Effect of Heat on Antioxidant Capacity of Black Radish (*Raphanus sativus* L. var *niger*) Root

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Abstract The aim of this study was to identify the influence of drying temperature on total phenolic content and antioxidative efficacy of black radish root and to investigate heat stability of antioxidant capacity of its juice. Hot water extracts from the roots dried at four different temperatures were rich in total phenolics and characterized for DPPH free radical and ABTS radical cation scavenging activity, and reducing power. The best oven drying temperature corresponding to maximum value of total phenolic content and antioxidant potential was 70°C. Antiradical activity and reducing power of the juice remained after pasteurization at 95°C for 2 min.

Keywords: antioxidant capacity, black radish root, juice, oven drying, pasteurization, phenolic compounds

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1. Introduction

Recently, black radish (*Raphanus sativus* L. var *niger*) roots have been commonly used by local people to lower blood glucose. The roots are cleaned, sliced, air-dried, powdered, and then infused in boiled hot water. A number of *in vitro* and *in vivo* studies have demonstrated that radish root has an antidiabetic effect and is very beneficial in diabetic conditions. For instance, Shukla et al. (2011) [1] have proved significant hypoglycemic as well as antioxidative potential of *Raphanus sativus* root juice by animal experiments. The antidiabetic effect of the juice was greater than glibenclamide, which is a synthetic hypoglycemic drug. These antidiabetic properties may be due to its ability to enhance the antioxidant defense mechanism and decrease oxidative stress and lipid peroxidation, improve hormonal-induced glucose hemostasis, promote glucose uptake and energy metabolism, and reduce glucose absorption in the intestine [2].

To apply plant materials as antioxidants in food and biological systems, it is crucial to consider the optimum technological conditions and processing factors such as pH, temperature, and pressure influencing the stability of their antioxidant potential.

Processing of foods involves heating with different energy transfer media such as water (boiling, blanching, pasteurization, sterilization, evaporation, and extrusion cooking), air (roasting, baking, and drying), oil (shallow and deep fat frying), and electromagnetic waves (microwave heating, irradiation, pulsed electric field, and ultrasound sonication) [3]. Drying is one of the oldest, most common, and most diverse food processing methods [4]. It combines the benefits of microbiological and physicochemical stability with reduction in weight and transport costs and has other advantages in handling and storage [5]. Fruits and vegetables are usually dried to extend shelf-life, enhance storage stability, minimize packaging requirements, and reduce transport weight [4]. In some cases where bioactive compounds extraction cannot be performed on fresh products, drying appears as a necessary step enabling their later use [6]. For drying vegetable materials, following methods are mainly applied: solar drying, sun drying, hot-air drying, freeze drying, and vacuum drying. Among drying methods, hot-air or convective drying is the most adopted technique in food production.

In hot-air drying, air temperature, relative humidity and velocity are the main parameters that influence the final product quality [6]. The most commonly applied temperatures for preserving food materials using convective air drying were reported to be in the range of 50 to 90°C [7]. Low temperatures generally have a positive influence on the quality of biological materials requiring nevertheless long processing times, which in turn have detrimental effects on product quality and induce high costs [6]. Drying at low temperatures between 30 and 50°C is recommended to preserve heat-sensitive active ingredients in medicinal plants or herbs [8]. Several authors have suggested 55-60°C as an optimal temperature for drying fruits and vegetables due to retention of color and nutrients, limiting structural damage, and spending relatively short time.

As described previously, chemical and physical changes that occur during heat treatments such as drying,
affect biologically active phytochemical composition and health-promoting effects of fruits and vegetables. After heat processing, both decreases and increases have been reported in the phenolic compound concentration and antioxidant capacity of plants depending on their types and species. The decrease of total phenolic content may perhaps be due to the increase in temperature that accelerates reactions leading to oxidation processes and thereby prompting the available phenolics to be oxidized to form compounds that do not react with Folin-Ciocalteu reagent that is used in total phenolic content analysis. In addition, phenolics available could have formed complexes with other non-phenolic compounds such as proteins and mineral ions [9]. Physical and biological factors such as temperature increase and enzymatic activity may result in destruction of phenolic antioxidants such as phenolic acids and anthocyanins [10]. Moyo et al. (2018) [9] reviewed that the possibility of a higher total phenolic content could be due to thermal inactivation of plant enzymes such as polyphenol oxidases, glucosidases, and peroxidases; the increase of phenolic compound extractability; and the release of dietary fiber-bound phenolic compounds and thus, forming free phenolic compounds. The enhanced antioxidant activity might be attributed to the fact that thermal processing can induce the formation of compounds with antioxidant properties such as Maillard reaction products or improve the activity of naturally occurring antioxidants [11].

In our previous study, black radish root and its juice were found to be valuable sources of antioxidant polyphenols. Particularly, the peeled root juice exhibited potent antioxidant activity due to its high phenolic content. However, the free radical (DPPH· and ABTS•+) scavenging ability and ferric reducing power of the unpeeled freeze-dried root was stronger than that of the peeled dried root [12]. Therefore, we developed technology to produce healthy drinks with antidiabetic properties, namely tea and juice from black radish roots. To produce the healthy tea, the unpeeled roots are oven-dried, powdered, and then extracted with boiling water. However, juice obtained from the peeled roots is diluted and pasteurized before bottling. Thus, this study was conducted to establish optimal drying temperature which can keep the antioxidant activity of the unpeeled root and evaluate the antioxidant activity of the peeled root juice after pasteurization. In case of our country, hot-air drying is a commercially feasible method used in the preservation of black radish root over a long period of time for use throughout the year due to its easy application, low cost, and readily available technology. In order to establish the optimum drying temperature, four different temperatures (40, 50, 60, and 70°C) were employed. When drying at an elevated temperature of 80 and 90°C, severe browning and burning occurred. Consequently, water infusions of the roots dried at elevated temperatures were dark in color and bitter in flavor. Although drying methods and the influence of drying conditions on quality characteristics, nutritional values and biological activities of numerous vegetables have been reported, little research has been conducted for radish species, especially black radish.

To ensure microbiological stability and retention of antioxidant phytochemicals and other nutrients, the juice was pasteurized at a temperature of 95°C for 2 min.

2. Materials and Methods

2.1. Chemicals

Folin-Ciocalteu reagent, 1,1-Diphenyl-2-picryl-hydrazyl (DPPH), 2,2′-azinobis(3-ethylbenzothiazoline-6-sulfonic acid (ABTS), 2,4,6-tripyridyl-S-triazine (TPTZ), gallic acid, L-ascorbic acid, and 6-hydroxy-2,5,7,8-tetramethylchroman-2-carboxylic acid (Trolox) were purchased from Sigma-Aldrich (MO USA). All other chemicals and reagents were of analytical grade from local suppliers in Mongolia. The water used was purified in a Milli-Q system (Millipore, Bedford, MA, USA). Spectrophotometric determinations were carried out using a Shimadzu UV mini 1240 spectrophotometer.

2.2. Sample Collection

Fresh black radish roots were procured from a local produce market in Ulaanbaatar, Mongolia, during the months of September-October 2020 and stored at room temperature. Prior to drying and juicing, the roots were thoroughly washed with cold running tap water to remove surface dirt as well as to lower microbial load and then cut-off their crown and tail.

2.3. Sample Drying and Extraction

The pre-cleaned roots with peel were quartered by using a stainless-steel knife and separated into four parts. Each part of the roots was sliced separately to a thickness of 2 mm with a vegetable slicer in order to dry thoroughly in relatively short time by low energy. An optimal thickness of 2-6 mm was reported previously [6]. The four parts of the sliced roots were dried at four different temperatures (40, 50, 60 and 70°C) in a laboratory-scale cabinet hot air dryer. The sliced roots were placed as a single layer on the drying shelves of the cabinet dryer and dried until the moisture content reached 12±0.5%. During drying the samples were turned periodically for uniform drying. The dried roots were ground separately by a laboratory mill and then sifted through a mesh 0.5 mm in size. The root powders were kept in air-tight containers at 4°C for future use.

The powdered samples (1 g) were extracted with 50 mL of 99.5% ethanol and 50% (v/v) aqueous ethanol on a magnetic stirrer for 2 h at room temperature and centrifuged at 5000 rpm for 10 min at 4°C. To prepare water extract, the powdered samples (1 g) were mixed with 50 mL of boiling water and stirred on the magnetic stirrer until cooling to room temperature around 1 h. Afterwards, the water extract was obtained by centrifuging at the same conditions as the ethanol extracts. Finally, three kinds of extracts were filtered (Whatman No.5) and stored at 4°C until to analyze.

2.4. Juice Preparation

Prior to juicing with a laboratory-scale juice processor, the pre-cleaned roots were peeled off manually by the knife. The juice was then filtered using a sterilized muslin cloth, diluted with distilled water 5 times and halved. One was pasteurized at a temperature of 95°C for 2 min and
then cooled in a water bath with ice. The cooled juice was filtered again with the muslin cloth as foam and precipitate formed during pasteurization. The crude and pasteurized juice were stored at refrigeration temperature (4°C) and analyzed within 2 days.

2.5. Determination of Total Phenolic Content

Total phenolics of the test samples were determined colorimetrically using Folin-Ciocalteu phenol reagent [13]. The sample solution (20 µL) was mixed with 1.58 mL of water and 100 µL of 1.8 N Folin-Ciocalteu reagents. After 5 min 300 µL of 20% sodium carbonate solution was added and the mixture was incubated in the dark at room temperature for 2 h, and then the absorbance was read at 765 nm. The blank was obtained by replacing the sample solution with water. The results were calculated based on the gallic acid calibration curve (R²=0.9989) prepared at various concentrations (0.1-1.0 mg/mL), and expressed in terms of gallic acid equivalents (GAE).

2.6. DPPH Free Radical (DPPH⁺) Scavenging Assay

DPPH⁺ scavenging ability was assayed by a previously reported procedure [14] with slight changes. The sample solution (100 µL) was mixed with 2 mL of 0.135 mM DPPH in ethanol (99.5%) and the absorbance was read at 517 nm after incubation in the dark for 30 min. The blank was obtained using ethanol instead of the sample solution. The percentage scavenging of DPPH⁺ was calculated by comparing the results of the test sample and the blank. Results were also expressed as Trolox equivalents (TE) by using a calibration curve (R²=0.9993) constructed with the standard Trolox (0-200 µM) under the same experimental conditions.

2.7. ABTS Radical Cation (ABTS⁺⁺) Scavenging Assay

The ABTS⁺⁺ scavenging ability was examined according to the method of Re et al. (1999) [15]. Firstly, 7 mM ABTS stock solution was mixed with 2.45 mM potassium persulfate and left in the dark at room temperature for 12-16 h to produce a stable ABTS⁺⁺. Prior to analysis, the absorbance of the ABTS⁺⁺ solution was adjusted to 0.75 ± 0.05 at 734 nm by diluting with water. After than 2 mL of ABTS⁺⁺ solution was mixed with 20 µL of the sample solution and absorbance was measured at 734 nm exactly after 7 min against the blank that was water. To express the scavenging ability as TE, the calibration curve (R²=0.9994) of standard Trolox (0.1-0.6 mM) was used.

2.8. Ferric Reducing Antioxidant Power (FRAP) Assay

The FRAP assay described by Benzei and Strain (1996) [16] was followed with minor modifications. The FRAP reagent was prepared freshly by mixing 5 mL of 2,4,6-tripyridyl-S-triazine (TPTZ, 10 mM) in 40 mM HCl, 5 mL of ferric chloride hexahydrate (20 mM), and 50 mL of acetate buffer (300 mM, pH 3.6), and warmed at 37°C. The sample solution (100 µL) was mixed with 3 mL of the FRAP reagent and the absorbance was read at 593 nm after incubation in the dark at 37°C for 30 min. Aqueous solutions (0-0.1 mg/mL) of ascorbic acid (vitamin C) that is the most effective natural antioxidant having the ferric reducing ability, were used for calibration (R²=0.9993) and the values were expressed as the concentration of ascorbic acid.

2.9. Statistical Analysis

All tests were performed five times and the results were expressed as mean value ± standard deviation. The data were analyzed using one-way ANOVA for mean differences. Statistical significance was declared at p<0.05.

3. Results and Discussion

We previously reported the effect of the peel on the antioxidant activity of black radish root and its juice. In this study, we evaluated the influence of drying temperature on the antioxidant activity of unpeeled black radish root to identify appropriate oven drying temperature for protecting antioxidant phytochemicals and heat stability of peeled black radish root juice to verify the antioxidant activity of the final product with health promoting properties and to provide consumers with higher quality products. Based on the results of our previous study, we developed technology to produce healthy tea from the unpeeled dried roots and juice from the fresh peeled roots of black radish. Process flow charts are shown in Figure 1 and Figure 2. It is well known that drying temperature is a major influencing factor on the quality of dehydrated food products. Among technological processes for juice production, pasteurization may have a mainly influence on its nutritional value and antioxidative efficacy. The antioxidant activity and total phenolic content of hot water extract obtained from unpeeled black radish root powder varied with oven-drying temperature. Moreover, total phenolics were dependent on solvent type. The antioxidant activity and total phenolic content of peeled black radish root juice were stable at a selected pasteurization temperature.

![Figure 1](image-url). Process flow chart for black radish powder
Black radish root
↓
Sorting and grading
↓
Cutting-off crown and tail
↓
Washing
↓
Peeling
↓
Juicing → pomace
↓
juice
Centrifuging
↓
Diluting
↓
Pasteurization
↓
Cooling
↓
Filtering
↓
Bottling

Figure 2. Process flow chart for black radish juice

3.1. Effect of the Drying Temperature on the Total Phenolic Content and Antioxidant Activity

First of all, the hot air-dried powder of unpeeled black radish roots was extracted in hot water, 50% (v/v) aqueous ethanol, and 99.5% ethanol in order to select suitable solvent for its biological active phenolics. Ethanol is an organic solvent permitted for drug and food production. The total amount of polyphenols ranged from 0.62 mg GAE/g dry weight in the 99.5% ethanol extract of the roots dried at a temperature of 40°C to 8.92 mg GAE/g dry weight in water extract of the roots dried at 70°C (Table 1). These results indicate that the total phenolic content of the hot-air dried roots was influenced by drying temperature and solvent type. Among the three kinds of extracts, the water extract of the hot-air dried roots contained the highest amount of total polyphenols (5.54-8.92 mg GAE/g). However, the lowest amount of total polyphenols (0.62-1.65 mg GAE/g) was detected in the 99.5% ethanol extract of the roots. In this study we found that the black radish roots dried at a temperature of 70°C were rich in total phenolics for all kinds of extracts examined. In contrast, the total phenolic content of Cosmos caudatus, which is an herb of the family Compositae and a common and popular vegetable, under different oven drying conditions (50, 70 and 90°C) decreased in range of 5.84-16.25 GAE/100 g dry weight as compared to the air-dried control sample at 22.3 GAE/100 g dry weights. Such a decrease could have been caused by thermal destruction of the cell walls, which then exposed the phenolic compounds increasing their sensitivity to oxidative degradation [19].

Even though the same roots were not used, the total phenolic content of 50% ethanol extract prepared from the roots dried at 70°C was similar to those of 50% ethanol extract from freeze-dried roots which was previously analyzed [12].

Due to higher total phenolics, water extracts from the black radish root powders dried at various temperatures (40, 50, 60, and 70°C) were examined for their DPPH• and ABTS•+ scavenging activities and reducing power. Figure 3 shows antiradical activity (expressed by % inhibition of DPPH• and ABTS•+) of the water extracts prepared from the black radish root powders at different drying temperatures, whereas the scavenging activities expressed as TE were shown in Table 2.

Table 1. Total phenolics of the unpeeled oven dried black radish root extracts

| Drying temperature (°C) | Total phenolic content (mg GAE per g of dry weight) |
|-------------------------|-----------------------------------------------------|
|                         | 99.5% ethanol extract | 50% ethanol extract | Water extract |
| 40                      | 0.62 ± 0.03           | 5.62 ± 0.25         | 7.00 ± 0.34   |
| 50                      | 0.87 ± 0.03           | 5.69 ± 0.11         | 6.61 ± 0.29   |
| 60                      | 1.26 ± 0.05           | 4.87 ± 0.07         | 5.34 ± 0.11   |
| 70                      | 1.65 ± 0.06           | 7.90 ± 0.06         | 8.92 ± 0.37   |
| Mean                    | 1.10                  | 6.02                | 7.02          |

In the case of 99.5% ethanol extract, total phenolics increased gradually depending positively on the drying temperature. However, total phenolics of 50% and water extract from the roots dried at 40 and 50°C were comparable to each other. Water and 50% ethanol extracted lower amounts of polyphenol compounds from the roots dried at 60°C and higher amounts of phenolics from the roots dried at 70°C. In this study we found that the black radish roots dried at a temperature of 70°C were rich in total phenolics for all kinds of extracts examined. In contrast, the total phenolic content of Cosmos caudatus, which is an herb of the family Compositae and a common and popular vegetable, under different oven drying conditions (50, 70 and 90°C) decreased in range of 5.84-16.25 GAE/100 g dry weight as compared to the air-dried control sample at 22.3 GAE/100 g dry weights. Such a decrease could have been caused by thermal destruction of the cell walls, which then exposed the phenolic compounds increasing their sensitivity to oxidative degradation [19].

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At a concentration of 20 mg/mL, the DPPH• scavenging percentages were 62.8 ± 0.58, 30.57 ± 0.45, 26.21 ± 0.28, and 74.01 ± 0.57% for the water extract of the roots dried at 40, 50, 60, and 70°C, respectively (Figure 3). In other words, DPPH• scavenging activities of the root dried at 50 and 60°C were comparable to each other. The most active sample was the root dried at a temperature of 70°C. Its activity to quench DPPH• was approximately 2.6-fold higher than those of the root dried at 50 and 60°C, as well as 1.2-fold higher than that of the root dried at 40°C.
of the roots dried at 70°C. However, the roots dried at 60°C showed the lowest reducing power. On the other hand, drying temperature influenced the reducing power of the black radish root by the same pattern as DPPH• scavenging activity, ABTS•+ quenching ability and reducing power gave r of 0.785, 0.944 and 0.747, respectively. This finding suggested that total phenolics present in the black radish root contributed significantly to its antioxidant potential. By statistical analysis, Nikolie et al. (2012) [21] found a positive correlation between the phenolic compounds content and total radical scavenging capacity examined by the DPPH radical method. The obtained correlation showed that higher phenolic compounds content in black radish root means higher scavenging capacity. According to Eveline and Pasau (2019) [18], phenolic component in radish (Raphanus sativus L.) extracts was normally contribute to antioxidant activity (r value of 0.50), while flavonoid gave more contribution to antioxidant activity (r value of 0.78).

### 3.2. Heat Stability of the Black Radish Root Juice

For evaluation of heat stability, peeled black radish root juice was pasteurized at a temperature of 95°C for 2 min and then residual total phenolics and antioxidative effects (DPPH• and ABTS•+ scavenging activity and reducing power) were determined. For production of packed vegetable and/or fruit juice, either pasteurization or sterilization must be conducted in order to kill disease-causing pathogens and to inactivate food deterioration-inducing enzymes.
Table 3. Effect of pasteurization on total phenolics and antioxidant activity of the black radish root juice

| Total phenolics and antioxidant activity | Before pasteurization | After pasteurization |
|-----------------------------------------|-----------------------|----------------------|
| Total phenolics¹                       | 22.52 ± 0.48          | 23.68 ± 0.95         |
| DPPH• scavenging activity²            | 9.75 ± 0.14           | 9.89 ± 0.12          |
| ABTS•+ scavenging activity²           | 44.75 ± 1.61          | 44.76 ± 1.01         |
| Fe³⁺ reducing power³                   | 11.69 ± 0.12          | 11.39 ± 0.15         |

¹ Expressed as mg gallic acid equivalents/100 mL
² Expressed as mmol Trolox equivalents/100 mL
³ Expressed as mg ascorbic acid/100 mL

Figure 4. Comparison of DPPH• and ABTS•+ scavenging activity of the black radish root juice before and after pasteurization (%) (The vertical bars represent the standard deviations for each data point. Values with different superscript letters are significantly different (p<0.05))

After being pasteurized at 95°C for 2 min, the total phenolic content of black radish root juice increased by 5%, while the antioxidant capacity remained (Table 3). The black radish root juice exhibited equal activity (p<0.05) to quench DPPH• and ABTS•+ before and after pasteurization. It scavenged approximately 35.5% of DPPH• and 48.0% of ABTS•+ in the test system (Figure 4). The short-time heat treatment also did not influence the ferric reducing antioxidant power of the juice (Table 3).

The antioxidant activity of a number of vegetable juices was stabilized by boiling, suggesting that the initial pro-oxidant activity was due to pro-oxidases, which are inactivated at high temperatures [22]. Similar results have been reported by Reddy et al. (2010) [23] on the antioxidant stability of Raphanus sativus extracts. Among three extracts of Raphanus sativus leaves, ethanol extract showed maximum stability as measured by radical scavenging activity, and the antioxidant activity of water extract was increased by 3% after being heated at a temperature of 100°C for 15 min. However, the activity of methanol extract decreased from 36% to 30%.

4. Conclusion

Based on the results of this study, the best oven drying temperature for black radish root was determined to be a temperature of 70°C because the antioxidant potential (free radical scavenging ability and reducing power) of unpeeled black radish root dried at 70°C was higher than those for the other three temperatures (40, 50, and 60°C). Therefore, black radish root might dry at 70°C in order to preserve it for production of healthy tea with antioxidant potential. Moreover, phenolic compounds in the black radish root powder were effectively released by hot water.

There was no significant difference in the antioxidant capacity of black radish root juice before and after pasteurization at a temperature of 95°C for 2 min, indicating that it may possess heat-stable antioxidant potential, which can be attributed to its phenolic content. Furthermore, it can be used for the production of healthy drinks with antioxidant potential. This pasteurization condition can be used in the production of ready-to-drink tea from the black radish root powder.

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Statement of Competing Interests

The authors have no competing interests.

References

[1] Shukla, S., Chatterji, S., Mehta, S., Rai, P.M., Singh, R.K., Yadav, D.K. and Watul, G., “Antidiabetic effect of Raphanus sativus root juice”, Pharmaceutical Biology, 49 (1). 32-37. Aug.2011.

[2] Banihani, S.A., “Radish (Raphanus sativus) and diabetes”, Nutrients, 9. 1014. Sep.2017.

[3] Nayak, B., Liu, R.H. and Tang J., “Effect of processing on phenolic antioxidants of fruits, vegetables, and grains- A review”, Critical Reviews in Food Science and Nutrition, 55 (7). 887-919. Jan.2015.

[4] Ahmad J., “Drying of vegetables: principles and dryer design”, Handbook of vegetables and vegetable processing, Wiley-Blackwell publishing. 2011. [Online]. Available: https://ubblab.weebly.com/uploads/4/7/4/6/47469791/handbook_o f_vegetables_&_vegetable_processing.pdf.

[5] Masarirambi, M.T., Mavuso, V., Songwe, V.D., Nkambule, T.P. and Mhazo N., “Indigenous post-harvest handling and processing of traditional vegetables in Swaziland: A review”, African Journal of Agricultural Research, 5 (24). 3333-3341. Dec.2010.
[6] Karam, M.C., Petit, J., Zimmer, D., Djantou, E.B. and Scher, J., “Effects of drying and grinding in production of fruit and vegetable powders: A review”, Journal of Food Engineering, 188, 32-49. May.2016.

[7] Krokida, M. and Maroulis, Z., “Quality changes during drying of food materials”, Drying technology in agriculture and food sciences, 4 (2), 61-68. 2000.

[8] Muller, J. and Heindl, A., “Drying of medicinal plants”, Medicinal and aromatic plants, 237-252. Jan. 2006. [Online]. Available: https://www.researchgate.net/publication/266214502_Drying_of_Medicinal_Plants

[9] Moyo, S.M., Mavumengwana, V. and Kayitesi, E., “Effects of cooking and drying on phenolic compounds and antioxidant activity of African green leafy vegetables”, Food Reviews International, 34 (3), 248-264. 2018.

[10] Rossi, M., Giussani, E., Morelli, R., Lo Scalzo, R., Nani, R.C. and Torreggiani, D., “Effect of fruit blanching on phenolics and radical scavenging activity of highbush blueberry juice”, Food Research International, 36 (9-10), 999-1005. Sep.2003.

[11] Kaur, C. and Kapoor, H.C. ”Antioxidants in fruits and vegetables- The millennium’s health”, International Journal of Food Science and Technology, 36 (7), 703-725. Oct.2001.

[12] Enkhtuya, E. and Tsend, M., “The effect of peeling on antioxidant capacity of black radish root”, Italian Journal of Food Science, 32 (3), 701-711. Jun.2020.

[13] Singleton, V.L., Orthofer, R. and Lamuela-Raventos, R.M., “Analysis of total phenols and other oxidation substrates and antioxidants by means of Folin-Ciocalteau reagent”, Methods in Enzymology, 299. 152-178. 1999.

[14] Adebajo, A.A., Jimoh, F.O., Afolayan, A.J. and Masika, P.J., “Antioxidant properties of the methanol extracts of the leaves and stems of Caltis africana”, Records of Natural Products, 3 (1). 23-31. 2009.

[15] Re, R., Pellegrini, N., Proteggente, A., Pannala, A., Yang, M. and Rice-Evans, C., “Antioxidant assay applying an improved ABTS radical cation decolorization assay”, Free Radical Biology and Medicine, 26 (9/10), 1231-1237. 1999.

[16] Benzei, I.F.F. and Strain, J.J., “The ferric reducing ability of plasma (FRAP) as a measure of “Antioxidant power”: The FRAP assay”, Analytical Biochemistry, 239 (1). 70-76. Jul.1996.

[17] Bors, M.D., Semeniuc, C.A., Socaci, S. and Varva, L., “Total phenolic content and antioxidant capacity of radish as influenced by the variety and vegetative stage”, Bulletin UASFM Food science and technology, 72 (1). 77-81. 2015.

[18] Eveline, E. and Pasau, R.L., “Antioxidant activity and stability of radish bulbs (Raphanus sativus L.) crude extract”. IOP Conference Series: Earth and Environmental Science, 292. 2019.

[19] Mediana, A., Abus, F., Khatib, A. and Tan, C.P., “Cosmos Caudatus as a potential source of polyphenolic compounds: Optimisation of oven drying conditions and characterisation of its functional properties”, Molecules, 18. 10452-10464. 2013.

[20] Bochnak, J. and Swicca, M., “Potentially bioaccessible phenolics, antioxidant capacities and the colour of carrot, pumpkin and apple powders – effect of drying temperature and sample structure”, International Journal of Food Science and Technology, 55 (1). 136-145. Jul.2019.

[21] Nikolic, N.C., Stojanovic, J.S., Lazic, M.L., Karabegovic, I.T., Stojicevic, S.S. and Stojanovic, G.S., “The content and radical scavenging capacity of phenolic compounds from black radish roots of various sizes”, 6th Central European Congress on Food, CEFood2012. 29-33.

[22] Gazzani, G., Papetti, A., Massolini, G. and Daglia, M., “Anti- and prooxidant activity of water soluble components of some common diet vegetables and the effect of thermal treatment”, Journal of Agricultural Food Chemistry, 46 (10), 4118-4122. Sep.1998.

[23] Reddy, P.V., Desai, S., Ahmed, F. and Urooj, A., “Antioxidant properties and stability of Raphanus sativus extracts”, Journal of Pharmacy Research, 3 (3). 658-661. Nov.2010.

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