.37$^{a}$ | 9.80 ± 0.54$^{a}$ | 1.31 ± 0.02$^{a}$ | 18.06 ± 2.80$^{a}$ |
| Dill | 13.35 ± 1.14$^{b}$ | 10.92 ± 0.19$^{b}$ | 1.75 ± 0.20$^{b}$ | 18.38 ± 0.09$^{a}$ |
| Green pepper | 8.42 ± 0.18$^{c}$ | 6.04 ± 0.32$^{c}$ | 1.32 ± 0.05$^{ac}$ | 6.93 ± 1.16$^{b}$ |
| Celery leaves | 7.07 ± 0.49$^{d}$ | 6.53 ± 0.96$^{c}$ | 1.23 ± 0.01$^{d}$ | 7.14 ± 1.18$^{b}$ |
| Parsley | 6.37 ± 0.42$^{e}$ | 3.79 ± 0.57$^{d}$ | 1.15 ± 0.19$^{e}$ | 3.35 ± 0.35$^{c}$ |
| Red pepper | 5.31 ± 0.69$^{f}$ | 5.50 ± 0.02$^{e}$ | 1.63 ± 0.15$^{bf}$ | 4.51 ± 0.11$^{d}$ |
| White cucumber | 2.66 ± 0.39$^{g}$ | 1.58 ± 0.06$^{f}$ | 0.50 ± 0.03$^{g}$ | 2.19 ± 0.25$^{e}$ |
| Tomato | 1.82 ± 0.28$^{h}$ | 4.01 ± 0.22$^{dg}$ | 1.07 ± 0.05$^{eh}$ | 2.02 ± 0.11$^{e}$ |
| Onion | 1.48 ± 0.18$^{j}$ | 1.07 ± 0.13$^{h}$ | 0.75 ± 0.04$^{j}$ | 1.21 ± 0.20$^{f}$ |
| Leek | 1.44 ± 0.08$^{j}$ | 2.02 ± 0.09$^{j}$ | 0.65 ± 0.03$^{k}$ | 2.00 ± 0.15$^{eg}$ |
| String beans | 1.03 ± 0.02$^{k}$ | 0.78 ± 0.01$^{k}$ | 0.68 ± 0.01$^{l}$ | 0.78 ± 0.04$^{h}$ |
| Garlic | 0.66 ± 0.05$^{l}$ | 1.34 ± 0.13$^{hl}$ | 0.50 ± 0.04$^{gm}$ | 0.66 ± 0.01$^{j}$ |
| Zucchini | 0.54 ± 0.04$^{m}$ | 0.74 ± 0.01$^{km}$ | 0.69 ± 0.03$^{ln}$ | 0.75 ± 0.03$^{k}$ |

Table 5. Total antioxidant capacity (TAC) by CUPRAC assay (mg TEAC/ g sample) of dried vegetables before, during and after *in vitro* digestion.

| Sample | Initial | Post Gastric | Post Intestine | |
|---|---|---|---|---|
| | | | IN | OUT |
| Eggplant | 72.59 ± 2.39$^{a}$ | 86.86 ± 2.41$^{a}$ | 7.61 ± 0.10$^{a}$ | 34.00 ± 0.99$^{a}$ |
| Celery leaves | 36.96 ± 0.37$^{b}$ | 52.30 ± 1.06$^{b}$ | 9.43 ±0.23$^{b}$ | 58.56 ± 0.59$^{b}$ |
| Red pepper | 24.73 ± 5.90$^{c}$ | 31.41 ± 3.66$^{c}$ | 4.57 ± 0.18$^{c}$ | 22.73 ± 0.59$^{c}$ |
| Green pepper | 23.43 ± 2.25$^{c}$ | 27.30 ± 0.16$^{c}$ | 5.02 ± 0.35$^{d}$ | 14.35 ± 1.30$^{d}$ |
| Dill | 20.68 ± 1.91$^{d}$ | 18.03 ± 2.48$^{d}$ | 4.93 ± 0.40$^{d}$ | 19.96 ± 2.35$^{e}$ |
| Parsley | 20.68 ± 6.81$^{d}$ | 36.48 ± 1.29$^{e}$ | 6.19 ± 0.27$^{e}$ | 18.06 ± 0.53$^{e}$ |
| Tomato | 16.45 ± 0.23$^{e}$ | 51.42 ± 1.25$^{bf}$ | 7.89 ± 0.55$^{f}$ | 11.78 ± 0.22$^{f}$ |
| White cucumber | 13.10 ±1.67$^{f}$ | 13.74 ± 1.18$^{g}$ | 2.92 ± 0.11$^{g}$ | 12.16 ± 0.38$^{f}$ |
| Leek | 11.44 ± 0.90$^{g}$ | 13.25 ± 1.27$^{g}$ | 3.04 ± 0.28$^{h}$ | 9.61 ± 0.76$^{g}$ |
| Onion | 9.53 ± 0.79$^{h}$ | 10.90 ± 0.66$^{h}$ | 2.44 ± 0.10$^{j}$ | 6.82 ± 0.48$^{h}$ |
| Zucchini | 6.97 ± 0.26$^{j}$ | 8.81 ± 0.23$^{j}$ | 2.29 ± 0.20$^{k}$ | 9.86 ± 0.70$^{gj}$ |
| String beans | 3.36 ± 0.36$^{k}$ | 11.13 ± 0.49$^{hk}$ | 3.77 ± 0.13$^{l}$ | 7.33 ± 0.35$^{k}$ |
| Garlic | 0.69 ± 0.08$^{l}$ | 6.45 ± 0.26$^{l}$ | 4.96 ± 0.27$^{dm}$ | 2.83 ± 0.27$^{l}$ |

TAC bioaccessibility (%) measured. On the other hand, TAC bioaccessibility of zucchini (127%) in DPPH assay and garlic (718%) in CUPRAC assay was more than 100%. The increment of radical scavenger activity could be attributed to the deprotonation of the hydroxyl moieties present on the aromatic rings of the phenolic compounds at higher pH values (Tagliazucchi *et al*., 2010). Therefore, the bioaccessibility of IN samples was over 100%. Moreover, different TAC determination assays and chemical composition of each dried vegetables may have affected the bioaccessibility.

Combination of at least two antioxidant capacity assays was recommended by several authors to provide a more reliable result of the TAC of a food product (Karadag *et al*., 2009; Chen *et al*., 2013; Kamiloglu *et al*., 2014). For this reason, three different antioxidant capacity assays were performed in the present work. The determination of antioxidant capacity depends on different mechanisms of the assays. While ABTS and DPPH assay determined the TAC value via direct free radical inhibition (Miller *et al*., 1993; Kumaran and Karunakaran, 2006); CUPRAC assay based on determination of the reduction capacity (Apak *et al*., 2004). Because of these differences, the TAC values were different for each sample. Prior to *in vitro* digestion there was a relatively high correlation between CUPRAC and

DPPH ($R^2$ = 0.906) and CUPRAC and ABTS ($R^2$ = 0.830) assays. The correlation was relatively poor for PG, IN and OUT samples except for ABTS-CUPRAC ($R^2$ = 0.781) for PG samples and DPPH-ABTS for IN samples ($R^2$ = 0.807) and OUT samples ($R^2$ = 0.891). The TAC of dried vegetables were higher when determined by CUPRAC assay which could be more suitable for the identification the antioxidant capacity of dried vegetables.

## Conclusion

In the present work, the changes of TPC, TFC and TAC values of 13 dried vegetables commonly available in Turkey were investigated with *in vitro* GI digestion. Garlic showed the highest TPC, TFC and TAC bioaccessibility by ABTS and CUPRAC assays, while with DPPH assay the maximum TAC bioaccessibility was found in zucchini. Conversely, eggplant had the lowest TPC, TFC and TAC bioaccessibility. CUPRAC assay could be more suitable for the determination of antioxidant capacity of dried vegetables. Since the bioaccessibility of TPC, TFC and TAC of dried vegetables are affected by chemical composition, the identification of polyphenol profile and possible changes in chemical structure of polyphenols in dried vegetables during *in vitro* digestion using instrumental methods is thus recommended. The data on the antioxidant content of the studied vegetables may be useful for epidemiological research and human diet enrichment.

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