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Effect of Air-Frying on the Bioactive Properties of Eggplant (*Solanum melongena* L.)

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Abstract: The eggplant is an important vegetable that is used all over the world and it contains valuable bioactive properties. Cooking methods affect the nutritional value as well as the functional characteristics of vegetables. This study investigated the effect of air-frying at different temperatures and the extraction solvents on the bioactive properties of eggplant. The eggplant air-fried for 25 min and extracted with 50% ethanol exhibited the highest total flavonoid content (35.10 mg catechin equivalent per gram dry weight), while its total polyphenol content was found as 87.81 mg gallic acid equivalent per gram dry weight. The uncooked sample exhibited the lowest DPPH scavenging (IC₅₀: 422.12 mg/mL reducing power: 0.914), while the highest DPPH scavenging activity (IC₅₀: 2.87 mg/mL; reducing power: 0.936) was recorded for the sample air-fried for 25 min and extracted with 50% ethanol. The highest amount of tannic acid was found in medium-cooked eggplant, while chlorogenic acid was the highest in the high-cooked sample. These results might be helpful for functional food processors.

Keywords: eggplant; air-fry; cooking method; phenolic compounds



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1. Introduction

Eggplant (*Solanum melongena* L.) is a very notable crop that is consumed globally. It is widely cultivated in tropical and subtropical areas of the world [1]. In 2018, its world production was around 54.07 million tons [2]. China is the leading producer of eggplant, followed by India, Egypt, Turkey, and Iran [1]. Its caloric value is quite low [3], and it is known for its high content of minerals, vitamins (Table 1), and phytochemicals such as flavonoids and phenolics that possess high antioxidant activity [4,5]. Most parts of the eggplant, such as the pulp, peel, leaf, calyx, and stem, possess antioxidant activity and are rich in phenolic compounds [4]. Its bioactive properties are mostly related to its phenolic compounds, particularly chlorogenic acid, which is the most abundant polyphenol in the fruit flesh, accounting for 70% to 90% of all of the polyphenol contents [6,7] and anthocyanins in the fruit skin [8]. A negative correlation between the consumption of phytochemicals and chronic diseases has been reported in various studies [9,10].

Processing is a prerequisite for most foods in order to enhance the metabolism and digestion in the human digestive system [11]. However, numerous alterations in the physical characteristics of foods, such as appearance, sensory properties, as well as chemical composition, occur during processing [12,13]. Studies have reported an upsurge in the concentration of polyphenols and flavonoids and have shown certain stability at high temperatures [14,15]. Miglio et al. [16] reported increases in Trolox equivalent antioxidant capacity, ferric reducing antioxidant power, and total radical antioxidant parameter with different degrees of grilling of eggplants.

Table 1. Nutritional components of eggplant [17].

Nutrient	Unit	Value Per 100 g
Main components		
Energy	kJ	100
Total carbohydrates	G	5.88
Sugars	G	3.53
Protein	G	0.98
Fiber	G	3.00
Lipid	G	0.18
Water	G	92.3
Minerals		
Calcium	mg	9.00
Iron	mg	0.23
Sodium	mg	2.00
Potassium	mg	229.0
Magnesium	mg	14.0
Phosphorus	mg	24.0
Zinc	mg	0.16
Vitamins		
Vitamin C	mg	2.20
Thiamin	mg	0.039
Niacin	mg	0.649
Riboflavin	mg	0.037
Folate	µg	22.0
Vitamin B6	mg	0.084
Vitamin A, RAE *	µg	1.00
Vitamin E (α-tocopherol)	mg	0.30
Vitamin K (phylloquinone)	µg	3.50
Lipids		
Fatty acids, total saturated	G	0.034
Fatty acids, total monosaturated	G	0.016
Fatty acids, total polysaturated	g	0.076

* RAE: Retinol Activity Equivalents.

Eggplant is a rich source of nutrients (Table 1) and is usually consumed after boiling in water, grilling, or frying [18]. Frying reflects a dehydration process in which a simultaneous heat and mass transfer happens [19]. Various factors such as moisture content of food, frying time, and types of batter used for frying affect the quantity of oil absorbed by food [20]. Various diseases, such as diabetes, obesity, cardiovascular disease, hypertension, and cancer, have been found to be associated with higher consumption of fried food [21,22]. The current trends in population demographics and socio-economic changes, such as the desire for enhanced quality of life as well as the growing costs of health care, have been the driving force for the food industry to produce low-fat and fat-free products without affecting the sensory qualities. Many techniques such as low pressure microwave application and different pretreatments have been projected to reduce the oil content in fried foodstuffs.

The air-frying method of cooking is an alternative to conventional means of frying foods that employs the circulation of heated air by rapid air technology. It involves the direct interaction between the food product, which used to be continuously in motion to endorse homogeneous contact between both phases, and a diffusion of oil droplets in hot

air in a frying chamber [23]. The hot air movement cooks food item from inside, and the typical crust of fried products gradually appears outside [24]. Therefore, the present study was undertaken to investigate the effects of different cooking times of eggplant at 150 °C via air-frying on its total polyphenol content, total flavonoid content, and antioxidant activity in terms of DPPH (2, 2-diphenyl-1-picryl-hydrazyl) and reducing power.

2. Materials and Methods

2.1. Microwave Cooking and Sample Preparation

Black eggplants were procured from a local market in Riyadh, Saudi Arabia. The whole eggplant was cut into uniform pieces of 1 cm thickness and placed in the household air-fryer (Philips Avance Collection 1.4 Kg Airfryer XXL. Model No: HD9650/94. Made in Turkey). The heating of the eggplant was performed at 150 °C for 5 min, 15 min, and 25 min where were termed as low-cooked (LC), medium-cooked (MC), and high-cooked (HC), respectively (Figure 1). After cooking, the samples were cooled to room temperature (23 °C) and then were placed in an oven dryer at 40 °C for 72 h. Uncooked eggplant was dried under the same conditions and was used as a control. The dried samples were ground into powder, sieved through 60 mesh, and stored in air-tight plastic bags at room temperature for further use.

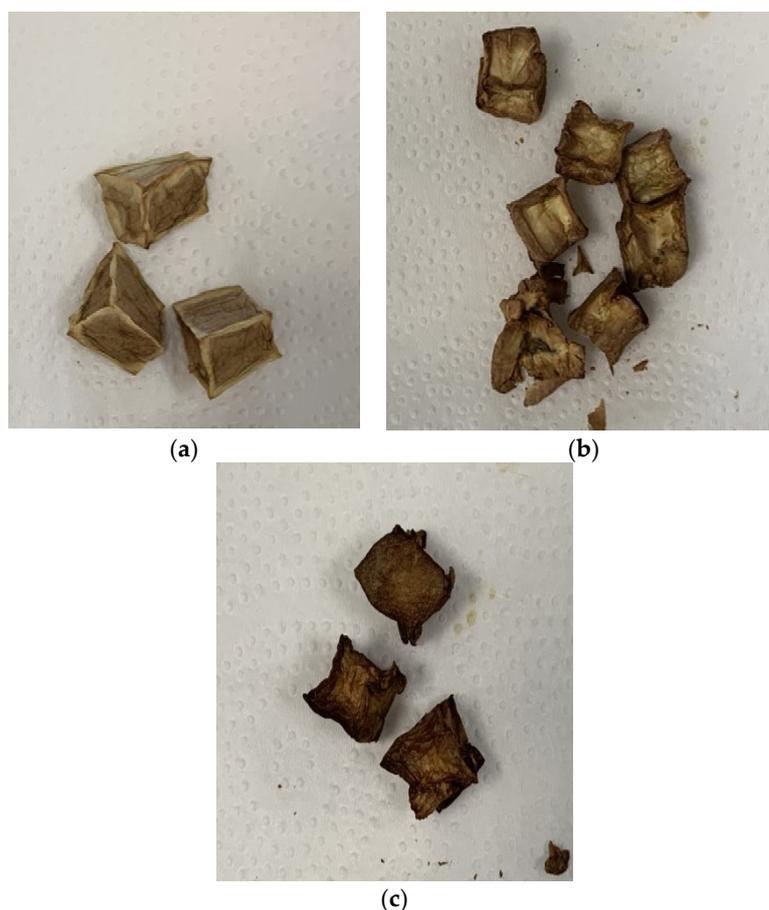


Figure 1. Eggplant samples air-fried at 150 °C for 5 min (a), 15 min (b), and 25 min (c).

2.2. Extraction

The eggplant sample (2 g) was extracted with different concentrations of ethanol (20 mL), such as 100% ethanol, 50% (v/v) ethanol, and 25% (v/v) ethanol, employing ultrasound extractions for 1 h at 23 °C. The mixture was then centrifuged at 3000× g for 10 min at room temperature. The supernatant was then filtered using a Whatman filter

paper number 2. The extract was stored at 4 °C for further analysis. For HPLC analysis of phenolic compounds, the samples were extracted with 100% ethanol.

2.3. Total Polyphenol Content

Folin–Ciocalteu (FC) reagent was used to determine the total polyphenol content (TPC) according to the procedure described by Hayat [25]. Briefly, 125 µL of FC was added to 25 µL of extract containing 1500 µL of nanopure water and the mixture was allowed to stand for 30 min. Subsequently, with the addition of 375 µL of 20% Na₂CO₃, the final volume of the mixture was made up to 2500 µL. After 30 min of incubation at room temperature, the absorbance was noted at 760 nm. Gallic acid was used at different concentrations to construct the calibration curve. The results were calculated as gallic acid equivalent per gram dry weight of the sample (mg GAE/g DW).

2.4. Total Flavonoid Content

The total flavonoid content (TFC) was determined as described previously [25]. The extract (250 µL) was mixed with water (1000 µL) and 75 µL each of NaNO₂ and AlCl₃ and then incubated at room temperature. After 5 min of incubation, 600 µL of water and 500 µL of 1 M NaOH were added and the absorbance was measured at 510 nm. The results were given as catechin equivalent per gram dry weight of the sample (mg CE/g DW)

2.5. DPPH Scavenging

To determine the free radical scavenging capacity of the extract, a DPPH assay was used as described earlier, with some modifications [26]. The reaction mixture contained 130 µL of aliquot of the extract and 0.1 mM DPPH solution (2 mL). Following incubation for 30 min in the dark, the absorbance of the reaction mixtures was read at 510 nm. The control was prepared by ethanol instead of extract and the percentage of DPPH radical scavenging activity was calculated as follows:

$$\text{DPPH scavenging \%} = \frac{A_{\text{control}} - A_{\text{sample}}}{A_{\text{control}}} \times 100 \quad (1)$$

The sample was tested at different concentrations to determine the 50% inhibitory concentration (IC₅₀) value, which was calculated by plotting the sample concentration along the X-axis and the inhibition percentage on the Y-axis.

2.6. Reducing Power

The reducing power was estimated according to the method used by Sharma and Vig with some modifications [27]. Briefly, the extract (0.5 mL) was mixed with 1.25 mL buffer (0.2 M, pH 6.6) and 1.25 mL of potassium ferricyanide and then incubated at 50 °C for 20 min. Next, trichloroacetic acid (1.25 mL) was added and the centrifugation was performed for 10 min at 3000 × g. Lastly, an aliquot (1.25 mL) was acquired from the supernatant, to which 1.25 mL of water and 0.25 mL of ferric chloride were added and the absorbance was measured at 700 nm.

2.7. HPLC Analysis of Phenolic Compounds

The presence of phenolic compounds (tannic acid, resorcinol, chlorogenic acid, caffeic acid, vanillin, acetyl salicylic acid) in eggplant samples was carried out using HPLC analysis, as described earlier with some modifications [28]. The prominence HPLC system Shimadzu (Kyoto, Japan) was equipped with an LC-20AB binary pump and variable Shimadzu SPD-10A UV detector. The Zorbax SB-C18 column (250 × 4.6 mm, 5 µm; Agilent, Santa Clara, CA, USA), mobile-phase Milli Q water (1% acetic acid, A), and MeOH (B) were used. The binary gradient program used was 0–10 min 15–30% B; 10–20 min 30–40% B; 20–30 min 40–50% B; 30–41 min 50–60% B; and 41–45 min 15% B. The flow rate was 1.0 mL/min. The injection volume was 10 µL, and the detector was set at 280 nm. Compounds in eggplant samples were identified by comparing their peak retention time with those of standards. All samples were analyzed in duplicate.

2.8. Statistical Analysis

One-way analysis of variance (ANOVA) was performed by SAS (Version 9.2, 2000–2008; SAS Institute Inc., Cary, NC, USA) at a significance level of $p \leq 0.05$ to identify the differences among the treatment groups. If significant differences were found, a post-hoc analysis using Duncan's multiple range test was performed at a confidence interval of 95%. All analyses otherwise stated were performed in triplicate and the standard deviations were evaluated.

3. Results and Discussion

3.1. Effect of Air-Frying and Extraction Solvents on the Total Polyphenol Content of Eggplant

Figure 2 shows the total polyphenol content (TPC) of eggplant air-fried for different times and extracted with different solvents. The high-cooked sample air-fried for 25 min and extracted with 25% ethanol (v/v) (HC25) gave the highest TPC. The eggplant air-fried for 25 min and extracted with 50% ethanol (HC50) ranked second in terms of its total polyphenol content, and it was followed by the samples air-fried for 15 min and extracted with 50% ethanol (MC50) and 25% ethanol (MC25). The TPCs of all of these eggplant samples were significantly dissimilar from each other ($p < 0.05$). The eggplant extracted with absolute ethanol showed the significantly lowest level of TPC amongst all of the other treatments. For example, the TPC of low-cooked eggplant extracted with absolute ethanol (LC100), 50% ethanol (LC50), and 25% ethanol (LC25) was 3.94, 10.48, and 26.18 mg GAE/g dry weight, respectively. Moreover, the TPC of the control (untreated) sample was significantly lower than all of the other samples, which showed that air-frying helped to increase the total polyphenol content of eggplant. Many studies have reported an increase in the total phenolic content upon heating or roasting of the plant samples, which could be ascribed to the release of bioactive compounds from their conjugates [29,30]. Das et al. [31] reported a higher total polyphenol content in grilled eggplant as compared to a raw sample. There was an increase in the total polyphenol content of deep-fried eggplant as compared to the raw fruits. Lo Scalzo et al. [32] reported increased polyphenolic content in grilled eggplant slices. Another study also reported the increased total polyphenol content of deep-fried eggplant [33].

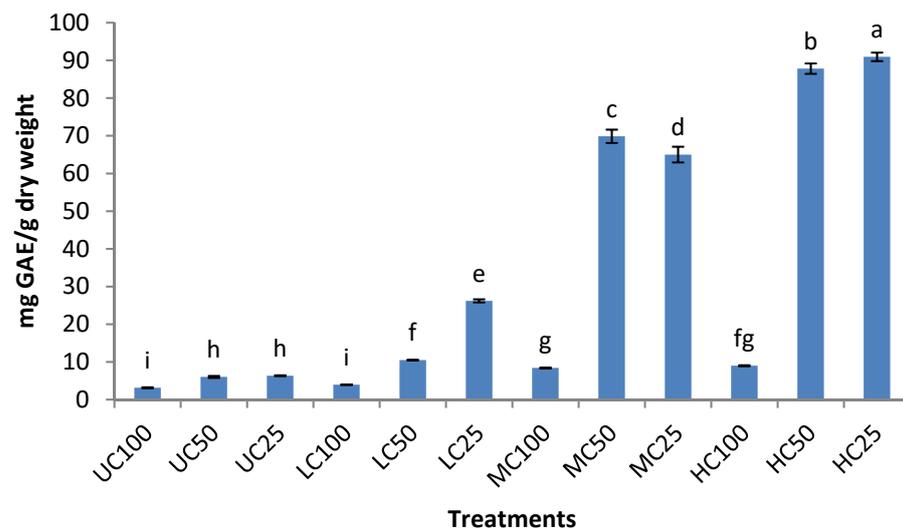


Figure 2. Total polyphenol content of air-fried eggplant. The treatment codes consisting of different letters and digits represent the uncooked (UC), high-cooked (HC), medium-cooked (MC), and low-cooked (LC) eggplant samples extracted with absolute ethanol (100), 50% ethanol (50), and 25% ethanol (25). The bars containing different letters are significantly different from each other ($p < 0.05$). GAE: gallic acid equivalent.

3.2. Effect of Air-Frying and Extraction Solvents on the Total Flavonoid Content of Eggplant

The total flavonoid content (TFC) of eggplant as affected by air-frying and extraction solvent is shown in Figure 3. It can be seen that the TFC was greatly influenced by the air-frying time and the extraction solvents. The eggplant air-fried for 25 min and extracted with 50% ethanol (HC50) exhibited the highest TFC (35.10 mg catechin equivalent per gram dry weight), followed by the sample air-fried for 15 min and extracted with 50% ethanol (MC50) (31.75), air-fried for 25 min and extracted with 25% ethanol (HC25) (28.30), and air-fried for 15 min and extracted with 25% ethanol (MC25) (18.75). Similar to our findings, a previous study reported that the TFC of both conventionally and organically grown eggplant fruits was increased during their steam processing [34]. On the contrary, Arkoub-Djermoune et al. [14] reported that flavonol content increased but flavonoids decreased in fried, grilled, and baked eggplant fruits as compared to fresh eggplants. Similar to the TPC, the TFC of the control sample and the samples extracted with absolute ethanol were significantly lower ($p < 0.05$) than all of the other samples. Among other solvents, the 50% ethanol showed better extraction of eggplant total flavonoids. The solubility of the phenolic compounds depends on the polarity of the extraction solvent. Several studies have showed that the recovery of phenolic acids increased using ethanol and water as cosolvents due to the enhancement of solvent polarity [35–37].

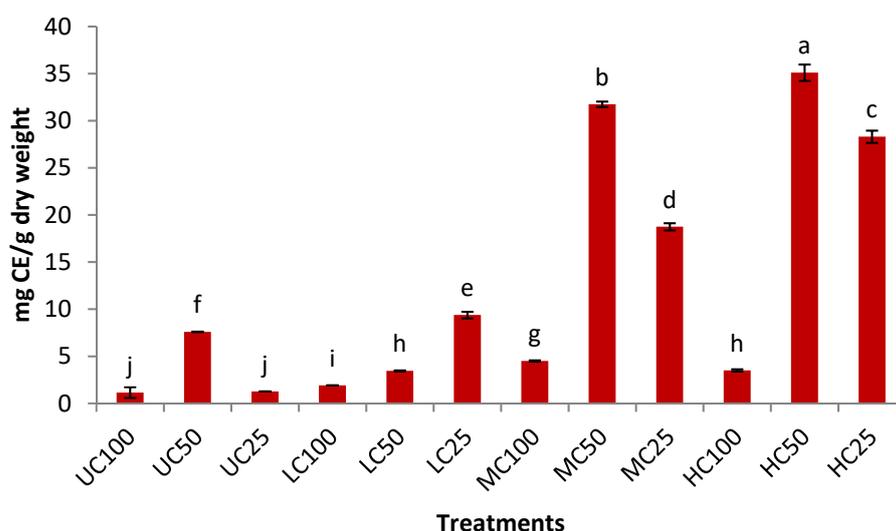


Figure 3. Total flavonoid content of air-fried eggplant. The treatment codes consisting of different letters and digits represent the uncooked (UC), high-cooked (HC), medium-cooked (MC), and low-cooked (LC) eggplant samples extracted with absolute ethanol (100), 50% ethanol (50), and 25% ethanol (25). The bars containing different letters are significantly different from each other ($p < 0.05$). CE: catechin equivalent.

3.3. Effect of Air-Frying and Extraction Solvents on the DPPH Scavenging of Eggplant

The effect of air-frying and extraction solvents on the 2,2-diphenyl, 1-picrylhydrazyl (DPPH) radical scavenging of eggplant is shown in Figure 4. The DPPH scavenging potential of the eggplant was expressed as its 50% inhibitory concentration (IC_{50}). The lower the IC_{50} , the higher the scavenging potential. As can be seen in Figure 3, the lowest IC_{50} (2.87 mg/mL) was recorded for the high-cooked sample that was extracted with 50% ethanol (HC50). The IC_{50} values of the high-cooked sample extracted with 25% ethanol (HC25) and the medium-cooked extracted with 50% (MC50) and 25% (MC25) ethanol were 3.16, 3.74, and 4.19 mg/mL, respectively. The uncooked sample exhibited the highest IC_{50} , showing that it had the lowest DPPH scavenging among all of the other samples. In a previous study, the DPPH radical scavenging capability of the eggplant fruit was increased upon boiling, steaming, or microwaving compared with the untreated sample [38]. Uthumporn et al. [39] investigated the effect of various cooking procedures

on the nutritional value of eggplant, and he found the DPPH scavenging potential in the following order: control < frying < grilling < superheated steam method. All the heating procedures applied to onion, green pepper, and cardoon led to an increase in DPPH radical scavenging potential of these vegetables [40]. The increase in antioxidant capacity might be due to the isomerization and hydrolysis of phenolic compounds; as additionally, the Maillard reaction products possessing antioxidant potential may contribute towards the increased antioxidant potential of the heated food products [14,41].

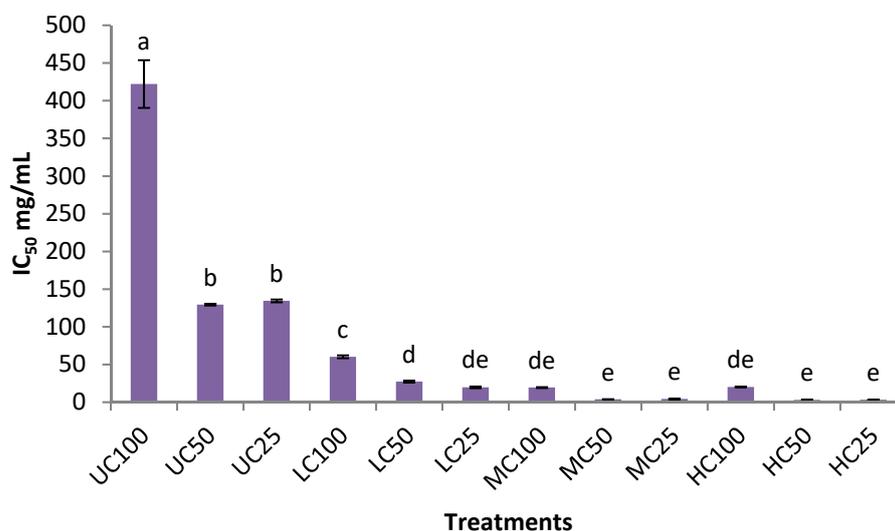


Figure 4. DPPH scavenging of air-fried eggplant. The treatment codes consisting of different letters and digits represent the uncooked (UC), high-cooked (HC), medium-cooked (MC), and low-cooked (LC) eggplant samples extracted with absolute ethanol (100), 50% ethanol (50), and 25% ethanol (25). The bars containing different letters are significantly different from each other ($p < 0.05$).

3.4. Effect of Air-Frying and Extraction Solvents on the Reducing Power of Eggplant

The reducing power of eggplant as affected by air-frying and extraction solvent is shown in Figure 5. The reducing power of the eggplant was significantly affected by both the air-frying and extraction solvents. The highest reducing power was exhibited by HC50, the high-cooked sample extracted with 50% ethanol (1.936), followed by HC25, the high-cooked eggplant extracted with 50% ethanol (1.868). Though the medium- and light-cooked samples extracted with 25% ethanol, MC25 (1.795) and LC25 (1.795), respectively, showed similar reducing power to each other, these were significantly different ($p > 0.05$) from all of the other samples. In general, while the 100% ethanol extract of eggplant showed the lowest reducing power, the 50% ethanol extract gave the highest activity. On the other hand, the uncooked samples exhibited the lowest activity, while the high-cooked samples showed the highest reducing power among all of the samples. These findings somewhat echoed the results of TPC and TFC, which showed that the reducing power of the eggplant was to some extent the function of its bioactive compounds. Our results are in accordance with a recent study that demonstrated that the antioxidant activity of eggplant was increased by cooking, with grilled samples showing the highest activity among fresh and baked eggplant [42]. Other previous studies also reported similar findings where the antioxidant activity of the eggplant fruits was increased by thermal treatment [14,34].

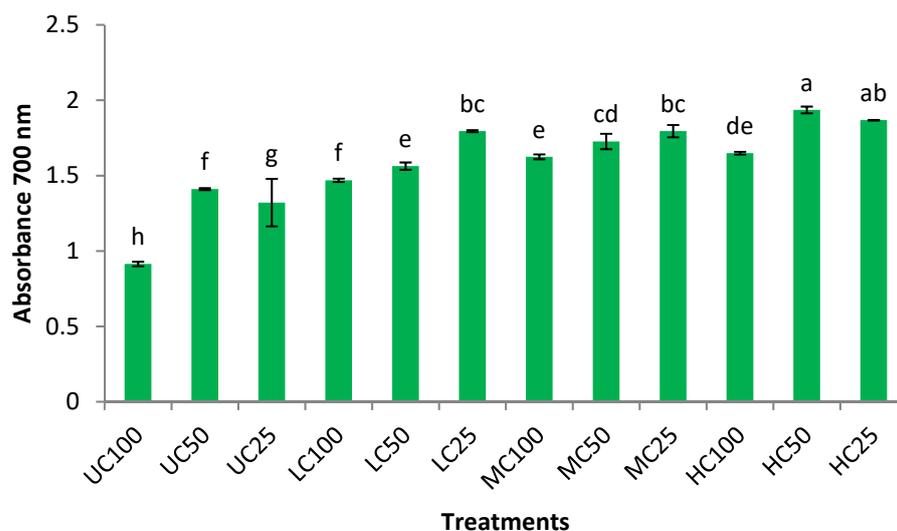


Figure 5. Reducing power of air-fried eggplant. The treatment codes consisting of different letters and digits represent the uncooked (UC), high-cooked (HC), medium-cooked (MC), and low-cooked (LC) eggplant samples extracted with absolute ethanol (100), 50% ethanol (50), and 25% ethanol (25). The bars containing different letters are significantly different from each other ($p < 0.05$).

3.5. Correlation among Total Phenols, Total Flavonoids, and the Antioxidant Activities of Eggplant

Table 2 shows the correlation among total polyphenol content, total flavonoid content, and the antioxidant assays. The lowest IC_{50} for DPPH reveals the highest antioxidant activity of the sample. So, for DPPH, a negative correlation would mean the contribution of TPC or TFC towards the antioxidant activity. The results showed that the TPC and TFC had significant correlation ($R^2 > 0.698$) with the reducing power of the eggplant sample, while they did not contribute much to the DPPH scavenging, as the correlation coefficients were relatively low.

Table 2. Correlation coefficients among total polyphenols, total flavonoids, and antioxidant activities of the eggplant.

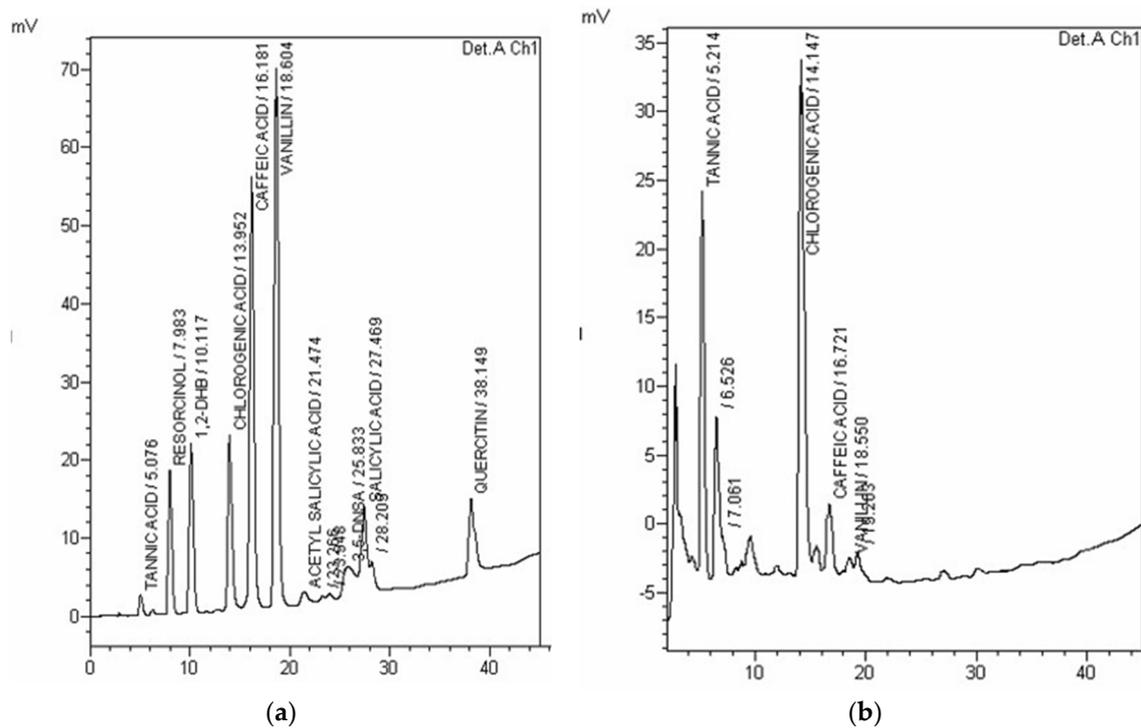
	Reducing Power	DPPH Scavenging (IC_{50})
Total polyphenol content	0.723	−0.471
Total flavonoid content	0.698	−0.460

3.6. HPLC Analysis of Phenolic Compounds

The average quantitative phenolic constituents found in eggplant samples are reported in Table 3 and respective chromatograms of standards and air-fried sample are given in Figure 6a,b, respectively. Uncooked (raw) eggplant sample had the lowest concentration of the phenolic compounds (13.86 mg/100 g) as compared to the air-fried eggplant samples. Medium-cooked samples had the highest phenolic compounds (335.5 mg/100 g) compared to high-cooked (216.15 mg/100 g) and light-cooked (26.92 mg/100 g) samples. Tannic acid was the main phenolic compound in all samples of eggplant followed by chlorogenic acid (Table 3). Tannic acid is the hydrolysable tannins present abundantly in parts of the fruit [43]. Alkurd et al. [44] obtained 413.7 mg tannic acid equivalents/100 g from whole eggplant extract.

Table 3. Concentration of phenolic compounds in air-fried eggplant (mg/100 g dry weight); ND: not detected.

Compound Name	UC	LC	MC	HC
Tannic acid	8.67	14.64	283.29	138.39
Resorcinol	0.09	0.15	ND	ND
Chlorogenic acid	4.79	12.13	48.93	77.04
Caffeic acid	0.21	ND	2.77	0.57
Vanillin	0.08	ND	0.54	0.15
Acetyl salicylic acid	ND	ND	ND	ND

**Figure 6.** HPLC chromatograms: (a) standard compounds; (b) high-cooked eggplant extracted with 100% ethanol.

Chlorogenic acid is the second major phenolic compound found in the eggplant samples. High-cooked samples had the highest chlorogenic acid content (77.04 mg/100 g), followed by medium-cooked sample (48.93 mg/100 g) and then low-cooked samples (12.13 mg/100 g).

4. Conclusions

The effect of air-frying along with extraction solvents on the bioactive properties of eggplant was investigated in this study. Both factors showed a promising effect, and the eggplant sample air-fried for a longer time (25 min) showed better results as compared to the other samples, while the 50% ethanol was found to be a better extraction solvent. Medium-cooked samples had the highest phenolic compounds (335.5 mg/100 g) compared to high-cooked and low-cooked eggplant. The uncooked sample exhibited the lowest DPPH scavenging and reducing power, while the highest DPPH scavenging activity was recorded for the sample air-fried for 25 min and extracted with 50% ethanol. Moreover, the uncooked eggplant sample had the lowest concentration of the phenolic compounds as compared to the air-fried eggplant samples. The tannic acid content was the highest in the medium-cooked sample, whereas the chlorogenic acid content was found to be the highest

in the high-cooked sample. The results of this study could be helpful for the processing of eggplant.

Author Contributions: Conceptualization, A.M.S. and K.H.; methodology, A.M.S., M.A.A. and K.H.; software, K.H.; validation, M.S.A., N.S.A. and A.M.A.-D.; formal analysis, N.S.A., K.H. and M.A.A.; investigation, A.M.S., S.A. and L.N.A.-H.; resources, A.M.S.; data curation, K.H. and L.N.A.-H.; writing—original draft preparation, K.H. and A.M.S.; writing—review and editing, S.A., A.M.A.-D. and M.A.A.; visualization, K.H. and S.A.; supervision, A.M.S. and K.H.; project administration, M.S.A. and M.A.A.; funding acquisition, A.M.S. All authors have read and agreed to the published version of the manuscript.

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