Journal of Agriculture and Food Research 14 (2023) 100789

Contents lists available at ScienceDirect

Journal of Agriculture and Food Research

journal homepage: www.sciencedirect.com/journal/journal-of-agriculture-and-food-research

Reduction of microbial population of fresh vegetables (carrot, white radish) and dried fruits (dried fig, dried peach) using atmospheric cold plasma and its effect on physicochemical properties

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ARTICLE INFO

Keywords:
Aspergillus
Cold plasma
Dried fruits
Enterococcus
Fresh vegetables
Inactivation

ABSTRACT

Non-observance of hygiene principles during storage causes excessive growth of microorganisms in these products and the return of export products to the manufacturer. The purpose of this research is to examine the antimicrobial effects of the jet cold plasma device and its impact on the physicochemical and sensory characteristics of a carrot, white radish, dried fig, and dried peach. For this purpose, the samples were inoculated with *Escherichia coli* O157:H7, *Enterococcus faecalis*, and *Aspergillus niger*. Then samples were treated with atmospheric cold plasma in the form of a jet probe and DC pulse source with 17 KV and 2.26A for 0, 3, 6, 9, and 12 min. The results showed that the rate of inactivation of microorganisms increases with increasing exposure time to atmospheric cold plasma. The maximum reduction of the microbial load was observed at 17 kV and 12 min. The resistance of microorganisms in dried fig and dried peach was higher than in carrot and white radish due to lower humidity. Also, *A. niger* showed the highest resistance to cold plasma compared with *E. coli* O157:H7, and *E. faecalis*. By comparing the average indices of a, and b, no significant change was observed between the treated and the control samples ($p > 0.05$). The texture structure remained intact after plasma application, and the plasma had no destructive effect on the texture. The samples treated with cold plasma did not show a significant effect on the physicochemical and sensory characteristics of different food products. Therefore, atmospheric cold plasma technology can be used as an efficient maintenance technique to enhance the shelf life of food products.

1. Introduction

According to FAO statistics, the world production of fig in 2022 was 84 million tons, and Iran ranked third after Turkey and Egypt. About 85% of Iran's total fig production is for dry consumption. Estahban (Fars province, southern Iran) is the largest dried fig producing region in Iran with an annual production of 30000 tons. Figs are one of the most perishable fruits even in refrigerated conditions due to its high moisture and sugar content. Figs are one of the most popular fruits that increase their useful life by drying them. There are concerns about the safety of the finished product (FAO, 2022; https://www.mundus-agri.eu/). Also, Peach is as summer fruits that are native to China and South Asia. Its scientific name is Prunus persica and it grows in temperate regions. Annually, about seven million tons of peaches are produced in the world. With a production of 600000 tons, Iran has eight percent of the production of this fruit in the world and is ranked sixth in the world in terms of peach production. Among the countries of the world, China is the first producer of peaches and Italy is the second largest producer of this fruit, followed by the United States, Greece, France, Iran, Turkey, Chile, Spain and Argentina (FAO, 2022). Among the major producers of peaches, we can mention Chahar mahal-o-Bakhtiari Province especially in beautiful tourist city of Saman, Alborz province, Baye Kola village of Neka in Mazandaran province, Shandabad of Shabestar of East Azerbaijan province. One of the peach products is dried peach, that with maintaining all the properties of peach, can be consumed in winter and other seasons and by mixture it with dried fruits you can take advantage

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https://doi.org/10.1016/j.jafr.2023.100789
Received 27 June 2023; Received in revised form 11 September 2023; Accepted 14 September 2023
Available online 19 September 2023

of all its properties and use it in parties. Dried peach is a very delicious and tasty snack which has a wonderful and amazing benefit. Most people like dried peach slices because they can use the peach and its benefits in all seasons. It also used for baking cakes and has many adherents. Furthermore being a delicious food, dried peach is a tasty goody for decorating tables and holding ceremonies, parties and celebrations for Iranians (https://www.mundus-agri.eu/). Iranian yellow carrot and white horseradish are products of tropical regions of Iran in cold seasons. Methods should be used to reduce the microbial load and increase the shelf life of vegetables due to the large distance involved in transporting products to different parts of the country and the world.

Most agricultural products are perishable due to high humidity and water activity. After harvest, they should be consumed as soon as possible or stored under favorable conditions [1]. Dried fruits may also be contaminated by mold, yeast, or bacteria. Microorganisms can be cited as major factors in dried fruit contamination and spoilage. Sometimes these contaminations are outside the normal limits, so that the product produced is no longer of the right quality to be offered on the sales market [2]. The growth of fungi on dried fruit is another type of contamination that can cause an unpleasant appearance and taste in these products and thus economic losses [3]. Unpackaged dried fruits and fresh vegetables are affected by microorganisms everywhere, including in the air or on the hands. In addition, humidity or place of storage can also be one of the factors for contamination of these products [4]. Also, the entry of insects and rodents into these products and the contamination of food with their saliva, urine and feces lead to the provision of unsanitary products, making their consumption unacceptable and endangering the health of consumers [5].

Decontamination of fresh and dried agricultural products is the first step in developing and promoting sales of these products. The common methods used to control storage pests are the use of gaseous chemical compounds such as methyl bromide, phosphine, and sulfur anhydride gas [6]. These chemicals in high doses can cause poisoning in humans and also damage the environment. Therefore, researchers are looking for ways to use environmentally friendly methods as an alternative to the use of chemicals [5].

One of the technologies that have attracted the attention of researchers in the food industry in recent years, especially in the field of fruits and vegetables, is cold plasma technology. Plasma is generated by applying an electric field to a neutral gas [7]. Plasma is an ionized gas that contains ions, electrons, ultraviolet rays, and reactive substances such as radicals, atoms, and excited molecules that can inactivate microorganisms [8]. Recently, cold plasma at atmospheric pressure has been considered as a food disinfectant because cold plasma is a dry, non-thermal technology that does not require chemicals and can operate continuously at atmospheric pressure [3]. The advantages of this method include the low-temperature process, shorter operating time, lack of toxic side effects, and significant reduction in water consumption during sterilization compared to other methods. In addition, this method causes minimal damage to the food [5].

The aim of this study is to investigate the antimicrobial effect of cold plasma from a plasma jet and its effects on the physicochemical and sensory properties of carrots, white radish, dried figs, and dried peaches. For this purpose, the samples were treated with atmospheric cold plasma for 0, 3, 6, 9 and 12 min. Based on the results of previous studies, air (80% nitrogen and 20% oxygen) may have the greatest effect on inactivating microorganisms due to the production of more ozone and reactive nitrogen species [2,9]. For this reason, air was used as the gas in this study.

2. Material and method

2.1. Preparation of samples

Fresh vegetables and dried fruits such as carrots, white radish, dried figs, and dried peaches were purchased from local markets (Mashhad, Khorasan Razavi, Iran). The fruits were dried using sodium metabisulfite and cabinet dryers in the manufacturer. Initially, 10 g of sodium metabisulfite (chemical formula Na2S2O5) were added to 1 kg of fruit. The temperature can be set at 62 °C when there is surface moisture on the fruit or vegetable. After 1 h, reduce the temperature to 57–60 °C to finish drying. The samples were divided into two groups, the control group and the cold plasma treated group. Then, the samples were stored at 4 °C until testing.

2.2. Preparation of inoculum

The microbial culture of *Escherichia coli* O157:H7 (ATCC 35150), *Enterococcus faecalis* (ATCC 33186), and *Aspergillus niger* (ATCC 13794) were obtained from the Iranian Research Organization for Science and Technology. All microorganisms were prepared as lyophilized. Bacteria were then linearly cultured in a special nutrient medium and incubated at 37 °C for 24 h. In two consecutive periods, they were inoculated separately into nutrient broth medium and incubated at 37 °C for 24 h. The culture medium of each bacterium was centrifuged at a speed of 4000 rpm for 15 min at room temperature (to separate the microorganisms from the nutrient broth culture medium). The resulting bacterial sediment was washed with in three steps 0.1% peptone water. They were centrifuged at 4000 rpm for 15 min.

Later, the number of bacteria was determined using a spectrophotometer at 570 nm, resulting in an optical absorbance of 0.08–0.1 equivalent of each bacterium, 10^8 CFU/ml [10]. *A. niger* was also cultured in yeast extract dextrose chloramphenicol agar (YGC). It was incubated at 25 °C for 3–5 days to form black hyphae. Then, some mold spores were transferred into 1 ml of sterile distilled water. Finally, the mold with a population of 10^5 CFU/ml was inoculated into the samples under sterile conditions and under a laminar hood. The stock culture of microorganisms was stored with 15% glycerol at −20 °C [11].

Samples were disinfected with 70% ethanol and then washed with deionized water before surface inoculation. For inoculation, samples that were shown to be free of microbial flora (based on previous testing) were placed in sterile petri dishes. 150 μl of each microorganism was inoculated into the samples under a laminar hood under completely sterile conditions. They were then dried at 22 °C for 1 h [12]. Samples were treated with an atmospheric pressure plasma jet as a cold plasma generator (manufactured by Nab Zist Company of Iran, model: sp141). The device consisted of a jet probe, a high purity air inlet gas and a high voltage DC pulse source with a maximum voltage of 17 KV and a current of 2.26 A. The gas flow rate was set to 10 standard L/min (SLM) and kept constant. The distance from the jet probe to the samples was 2 cm and was constant for all experiments. Samples were exposed to cold plasma under the laminar hood and sterile conditions for 0, 3, 6, 9, and 12 min at room temperature (25 °C). Treated samples were immediately packed in containers and placed in an incubator at 25 °C. Samples were analyzed for physicochemical, sensory, and microbial properties.

2.3. Microbial count

For microbial culture, 0.1 ml of each of the prepared dilutions was taken and cultured superficially in selective media. Eosin-Methylene Blue Agar (EMB), Kenner Fecal Agar (KF), and YGC were used to count *E. coli*, *E. faecalis*, and *A. niger*, respectively. Plates were incubated for bacteria and mold at 37 °C for 24 h and 25 °C for 3–5 days. After the specified period of incubation, select the dishes containing < 150 colonies/propagules/germs and count these colonies/propagules/germs. If fast-growing molds are a problem, count colonies/propagules/germs after 2 days and again after 5-7 days of incubation [13,14]; ISO 21527-1 [15].

2.4. Color

The color parameters (L*, a*, and b*) of the samples were measured

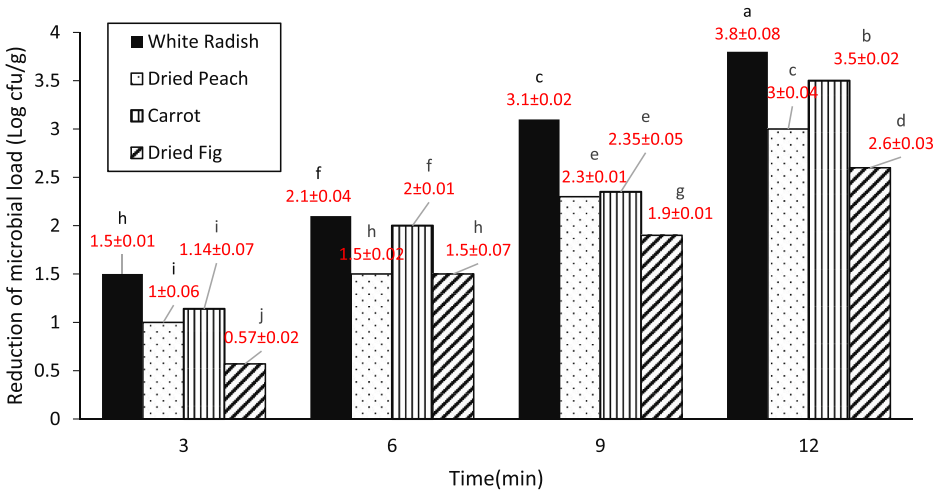

Fig. 1. Effect of cold plasma exposure time on *E. coli* O157:H7 (Duncan's test, $p < 0.05$).

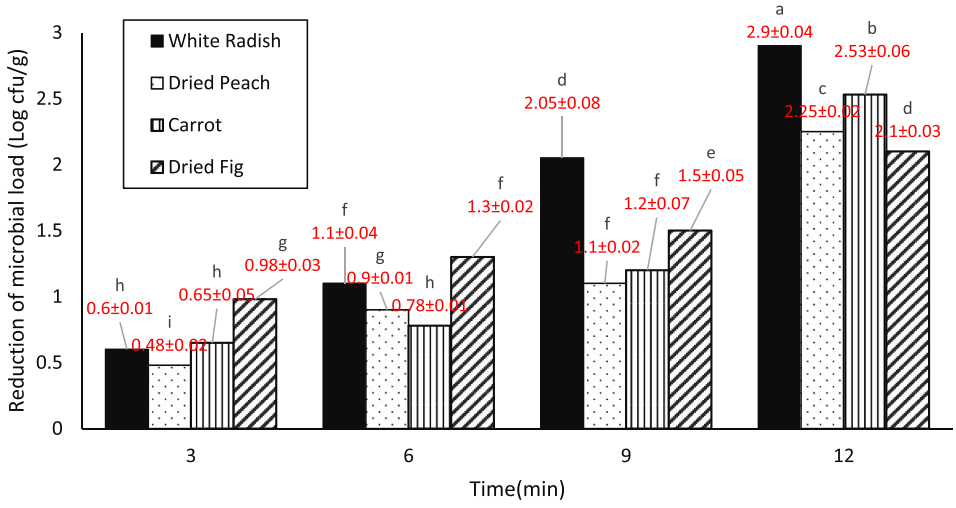

Fig. 2. Effect of cold plasma exposure time on *E. faecalis* (Duncan's test, $p < 0.05$).

with a HunterLab XE (Hunter AsSDSCiates Laboratory Inc., Reston, USA) [16].

2.5. Water activity

Water activity (aw) values of the samples were measured at 25 °C using water activity meter 3012-66 (Novasina, Japan) before and after treatment [5,16]].

2.6. Texture (hardness)

Texture (hardness) of the samples was measured by a Texture analyzer model AMETEK Lloyd TA-Plus Instruments Ltd, USA. The samples of 20 × 20 × 20 mm were compressed up to 5% of the initial height. The penetration rate was 1 mm per second. The probe used was 100 N [17]. The number obtained from the software showed the hardness of the texture [18].

2.7. Sensory evaluation

A number of samples of each food were treated with cold plasma and then sensory evaluated. The sensory characteristics of the samples were rated by 20 trained individuals in terms of color, taste, sweetness, hardness, and overall acceptability on a 5-point hedonic scale. In this test, the excellent sample received a score of 5, the good 4, the average 3, the poor 2, and the very poor 1 [19].

2.8. Statistical method

Experiments were performed in a completely randomized factorial design with 3 replicates. Statistical analysis of the data was performed using SPSS software. Duncan's test was used to compare means and examine the effects of treatments ($p \leq 0.05$).

3. Results and discussion

3.1. Effect of cold plasma exposure time on E. coli O157:H7, E. faecalis, A. niger count

As can be seen in Figs. 1–3, the antimicrobial effect increased with increasing exposure time of the cold plasma to the cold plasma samples. The strongest effect of the cold plasma on reducing microbial load was

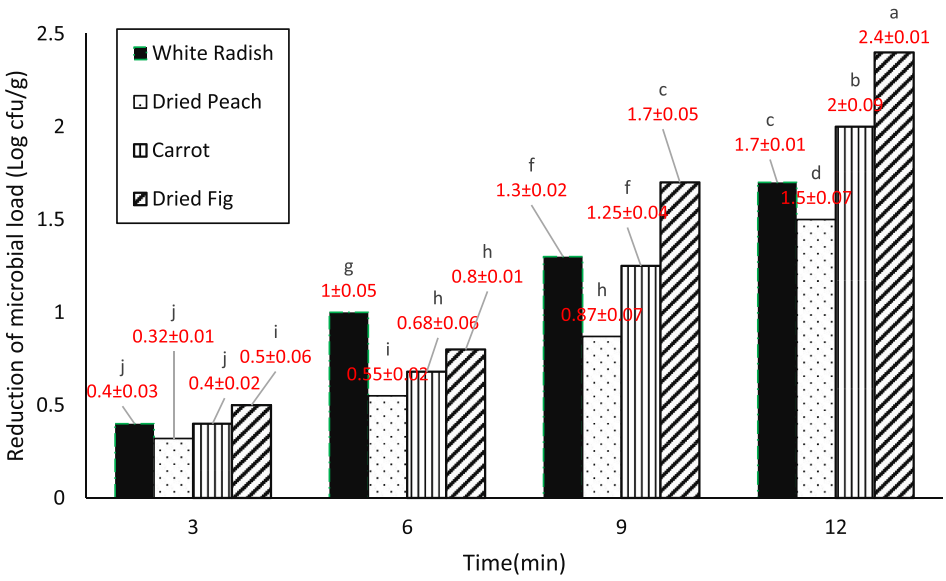

Fig. 3. Effect of cold plasma exposure time on *A. niger* (Duncan's test, $p < 0.05$).

achieved after 12 min. As the exposure time of the cold plasma increases, the content of reactive radicals, atoms and molecules increases. Reactive compounds cause lipid peroxidation, enzyme inactivation, and DNA degradation, ultimately leading to inactivation of microorganisms [8]. In addition, the emitted UV photons dimerize thymine-containing bases in DNA and prevent its replication [3]. Therefore, prolonging the time has a significant impact on the inactivation of microorganisms. [9,13]; and [20] reported similar results. Using scanning electron microscope images (SEM) [21], showed DNA damage, cellular leakage, and damage to the cell structure of bacteria caused by exposure to cold plasma at 15–25 kV. Based on the results of [22]; the inhibition of *Penicillium italicum* increased with increasing cold plasma exposure time [12]. investigated the effect of time on the reduction of *Salmonella*, *E. coli*, and *Listeria*. Their results showed that the antimicrobial effect of cold plasma against the studied bacteria increased with increasing time.

Examination of Figs. 1–3 has shown that the resistance of microorganisms depends not only on the inherent properties of the microorganisms, but also on the food to which the process is applied. The greatest decrease in the count of *E. coli* O157:H7 (3.8 log CFU/g) and *E. faecalis* (2.9 log CFU/g), *A. niger* (2.4 log CFU/g) was observed in the sample of white radish after 12 min of cold plasma treatment. The resistance of microorganisms was higher in dried figs and dried peaches than in carrots and white radish due to lower moisture. Also, no significant difference was observed between cold plasma treated samples at 3 and 6 min. A significant decrease in the log of unit cycle of *E. faecalis* (log cfu/g) was observed with increasing time. Therefore, there was a significant difference between samples treated for 12 min and all others (<0.05). Dasan et al. (2016) studied the effect of cold plasma on *A. parasiticus* and *A. flavus* inoculated on corn seeds. They reported a reduction of 5.48 cycles for *A. flavus* and 5.2 cycles for A. *parasiticus* after 5 min of plasma treatmentSchnabel et al. (2015) and Nishim (2017) reached similar conclusions regarding the greater resistance of *Candida albicans* to cold plasma than bacteria [23,24].

3.2. Comparing the effect of cold plasma on Gram-negative, Gram-positive bacteria and molds

E. coli O157:H7 is a serotype of the bacterial species *E. coli* that causes disease in humans. It expresses somatic (O) antigen 157 and flagellar (H) antigen 7, which cause disease through consumption of contaminated and raw foods [12]. It is a gram-negative bacterium covered by a thin peptidoglycan layer and a lipopolysaccharide outer membrane [8]. The decrease in *E. coli* population in the plasma-treated sample can be attributed to the reactive oxygen and nitrogen species generated in the cold plasma process. This is because these species can react with *E. coli* lipopolysaccharide and peptidoglycan [9]. As a result, the structure of the molecule is damaged by breaking the CON, COO and COC bonds, leading to the destruction of *E. coli.*Han et al. (2016) cited the oxidation of *E. coli* cell membrane lipopolysaccharides by reactive species as the reason for the decline in the population of these bacteria [10]. Lu et al. (2014) also cited the destruction of cell membranes by reactive species as the main reason for the decline in the *E. coli* population under cold plasma treatment [25]. Choi et al. (2016) reported similar results when investigating the effects of cold plasma treatment of meat on the *E. coli* population [26].

Table 1
Comparison of the effect of cold plasma on reduction microbial load (Log cfu/g) at 17 kV and 12 min.

Sample	*E. coli* O157:H7	*E. faecalis*	*A. niger*
White radish	2.6 ± 0.03	2.1 ± 0.02	2.4 ± 0.08
Dried peach	3.8 ± 0.07	2.9 ± 0.11	1.7 ± 0.00
Carrot	3.5 ± 0.06	2.53 ± 0.05	2 ± 0.01
Dried fig	3 ± 0.01	2.25 ± 0.09	1.5 ± 0.04

Examination of the data showed that *A. niger* had the highest resistance to cold plasma (Table 1). This difference in the intensity of inactivation may be caused by the thick structure of the cell wall of fungi compared to the peptidoglycan membrane of bacteria. The structure of fungi consists of components such as chitin, cellulose fibrils, and a polysaccharide matrix. These factors increase the resistance of the cell wall and consequently reduce DNA damage in fungi [11]. Suhem et al. (2013) reported that the conidiophores and vesicle of *A. flavus* in brown rice sticks were broken with cold plasma, resulting in cell escape and cell death [27]. Similar results regarding further reduction of Gram-negative bacterial population compared to *C. albicans* mold during cold plasma treatment were reported by Nishime et al., 2017 [24]. Based on the results, the reduction rate of *E. coli* gram-negative bacteria was higher than that of *E. faecalis* gram-positive bacteria. Reactive oxygen and nitrogen species produced in plasma react with lipopolysaccharide and peptidoglycan of Escherichia coli, thus causing damage to the molecular structure by breaking bonds such as C–O, C–N, and C–C [12]. Also, the different thickness of the peptidoglycan layer of Gram-positive bacteria (20–30 nm) compared to Gram-negative bacteria (6–7 nm) is the reason

Table 2
Effect of cold plasma exposure time on color parameters of samples.

Time (min)	Dried peach			Dried fig			Carrot			White radish		
	L*	a*	b*	L*	a*	b*	L*	a*	b*	L*	a*	b*
0	49.54 ± 0.08	14.74 ± 0.72	16.26 ± 0.22	29.61 ± 0.35	13.24 ± 0.42	9.93 ± 0.22	19.28 ± 0.62	21.09 ± 0.08	24.53 ± 0.17	54.87 ± 0.35	−1.48 ± 0.05	6.68 ± 0.17
3	58.04 ± 0.17	14.81 ± 0.31	16.60 ± 0.14	29.94 ± 0.27	13.33 ± 0.09	9.69 ± 0.16	19.80 ± 0.35	22.13 ± 0.31	25.04 ± 0.42	55.13 ± 0.28	−1.53 ± 0.17	6.81 ± 0.21
6	49.36 ± 0.11	14.02 ± 0.26	16.23 ± 0.54	30.76 ± 0.22	13.21 ± 0.30	9.31 ± 0.43	20.15 ± 0.24	20.97 ± 0.24	23.62 ± 0.26	55.06 ± 0.07	−1.50 ± 0.09	6.36 ± 0.27
9	50.68 ± 0.35	13.46 ± 0.08	16.20 ± 0.72	32.18 ± 0.18	13.15 ± 0.26	9.12 ± 0.38	20.63 ± 0.18	20.85 ± 0.21	22.75 ± 0.34	55.75 ± 0.37	−1.42 ± 0.06	5.9 ± 0.22
12	51.97 ± 0.22	13.92 ± 0.13	16.17 ± 0.17	33.03 ± 0.52	13.09 ± 0.15	8.82 ± 0.32	21.1 ± 0.26	20.61 ± 0.11	23.62 ± 0.47	56.3 ± 0.19	−1.38 ± 0.13	5.83 ± 0.15

for the different effect of plasma on the cell wall and consequently the different degree of inactivation of these bacteria. In general, reactive compounds chemically and physically alter the tissue and surface of the cells of microorganisms [24].

3.3. Effect of cold plasma on color of samples

The color of fruits and vegetables offered to consumers is a crucial factor in determining their quality. Therefore, it is important to check the number of color changes in the samples [1]. By comparing the average indices, a* and b*, no significant color change was found between the treated and control samples ($p > 0.05$) (Table 2 and Figs. 1 and 2 Supplementary). The absence of color changes in the samples could be related to their high phenolic content. The major phenolic components of peach are catechin, procyanidin B1, neochlorogenic acid, and chlorogenic acid [28]. Also, quercetin, ECTC, chlorogenic acid, the phenols gallic acid, catechin, 4-hydroxybenzoic acid, and kaempferol are the most abundant phenolic compounds in fig, carrot, white radish, and green radish roots [29].

As shown in Table 2, the samples treated with cold plasma for 12 min were brighter than the control samples. The L* index of dried peach, dried fig, carrot, and white radish treated with cold plasma were 51.97, 33.03, 21.1, and 56.3, respectively, while the value for the control samples were 49.54, 29.61, 19.28, and 54.87, respectively (Fig. 3, Supplementary). During the cold plasma process, the L* index of the samples increased, while a slight decrease in the a* (redness) and b* (yellowing) indices of the samples was observed compared to the control sample. Thirumdas et al. (2016) reported an intensification of the whiteness of rice samples after treatment with cold plasma [30]. Vukić (2018), Hou et al. (2019), and Zhang et al. (2021) reported similar results regarding the effect of plasma on the color of orange and carrot juice, blueberry juice, and fresh-cut pears, respectively [19,20,31]. Hertwig et al. (2015), when studying the effect of plasma on the color of paprika and red pepper powder, concluded that the index values decreased over time, while the values of indices L* and b* increased [32].

Considering the presence of carotenoids as pigments in dried peaches and carrots, the reason for the color changes of the plasma treated samples can be attributed to these compounds. The color of carotenoids is due to the presence of a system of conjugated double bonds. There is a direct relationship between the number of conjugated double bonds and the color intensity of food. The higher the number of these bonds, the stronger the color intensity of the sample [29]. One of the most important factors for the loss of carotenoid pigments is the isomerization of the Trans form into the cis form due to the presence of oxygen or peroxide and photosensitivity [20]. According to the production of reactive compounds during the treatment of samples with cold plasma, the increase in color may be due to the sensitivity of conjugated double bonds of carotenoids to reactive compounds. Vukic et al. (2017) also attributed the color changes of saffron samples to the sensitivity of saffron carotenoids to compounds such as ultraviolet rays and oxygen produced during plasma treatment.

3.4. Effect of cold plasma exposure time on a_w of samples

The result of comparison of water activity of carrots, white radish and dried figs treated with cold plasma with control samples showed no significant changes ($P > 0.05$) (Figs. 4 and 5). The results of this study

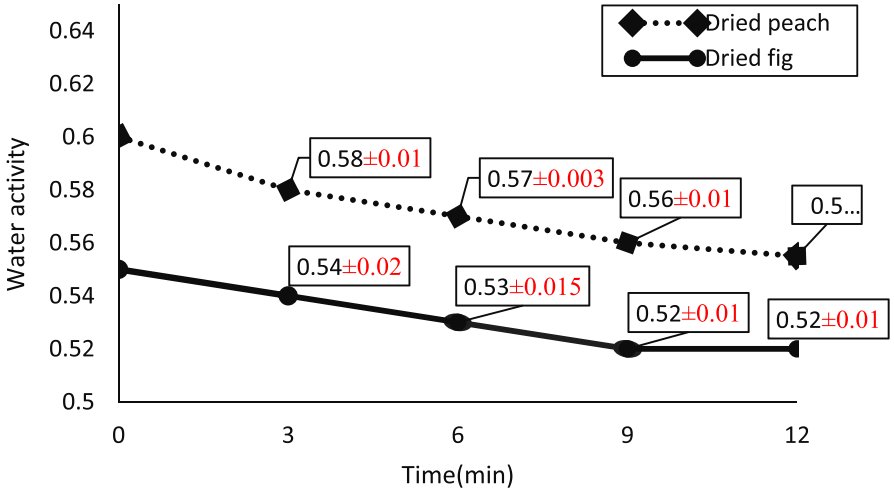

Fig. 4. Effect of cold plasma on water activity of dried peach and dried fig.

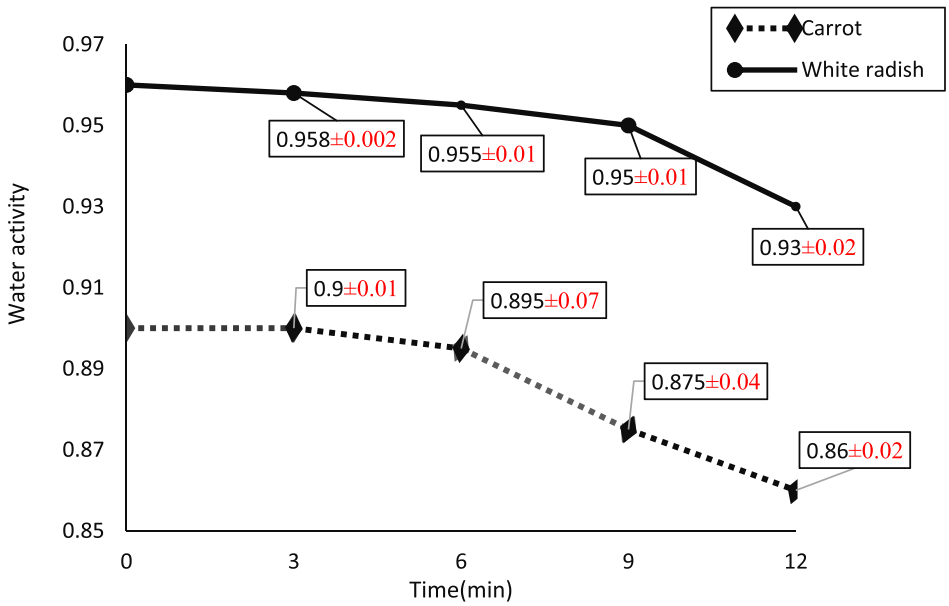

Fig. 5. Effect of cold plasma on water activity of carrot and white radish.

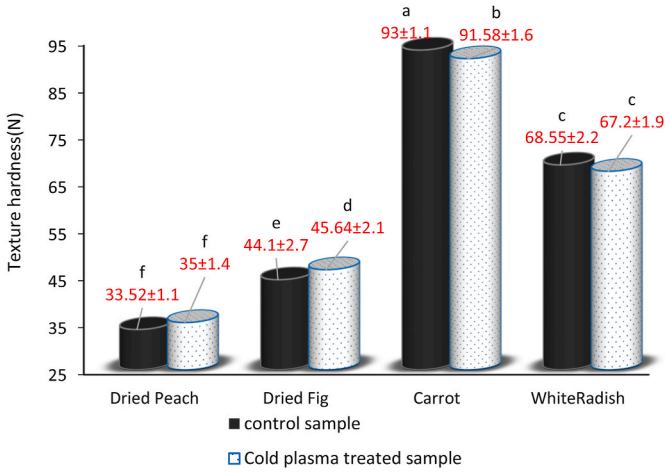

Fig. 6. Effect of cold plasma on texture hardness of samples at 17 kV and 12 min (Duncan's test, $p < 0.05$).

are in close agreement with the results of Lee et al. (2015). Thus, the texture structure remained intact after plasma application, and the plasma had no destructive effect on the texture.

3.5. Effect of cold plasma on texture hardness of samples

Texture is one of the most important quality factors of the sample, which plays an important role in the overall acceptance of the food by the consumer [5]. As shown in Fig. 6, the texture hardness of the samples changed slightly after plasma application, but the effect of plasma on it was not significant ($p > 0.05$). The minor changes were related to the transformations of the cell wall polymers. Therefore, the structure of the texture remained intact after plasma application, and the plasma had no destructive effect on the texture. Texture hardness of dried fruits slightly increased after cold plasma application, while this parameter decreased in fresh vegetables. The decrease in moisture content of dried fruits due to plasma application resulted in a slight increase in their hardness. Shirani et al (2020) also reported an increase in texture hardness in almonds treated with cold plasma compared with the control sample [33]. After the application of cold plasma, the texture hardness of carrot and radish samples slightly decreased, which could be due to the reduction of their moisture content by the effect of cold plasma, which is consistent with the results of Chen et al. (2020) and Zhang et al. (2021) for fresh noodles and fresh-cut pears, respectively [20,34]. Tapi et al. (2016) measured the texture hardness of cantaloupe slices after 30- and 60-min applications of dielectric barrier discharge in plasma. They could not find any significant difference between the control and plasma-treated samples. Ziuzina et al. (2016), Ma et al. (2016), and Gavahian et al. (2020) reported similar results for the textural properties of their samples [35–37].

3.6. Effect of cold plasma on sensory properties

In the food industry, consumer acceptance of the product is a guarantee that it will continue to be sold on the market. Therefore, the evaluation of sensory properties plays an essential role in the choice of food processing method [19]. In Fig. 7, the results of the comparison of the average effect of cold plasma treatment on the sensory properties of dried peach, dried fig, carrot and white radish treated in comparison with the control sample have been studied. The results show that plasma treatment resulted in a decrease in taste, odor, and color values for dried peach and white radish. In terms of texture, the results showed that plasma treatment affected the sensory evaluation of carrot. Thus, the tissue score decreased from 4.9 to 4.5 for the control and treated samples. No significant difference was found in the texture of dried peach, dried fig, and white radish between the treated and control samples. Examination of the results for overall acceptability shows that the plasma-treated samples and the control sample had almost the same overall acceptability and that the plasma had no significant effect on the sensory characteristics of the samples studied. These results are in agreement with the results of Min et al. (2018) and Hou et al. (2019) [31,38]. The results of Vukić et al. (2018) showed the potential of treatment as a browning inhibitor in orange and carrot juice blends during processing [19]. Zhang et al. (2021) reported an improvement in sensory evaluation related to aroma, odor, and color of fresh-cut pears treated with cold plasma compared to the control sample. They found that cold plasma was beneficial in reducing quality loss in fresh-cut pears and preserving other products [20].

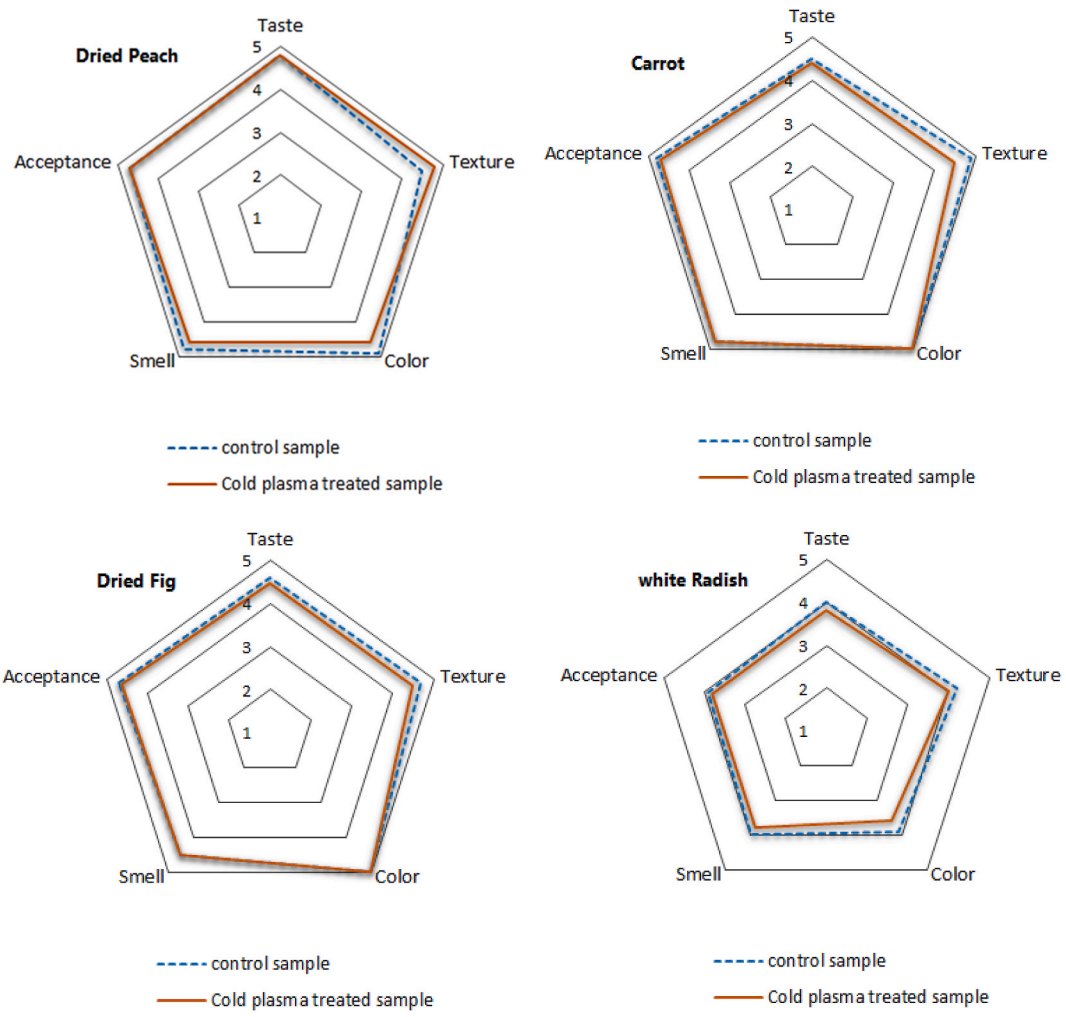

Fig. 7. Effect of cold plasma on sensory properties of samples at 17 kV and 12 min (Vegetables and dried fruits without being inoculated with microorganisms treated using a cold plasma device. The control sample was the products without treatment with cold plasma).

4. Conclusion

Cold plasma treatment was performed to reduce the microbial load and increase the safety and shelf life of the samples. It significantly inactivated *E. coli* O157:H7, *E. faecalis* and *A. niger* in carrots, white radish, dried figs and dried peaches ($p < 0.05$). Higher inactivation rate for *E. coli* compared to *E. faecalis* and *A. niger*. Inactivation of *E. coli* was mainly mediated by DNA damage and cellular leakage. Sensory and physicochemical properties of the samples, including texture hardness, color, and water activity, did not change significantly by cold plasma treatment ($p > 0.05$). These results may help to reduce the microbial contamination of vegetables and dried fruits as highly consumed and perishable products using atmospheric cold plasma technology while minimizing the changes in their physicochemical properties.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper

Data availability

Data will be made available on request.

Acknowledgments

The authors are highly thankful to the Science and Technology Center of the Ferdowsi University of Mashhad for their help during this study (Grant # 3/48396).

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jafr.2023.100789.

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