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Research Article

Effects of Multihollow Surface Dielectric Barrier Discharge Plasma on Chemical and Antioxidant Properties of Peanut

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An experiment was conducted to investigate the effects of atmospheric pressure plasma generated by multihollow surface dielectric barrier discharge on chemical and antioxidant properties of peanut. Multihollow surface dielectric barrier discharge is a novel plasma device applicable in food industry applications due to the capacity of the generated plasma to treat the surface of food without changing the quality. Peanut seeds were exposed to the multihollow plasma for different plasma power (10–40 W), air flow rate (0.5–20 l/min), and time (1–15 min). The fatty acid profile, peroxide value, acid value, moisture content, total polyphenols, and antioxidant activity were evaluated during cold plasma treatment. The result revealed that, due to the variation plasma power, treatment time and air flow rate caused a decrease in unsaturated fatty acid and moisture content and increased saturated fatty acids, peroxide value, acid value, and total polyphenols of the peanut.

1. Introduction

Peanuts (*Arachis hypogaea* L.) are a globally important oilseed valued as a source of high-quality cooking oil, crude protein, crude fat, crude fiber, water, ash, total sugar, amino acids, fatty acids, vitamins, minerals, phytosterol, resveratrol, squalene, and other antinutritional factors [1] and appreciated worldwide as an affordable, flavorful, serving as a primary ingredient for peanut butter, confections, and nutritional bars, among other finished products. It is widely used as an economic food enhancement to counter malnutrition owing to its high nutritional value [2]. However, the aforementioned characteristics led the peanut to become sensitive to molds contamination, in the whole supply chains [3] and other biotic and abiotic stresses constrain production and use of peanut [4, 5]. Different microorganisms infect peanuts and cause spoilage, leading to the production of toxic metabolites [6–8]. Various methods have been applied to decontaminate the growth of molds in peanut such as conventional and nonthermal treatments, but none of these methods offers a complete control of toxigenic molds.

A lot of nonthermal technologies have been investigated and applied in food industries to assure and improve the quality of the food. The use of nonthermal surface decontamination processes and surface treatment is desirable for a variety of food products, in particular for those in which it is important to heat sensitive agricultural products. Among those nonthermal technologies, plasma is one of the latest green technologies used now a days around the world for various applications [9, 10].

According to Fridman et al. [11], plasma is often referred to as the fourth state of matter, comprised of several excited atomic, molecular, ionic, and radical species, coexisting with numerous reactive species, including electrons, positive and negative ions, free radicals, gas atoms, molecules in the ground or excited state, and quanta of electromagnetic radiation (UV photons and visible light). Plasma can be

generated using any kind of energy which can ionize the gases, such as electrical, thermal, optical, and radioactive and X-ray electromagnetic radiation. However, electric or electromagnetic fields are widely used for cold plasma generation [12]. Plasma can be generated at low or high pressure but plasma generated at atmospheric pressure is of interest to the food industry because it does not require extreme process conditions [13]. Cold Plasma is also known as nonequilibrium plasma, because of its low gas temperature of <70°C, because the applied energy leads to an elastic collision of the gas particles, atoms, and electrons. The gas particles are less energetic than the electrons in the discharge where the heavy particles have kinetic temperatures close to ambient because the transfer of kinetic energy to other particles in such a way that the cooling of the uncharged particles and neutral ions is more rapid than the energy transfer from the electrons [11, 14, 15].

Cold plasma is a better alternative to other existing surface decontamination methods due to operation at atmospheric pressure, low-temperature, long operative duration, and economical and simple systems [16], and it is a novel and green food preservation technology and has only been applied at very small scales [17]. This technology is gradually finding acceptance among food researchers for the surface sterilization but the effect of cold plasma on the sensitive constituents of foods mainly lipids, vitamins, and bioactive compounds, and the physical quality of the product being treated not addressed [13].

Atmospheric cold plasma surface treatment process offers novel food preservation properties and has been tested with different plasma setup and gas sources in different cereal grains [8, 18], peanuts [6, 8, 19, 20], dairy [21], fruits and vegetables [22], meat [23–25], and spices [26, 27] but none of them have investigated the synergetic effect of cold plasma operating conditions (plasma power, air flow rate, and treatment time) on the quality of the treated food product.

Numerous researches have been done to investigate the effects of plasma on food constituents, and various chemical reactions are induced by plasma, but there has been speculation on the free radical formation when fatty foods and with high antioxidant and polyphenol compounds are exposed to plasma energy. Cold plasma can generate reactive and free radical species, and these species that have strong oxidation capacities. Treating high lipid-containing materials with cold plasma could lead to lipid and consequently to development of off-flavor and off-odor and in loss of natural antioxidants and caused the formation of many volatiles related to lipid oxidation [24]. Peanut contains the high percentage of mono- and polyunsaturated fatty acids and the low percentage of saturated fatty acids [1].

Little information is available about the synergistic influence of cold plasma operation conditions (plasma power, air flow rate, and treatment time) peroxide value, acid value, fatty acid profile, antioxidant activity, total polyphenols, and moisture contents of peanuts. Therefore, the current objective was to study the influence of multihollow surface dielectric barrier discharge plasma operating conditions on chemical and antioxidant properties of peanut.

2. Experimental Details

2.1. Chemicals and Samples. *n*-Hexane, methanol, 95% ethanol, potassium hydroxide, sodium thiosulphate, potassium iodide, chloroform, glacial acetic acid, 2,2-diphenyl-1-picryhydrzyl radical (DPPH), Folin–Ciocalteu, sodium carbonate, starch, and gallic acid. A domestic, commercial peanut (Roba variety) was obtained from the Were Research Center, Oromia, Ethiopia.

2.2. Plasma Treatment of Peanuts. Plasma surface modification of peanuts was carried out using a special reactor for plasma treatment of small peanut samples. The rector was based on commercial coplanar-type multihollow surface dielectric barrier discharge unit for which the detail characteristics and properties were reported by [28]. A schematic draw of the experimental setup is shown in Figure 1. Multihollow surface dielectric barrier discharge plasma (MSDBD) is composed of two planar metal electrodes at distance 0.5 mm, both embedded in alumina ceramic. The entire surface is perforated by creating the18×18.9 mm ($\sim 3.4\ cm^2$). Multihollow surface DBD plasma was generated by a sinusoidal alternate current (~27 kHz), high-voltage (10 kV) power source. An MSDBD unit was embedded in a feed chamber enabling the plasma generation at a certain flow of plasma forming gas.

Plasma treatment of peanuts was done at varied treatment conditions. Total input power, monitored by a commercial wattmeter, was 10–40 W. The flow rate of ambient air with humidity 20–30% was controlled by the thermal mass flow controller RED-Y in the range (0.5–20 L/min). The treatment time was varied from 1–15 min, based on rotatable central composite design. IR thermometer, FLUKE 62 MAX, 3 M DROP water/dust resistance, IP54, with the temperature range −30 to 500°C was used to measure the temperature of the ceramic during the experiment. Six peanuts were treated by plasma in one batch. The peanuts were mechanically moved and turned around by inert plastic rod during the plasma treatment to provide a homogeneous surface treatment of peanuts. The samples were taken from the plasma field after treatment, and the treated peanuts were cooled to room temperature, packed in polyethylene bags, and kept at 4°C for further analysis.

2.3. Sample Preparation for Extraction. The cold plasma-treated and the untreated peanut seeds were milled (High-Speed Universal Disintegrator (FW100) Grinder, China) with a speed of rotating knife (2400 rpm) and passed through a mesh size 16 sieve to obtain identically sized particles and then was retained in a sealed bag in a refrigerator (1-2°C) until use. Milled peanut seed particle size is important to facilitate analyses of mass transfer during the extraction of oil and antioxidant.

2.4. Extraction Methods. The extraction was performed in duplicate, with solvent, *n*-hexane (99% purity). An automated Soxhlet set (The Soxhlet extractor SXT-06,

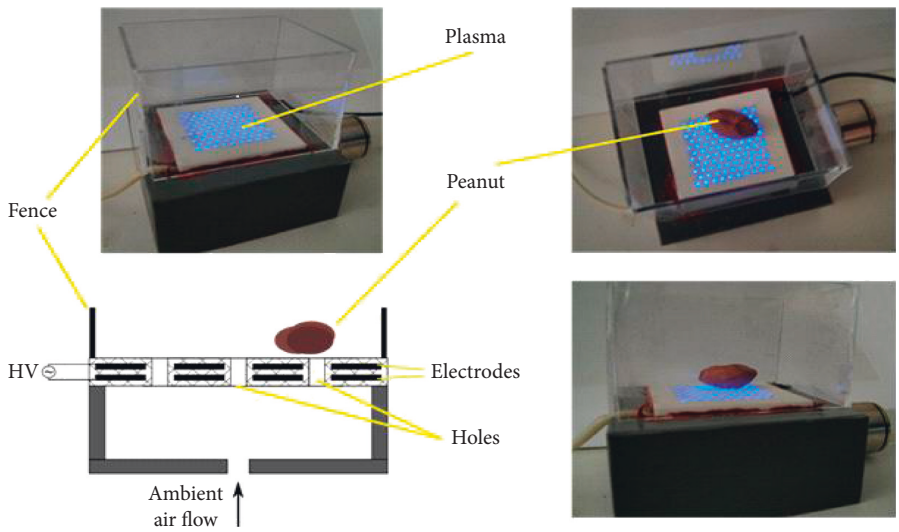

Figure 1: Multihollow surface DBD electrode setup.

Shaanxi, China) was used to extract peanut oil. To achieve this, 5 g of sample was packed in a cartridge placed inside a 250 mL extractor device. The sample was extracted for 8 h. Then extra solvent form sample oil was removed by the rotary vacuum evaporator. The extracted solvent was stored in a brown bottle in the refrigerator for further analysis.

2.5. Extraction of Antioxidant Components. The plasma-treated peanut seeds were defatted first with *n*-hexane (10% w/v) using a Soxhlet extraction unit for 8 h. The defatted samples were then air-dried and extracted with methanol (100 mL) using an incubator shaker (Thermo Shaker Incubator, Model, THZ-103B, China). All suspensions were then filtered through a Whatman No. 1 filter paper, and the residues re-extracted twice, each time with an additional 100 mL of the same solvent. The filtrates were combined and the solvent evaporated under reduced pressure using a rotary evaporator (Eyela, Model N-1000) at 40°C. The methanolic extracts were used for the determination of total polyphenol and antioxidant activity.

2.5.1. Extraction of Peanut for Analysis of the Antioxidant and Polyphenols. Samples were extracted based on the procedures used by Bishi, et al. [29]. Briefly, five grams of dried groundnut powder was extracted by stirring with 50 ml of methanol at 25°C at 150 rpm for 24 h using the temperature shaker incubator (ZHWY-103B) and then filtered through Whatman No. 4 paper. The residue was then extracted two wises with the addition of 50 mL methanol as the above procedure. The combined methanol extracts were evaporated at 40°C to dryness using a rotary evaporator (Stuart R3300). The crude extracts were weighed to calculate the yield and redissolved in methanol at the concentration of 30 mg/ml and stored in a refrigerator (−4°C) until used for further work.

2.5.2. Measurement of Antioxidant Activities and Total Polyphenol

(1) Total Polyphenols Contents (TPC) Determination. A modified Folin–Ciocalteu procedure as described by [30] was used for the determination of total polyphenol contents. Samples (0.1 mL) were mixed with 1.0 mL of the Folin–Ciocalteu reagent (previously diluted with distilled water 1 : 10 v/v), and the reaction was terminated using 1 mL of 7.5% sodium carbonate. The mixture was vortexed for 15 sec for color development. After 30 min incubation at room temperature (28 ± 1°C), the absorbance was measured at 765 nm using a UV-Vis spectrophotometer (PerkinElmer Lamda 950 UV/Vis/NIR). The standard curve was prepared using gallic acid standard solutions of known concentrations, a linear calibration graph (Figure 2) was constructed with gallic acid concentrations of 20, 50, 100, 150, 200, and 250 μg/mL, and the results were expressed as mg gallic acid equivalent/100 g sample:

$$\text{TPC} = \frac{\text{C} \times \text{V}}{\text{M}}, \quad (1)$$

where TPC = total polyphenol content(mg/gm); C = concentration of gallic acid (mg/mL); V = volume of extract in assay (mL), and M = mass of pure plant methanolic extract (gm).

2.5.3. Free Radical Scavenging Assay (DPPH). The effect of methanol extracts on DPPH radical was estimated according to Win et al. [31]. A 0.004% freshly prepared solution of DPPH radical solution in methanol was prepared, and then 4 mL of this solution was mixed with methanol extract (40 μL) of the sample. Finally, the samples were incubated for 30 min in the dark at room temperature. Scavenging capacity was read by spectrophotometer (PerkinElmer Lamda 950 UV/Vis/NIR) by monitoring the decrease in absorbance at 517 nm. This absorption maximum was first verified by scanning freshly prepared DPPH from

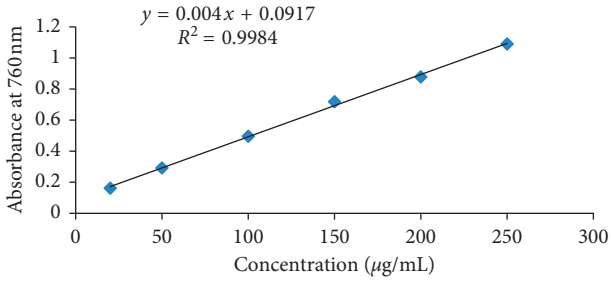

Figure 2: Gallic acid standard curve for the calculation of total polyphenols content.

200–800 nm using the scan mode of the spectrophotometer. Free radical scavenging activity DPPH in percent (%) was then calculated:

$$\text{radical scavenging activity}\,(\%) = \frac{(A_o - A_1)}{A_o} * 100, \quad (2)$$

where A_o is the absorbance of the control and A_1 is the absorbance of the sample.

2.6. Moisture Content. Before and after plasma treatment, whole peanut from treatment (triplicate) was dried in a forced air oven at 130°C for 6 hours [32]. The weight differences before and after oven drying will be used to calculate moisture content (MC; % dry weight).

2.7. Acid and Peroxide Values. Acid value in mgKOH g^{-1} oil and peroxide value in mEqO_2 kg^{-1} oil were determined according to standard methods (AOAC, 2010).

2.8. Fatty Acid Determination. The lipid fraction of peanut seed oil samples was extracted and fatty acids methyl esters were prepared [33], and the fatty acid profile was determined by gas chromatography with a mass spectrophotometer (GC-MS).

2.9. Statistical Analysis. Data were subjected to the analysis of variance test (one-way ANOVA) using the JMP 7.01 SAS Institute Inc., 2007 software computer package. A comparison test on treatment means was conducted using the post hoc Tukey test at ($p < 0.05$) differences with 95% confidence level.

3. Results and Discussion

3.1. Fatty Acid Profiles. Surface oxidation and development of undesirable changes may occur in food from extreme doses of cold plasma, and cold plasma generates free radicals and reactive species that may modify the functions of fatty acids, inducing lipid oxidation [15]. However, several authors have reported that atmospheric cold plasma treatment did not cause any negative effects on the chemical quality of food products.

Table 1 shows fatty acid compositions of peanut oils variations depending on the cold plasma conditions. The fatty acids identified from untreated (control) peanut oil were 13.34% palmitic acid (C16 : 0), 4.47% stearic acid (18 : 0), 43.46% oleic acid (C18 : 1), 32.56% linoleic acid (18 : 2), 1.35% arachidic acid (20 : 0), 1.39% gadoleic acid (C20 : 1), and 2.89% behenic acid(22 : 0). This is in agreement with previously reported data [1, 34]. The major fatty acids of the unsaturated fatty acids suggest that the peanuts oil is highly nutrient. The ratio of oleic-to-linoleic acid (O/L) is a quality index employed to decide peanut shelf-life and oil stability, ranging from 1 to 1.5, 1.5 to 9.0, and above 9.0, classified as normal, mid, and high-oleic type, respectively [35]. The present study was carried out with normal oleic peanuts (O/L = 1.335). The total saturated fatty acids and unsaturated fatty acids in oil extracted from nonplasma-treated (control) samples of peanut seed oil was 21.92% and 77.41%, respectively.

Palmitic acid contents of all treatments ranged from 13.34% (control) to 15.23% (cold plasma treated).This type of fatty slightly increased in all cold plasma operating conditions but there were no significant ($p > 0.5$) differences between all samples (Table 1). Stearic acid contents of untreated and cold plasma treated peanut samples were found increased but utmost nonsignificant ($p > 0.05$) in all experiments. In addition, while oleic acid contents of untreated peanut oil samples change between 43.47% (control) and 35.74% (plasma treated), linoleic acid contents of peanut oils ranged between 32.56% (control) and 24.49% (plasma treated).

Oleic and linoleic acid content was decreased, and significant ($p < 0.05$) difference was observed at different plasma operating conditions (plasma power, air flow rate, and treatment time). The same result was reported by Albertos et al. [36]; the cause might be reaction produced by the H and OH plasma species. Gadoleic acid (C20 : 1) is one of the unsaturated types of fatty acid and occurs in minor proportions. During this experiment, its amount was decreased but there was no significant ($p > 0.05$) difference throughout the experiments as shown in Table 1. Significant increase in behenic and arachidic acids at various plasma parameters rates in peanut seed oils and significant difference ($p < 0.05$) was observed between same treatments. Generally, a slight increase in saturated fatty acids and a decrease in unsaturated fatty acids were observed during the experiment (Table 1). The results at 25 W, 10 L/min, and 1 min were similar to the control as shown in Table 1. This might be the reaction between the sample, and the energetic particles especially oxygen reacting species from plasma was short, thus leading fatty acid profiles to remain unaffected.

The available studies on the effects of cold plasma on lipids in different food products are very limited. However, based on the reported studies, treatment time and plasma gas could be considered as critical factors affecting lipid oxidation [37]. According to Cämmerer and Kroh [38], conventional roasting at 120–160°C for long time treatment, the structure of lipid storage cells is damaged and oil exposure to oxidation rate increase, but as indicated in Figure 3, in this study, the variation of temperature the ceramic of the cold plasma was below 80°C; therefore, atmospheric cold plasma would significantly decrease the risk of oil

Table 1: Mean values comparison of fatty acid profiles of the cold plasma-treated peanut ($p < 0.05$).

	Plasma treatment condition	C16 : 0	18 : 0	C18 : 1	C18 : 2	20 : 0	20 : 1	22 : 0
1	34 W, 16 L/min, 12 min	14.32 ± 1.84^{a}	7.12 ± 0.35^{a}	38.19 ± 1.63^{c}	28.00 ± 1.41^{bcd}	4.09 ± 0.14^{abc}	1.08 ± 0.25^{a}	5.73 ± 0.66^{ab}
2	34 W, 16 L/min, 4 min	14.22 ± 0.35^{a}	6.14 ± 1.21^{ab}	38.42 ± 0.71^{bc}	29.06 ± 0.14^{abc}	3.99 ± 0.14^{abc}	1.06 ± 0.21^{a}	$5 \pm 0.01a^{bc}$
3	25 W, 10 L/min, 15 min	14.00 ± 0.14^{a}	6.24 ± 0.35^{ab}	38.36 ± 2.05^{bc}	25.76 ± 0.92^{bcd}	5.73 ± 0.85^{a}	0.29 ± 0.28^{a}	5.54 ± 0.64^{ab}
4	25 W, 20 L/min, 8 min	15.08 ± 0.21^{a}	7.01 ± 0.02^{a}	37.12 ± 2.97^{c}	25.04 ± 0.92^{bcd}	4.89 ± 0.28^{abc}	0.54 ± 0.64^{a}	7.53 ± 0.46^{a}
5	34 W, 4 l/min, 4 min	15.23 ± 0.42^{a}	7.03 ± 0.19^{a}	37.40 ± 0.71^{c}	26.62 ± 0.85^{bcd}	4.03 ± 0.07^{abc}	0.97 ± 0.07^{a}	6.93 ± 1.34^{a}
6	10 W, 10 L/min, 8 min	14.45 ± 0.78^{a}	6.07 ± 0.14^{ab}	39.39 ± 0.71^{abc}	29.93 ± 1.32^{ab}	3.56 ± 0.49^{bc}	1.06 ± 0.14^{a}	3.84 ± 1.16^{bc}
7	25 W, 10 L/min, 8 min	14.32 ± 0.46^{a}	6.40 ± 0.70^{ab}	39.38 ± 0.71^{abc}	26.98 ± 0.67^{bcd}	3.42 ± 0.62^{c}	1.05 ± 0.13^{a}	5.66 ± 0.49^{ab}
8	25 W, 0.5 L/min, 8 min	13.99 ± 0.07^{a}	7.10 ± 0.28^{a}	39.7 ± 0.86^{abc}	26.59 ± 0.78^{bcd}	3.43 ± 0.62^{c}	0.98 ± 0.07^{a}	6.53 ± 0.57^{a}
9	16 W, 4 L/min, 4 min	14.13 ± 0.42^{a}	5.42 ± 0.50^{ab}	37.60 ± 0.64^{c}	29.68 ± 0.71^{ab}	4.04 ± 0.14^{abc}	0.96 ± 0.11^{a}	3.48 ± 0.57^{bc}
10	25 W, 10 L/min, 1 min	13.24 ± 0.35^{a}	4.51 ± 0.35^{b}	43.27 ± 0.99^{ab}	32.46 ± 0.85^{a}	1.60 ± 0.26^{d}	1.26 ± 0.28^{a}	2.87 ± 0.19^{c}
11	16 W, 16 L/min, 4 min	14.11 ± 0.21^{a}	6.37 ± 0.42^{ab}	36.89 ± 0.28^{c}	29.41 ± 0.64^{abc}	4.43 ± 0.71^{abc}	1.14 ± 0.21^{a}	5.03 ± 0.06^{abc}
12	16 W, 16 L/min, 12 min	14.29 ± 0.35^{a}	7.19 ± 0.96^{a}	38.88 ± 1.23^{abc}	26.26 ± 1.2^{bcd}	4.07 ± 0.21^{abc}	0.52 ± 0.52^{a}	6.68 ± 0.54^{a}
13	40 W, 10 L/min, 8 min	15.06 ± 0.09^{a}	6.98 ± 0.14^{a}	35.74 ± 1.21^{c}	24.49 ± 2.04^{d}	5.34 ± 0.71^{ab}	0.32 ± 0.85^{a}	7.4 ± 0.69^{a}
14	34 W, 4 L/min, 12 min	14.27 ± 1.03^{a}	7.41 ± 0.49^{a}	36.85 ± 0.47^{c}	25.58 ± 20^{bcd}	5.23 ± 0.42^{ab}	0.11 ± 0.17^{a}	7.45 ± 0.71^{a}
15	16 W, 4 L/min, 12 min	15.00 ± 0.02^{a}	7.50 ± 0.69^{a}	36.27 ± 0.94^{c}	24.99 ± 0.07^{cd}	5.04 ± 0.06^{abc}	0.48 ± 0.57^{a}	6.92 ± 0.49^{a}
16	Control	13.34 ± 0.85^{a}	4.47 ± 0.32^{b}	43.46 ± 0.72^{a}	32.56 ± 1.13^{a}	$1.35 \pm .01^{d}$	1.39 ± 0.49^{a}	2.89 ± 0.27^{c}

All values are mean ± SD. $^{a-d}$Values in the same column with different superscripts are significantly different.

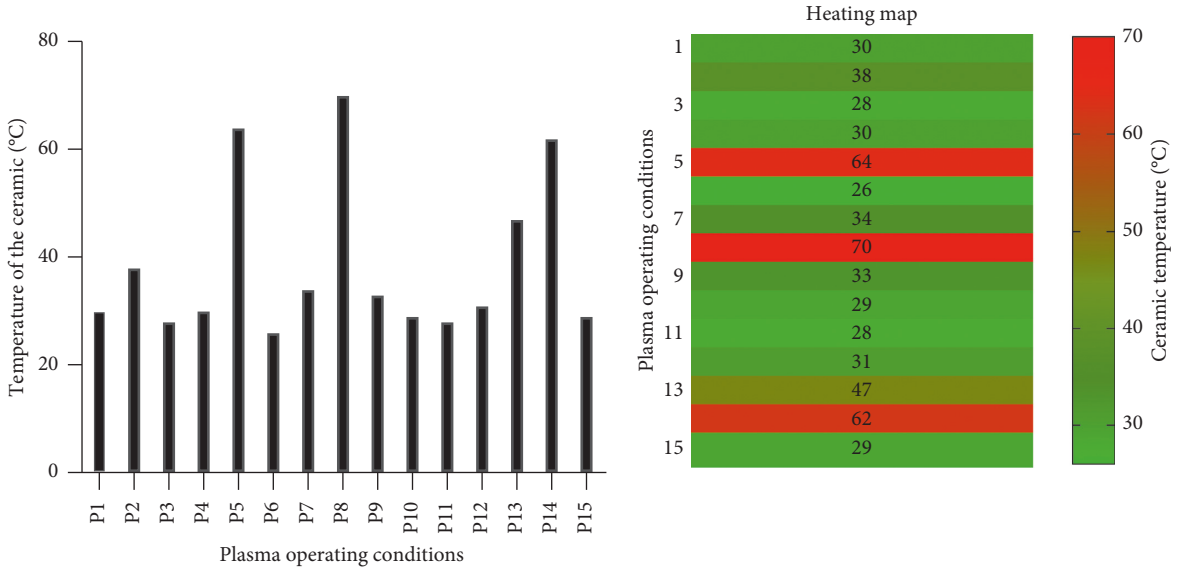

Figure 3: Temperature of ceramic at different plasma operating conditions.

exposure to thermal oxidation. The changes in fatty acid compositions by application of cold plasma could be due to the detrimental effect of the reactive species of cold plasma [21]. Recently, Sarangapani et al. [39] have indicated that cold plasma oxidation of lipids.

Plasma treatment produces free radicals such as hydroperoxyl radicals, superoxide radicals, and singlet oxygen that attack unsaturated fatty acids, which causes to decreases and increased total saturated fatty acids gradually [21]. According to another study by Mexis and Kontominas [40], monounsaturated fatty acids, as opposed to polyunsaturated fatty acids, were preferentially attacked by oxygen to produce primary and secondary oxidation products under gamma irradiation. Irradiation caused a significant gradual decrease in the unsaturated fatty acid content and a significant saturated fatty acid content increase as irradiation dose increased in sesame seeds [41]. Another study suggested that the decrease in unsaturated fatty acids during the irradiation exposure of oil was mainly due to a molecular structure change in fatty acids [42].

3.2. Acidity Value (AV). Acidity value is an indicator for edibility of oil and suitability for industrial use and any extreme change could lead to an unwanted influence on the sensory acceptability and shelf-life of the treated food product. Peanut is a high oil content product (50–55%), with high unsaturated fatty acids, which are susceptible to oxidation [43, 44]. The oil extracted from untreated (control) peanut seeds has an acid value of 0.82 mg KOH g^{-1} (Table 2), which is already in use for edible purpose, and this falls within the recommended by Alimentarius codex [45]. Results obtained from this work indicated that the acid value of the peanut oil corresponds to low levels of free fatty acids

Table 2: Mean values comparison of chemical and antioxidant properties of cold plasma-treated peanut ($p < 0.05$).

	Plasma treatment condition	DPPH (%)	PV (mEq $O_2 kg^{-1}$)	AV (mg $KOHg^{-1}$)	TPC (mg gallic acid/100 g)	MC (%)
1	34 W, 16 L/min, 12 min	93.29 ± 0.35^{c}	2.30 ± 0.11^{e}	3.12 ± 0.18^{a}	213.48 ± 0.71^{ef}	4.67 ± 0.08^{cd}
2	34 W, 16 L/min, 4 min	94.32 ± 0.21^{ab}	2.53 ± 0.09^{e}	1.40 ± 0.15^{bc}	200.73 ± 1.41^{gh}	4.88 ± 0.03^{bc}
3	25 W, 10 L/min, 15 min	94.67 ± 0.28^{a}	2.33 ± 0.05^{e}	1.06 ± 0.11^{c}	200.20 ± 0.64^{gh}	4.89 ± 0.14^{bc}
4	25 W, 20 L/min, 8 min	94.32 ± 0.07^{ab}	2.40 ± 0.09^{e}	1.11 ± 0.16^{c}	197.45 ± 3.77^{h}	5.20 ± 0.03^{ab}
5	34 W, 4 l/min, 4 min	94.41 ± 0.21^{ab}	8.33 ± 0.51^{c}	3.05 ± 0.09^{a}	226.05 ± 3.50^{de}	4.5 ± 0.013^{d}
6	10 W, 10 L/min, 8 min	94.42 ± 0.35^{a}	2.33 ± 0.05^{e}	1.05 ± 0.08^{c}	202.05 ± 3.22^{fgh}	5.17 ± 0.08^{ab}
7	25 W, 10 L/min, 8 min	94.9 ± 0.07^{a}	2.78 ± 0.04^{e}	1.10 ± 0.16^{c}	212.70 ± 4.17^{fg}	5.19 ± 0.08^{ab}
8	25 W, 0.5 L/min, 8 min	93.25 ± 0.07^{c}	13.95 ± 0.86^{a}	3.16 ± 0.12^{a}	341.15 ± 2.12^{a}	3.30 ± 0.01^{f}
9	16 W, 4 L/min, 4 min	94.47 ± 0.42^{ab}	1.71 ± 0.29^{e}	1.12 ± 0.17^{c}	202.24 ± 3.17^{fgh}	5.28 ± 0.02^{a}
10	25 W, 10 L/min, 1 min	94.75 ± 0.14^{a}	1.59 ± 0.13^{e}	0.84 ± 0.08^{c}	202.7 ± 3.61^{fgh}	5.33 ± 0.04^{a}
11	16 W, 16 L/min, 4 min	94.73 ± 0.21^{a}	2.44 ± 0.07^{e}	1.05 ± 0.22^{c}	199.23 ± 1.41^{h}	5.29 ± 0.10^{a}
12	16 W, 16 L/min, 12 min	94.37 ± 0.14^{ab}	2.17 ± 0.38^{e}	1.15 ± 0.05^{c}	194.11 ± 5.47^{h}	4.88 ± 0.15^{bc}
13	40 W, 10 L/min, 8 min	94.69 ± 0.07^{a}	2.37 ± 0.19^{e}	1.53 ± 0.49^{bc}	243.92 ± 5.56^{c}	4.40 ± 0.12^{d}
14	34 W, 4 L/min, 12 min	93.59 ± 0.28^{bc}	6.81 ± 0.69^{d}	3.29 ± 0.68^{a}	303.98 ± 2.83^{b}	3.42 ± 0.11^{f}
15	16 W, 4 L/min, 12 min	94.13 ± 0.07^{abc}	10.20 ± 0.15^{b}	2.41 ± 0.60^{ab}	230.54 ± 2.08^{d}	3.91 ± 0.01^{e}
16	Control	94.72 ± 0.35^{a}	1.56 ± 0.20^{e}	0.82 ± 0.22^{c}	200.23 ± 1.41^{gh}	5.38 ± 0.10^{a}

All values are mean ± SD. $^{a-h}$Values in the same column with different superscripts for each type of analysis are significantly different. DPPH, 1,1-diphenyl-2-picrylhydrazyl; PV, peroxide value; AV, acid value; TPC, total phenolic content; MC, moisture content.

present in the oil in most experiment trials, which suggested low levels of hydrolytic and lipolytic activities in the oil.

The acid value of the oil extracted from noncold plasma-treated peanut oils samples increased from 0.82 ± 0.22 to 3.16 ± 0.12 mg KOH g^{-1} oil during the treatment. The increase in the acid value of oil during the treatment might be due to slight and random hydrolysis of triglycerol molecules to free fatty acids and diacylglycerols [46]. Recently, Kim et al. [47] evaluated the physicochemical characteristics of milk that was treated with cold plasma and reported an increase in acidity. When peanut seeds were treated with optimum cold plasma condition rates, the fatty acid was oxidized rapidly, and the AV would increase. It is clear that no significant difference ($p > 0.05$) was observed between treated and untreated groups (Table 2) except at extreme conditions. The results demonstrate that the peanuts treated under the optimal cold plasma conditions were stable in the acid value.

3.3. Peroxide Value (PV). Lipid oxidation is a complex process involving free radical chain mechanisms forming fatty peroxidation products [48] and peroxide (PV) important parameters for elucidating the peanut oil quality and assessing the oxidation extent [49]. Since cold plasma is often considered as an advanced ionized new technology, it is important to analyze its influence on the lipids present in the fatty foods. As Table 2 indicates, the PV produced from control and cold plasma-treated peanut oil was almost below 10 mEqO_2 kg^{-1} oil except for few experiment trials, and it is low as the Codex Alimentarius Commission stipulated permitted maximum peroxide levels of 10 mEqO_2 kg^{-1} oil [45]. As the plasma power and treatment time increased, the air flow rate decreased, the overall lipid oxidation increased, and significantly different ($p < 0.05$) from other plasma operating conditions.

Different researchers have done different experiments and have reported different results. After cold plasma treatment in fresh and frozen pork [50], beef jerky [25], and raw pork [51] have observed no significant effect on lipid oxidation. However, in [52] an increase has been reported in lipid oxidation in fresh pork and beef after treating them for an extended time period. Recently, Albertos et al. [36] have reported that cold plasma treatment led to a significant lipid oxidation in fresh mackerel fillets. It has been reported in [47, 52] that plasma treatment of meat products increased lipid oxidation when subjected to higher treatments.

A comparison of different voltages and treatment time showed both variables increased the rate of oxidation [36]. Joshi et al. [53] also suggested that lipid oxidation is proportional to the amount of plasma energy applied. Van Durme et al. [54] also revealed that cold plasma caused the formation of many volatiles related to lipid oxidation. During this study, the peroxide value of the oils tested significantly increased ($p < 0.05$) (an increase from 1.56 to 13.95 mEqO_2 kg^{-1} oil), which might be attributed the lack of optimum operating conditions of cold plasma. Cold plasma can generate reactive (free radicle) species that have strong oxidation capacities and that cause lipid oxidation [24]. Thirumdas et al. [55] reported that the main problem encountered was an increase in PV which is at higher power and treatment time. Similar results were observed in the case of our results cold plasma-treated peanuts samples.

3.4. Total Polyphenols. Polyphenols are common constituents in plant products and important antioxidants, which are contained, in large amounts, in peanut [56] and used as antifungal infections in peanuts. Polyphenols play a role in the prevention of degenerative diseases, mainly cardiovascular diseases and cancers with their antioxidative properties [57].

In this study, polyphenols were used as indicators to assess the degree of oxidation by cold plasma. Total polyphenol of untreated and cold-plasma treated peanut seeds is shown in Table 2. The total polyphenol content of untreated (control) peanut seeds was 200.23 mg Gallic acid 100^{-1}. This amount is similar to that in the literature [58–60]. In this study, there was a variation in total polyphenol contents and significant variations between untreated and cold plasma

treated ($p < 0.05$). The reported results on the effects of cold plasma treatment on the total phenolic contents of the food products have a wide degree of variation. A decrease in the total polyphenols was reported in orange juice [61], white grape juice [12], and lamb's lettuce [62]. On the other hand, no significant effect in apples [63] but a significant increase in cashew apple juice [64] and blueberries [65] were also reported. Recent studies using microwave plasma treatment of mandarins increased the total phenolic content [66].

Garofulić et al. [9] studied the effect of atmospheric-pressure plasma treatment on the phenolic acids of sour cherry Marasca juice, the result reveal that enhanced the concentration of phenolic acids. Herceg et al. [67] evaluated the effect of gas plasma on the phenolic content of pomegranate juice, and an increase in total phenolic content was observed. As Table 2 shows, in some experiments, phenolic content was increased. UV radiations and reaction oxygen species formed may be responsible for the increasing phenolic compounds which are extracted from the upper cells because phenols protect cells against the damaging effects of external stress such as reactive oxygen species.

Therefore, the amounts of polyphenols may vary depending on the cold plasma operating conditions applied, and total polyphenols were not affected by cold plasma under the optimal conditions. Most setups as shown in Table 2 except 34 W, 16 L/min; 12 min; 34 W, 4 L/min, 4 min; 25 W, 0.5 L/min, 8 min; 34 W, 10 L/min, 8 min; 40 W, 4 L/min, 12 min, and 16 W, 4 L/min, 12 min were optimum when compared to the control.

3.5. Antioxidant Activity. Although antioxidant activity is not a direct quality attribute used in the food industries, it is a close indicator of various polyphenols present in the food products. The antioxidant effects of phenolic compounds could be due to their redox properties, which include possible mechanisms such as free-radical scavenging activity, transition metal-chelating activity and singlet-oxygen quenching capacity [68].

There was no significant difference ($p > 0.05$) in antioxidant activity between utmost cold plasma operating conditions as indicated in Table 2 during this research study. In previous research, no significant changes in the antioxidant capacity after cold treatment were reported in radish sprouts, kiwifruits, red chicory, and onion powder [69–72]. However, some studies have shown a reduction in antioxidant activity after cold treatments in apples, white grape juice, and cashew apple juice on an extended exposure [12, 63, 64]. Almeida et al. [61] reported a reduction in the antioxidant capacity of prebiotic orange juice after a direct mode of plasma treatment, whereas insignificant effects were reported when treated under indirect mode.

3.6. Moisture Content. Attree et al. [58] reported the moisture content of raw peanut seed ranged from 5 to 6%, and our result was 5.38% as indicated in Table 2. The moisture loss was found to be a function of the linear effect of power, air flow rate, and treatment time and a significant ($p < 0.05$) difference was observed (Table 2). The causes of loss in the moisture of the peanut are the interaction of ions, electrons, and energetic species of neutral atoms, and UV-Vis radiations cause a rapid removal of low molecular contaminants such as additives, processing aids, and adsorbed species. The moisture content of peanut is a critical factor to be measured and controlled in its marketing, processing, and storage [73]. Additionally, it has a profound effect on its characteristics, texture, palatability, consumer preferably, and preservation time, and related studies indicated that moisture content accelerated the process of oxidative rancidity reactions and further affected the product taste when the moisture is too high or too low, but during this study, the moisture of the peanut was not severely reduced and it is near to the optimum moisture content of peanut for storage (5.15%) according to [74].

According to Thirumdas et al. [18], plasma treatment loss of moisture from the surface was due to etching. Therefore, it was observed that the moisture loss increases with an increase in plasma power, treatment time, and decreases in air plasma rate. Moisture loss depends mainly on water loss, and it is important because it affects the visual appearance and texture of the peanut and causes a reduction in saleable weight.

4. Conclusion

The applications of plasma in the food industry is still an emerging field with promising results for fast, effective, safe, and green modification of food. It was shown that the PV, AV, total polyphenols, antioxidant activity, moisture content, and fatty acid values were analyzed using cold plasma, where slight changes were observed on some physical parameters. The most important finding of this research was the observation of the strong relationship between power plasma, air flow rate, and treatment time toward the effect on peanut quality. From this study, it is possible to build a better understanding of how the quality parameters of peanuts are subjected to atmospheric plasma treatment conditions and could help to obtain the optimum condition of plasma power, air flow rate, and treatment time.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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