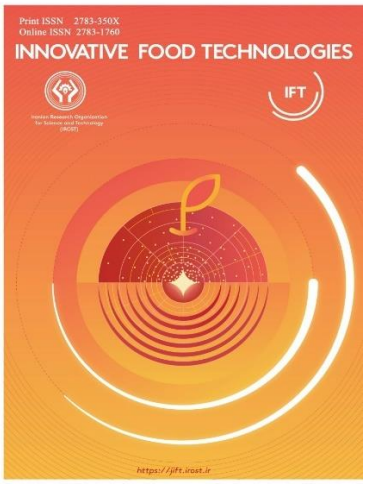
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DOI: https://doi.org/ 10.22104/ift.2026.8521.2329

To appear in: Innovative Food Technologies (IFT)

Received Date: 31 August 2026
Revised Date: 21 October 2026
Accepted Date: 2 November 2026

Please cite this article as Mobina Omidi, Akram Sharifi1, Rouzbeh Abbaszadeh, Investigating the effect of plasma activated water and dielectric barrier discharge method on the physicochemical, sensory and microbial properties of Shahani raisins, *Innovative Food Technologies (2026)*, doi: https://doi.org/ 10.22104/ ift. 2026.8521.2329

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# Investigating the effect of plasma activated water and dielectric barrier discharge method on the physicochemical, sensory and microbial properties of Shahani raisins

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**Abstract**
This study investigates the effects of cold plasma on the physicochemical, sensory, and microbial properties of Shahani raisins from Qazvin Province, Iran. Dielectric Barrier Discharge (DBD) plasma and Plasma-Activated Water (PAW) were applied to raisin samples for durations of 10, 20, and 30 min. The results demonstrated that cold plasma treatments significantly affected moisture content and acidity ($P < 0.05$). Moisture content increased from 12.87% in the control to 17.28% in PAW30, while dry matter decreased from 87.13% to 82.72%, respectively. Regarding texture, the control sample exhibited the highest firmness, at 99.19 N, whereas the DBD30 sample showed the lowest firmness, at 32.90 N. Color measurements revealed that the highest $a^*$ value was observed in PAW20 (0.27), while the lowest $a^*$ value was recorded in DBD30 (−0.73). The highest $b^*$ and $L^*$ values were observed in PAW30 (3.19 and 22.59, respectively), whereas the control sample exhibited the lowest $b^*$ and $L^*$ values (0.99 and 17.11, respectively). The antimicrobial effects varied depending on the treatment type, treatment duration, and microbial indicator. DBD treatment resulted in no detectable *E. coli* at all tested durations, whereas PAW treatment resulted in no detectable *E. coli* after 30 min. Both treatments reduced microbial counts, although their relative effectiveness differed among the microbial indicators. Overall, the findings indicate that cold plasma treatments can reduce microbial counts in Shahani raisins; however, the effects on physicochemical properties varied with treatment type and duration. The selection of a suitable treatment should therefore consider both microbial reduction and the preservation of the quality characteristics required for dried raisins.
**Keywords:** Cold Plasma, Shahani Raisin, Color, Microbial Load.

## 1 Introduction

Dried fruits are among the most widely consumed and valuable food products. Raisins, in particular, possess high nutritional value and can be considered a rich source of carbohydrates and energy for the human body. They also contain essential nutrients, including iron, minerals, and vitamins such as A, $B_1$, $B_2$, $B_3$, and $B_6$. In addition to being consumed directly, raisins are extensively used in the food industry, especially in cereal and confectionery products (Doymaz, 2006). It is essential to evaluate safe and efficient processing methods that maintain product quality. Raisins are often added to enhance sweetness and improve flavor in various food items (Jeszka-Skowron et al., 2017). Iran is one of the world's major raisin producers, and dried fruits especially raisins have historically been key export products. European and Asian countries, particularly those in the Persian Gulf region, are the primary markets for Iranian raisins (Doymaz, 2006).

Traditional thermal methods used for food sanitization have several drawbacks, including nutrient degradation, formation of undesirable or harmful compounds, and negative impacts on taste, color, and other sensory attributes. These methods often lead to the loss of heat-sensitive vitamins such as vitamin C, B-complex, and antioxidants, thereby reducing the nutritional value of food products (Liu, Bi et al. 2020). Additionally, high-temperature treatments can cause the Maillard reaction and lipid oxidation, which are associated with the formation of potentially harmful compounds such as acrylamide and heterocyclic amines(Wang, Xu et al. 2019). Furthermore, thermal processing may alter the natural texture and flavor profiles of food, diminishing consumer acceptability. These limitations have driven growing interest in the development of non-thermal technologies that can ensure microbial safety while better preserving the nutritional and sensory quality of food (Knorr, Froehling et al. 2011).

Cold plasma technique is an emerging non-thermal method increasingly used in different industries, including food industries for processing and preservation. Researchers demonstrated that cold plasma can effectively modulate food macromolecules and bioactive compounds, improving nutritional quality, safety, and functional properties, especially when combined with other emerging non-thermal technologies (Rout et al., 2024). Its non-thermal nature makes it a promising alternative to conventional chemical (e.g., chlorine-based) and physical (e.g., high-pressure, pulsed electric field, and ionizing radiation) methods. Cold plasma offers efficient, fast (ranging from seconds to an hour), and low-temperature (<70°C) treatment options (Schlüter et al., 2013). In the cold plasma generation process, most of the electrical energy is used to excite and ionize gas particles, while the overall temperature remains near ambient. This makes cold plasma suitable for treating heat-sensitive materials and effective for surface decontamination. Advantages of this technology include low initial cost, the ability to deactivate a broad range of microorganisms, environmental sustainability, and operation at room temperature and atmospheric pressure, minimizing thermal degradation (Bárdos & Baránková, 2010).

Studies have shown that cold plasma is capable of inactivating microorganisms in various forms, including vegetative cells, spores, and fungi (Pankaj et al., 2018). Cold plasma exerts its antimicrobial effects through oxidation of lipids and proteins in microbial cell walls and cytoplasmic membranes, leading to functional disruption, membrane damage, and ultimately cell death (Pankaj et al., 2014; Pankaj et al., 2018). Cold plasma has been shown to effectively inactivate microorganisms and to modulate the structural and functional properties of food biomolecules, improving their quality, safety, and stability through oxidative and conformational modifications (Rout et al., 2025). Rout & Srivastav (2024) showed that high-voltage DBDs cold plasma significantly modified the structural, rheological, and techno-functional properties of soy and pea protein isolates, enhancing solubility and digestibility through reactive oxygen species-mediated oxidation (Rout & Srivastav, 2024). Plasma technology is considered one of the modern approaches extensively utilized in various sectors, including the food industry. Plasma is often referred to as the fourth state of matter. When energy is added to a substance, it transitions from solid to liquid, to gas, and eventually to plasma (Liao et al., 2017). With increasing energy, atoms and molecules in a gas are ionized. When external energy sources (thermal or electrical) are applied, they cause molecular dissociation and ionization (Tendero et al., 2006). Plasma or properly (plasma gas) is a mixture of ionized gas containing passive species, such as electrons, positive and negative ions, free radicals, gas atoms, and photons. These reactive species, generated through electron collisions, play a critical role in microbial inactivation (Stoica et al., 2014). Plasma generates various antimicrobial agents, including UV

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radiation, charged particles, and reactive species like superoxide, hydroxyl radicals, nitric oxide, and ozone (Rød et al., 2012).

Given the growing global demand for high-quality dried fruits and the economic importance of raisin exports, there is a critical need for effective, non-thermal decontamination technologies that ensure microbial safety while preserving nutritional and sensory quality. Traditional thermal methods may compromise the physicochemical and sensory quality of dried fruits. Although cold plasma offers a promising non-thermal alternative, comparative evidence on the effects of dielectric barrier discharge (DBD) plasma and plasma-activated water (PAW) on Shahani raisins remains limited. Therefore, this study aimed to compare DBD and PAW treatments applied for 10, 20, and 30 min by assessing their effects on microbial populations (total bacteria, coliforms, molds, yeasts, and *Escherichia coli*) and physicochemical properties (moisture content, dry matter, color, and firmness). The findings may help identify effective treatment conditions for reducing microbial loads while maintaining raisin quality.

## 2 Materials and Methods

### 2.1 Sample Preparation

Shahani Raisins (*Vitis vinifera L.*) were purchased from a verified local supplier, with the cultivar identity confirmed as Shahani. The raisins were stored in polyamide plastic pouches (25 µm thickness) at room temperature (25 °C) for one week to preserve their physicochemical and sensory properties, including moisture content, aroma, and flavor. All chemicals and microbial culture media were obtained from Merck (Germany).

### 2.2 Cold-Plasma Treatment of Shahani Raisin

#### 2.2.1 Plasma Activated Water (PAW)

Plasma activation was performed using a generator at the Iranian Research Organization for Science and Technology (Tehran, Iran). The generator was a dielectric barrier discharge (DBD) system operating at atmospheric pressure, with air as the working gas. The system consisted of a high-voltage electrode connected to a pulsed power supply. Figure 1 illustrates the cold plasma system used in this study. The device operated at a maximum power output of 30 W and a voltage of 12 kV, with a maximum current of 1 mA and a nominal frequency of 23 kHz. **The working frequency during the experiments was approximately 6 kHz.** The setup included a glass tube, an air pump, rubber tubing, an electrode wire, an air stone, and aluminum mesh. Plasma discharge occurred inside the tube, and the resulting plasma-treated gas was introduced into the water to generate PAW.

Raisins were immersed in the PAW for 10, 20, and 30 min. After treatment, the samples were removed from the PAW solution and gently blotted with absorbent paper towels to remove excess surface water. Subsequently, the raisins were allowed to dry at room temperature (25 °C) until the surface moisture was removed. The reported treatment durations (10, 20, and 30 min) refer to the immersion of raisins in plasma-activated water (PAW). Due to existing limitations, the physicochemical characterization of PAW was not fully performed; therefore, the specific contributions of individual reactive species to the observed changes in raisin properties could not be determined. In addition, a distilled-water immersion control without plasma activation was not included in the experimental design. Consequently, the effects of PAW treatment cannot be fully distinguished from those associated with water immersion.

**Figure 1**

### 2.2.2 Dielectric Barrier Discharge (DBD) Cold Atmospheric Plasma

The DBD system operated with an input voltage of 232 V and produced a pulsed AC output of approximately 100 kV with a power of 150 W. The raisins were directly exposed to plasma radiation for 10, 20, and 30 min, respectively (Abbaszadeh et al., 2018).

## 2.3 Physicochemical Analysis

### 2.3.1 Moisture Content

Moisture content of raisin samples was measured according to ISO 665:2020 (Standardization, 1977). Dry matter content (%) was calculated as 100% minus the moisture content (%). Since dry matter was calculated from moisture content, it was not determined independently using a separate gravimetric method.

### 2.3.2 pH Measurement

pH was measured using a calibrated digital pH meter (Ohaus 3100, USA) at 25 °C. Before use, the pH meter was calibrated with standard buffer solutions at pH 4.0, 7.0, and 10.0 to ensure accurate measurements over the relevant pH range (AOAC, 1990).

### 2.3.3 Determination of Titratable Acidity

Acidity of raisin samples was determined following the AOAC (1997) method. Approximately 10 g of the sample was distilled with an equal volume of water. The titration was performed using 0.1 N NaOH until the pH reached 8.3 (Cunniff & Washington, 1997).

### 2.3.4 Color Analysis

The color space *L**, *a**, and *b** through HunterLab colorimeters (HunterLab ColorFlex, Hunter Associates Inc., Reston, VA, USA) was used to examine color features. The color space *L**, *a**, and *b** was used to assess color characteristics. The component *L** represents the lightness rate its range varies between zero (pure black) and 100 (pure white). The component *a** indicates red color in positive values and green color in negative values. The component *b** represents blue and yellow in negative and positive values, respectively (Shavandi et al., 2023).

### 2.3.5 Texture Analysis

Texture firmness was evaluated using a penetration test with an Instron 4302 Universal Testing Machine (Canton, MA, USA). The probe had a length of 10 cm and diameter of 2 mm, with a test speed of 60 mm/min (Rolle et al., 2012).

### 2.3.6 Microbial Analysis

Microbial tests were conducted to evaluate the effects of plasma treatment on the microbiological quality of Shahani raisins. The analyses included the enumeration of total bacteria, coliforms, molds, and yeasts, as well as the assessment of *Escherichia coli* following plasma treatment. The procedures used for microorganism preparation and inoculation, together with the methods used for microbial enumeration, are described in the following subsections.

#### 2.3.6.1 Microorganisms Preparation and Inoculation

A fresh *E. coli* culture (ATCC11775) was prepared in Mueller-Hinton Broth (MHB). Bacterial concentration was standardized using a spectrophotometer (Lambda 35 UV/VIS, USA) at 560 nm and adjusted to 0.5 McFarland standard. One ml of this suspension was surface-inoculated

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onto 1 g of raisins (front and back) (Matuschek et al., 2014). The *A. niger* strain (ATCC 64974-N 402) was cultured in Yeast Extract Glucose Chloramphenicol Agar and incubated at 25–27°C for 3–5 days. The black hyphae were suspended in 1 ml distilled water, counted using a Neubauer Chamber and optical microscope, and inoculated onto raisins at a concentration of $10^5$ CFU/g under sterile laminar conditions (Noshirvani et al., 2017).

**2.3.6.2 Total Bacterial Count**

One gram of each sample was mixed with 9 ml of sterile normal saline (0.9% NaCl), and appropriate dilutions were prepared. Then, 0.1 ml of the diluted sample was spread onto Nutrient Agar plates and incubated at 30 °C for 48 h. The results were expressed as colony-forming units per gram (CFU/g) (Hemmati et al., 2021).

**2.3.6.3 *E. Coli* Count**

E. coli counts were determined by plating appropriate serial dilutions of the samples on Sorbitol MacConkey Agar (SMAC) (Oxoid, CM0107). The inoculated plates were incubated at 37 °C for 24 h. After incubation, typical colonies were counted and the results were expressed as colony-forming units per gram (CFU/g) (Çelik & Ergönül, 2020).

**2.3.6.4 Coliform Count**

Coliforms were assessed using a tube-based procedure. The reported method involved inoculation into three tubes containing double-strength Lauryl Sulfate Broth, followed by incubation at 37 ± 1°C for 24 ± 2 h. Gas production in Durham tubes was considered indicative of presumptive coliform presence. Positive tubes were subsequently examined using Brilliant Green Broth for confirmation (Geissler et al., 2000).

**2.3.6.5 Mold and Yeast Count**

One ml of the initial suspension was poured into sterile Petri dishes in duplicate. 15–20 ml of YGC agar (44–47°C) was added, and plates were inverted and incubated at 25±1°C for 5 days. Colony counts were taken after 3, 4, and 5 days (Bagheri et al., 2020). Yeast and mold colonies were differentiated based on their morphological characteristics; yeast colonies were smooth, round, creamy, and moist, while mold colonies showed filamentous or fuzzy mycelial growth.

**2.3.7 Sensory Evaluation**

A panel of 16 trained individuals (8 males and 8 females) evaluated the sensory characteristics of the treated raisins. The panelists were trained prior to the evaluation to familiarize them with the sensory attributes and the scoring procedure, with particular emphasis on raisin texture, color, aroma, flavor, appearance, and overall acceptability. The sensory attributes were assessed using a 5-point hedonic scale (1 = very poor, 5 = excellent) at room temperature. Samples were labeled with randomly assigned three-digit codes to minimize potential bias and prevent the identification of treatment groups by the panelists. All panelists were informed about the purpose and procedure of the evaluation, and informed consent was obtained before participation. All samples were evaluated under the same environmental conditions and presented to the panelists using a standardized procedure to minimize potential bias (Civille et al., 2024).

**2.4 Statistical Analysis**

Data were analyzed using a completely randomized design (CRD), with three replicates per treatment. The plasma-treated groups consisted of two treatment types (DBD plasma and

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plasma-activated water [PAW]) applied for three treatment durations (10, 20, and 30 min). The untreated control group was included in the comparisons among treatments. Analysis of variance (ANOVA) was used to evaluate differences in physicochemical, sensory, and microbial parameters. Where significant differences were detected, means were compared using Duncan's Multiple Range Test (DMRT) at the 5% significance level ($P < 0.05$). All statistical analyses were performed using SAS software, version 9.3 (SAS Institute Inc., Cary, NC, USA).

## 3 Results and Discussion

### 3.1 Results of Chemical Properties of Shahani Raisin Treatments

The results of chemical analyses for Shahani raisin samples subjected to DBD plasma and PAW treatments are summarized in Table 1.

#### 3.1.1 Moisture Content

Moisture content varied significantly with treatment duration ($P < 0.05$). For samples treated with DBD plasma, the lowest moisture content was observed after 30 min of exposure, which may be associated with moisture loss during direct plasma treatment. In contrast, PAW-treated samples showed the highest moisture content after 30 min. This increase may be related to water uptake during immersion in PAW; however, the absence of a distilled-water immersion control prevents the effects of water immersion from being distinguished from those specifically associated with PAW treatment (Table 1). Despite these differences, moisture levels remained within an acceptable range across all treatments. Similar findings were reported by Ahangari et al. (2021), who observed changes in the moisture content of dried walnut kernels under different low-pressure cold plasma (LPCP) treatment conditions (Ahangari et al., 2021). Bagheri et al. (2021) also reported changes in the moisture content of dried nuts subjected to cold plasma treatment during extended storage (Bagheri et al., 2021). These results suggest that non-thermal plasma treatments may influence the moisture content of food products, although the magnitude and underlying mechanisms of these changes depend on the treatment conditions and food matrix (Javanmard Dakheli & Shavandi, 2022).

A significant reduction in dry matter content was observed in PAW-treated samples with increasing treatment time ($P < 0.05$), particularly after 30 min (Table 1). In contrast, the dry matter content of DBD-treated samples showed an increasing trend with longer treatment time. The reduction in dry matter content in PAW-treated samples may be associated with changes occurring during immersion, potentially including the transfer of water-soluble components from the raisins into the treatment water. However, this explanation remains tentative because the transfer of soluble components was not directly measured and a distilled-water immersion control was not included. Tappi et al. (2016) reported minor changes in the dry matter content of fresh-cut melon following plasma treatment. Although this finding provides relevant context, differences in the food matrix and treatment conditions should be considered when comparing the results of the present study with those of previous research (Tappi et al., 2016).

#### 3.1.2 pH

The pH values of the raisin samples exhibited a non-linear trend with increasing treatment time (Table 1). An initial increase in pH was followed by a significant decrease at longer durations ($P < 0.05$). The highest pH values were recorded at the 10-minute mark for both DBD and PAW treatments. This transient increase may be associated with changes in the chemical composition of the treated samples, while the subsequent decrease in pH at longer treatment durations may reflect further chemical changes. However, the underlying mechanisms were not directly investigated in this study. These observations align with Ma et al. (2015), who reported no significant pH changes in strawberries treated with PAW (Ma et al., 2015). Likewise, Pankaj et

al. (2017) found that high-voltage atmospheric cold plasma (HVACP) treatment of white grape juice (80 kW, 45 min) did not significantly alter pH, acidity, or electrical conductivity ($P > 0.05$), despite effective microbial reduction (Pankaj et al., 2017).

### 3.1.3 Titratable Acidity

Treatment time had a significant impact on acidity ($P<0.05$), with longer exposure resulting in increased titratable acidity (Table 1). The lowest acidity values were recorded at 10 min for both DBD and PAW treatments. Increased acidity was almost matched with the results of pH reduction, and increased treatment time led to higher acidity or lower pH. This trend is consistent with findings by Tappi et al. (2016), who investigated the effect of DBD plasma on fresh-cut melon. Their study found only minor changes in quality attributes such as titratable acidity, soluble solids, dry matter, color, and texture over a 4-day storage period at 10°C (Tappi et al., 2016).

**Table 1**

### 3.1.4 Color and Texture Firmness

Table 2 presents the color parameters and texture firmness of Shahani raisin samples subjected to different cold plasma treatments.

### 3.1.5 Color Parameters

The results show that plasma treatments had limited effects on the color indexes of the raisin samples. No significant differences were observed in overall color, although specific changes were noted in individual parameters ($P < 0.05$). The $L^*$ value, representing lightness, varied among the treatments, with the highest value observed in the PAW30 sample and the lowest value recorded in the control sample ($P < 0.05$). Regarding redness ($a^*$), the highest value was observed in the PAW20 sample, whereas the lowest value was recorded in the DBD30 sample ($P < 0.05$). The $b^*$ index, indicating yellowness, was highest in the PAW30 sample and lowest in the control sample ($P < 0.05$). These results indicate that plasma treatment, particularly PAW treatment, affected the color characteristics of the raisins, with the most pronounced changes observed after 30 min of PAW treatment.

The observed changes in redness may be associated with chemical or structural changes occurring during plasma treatment. However, the specific mechanisms responsible for these changes were not directly investigated in this study. In addition, because a distilled-water immersion control was not included, the effects of water immersion cannot be separated from those specifically attributable to PAW treatment.

Similar findings have been reported in previous studies. Akhari et al. (2018) observed increased brightness and redness in barberry juice treated with cold plasma, compared to samples pasteurized at 80°C (Akhari et al., 2018). In contrast, Hosseini et al. (2018) found no significant changes in the overall color of garlic powder after plasma treatment (Hosseini et al., 2018). A study on turmeric powder by Sanaei et al. (2020) indicated that although gas type (air, nitrogen, argon) did not significantly affect color indexes, prolonged plasma treatment (15 and 25 min) significantly reduced $L^*$, $a^*$, and $b^*$ values (Sanaei et al., 2020).

In another study, Low-Pressure Cold Plasma (LPCP) treatment caused darkening of dried walnut kernels, although firmness remained unaffected (Ahangari et al., 2021). LPCP also darkened dried mint leaves (Kashfi et al., 2020). Similarly, Almeida et al. (2015) reported increased $L^*$ values in cold plasma-treated orange juice (Almeida et al., 2015), while Lee et al. (2016) found increases in $L^*$ and decreases in $a^*$ and $b^*$ values in brown rice (Lee et al., 2016). However, no

significant changes in *b** or *L** were observed in plasma-treated pork (Jayasena et al., 2015) or mackerel fish fillets, where only *L** was slightly affected (Albertos et al., 2017).

### 3.1.6 Texture Firmness

## Texture Firmness

Plasma treatment had a significant effect on the firmness of raisin samples ($P < 0.05$). The control sample exhibited the highest firmness, whereas the lowest firmness was recorded in the PAW30 sample. A clear trend was observed: as plasma treatment duration increased, firmness decreased significantly for both DBD and PAW methods ($P < 0.05$). This softening effect may be attributed to changes in the structural properties of the raisins during treatment. In PAW-treated samples, water uptake during immersion may also have contributed to the reduction in firmness. However, in the absence of a distilled-water immersion control, the individual contributions of water immersion and PAW treatment cannot be distinguished. Findings from Shirani et al. (2020) showed no significant change in almond slice firmness after 20 min of plasma treatment, indicating that the effect on firmness may vary with product type and structure (Shirani et al., 2020).

**Table 2**

### 3.2 Microbial Results

Table 3 presents the total bacterial count, coliforms, molds, and yeasts in various Shahani raisin samples. Analysis of variance (ANOVA) confirmed a significant effect of plasma treatment on all microbial counts ($P < 0.05$). Across both DBD and PAW treatments, the highest microbial counts were observed in the control samples, while the lowest were recorded in samples treated for 30 min (P30) ($P < 0.05$). Increasing plasma exposure time significantly reduced the total bacterial count, coliforms, molds, and yeasts ($P < 0.05$). In the PAW method, the total count was reduced by approximately 0.75, 0.11, and 0.4 log cycles, respectively.

Regarding E. coli, detectable levels were observed in the untreated control sample. However, the available information does not establish whether the detected E. coli originated from natural contamination or the inoculation procedure. E. coli was not detected in any of the samples treated with DBD plasma at 10, 20, or 30 min. In contrast, E. coli remained detectable following PAW treatment for 10 and 20 min, whereas no E. coli was detected after 30 min of PAW treatment, indicating complete inactivation under the applied detection conditions. These findings demonstrate that DBD plasma was more effective than PAW in eliminating detectable E. coli, while PAW required a longer treatment duration to achieve complete inactivation.

Cold plasma (CP) is known to effectively inactivate a range of microorganisms, including vegetative cells, spores, and fungi, through selective mechanisms that target pathogens while preserving host material. Recent studies also highlight the antimicrobial efficacy of PAW, which can be produced via plasma discharge either in or above water. The latter method offers improved energy efficiency by transferring reactive species from the gas phase into the liquid interface, creating high oxidation-reduction potential (ORP) and low pH environments. PAW inactivates microbes through chemical reactions involving reactive oxygen and nitrogen species (RONS), without relying on harmful physical interactions (e.g., UV radiation or electric fields). Unlike conventional chemical disinfectants, PAW poses minimal risk of carcinogenic byproducts and is considered eco-friendly and cost-effective (Ma et al., 2015). A similar trend has been reported in the study which investigated the influence of pin-to-plate atmospheric cold plasma on

two raisin varieties, where plasma treatment improved microbial safety while maintaining acceptable physicochemical and nutritional quality during storage. Their findings highlight the capacity of cold plasma technologies to enhance product stability and extend shelf-life without compromising key quality attributes (Ramkumar et al., 2024). Cold plasma's antimicrobial mechanism includes oxidative damage to microbial DNA, proteins, and lipids, particularly targeting the unsaturated fatty acids and amino acid residues in the cell membrane (Shashi et al., 2018). For *E. coli*, the outer membrane of lipopolysaccharides and peptidoglycan is particularly vulnerable to RONS, which can cleave C–O–C, C–O–O, and C–O–N bonds, leading to cell lysis (Lee HanNa et al., 2015).

Previous studies support these findings. Haj Hosseini et al. (2016) reported up to 80% reduction in *E. coli* in ground meat after atmospheric plasma treatment. Similarly, Hosseini et al. (2018), observed full inactivation of *E. coli* and *Aspergillus flavus* in garlic powder after 20 min of CP exposure. Other researchers have also reported significant microbial reduction across a variety of matrices: *Staphylococcus aureus* in meats (Jahandideh et al., 2020), *Salmonella enteritidis* in poultry (Bohlouli et al., 2020), turmeric (Sanaei et al., 2020), almonds (Niemira, 2012)., spices (Hertwig et al., 2015), and walnuts (Ahangari et al., 2021; Shirani et al., 2020).

**Table 3**

### 3.3 Sensory Evaluation

Figure 2 displays the sensory evaluation results for Shahani raisin samples. There were no statistically significant differences between control and plasma-treated samples in terms of flavor, texture, appearance, or overall acceptability ($P > 0.05$). A significant difference was only observed in color, with both DBD and PAW treatments receiving higher color ratings ($P < 0.05$).

Another study about effect of plasma on ochratoxin degradation and raisin properties, demonstrated that plasma treatment can effectively reduce fungal toxins while inducing only limited and manageable changes in the physicochemical and sensory attributes of raisins. These observations reinforce the potential of plasma-based technologies as a safe and compatible approach for improving the quality and safety of dried fruit products (Wang et al., 2024). These findings are consistent with earlier studies. Hosseini et al. (2018) reported that CP did not affect the color, aroma, or overall acceptance of garlic powder. Similarly, Sanaei et al. (2020) found that gas type had no significant effect on sensory attributes of turmeric, though prolonged plasma exposure slightly reduced some sensory scores. Sen et al. (2019) demonstrated that atmospheric pressure CP preserved the sensory quality of treated foods (Sen et al., 2019). Additionally, Shirani et al. (2020), observed no change in almond sensory properties post-treatment (Shirani et al., 2020)., while Bagheri and Abbaszadeh (2020) noted a decline in sensory acceptance of dried snacks only during extended storage, not immediately after plasma exposure (Bagheri & Abbaszadeh, 2020).

**Figure 2**

## 4 Conclusion

Raisins are valuable food products with significant economic and export potential, making it essential to preserve their quality during processing. This study evaluated the effects of Dielectric Barrier Discharge (DBD) plasma and Plasma-Activated Water (PAW) on the physicochemical, microbial, and sensory properties of Shahani raisins. The results indicated that PAW treatment increased sample moisture, while prolonged treatment time initially raised the pH before significantly reducing it ($P < 0.05$). A notable decline in dry matter content was

observed with extended PAW exposure ($P < 0.05$). In terms of color, PAW30 showed the highest L* and b* values, while the control sample exhibited the lowest values for both parameters. The highest a* value was observed in PAW20, whereas the lowest a* value was recorded in DBD30 ($P < 0.05$). Microbiological analysis demonstrated that cold plasma treatments reduced microbial counts, including total bacteria, coliforms, molds, and yeasts. The effectiveness of the treatments varied depending on the microbial indicator and treatment duration. DBD treatment resulted in no detectable *E. coli* at all tested durations, whereas no *E. coli* was detected after 30 min of PAW treatment. According to the results presented in Table 3, PAW30 resulted in the lowest total bacterial count, whereas DBD30 resulted in the lowest mold count. Sensory evaluation revealed no significant differences between plasma-treated and control samples in flavor, texture, appearance, or overall acceptability ($P > 0.05$). Overall, both DBD plasma and PAW showed potential for reducing microbial contamination in Shahani raisins while maintaining the measured sensory attributes. However, the increase in moisture content and decrease in firmness associated with PAW treatment should be considered when evaluating its suitability for dried raisins, particularly with respect to storage stability. Therefore, PAW30 may be considered a promising treatment for reducing certain microbial indicators; however, it cannot be considered the overall optimal treatment based on the present results. Further studies evaluating storage stability and the balance between microbial reduction and physicochemical quality are needed to identify the most suitable treatment conditions for Shahani raisins.

Future studies should investigate the storage stability and shelf life of plasma-treated Shahani raisins, particularly considering the moisture increase following PAW treatment. Further research should also optimize treatment conditions to balance microbial reduction with the preservation of physicochemical quality and validate the effectiveness of these treatments under commercial processing conditions.

**Funding:** This research received no external funding.

**Data Availability Statement:** The supporting documents and data of this study are available from the corresponding author upon reasonable request.

**Conflicts of Interest:** The authors declare that they have no conflict of interest.

**Acknowledgments:** The authors gratefully acknowledge the Agricultural Research Institute, Iranian Research Organization for Science and Technology (IROST), Tehran, Iran, for providing the facilities and technical support required to conduct the experimental analyses.

**Use of Artificial Intelligence:** ChatGPT (OpenAI) was used exclusively for English language editing to improve grammar, clarity, and readability. It was not used for translation, scientific content generation, data analysis, or interpretation. The authors take full responsibility for the final content.

## References

Abbaszadeh, R., Alimohammad, K., & Zarrabi Ekbatani, R. (2018). Application of cold plasma technology in quality preservation of fresh fig fruit (Siyah): a feasibility study. *International Journal of Horticultural Science and Technology*, *5*(2), 165-173 .

Ahangari, M., Ramezan, Y., & Khani, M. R. (2021). Effect of low pressure cold plasma treatment on microbial decontamination and physicochemical properties of dried walnut kernels (Juglans regia L.). *Journal of Food Process Engineering*, *44*(1), e13593 .

Albertos, I., Martín-Diana, A., Cullen, P., Tiwari, B. K., Ojha, S., Bourke, P., Álvarez, C., & Rico, D. (2017). Effects of dielectric barrier discharge (DBD) generated plasma on microbial reduction and quality parameters of fresh mackerel (Scomber scombrus) fillets. *Innovative Food Science & Emerging Technologies*, *44*, 117-122 .

Journal Pre-proofs

Almeida, F. D. L., Cavalcante, R. S., Cullen, P. J., Frias, J. M., Bourke, P., Fernandes, F. A., & Rodrigues, S. (2015). Effects of atmospheric cold plasma and ozone on prebiotic orange juice. *Innovative Food Science & Emerging Technologies*, *32*, 127-135 .

AOAC. (1990). Official methods of analysis. *Assoc Anal Chem*, *62*, 2742-2744 .

Bagheri, H., & Abbaszadeh, S. (2020). Effect of cold plasma on quality retention of fresh-cut produce. *Journal of Food Quality*, *2020*(1), 8866369 .

Bagheri, H., Abbaszadeh, S., & Salari, A. (2020). Optimization of decontamination conditions for Aspergillus flavus inoculated to military rations snack and physicochemical properties with atmospheric cold plasma .*Journal of Food Safety*, *40*(6), e12850 .

Bagheri, H., Abbaszadeh, S., & Sepandi, M. (2021). Simultaneous effect of cold plasma and MAP on the quality properties of mixed nuts snack during storage. *Journal of Food Processing and Preservation*, *45*(4), e15381 .

Bárdos, L., & Baránková, H. (2010). Cold atmospheric plasma: Sources, processes, and applications. *Thin solid films*, *518*(23), 6705-6713 .

Basaran, P., Basaran-Akgul, N., & Oksuz, L. (2008). Elimination of Aspergillus parasiticus from nut surface with low pressure cold plasma (LPCP) treatment. *Food microbiology*, *25*(4), 626-632 .

Bohlouli,P,R.Jalalirad,D.Dorranian.(2020).Antimicrobial effects of cold plasma on the pathogenic bacterium salmonella enteritidis Existed on the egg shell.Journal of Food Technology & Nutrition.92-85:17.

Çelik, K., & Ergönül, B. (2020). Determination of Microbiological Attributes of Unpackaged and Packaged Raisin Samples Sold in Manisa Markets. *Acta Sci. Nutr. Heal*, *4*, 10-13 .

Civille, G. V., Carr, B. T., & Osdoba, K. E. (2024). *Sensory evaluation techniques*. CRC press .

Cunniff, P., & Washington, D. (1997). Official methods of analysis of AOAC International. *J. AOAC Int*, *80*(6), 127A .

Doymaz, I. (2006). Drying kinetics of black grapes treated with different solutions. *Journal of Food Engineering*, *76*(2), 212-217 .

Geissler, K., Manafi, M., Amoros, I., & Alonso, J. (2000). Quantitative determination of total coliforms and *Escherichia coli* in marine waters with chromogenic and fluorogenic media. *Journal of Applied Microbiology*, *88*(2), 280-285 .

Haj Hosseini,A,Sharifan ,A,Yousefi,H.(2016).The effect of atmospheric cold plasma on reducing the microbial load of *Escherichia coli* bacteria in mincead meat. Novel Findings in Food Industries &Healty Nutrition.

Hemmati, V., Garavand, F., Khorshidian, N., Cacciotti, I., Goudarzi, M., Chaichi, M., & Tiwari, B. K. (2021). Impact of cold atmospheric plasma on microbial safety, total phenolic and flavonoid contents, antioxidant activity, volatile compounds, surface morphology,S and sensory quality of green tea powder. *Food Bioscience*, *44*, 101348 .

Hertwig, C., Reineke, K., Ehlbeck, J., Erdoğdu, B., Rauh, C., & Schlüter, O. (2015). Impact of remote plasma treatment on natural microbial load and quality parameters of selected herbs and spices. *Journal of Food Engineering*, *167*, 12-17 .

Homa, K., Barney, W. P., Davis, W. P., Guerrero, D., Berger, M. J., Lopez, J. L., Wyenandt, C. A., & Simon, J. E .(2021) .Cold Plasma Treatment Strategies for the Control of Fusarium oxysporum f. sp. basilici in Sweet Basil. *HortScience*, *56*(1), 42-51 .

Hosseini,A.,Abdi ,S.,Moslehi Shad,M (2018). Investigating the effect of unipolar dielectric barrier discharge plasma on the disinfection and quality of garlic powder. Innovation magazine in food science and technology10,1.

Jahandideh,F.Shayegh,J.,HosseinZadeh,S.(2020). Effect of cold atmospheric plasma on growth and biofilm formation of staphylococus aureus isolated from mastitic bovine milk .Journal of Food Hygiene.91-102:01.

Javanmard Dakheli, M., & Shavandi, M. (2022). Novel pulsed infrared radiation: Effect on microbial, chemical and sensory properties of saffron (Crocus sativus L.). *Journal of Applied Microbiology*, *133*(3), 1757-1768 .

Journal Pre-proofs

Jayasena, D. D., Kim, H. J., Yong, H. I., Park, S., Kim, K., Choe, W., & Jo, C. (2015). Flexible thin-layer dielectric barrier discharge plasma treatment of pork butt and beef loin: Effects on pathogen inactivation and meat-quality attributes. *Food microbiology*, *46*, 51-57 .

Jeszka-Skowron, M., Zgoła-Grześkowiak, A., Stanisz, E., & Waśkiewicz, A. (2017). Potential health benefits and quality of dried fruits: Goji fruits, cranberries and raisins. *Food chemistry*, *221*, 228-236 .

Kashfi, A. S., Ramezan, Y., & Khani, M. R. (2020). Simultaneous study of the antioxidant activity, microbial decontamination and color of dried peppermint (Mentha piperita L.) using low pressure cold plasma. *LWT*, *123*, 109121 .

Knorr, D., et al. (2011). "Emerging technologies in food processing." Annual review of food science and technology **2**(1): 203-235

Lee HanNa, L. H., Kim JungEun, K. J., Chung MyongSoo, C. M., & Min SeaC, M. S. (2015). Cold plasma treatment for the microbiological safety of cabbage, lettuce, and dried figs .

Lee, K. H., Kim, H.-J., Woo, K. S., Jo, C ,.Kim, J.-K., Kim, S. H., Park, H. Y., Oh, S.-K., & Kim, W. H. (2016). Evaluation of cold plasma treatments for improved microbial and physicochemical qualities of brown rice. *LWT*, *73*, 442-447 .

Liao, X., Liu, D., Xiang, Q., Ahn, J., Chen, S., Ye, X., & Ding, T. (2017). Inactivation mechanisms of non-thermal plasma on microbes: A review. *Food control*, *75*, 83-91 .

Liu, J., et al. (2020). "Impacts of thermal and non-thermal processing on structure and functionality of pectin in fruit-and vegetable-based products: A review." Carbohydrate Polymers 250: 116890

Ma, R., Wang, G., Tian, Y., Wang, K., Zhang, J., & Fang, J. (2015). Non-thermal plasma-activated water inactivation of food-borne pathogen on fresh produce. *Journal of hazardous materials*, *300*, 643-651 .

Matuschek, E., Brown, D. F., & Kahlmeter, G. (2014). Development of the EUCAST disk diffusion antimicrobial susceptibility testing method and its implementation in routine microbiology laboratories. *Clinical microbiology and infection*, *20*(4), O255-O266 .

Niemira, B. A. (2012). Cold plasma reduction of Salmonella and *Escherichia coli* O157: H7 on almonds using ambient pressure gases. *Journal of food science*, *77*(3), M171-M175 .

Noshirvani, N., Ghanbarzadeh, B., Mokarram, R. R., & Hashemi, M. (2017). Novel active packaging based on carboxymethyl cellulose-chitosan-ZnO NPs nanocomposite for increasing the shelf life of bread. *Food Packaging and Shelf Life*, *11*, 106-114 .

Pankaj, S. K., Bueno-Ferrer, C ,.Misra, N., Milosavljević, V., O'donnell, C., Bourke, P., Keener, K., & Cullen, P. (2014). Applications of cold plasma technology in food packaging. *Trends in Food Science & Technology*, *35*(1), 5-17 .

Pankaj, S. K., Wan, Z., Colonna, W., & Keener, K. M.(2017) .Effect of high voltage atmospheric cold plasma on white grape juice quality. *Journal of the Science of Food and Agriculture*, *97*(12), 4016-4021 .

Pankaj, S. K., Wan, Z., & Keener, K. M. (2018). Effects of cold plasma on food quality: A review. *Foods* 4, (1)7.

*Rahnama, T., M., Javanmard , Abbaszade ,R.(2018). Effects of cold plasma on color changes anthocyanins content and microbial quality of barberry juice. Journal of Food sciences and technology.,15 (82) 373-385.*

Ramkumar, R., Arun Prasath, V., Karpoora Sundara Pandian, N., Patra, A., Sharma, P., Arulkumar, M., ... & Govindarasu, P. (2024). Investigating the influence of pin-to-plate atmospheric cold plasma on the physiochemical, nutritional, and shelf-life study of two raisins varieties during storage. *Journal of Food Measurement and Characterization*, 18(9), 7774-7793.

Rød, S. K., Hansen, F., Leipold, F., & Knøchel, S. (2012). Cold atmospheric pressure plasma treatment of ready-to-eat meat: Inactivation of Listeria innocua and changes in product quality. *Food microbiology*, *30*(1), 233-238 .

Rolle, L., Giordano, M., Giacosa, S., Vincenzi, S., Segade, S. R., Torchio, F., Perrone, B., & Gerbi, V. (2012). CIEL* a* b* parameters of white dehydrated grapes as quality markers according to

chemical composition, volatile profile and mechanical properties. *Analytica Chimica Acta*, *732*, 105-113 .

Rout, S., & Srivastav, P. P. (2024). Modification of soy protein isolate and pea protein isolate by high voltage dielectric barrier discharge (DBD) atmospheric cold plasma: Comparative study on structural, rheological and techno-functional characteristics. *Food Chemistry*, *447*, 138914.

Rout, S., Tripathy, S., & Srivastav, P. P. (2024). Effect of cold plasma for modulating macromolecules and bioactive composition of food: unveiling mechanisms and synergies with other emerging techniques. *Food Bioscience*, *61*, 104545.Sanaee F, Mortazavi S A, tabatabaei yazdi F, Shahidi F. (2020). Effect of cold plasma treatment on microbial load reduction and physicochemical properties of turmeric. Journal of Food Sciences and technology, 17 (99),153-161.

Rout, S., Panda, P. K., Dash, P., Srivastav, P. P., & Hsieh, C. T. (2025). Cold Plasma-Induced Modulation of Protein and Lipid Macromolecules: A Review. *International Journal of Molecular Sciences*, *26*(4), 1564.

Schlüter, O., Ehlbeck, J., Hertel, C., Habermeyer, M., Roth, A., Engel, K. H., Holzhauser, T., Knorr, D., & Eisenbrand, G. (2013). Opinion on the use of plasma processes for treatment of foods. *Molecular nutrition & food research*, *57*(5), 920-927 .

Sen, Y., Onal-Ulusoy, B., & Mutlu, M. (2019). Detoxification of hazelnuts by different cold plasmas and gamma irradiation treatments. *Innovative Food Science & Emerging Technologies*, *54*, 252-259 .

Shavandi, M., Javanmard, M., & Basiri, A. (2023). Novel infrared puffing: Effect on physicochemical attributes of puffed rice (Oryza sativa L.). *Food Science & Nutrition*, *11*(5), 2141-2151 .

Shirani, K., Shahidi, F., & Mortazavi, S. A. (2020). Investigation of decontamination effect of argon cold plasma on physicochemical and sensory properties of almond slices. *International Journal of Food Microbiology*, *335*, 108892 .

Standardization, I. O. f. (1977). *Oilseeds-Determination of Moisture and Volatile Matter Content*. International Organization for Standardization .

Stoica, M., Alexe, P., & Mihalcea, L. (2014). Atmospheric cold plasma as new strategy for foods processing-an overview. *Innovative Romanian Food Biotechnology*, *15* .

Tappi, S., Gozzi, G., Vannini, L., Berardinelli, A., Romani, S., Ragni, L., & Rocculi, P. (2016). Cold plasma treatment for fresh-cut melon stabilization. *Innovative Food Science & Emerging Technologies*, *33*, 225-233 .

Tendero, C., Tixier, C., Tristant, P., Desmaison, J., & Leprince, P. (2006). Atmospheric pressure plasmas: A review. *Spectrochimica Acta Part B: Atomic Spectroscopy*, *61*(1), 2-30 .

Thiex, N. (2009). Evaluation of analytical methods for the determination of moisture, crude protein, crude fat, and crude fiber in distillers dried grains with solubles. *Journal of AOAC international*, *92*(1), 61-73.

Wang, S., et al. (2019). "Brief introduction of food processing methods and chemical hazards formed during thermal processing." Chemical hazards in thermally-processed foods: 1-17.

Wang, Y., Zheng, Y., Wang, J., Mu, L., Zhang, W., Huang, M., & Li, Y. (2024). Effect of plasma on ochratoxin degradation and raisin properties. *Journal of Food Engineering*, 375, 112051.

**Table 1** Results of chemical properties of shahani raisin

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| Treatment | pH | Acidity (%) | Moisture(%) | Dry Matter(%) |
|---|---|---|---|---|
| C | 4.10 ± 0.06 $^{d}$ | 1.55 ± 0.06 $^{b}$ | 12.87 ± 0.28 $^{c}$ | **87.13 ± 0.69** $^{c}$ |
| DBD10 | 4.30 ± 0.05 $^{b}$ | 1.15 ± 0.03 $^{d}$ | 12.50 ± 0.37 $^{c}$ | **87.50 ± 0.61** $^{c}$ |
| DBD20 | 4.21 ± 0.03 $^{c}$ | 1.40 ± 0.02 $^{c}$ | 11.19 ± 0.41 $^{d}$ | **88.81 ± 0.73** $^{b}$ |
| DBD30 | 4.20 ± 0.04 $^{cd}$ | 1.51 ± 0.05 $^{b}$ | 8.37 ± 0.24 $^{e}$ | **91.63 ± 0.58** $^{a}$ |
| PAW10 | 4.46 ± 0.07 $^{a}$ | 1.12 ± 0.03 $^{d}$ | 11.60 ± 0.39 $^{d}$ | **88.40 ± 0.64** $^{b}$ |
| PAW20 | 4.30 ± 0.03 $^{b}$ | 1.11 ± 0.05 $^{d}$ | 14.53 ± 0.33 $^{b}$ | **85.47 ± 0.82** $^{d}$ |
| PAW30 | 4.22 ± 0.02 $^{c}$ | 1.83 ± 0.06 $^{a}$ | 17.28 ± 0.45 $^{a}$ | **82.72 ± 0.77** $^{e}$ |

Treatments: C = Control; DBD10, DBD20, DBD30 = dielectric barrier discharge treatments for 10, 20, and 30 min, respectively; PAW10, PAW20, PAW30 = plasma activated water treatments for 10, 20, and 30 min, respectively.

**Values are presented as mean ± SD (n = 3). Different superscript letters indicate significant differences among treatments (P < 0.05).*

**Table 2** Results of color and firmness of shahani raisin treatments

| Treatment | Texture Firmness (N) | *L** | *a** | *b** |
|---|---|---|---|---|
| C | 99.19 ± 4.46 $^{a}$ | 17.11 ± 0.45 $^{e}$ | 0.07 ±0.05 $^{c}$ | **0.99 ± 0.06** $^{f}$ |
| DBD10 | 71.14 ±3.77 $^{c}$ | 19.02 ± 0.14 $^{d}$ | -0.51 ± 0.04 $^{e}$ | **1.02 ± 0.15** $^{f}$ |
| DBD20 | 46.61 ± 2.37 $^{e}$ | 20.13 ± 0.25 $^{c}$ | 0.17±0.02 $^{b}$ | **1.54 ± 0.19** $^{e}$ |
| DBD30 | 32.90 ±4.15 $^{f}$ | 21.65 ± 0.19 $^{b}$ | -0.73 ± 0.04 $^{g}$ | **2.37 ± 0.08** $^{c}$ |
| PAW10 | 81.04 ± 2.69 $^{b}$ | 20.09 ± 0.28 $^{c}$ | -0.41 ±0.03 $^{d}$ | **1.93 ±0.14** $^{d}$ |
| PAW20 | 56.59 ± 4.98 $^{d}$ | 21.25 ±0.37 $^{b}$ | 0.27 ± 0.03 $^{a}$ | **2.58 ±0.11** $^{b}$ |
| PAW30 | 42.88 ± 5.24 $^{e}$ | 22.59 ±0.31 $^{a}$ | -0.63 ± 0.01 $^{f}$ | **3.19 ±0.16** $^{a}$ |

** Values are presented as mean ± SD (n = 3). Different superscript letters indicate significant differences among treatments (P < 0.05).*

**Table 3** Total bacterial count, coliforms (×10² MPN/g), molds (×10² CFU/g), and yeasts (×10² CFU/g) in Shahani raisin samples subjected to DBD plasma and PAW treatments. C = Control; DBD10, DBD20, DBD30 = Dielectric Barrier Discharge treatments for 10, 20, and 30 min, respectively; PAW10, PAW20, PAW30 = Plasma Activated Water treatments for 10, 20, and 30 min, respectively.

| Treatments | Total bacterial count (×10³ CFU/g) | coliforms (×10² MPN/g) | molds (×10² CFU/g) | yeasts (×10² CFU/g) |
|---|---|---|---|---|
| **C** | 620.5 ± 11.6 $^{a}$ | 30.5 ± 4.1 $^{a}$ | 2610.0 ± 24.7 $^{a}$ | 2035.0 ± 21.0 $^{a}$ |
| **DBD10** | 54.0 ± 5.1$^{b}$ | 1.0 ± 0.5 $^{c}$ | 19.0 ± 8.3 $^{c}$ | 27.5 ± 5.8 $^{b}$ |
| **DBD20** | 31.5 ± 6.0 $^{c}$ | 0.8 ± 0.3 $^{c}$ | 4.8 ± 2.5 $^{d}$ | 4.3 ± 1.6 $^{c}$ |
| **DBD30** | 9.0 ± 3.9 $^{d}$ | 0.8 ± 0.3 $^{c}$ | 3.0 ± 1.7 $^{d}$ | 2.0 ± 0.8 $^{c}$ |
| **PAW10** | 1.9 ± 1.1 $^{e}$ | 4.4 ± 1.5 $^{b}$ | 45.0 ± 11.9 $^{b}$ | 27.5 ± 5.8 $^{b}$ |
| **PAW20** | 1.2 ± 0.5 $^{e}$ | 0.1 ± 0.2$^{d}$ | 5.4 ± 2.9 $^{d}$ | 0.1 ± 0.0 $^{d}$ |
| **PAW30** | 0.8 ± 0.5 $^{e}$ | 0.1 ± 0.1 $^{d}$ | 3.7 ± 2.2 $^{d}$ | 5.0 ± 0.5 $^{d}$ |

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*Values are presented as mean ± SD (n = 3). Different superscript letters indicate significant differences among treatments (P < 0.05).*

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**Fig. 1** Top: Dielectric Barrier Discharge (DBD) system, Bottom: Plasma Activated Water (PAW) generation system

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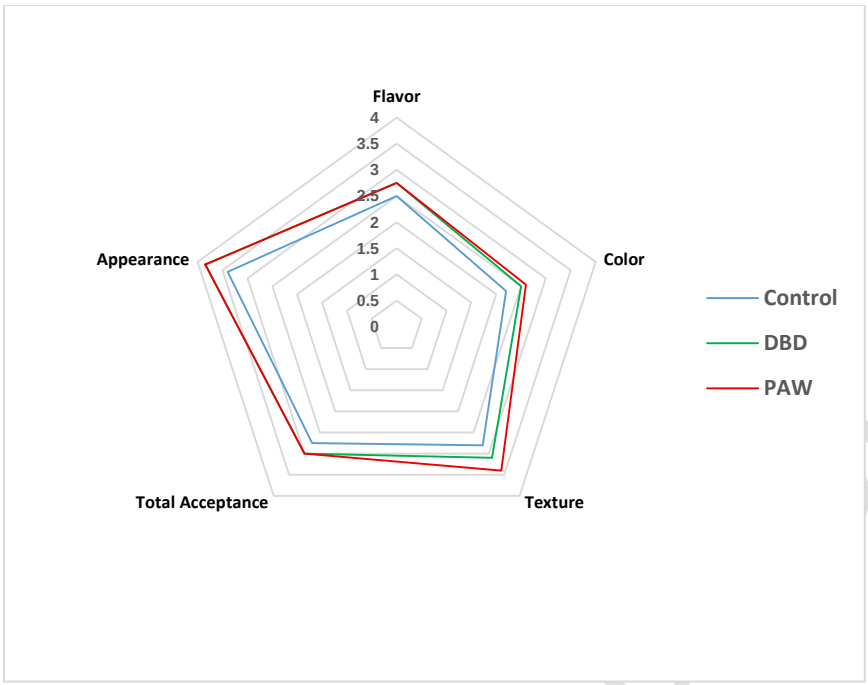



**Fig 2.** Sensory evaluation of Shahani raisin samples: flavor, texture, appearance, color, and overall acceptance.

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