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Yousif A. Elhassaneen[1], Abeer E. Elkhamisy[2], Mayada M. Younis[2], Naglaa F. Salem[2]

[1]Department of Nutrition and Food Science, Faculty of Home Economics, Minoufiya University.

[2]Department of Home economics Faculty of Specific Education, Port Said University.

yousif12@hotmail.com, abeer.elkhamisy@yahoo.com, bdrmyadt508@gmail.com, naglaa.fathi@spcd.psu.edu.eg.

يوسف عبد العزيز الحسانين [1]، عبير السيد الخميسى[2]، ميادة محمد يونس [2]، نجلاء فتحى سالم [2]

[1]قسم التغذية وعلوم الأغذية، كلية الاقتصاد المنزلي، جامعة المنوفية

قسم الاقتصاد المنزلي كلية التربية النوعية جامعة بورسعيد.[2]

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Yousif A. Elhassaneen[1], Abeer E. Elkhamisy[2], Mayada M. Younis[2], Naglaa F. Salem[2]

[1]Department of Nutrition and Food Science, Faculty of Home Economics, Minoufiya University.

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yousif12@hotmail.com, abeer.elkhamisy@yahoo.com, bdrmyadt508@gmail.com, naglaa.fathi@spcd.psu.edu.eg.

Abstract:

The current work aims to determine the bioactive compounds and antioxidant activity of plant parts from food processing by-products (orange peel powder, OPP, eggplant peel powder, EPP, and tomato pomace powder, TPP). Data of proximate chemical composition of the selected plant parts powder indicated that the moisture content was ranged 6.55 to 7.92%, total protein ranged 2.53 to5.42%, crude fat ranged 1.86 to 2.91, crude fiber ranged18.86 to 21.98, ash content ranged 1.87 to 3.94, and carbohydrates content ranged 62.36 to 65.40%. The TPP was recorded the highest content of protein while the highest values of crude fat, fiber and ash were recorded for OPP, OPP, EPP and EPP respectively. Also, TPP recorded the highest WHC followed by OPP, Mix and EPP, respectively. Furthermore, bioactive compounds content of the selected plant parts indicated that the total phenolics was ranged 754.65 to 989.67 mg EGA/100 g, total carotenoids content was ranged 202.65 to 369.56 mg/100g and The OPP was recorded the highest content of total carotenoids while EPP recorded the highest values of total phenolics. The samples also recorded several very high biological activities which include antioxidant and scavenging of free radicals (ROO^-) activities. When all selected food processing by-products were taken in the statistical analysis, there was a positive and highly significant (r^2= 0.799 to 0.8631, $p< 0.05$) relationship between total phenolics content and antioxidant activities. Also, the same behavior was recorded for the total carotenoids and AA. Such important biological effects could play important roles in strategies to combat/treat many diseases including obesity which oxidative stress is one of the mechanisms for its occurrence. Therefore, the present study recommended like of such plant parts powder to be included in our daily diets, drinks, food supplementation and pharmacological formulae.

Keywords:

Orange Peel, Eggplant Peel, Tomato Pomace, Chemical Composition, Water Holding Capacity, Free Radicals Scavenging Activity.

محتوى المركبات النشطة بيولوجيا ونشاط مضادات الأكسدة في أجزاء نباتية مختارة من المنتجات الثانوية لتصنيع الأغذية

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[1]قسم التغذية وعلوم الأغذية، كلية الاقتصاد المنزلي، جامعة المنوفية
[2]قسم الاقتصاد المنزلي كلية التربية النوعية جامعة بورسعيد.
yousif12@hotmail.com, abeer.elkhamisy@yahoo.com, bdrmyadt508@gmail.com, naglaa.fathi@spcd.psu.edu.eg.

مستخلص البحث:

يهدف العمل الحالي إلى تحديد المركبات النشطة بيولوجيا ونشاط مضادات الأكسدة لأجزاء النبات من منتجات التصنيع الغذائي الثانوية (مسحوق قشر البرتقال، OPP، مسحوق قشر الباذنجان، EPP، ومسحوق ثفل الطماطم، TPP). أشارت بيانات التركيب الكيميائي التقريبي لمسحوق الأجزاء النباتية المختارة إلى أن محتوى الرطوبة تراوح بين 6.55 إلى 7.92%، البروتين الكلي تراوح بين 2.53 إلى 5.42%، الدهن الخام تراوح بين 1.86 إلى 2.91، الألياف الخام تراوح بين 18.86 إلى 21.98، محتوى الرماد تراوح 1.87إلى 3.94، وتراوحت نسبة الكربوهيدرات بين 62.36 إلى 65.40 .% تم تسجيل أعلى محتوى من البروتين لـ TPP بينما تم تسجيل أعلى قيم للدهون الخام والألياف والرماد لكل من OPP EPP,EPP ,OPP,على التوالي .كما سجلت TPP أعلى WHC تليها OPP و Mixو EPPعلى التوالي .علاوة على ذلك، أشار محتوى المركبات النشطة بيولوجيًا في أجزاء النبات المختارة إلى أن إجمالي الفينولات تراوح بين 754.65 إلى 989.67 ملجم EGA/100 جرام، وتراوح إجمالي محتوى الكاروتينات من 202.65 إلى 369.56 ملجم/100 جرام، وسجل OPP أعلى محتوى من إجمالي الكاروتينات بينما EPP.سجلت أعلى القيم للفينولات الكلية .سجلت العينات أيضًا العديد من الأنشطة البيولوجية العالية جدًا والتي تشمل أنشطة مضادات الأكسدة وتفكيك الجذور الحرة .(ROO-) عندما تم أخذ جميع المنتجات الثانوية المختارة لتجهيز الأغذية في التحليل الإحصائي، كانت هناك علاقة إيجابية وعالية الأهمية ($r2= 0.799$) إلى 0.8631، ($p<0.05$)بين إجمالي محتوى الفينولات وأنشطة مضادات الأكسدة .كما تم تسجيل نفس السلوك لمجموع الكاروتينات والأحماض الأمينية .مثل هذه التأثيرات البيولوجية المهمة يمكن أن تلعب أدوارًا مهمة في استراتيجيات مكافحة/علاج العديد من الأمراض بما في ذلك السمنة التي يعد الإجهاد التأكسدي أحد آليات حدوثها .لذلك، أوصت الدراسة الحالية بإدراج مسحوق أجزاء النبات في نظامنا الغذائي اليومي والمشروبات والمكملات الغذائية والصيغ الدوائية

الكلمات المفتاحية:

قشر البرتقال، قشر الباذنجان، ثفل الطماطم، التركيب الكيميائي، القدرة على الاحتفاظ بالماء، نشاط طرد الجذور الحرة.

Introduction

Food processing in the Arab world represent a large proportion of waste was estimated at 18.14 million tons per year and represent remnants of fruit and vegetables processing about 6.14% of this amount. Fruits and vegetables processing are resulting in high amounts of by-products such as peels, skins, seeds, stones, meals etc. Such plant parts are rich in different nutrients i.e. protein, minerals, dietary fibers, colorants and bioactive compounds with positive health effects including anti-obesity (Vasso and Constantina, 2007). Such positive health effects mainly due to the different biological roles exhibited by the different categories of bioactive compounds including antioxidant and scavenging activities, inhibition of lipid oxidation, antimicrobial, anticarcinogenic etc., (Elbasouny et al., 2019; Abd Elalal et al., 2021; Elhassaneen, et al., 2021-d; Elhassaneen et al., 2022 (a,b and c); Elhassaneen et al., 2023 (a and b)

Some major source of food by-products are eggplant, tomato and orange, some of the most popular vegetables and fruits. Eggplant (*Solanum melongena* L. Family: S*olanaceae*) also known as aubergine, brinjal, melanzane, berenjena or patlıcan is very popular vegetable grown over 1.7 million hectares world-wide (Gramazio et al., 2014). In 2020, Egypt ranks third in the world in eggplant production with an annual production of approximately 1.34 million metric tons (https://www.tridge.com/intelligences/eggplant/EG). Egyptian black fruit are the most commonly marketed type, though purple and white cultivars have gained acceptability in recent years.

In the present study, the chemical composition, bioactive compounds content and antioxidant activities of three food processing by-products (orange peel, eggplant peel, and tomato pomace) will be investigated. Also, the relationship between the antioxidant activity and the bioactive compounds content in such plant parts will be in the scope of this investigation.

Material and Methods

Materials

Plant fruits

Eggplant (*Solanum melongena*) , orange (*Citrus sinensis* L.) and Tomato (*Lycopersicon esculentum* MILL.) fruits were purchased from Port Said City markets, Port Said Governorate, Egypt. The collected samples was transported to the laboratory and used immediately for peels and pomace powders preparation.

Chemicals

All chemicals, solvents and buffers (except mentioned on site) were purchased from Al-Gomhoryia Company for Trading Drugs, Chemicals and Medical Instruments, Cairo, Egypt.

Methods

Preparation of food by-products peel powder

Orange and eggplant peels powder

Orange (OPP) and eggplant (EPP) peels powder were prepared by the method of Elhassaneen et al., (2020-c).

Tomato pomace powder (TPP)

Tomato pomace powder (TPP) was prepared by the method of Elhassaneen et al., (2020-c).

Equipment's

Absorbance and fluorescence for different assays were measured using Labomed. Inc., spectrophotometer, CA and Schematzu fluorescence apparatus, Japan, respectively.

Analytical methods

Chemical analysis of the selected plant parts powder

Plant parts powders were analysed for moisture, protein (T.N. × 6.25, micro - kjeldahl method) , fat (soxhelt method, petroleum ether solvent), ash and fiber contents were determined using the methods described in the A.O.A.C. (1995). Carbohydrates calculated by the differences.

Water and oil holding capacity

Water holding capacity (WHC) and oil holding capacity (OHC) were determined according to the method of Larrauri *et al.,* (1996).

Determination of total phenolics and carotenoids

Total phenolics in selected plant parts were determined using Folin-Ciocalteu reagent according to Singleton and Rossi, (1965).

Antioxidant activity (AA)

Antioxidant activity (AA) of selected vegetables processing by-product extracts and standards (α-tocopherol and BHT) was determined according to the BCB assay following a modification of the procedure described by Marco, (1968).

β-carotene bleaching (BCB) assay

For β-carotene bleaching (BCB) assay, antioxidant activity (AA) against time (every 10 min thereafter for 120 min) for the all tested vegetables processing by-product extracts was measured/constructed according to Marco, (1968).

Peroxyl radical (ROO^-)-scavenging activity

Peroxyl radical-scavenging activity was determined by an improved oxygen radical absorbance capacity (ORAC) assay such as described by Ou *et al.*, (2001).

Statistical Analysis

All measurements were done in triplicate and recorded as mean±SD. Statistical analysis and corelation analysis were performed with the Student *t*-test and MINITAB 12 computer program (Minitab Inc., State College, PA).

Results and Discussion

Proximate chemical composition of food processing by-products

The proximate chemical composition of the selected food processing by-products and their mixture were illustrated in Table (1). From such table it could be noticed that the moisture content was ranged 6.55 to 7.92%, total protein ranged 2.53 to5.42%, crude fat ranged 1.86 to 2.91, crude fiber ranged18.86 to 21.98, ash content ranged 1.87 to 3.94, and carbohydrates content ranged 62.36 to 65.40%. The TPP was recorded the highest content of protein while the highest values of crude fat, fiber and ash were recorded for OPP, OPP, EPP and EPP respectively.

Table 1. Proximate chemical composition (g/100) of selected plant parts from food processing by-products.

Factor	Tomato pomace powder (TPP)	Eggplant peel Powder (EPP)	Orange peel powder OPP	Mixture (Mix)
Moisture	7.92 ± 0.97 [a]	6.55 ± 0.99 [b]	7.81 ± 0.66 [a]	7.35 ± 1.09 [a]
Total protein	5.42 ± 0.55 [a]	2.53 ± 0.14 [c]	3.07 ± 0.45 [b]	3.75 ± 0.47 [b]
Crude fat	1.97 ± 0.33[bc]	1.86 ± 0.09 [c]	2.91 ± 0.55 [a]	2.31 ± 0.66 [b]
Crude fiber	18.86 ± 1.24 [b]	21.54 ± 1.98 [a]	21.98 ± 3.14 [a]	18.89 ± 2.88 [b]
Ash	2.91 ± 0.22 [b]	3.94 ± 0.76 [a]	1.87 ± 0.80 [c]	2.30 ± 0.03 [bc]
Carbohydrates (by difference)	62.92 ± 2.89 [a]	63.58± 3.22 [a]	62.36 ± 232 [a]	65.40 ± 3.01 [a]

Physical properties of the selected plant parts from food processing by-products

The water holding capacity (WHO) and oil holding capacity (OHC) of the studied food processing by-products were arranged in Table (2). Such data indicated that TPP recorded the highest WHC followed by OPP, Mix and EPP, respectively, which indicating that the higher fiber content in food processing by-products hold more water. For OHC, TPP recorded the highest OHC followed by Mix, OPP and EPP, respectively, which indicating that the higher protein content in food processing by-products holds more oil.

Table 2. Physical properties of the selected plant parts from food processing by-products**.**

Factor	Tomato pomace powder (TPP)	Eggplant peel Powder (EPP)	Orange peel powder (OPP)	Mixture (Mix)
Water holding capacity (WHC, g H_2O/g)	10.74 ± 0.99[a]	7.98 ± 0.97 [b]	9.09 ± 0.48 [ab]	9.75 ± 0.85 [a]
Oil holding capacity (OHC, g oil/g)	3.69 ± 0.32 [a]	2.89 ± 0.12 [b]	2.97 ± 0.52 [b]	3.09 ± 0.60 [a b]

Some bioactive compounds content of the selected pant parts from food processing by-products

Some bioactive compounds content of the selected food processing by-products were shown in Table (3). Such data indicated that the total phenolics was ranged 754.65 to 989.67 mg EGA/100 g, total carotenoids content was ranged 202.65 to 369.56 mg/100g and The OPP was recorded the highest content of total carotenoids while EPP recorded the highest values of total phenolics. Such data are partially accordance with that reported by Essa, (2021) who found that the total carotenoids content in different parts including TPP and OPP was ranged 159.24 to 397.65 mg/100g and total phenolics was ranged 913 to 1270 mg EGA/100 g. Also, studying the bioactive compounds in potato peel powder, mango peel powder and orange peel powder indicated that the total carotenoids was ranged 89-348 mg/100g and total phenolics was ranged 1679 to 8946 mg EGA.100g (Ahmed, 2014).

Table 3. Some bioactive compounds content of the selected plant parts from food processing by-products

Factor	Tomato pomace powder (TPP)	Eggplant peel Powder (EPP)	Orange peel powder (OPP)	Mixture (Mix)
Total phenolics (mg GAE/100 g)	754.65 ± 32.11[c]	989.67 ± 26.79[a]	804.42 ± 35.98 [bc]	839.94 ± 13.05 [b]
Total carotenoids (mg/100g)	271.67± 4.36 [b]	202.65 ± 5.98 [c]	369.56 ± 10.90 [a]	258.90 ± 12.44 [b]

Antioxidant activities (AA) of selected plant parts from food processing by-products

The AA of the selected food processing by-products and their mixture are tabulated in Table (4).Such data indicated that the selected food processing by-products and their mixture showed slightly differences in antioxidant activity ranged 86.80 to 92.06%. All of the selected food processing by-products and their mixture showed strong activity because of their high bioactive compounds content.

Table 4. Antioxidant activity of the selected plant parts from food processing by-products**.**

Samples and Standards	**Antioxidant activity AA (%)**
Samples:	
Tomato pomace powder (TPP)	86.80 ± 2.33
Eggplant peel powder (BPP)	89.74 ± 1.89
Orange peel powder (OPP)	89.08 ± 1.07
Mixture (Mix) [c]	92.06 ± .88
Standard:	
BHT, 50 mg/L	92.65 ± 0.34
BHT, 100 mg/L	96.15 ± 0.27
a-toc, 50 mg/L	98.02 ± 0.19

β **-Carotene Bleaching activity of selected plant parts from food processing by-products**

β -carotene bleaching test based on determined the ability of an antioxidant to inhibit lipid peroxidation. The decrease in absorbance of β-carotene in the presence of different selected food processing by-products extracts (BHT and α–tocopherol were used as a reference) with the oxidation of β-carotene and linoleic acid is shown in Table (5) and Figure (1). From such data it could be noticed that that mixture of the selected food processing by-products (Mix) ehibited the lowest decreasing followed by EPP, TPP and OPP. The values of Mix and EPP absorbances throught 120 min are coming well i.e. closing the line of 50 mg α-tocopherol and 100 50 mg /L of butyhydroxy toluene (BHT) as well as up to the line of 50 mg /L of BHT followed by the rest of the selected food processing by-products.

Relationship between phenolic contents (TPC) and antioxidant activity (AA) of the selected plant parts from food processing by-products

The relationship between TPC and the AA of selected food processing by-products were shown in Tables (6 and 7). From such data it could be noticed that when all selected food processing by-products were taken in the statistical analysis, there was a positive and highly significant (r^2= 0.799 to 0.8631, $p< 0.05$) relationship between TPC and AA. Also, the same behavior was recorded for the total carotenoids and AA. These data indicates that TPC and total carotenoids can play a major role in the AA of tested food processing by- products. In similar study, Velioglu *et al*., (1998) reported that a highly significant correlation between TPC and AA of 28 plant products, including plant by-products. Also, several studies noticed that there was a positive and significant relationship between TPC and AA in different plant parts (Elhassaneen and Sanad, 2009; El-Mokadem, 2010; ElSafty, 2008; Hegazy, 2009; Ahmed, 2010; Elhassaneen *et al.,* 2016; Sayed-Ahmed, 2016; Abd Elalal et al., 2021).

Table 5. Antioxidant activity of selected food processing by-products assayed by the β-carotene bleaching method

Samples	Time (min)												
	0	**10**	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**	**100**	**110**	**120**
Tomato pomace powder	0.891	0.884	0.846	0.839	0.838	0.810	0.760	0.738	0.714	0.713	0.678	0.656	0.654
Eggplant peel powder	0.891	0.890	0.890	0.890	0.874	0.835	0.830	0.809	0.801	0.783	0.776	0.773	0.774
Orange peel powder	0.891	0.836	0.821	0.811	0.799	0.720	0.695	0.671	0.661	0.649	0.640	0.639	0.618
Mixture (Mix) [c]	0.891	0.891	0.890	0.890	0.884	0.840	0.837	0.813	0.802	0.790	0.783	0.780	0.780
Control	0.891	0.584	0.584	0.514	0.482	0.445	0.414	0.360	0.321	0.251	0.222	0.190	0.178

α-toc, 50 mg/L	0.891	0.891	0.891	0.891	0.891	0.858	0.848	0.829	0.818	0.810	0.795	0.795	0.793
BHT, 50 mg/L	0.881	0.881	0.881	0.881	0.881	0.849	0.838	0.820	0.809	0.801	0.787	0.786	0.785
BHT, 100 mg/L	0.891	0.897	0.822	0.815	0.814	0.748	0.727	0.705	0.662	0.650	0.636	0.622	0.615

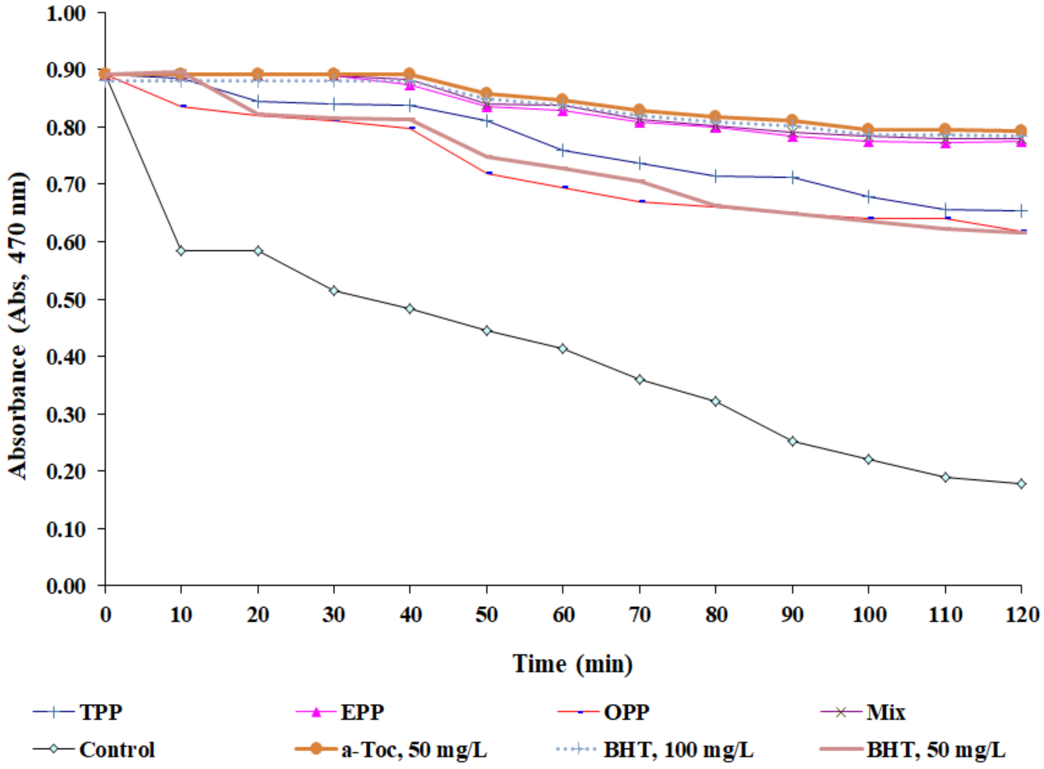

Figure 1. Antioxidant activity (AA, Abs at 470 nm) of selected plant parts from food processing by-products and their mixture assayed by the *β*-carotene bleaching method.

Table 6. Relationship between antioxidant activities (AA) and total phenolic contents of selected food processing by-products samples (n=17)

Relationship between antioxidant activities	r^2

and total phenolic contents		
Tomato pomace powder (TPP)	y = 19.496x - 831.6	0.799
Eggplant peel powder (EPP)	y = 62.067x - 4219.3	0.8444
Orange peel powder (OPP)	y = 26.203x - 1276.1	0.8296
Mixture (Mix) *	y = 58.822x - 4175.2	0.8631

Table 7. Relationship between antioxidant activities (AA) and total carotenoidscontents of selected food processing by-products samples (n=17)

Relationship between antioxidant activities and total carotenoids contents		r^2
Tomato pomace powder (TPP)	y = 6.4531x - 268.39	0.7774
Eggplant peel powder (EPP)	y = 10.129x - 665.7	0.609
Orange peel powder (OPP)	y = 7.53x - 353.97	0.7855
Mixture (Mix) *	y = 14.362x - 902.22	0.8215

Peroxyl radical (ROO-)-scavenging activity of selected plant parts from food processing by-products

The peroxyl radicals (ROO^-) prevention capacity assay, was used to compare the preventive capacity of the selected food processing by-products against ROO^-. The assay is based on the metal-chelating capability of the antioxidants; the so-called preventive capacity against ROO^- is actually related to the metal-chelating ones of the extract tested. AAPH is used to generate ROO^- and fluorescein is employed as the sensitive probe for free radical attack in this procedure. Results illustrated in Figure (2) revealed that as comparison to the selected food processing by-products extracts, the TPP, EPP, OPP and their mixture worked more dramatically in preventive capacity against ROO^- formation/scavenging activity. The Mix appeared to be more effective in scavenging ROO^- followed by EPP, TPP and OPP, respectively. Such data are match with that reported by Ali et al., (2017) who used such application with some phyto-extracts including onion skin, tomato pomace and eggplant peels. The peroxyl radicals (ROO^-) occur during oxidation of lipids in oxidative stress in living cells.

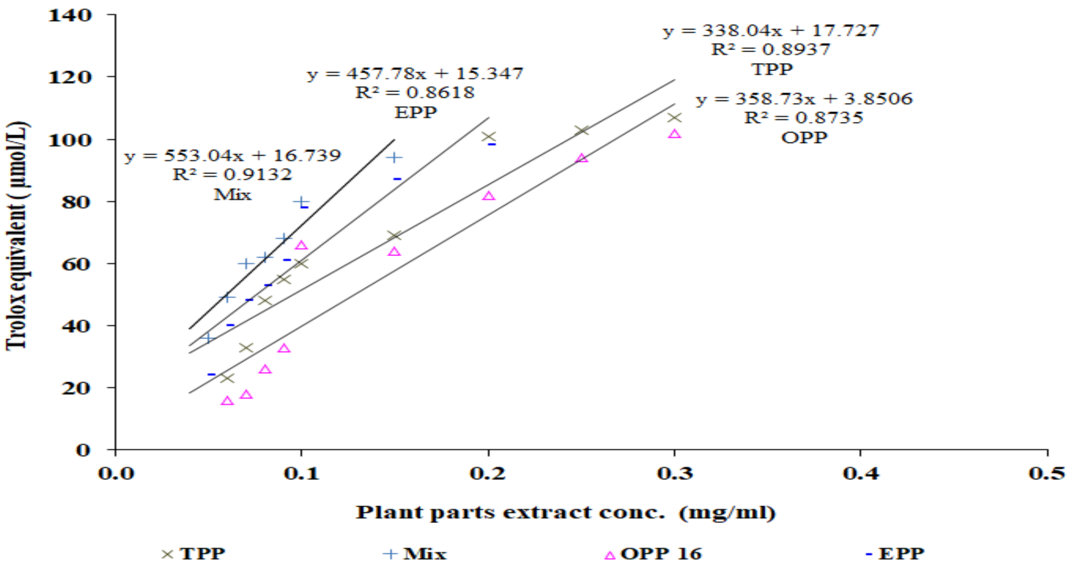

Figure 2. Dose-dependent ROO⁻ scavenging capacity of selected plant parts from food processing by-products as determined by improved oxygen radical absorbance capacity (ORAC) assay.

In conclusion, data of the current study could be represent the mile stone towards the extension of using food processing by-products such tomato pomace, eggplant, orange peel powders and their mixture, as natural antioxidants in many different food technological and therapeutic nutritional applications. Synthetic antioxidants such as most common ones, butylated hydroxyanisole (BHI) and butylated hydroxytoluene (BHT) have been used as antioxidants since the beginning of the last century but restrictions on the use of these compounds, however, are being imposed because of their carcinogenicity. Thus, the interest in natural antioxidants has increased considerably year after year.

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