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Application of Cold Plasma Technology in Quality Preservation of Fresh Fig Fruit (Siyah): A Feasibility Study

Rouzbeh Abbaszadeh[1*], Kosar Alimohammad[2] and Romina Zarrabi Ekbatani[3]
1. Assistant professor of Agriculture Research Institute, Iranian Research Organization for Science and Technology (IROST), Tehran, Iran
2. M.Sc. Student of Institute of Materials and Energy, Meshkin-Dasht, Karaj, Iran
3. Former Student of College of Agriculture & Natural Resources, University of Tehran, Karaj, Iran

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Abstract

Fig (*Ficus carica L.*) is a perishable fruit and there are demands to use new techniques in order to increase shelf life of this product. In the present study, atmospheric cold plasma as a non-thermal treatment was utilized for preserving fresh fig quality. Dielectric barrier discharge plasma was applied to fruits in two steps. Durations of first treatments were 1 and 5 minutes. Based on these results, main experiments were conducted for 30, 90 and 180s and cold plasma was applied to packed and unpacked fig samples. Quality was sensory evaluated in terms of color, texture, odor, appearance and overall acceptance. Firmness, color indices (L*, a* and b*), total soluble solids and pH were also determined. Subjective measurements showed significant shelf life improvement for the treated figs compared to the control samples while objective quality attributes were not altered except for pH and a* index which were not undesired. Direct application of plasma for 90 s and in-package treatment for 30 s were suggested for further investigation. Furthermore, considering the practical aspects, pulsed plasma processing of packed figs for 30 s is recommended. In conclusion, atmospheric cold plasma has the potential to be applied on fresh fig fruits to prolong its shelf life.

Keywords: Non-thermal treatment, Packaging, Sensory evaluation, Shelf life.

Introduction

Fig is a valuable fruit with nutritional advantages such as phytochemical properties and antioxidant activity (Çalişkan and Polat, 2011), but it is very perishable. Demand for fresh figs is large and requires advances in postharvest handling (Stover et al., 2007). Low temperature plasma as an environmentally friendly method has been suggested to have high performance to prevent hazards from foods (Phan et al., 2017). Cold plasma at temperature close to the room environment is an energetic substance, which consists of gas molecules, ionized particles, free radicals, electrons and photons. The cold plasma can be used to deactivate pathogenic agents on the food surface in the form of fresh and dried products, and packaging materials (Mirsa et al., 2011). Plasma was generated by applying an electric field and subsequently ionizing into the air. Plasma, which consists of ionized gas particles, UV, ozone and other free radicals has various mechanisms affecting the contents and walls of cells and genetic material of microorganisms (Moisan et al., 2001;

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[*] Corresponding Author, Email: abbaszadeh@irost.ir

Pivarnik and Worobo, 2014; Bourke et al., 2015). Various researches were conducted to study plasma influence on quality of fruits and vegetables. The effects of radio frequency plasma on lettuce were investigated and there was a little change in the color of the leaves (Smeu et al., 2012). To investigate relationships between enzyme activity and quality deterioration, peroxidase enzyme activity was investigated in tomatoes exposed to plasma treatment. Plasma generated by dielectric barrier discharges method was used for up to 5 min and 30, 40 and 50 kV. Inactivation was increased with time and voltage (Pankaj et al., 2013). The utilization of DBD plasma for 10 s, 20 s and 30 min on apple pieces was evaluated and the quality and metabolic indices were measured. Significant decrease was achieved in the browned areas of the treated samples. Generally, the metabolic rate of the tissues decreased. Little effects were found only for qualitative parameters (Tappi et al., 2014). In another study, the effect of plasma was studied on quality of tomato. It was generated inside the package through applying the method of dielectric-barrier discharges. In terms of weight loss, firmness and pH, the differences between control and treated tomatoes were negligible. Changes in respiration rate and color were a function of the treatment, but their amount were not very high (Mirsa et al., 2014). Plasma produced by microwave was used for indirect treatment of apple, cucumber, tomato and carrot. Cold plasma reduced the microbial contamination in 5 min. Significant effects of plasma on tomato and carrot color and chlorophyll fluorescence parameters were observed, while it had no effect on elasticity of product. The cold plasma for apple was more appropriate than the other fruits (Baier et al., 2015). Applying microwave plasma to dried figs decreased colonies of *Escherichia coli* and *Listeria*. The microbial inactivation was enhanced from 0.5 to 1.3 log and from 1 to 1.6 log for *E.coli* and Listeria, respectively with increasing water activity from 0.7 to 0.93. Increase of the plasma antimicrobial ability was also observed by reducing pH of figs from 6 to 4 (Lee et al., 2015). The effects of non-thermal plasma on anthocyanin and color of pomegranate juice were studied. The results showed that plasma jet had positive effects on the anthocyanin stability and color change of juice. Plasma application increased the anthocyanin content from 21% to 35 %.(Kovačević et al., 2016). Detoxification effect of plasma was evaluated to decontaminate hazelnuts by changing the gas, power and time of the treatment. Total aflatoxin and AFB1 decreased to 70%. Aflatoxin B1 and G1 were also more sensitive to plasma application than B2 and G2 (Siciliano et al., 2016). Therefore, the current study aimed to evaluate effects of cold plasma on quality of fresh figs.

Materials and methods

Figs (*Ficus carica* L. Siyah cv) which mainly produced in Lorestan or Semnan provinces (Hasanpour et al., 2016) were purchased from local market in Tehran. This cultivar is one of the main irrigated fig cultivar native to Iran named for its appearance (Maghsoudlou et al., 2017). The fig fruits were stored at 2-3 °C in refrigerator.

Non-thermal plasma was generated through dielectric barrier discharge (DBD) method. The plasma system included a 12 kV pulsed high voltage power supply used at approximately 7 KHz and a probe. The high voltage output of power supply was terminated to probe. The part of probe used for keeping by hand was insulated by poly tetra fluoro ethylene cylinder to avoid electric shock. The end of probe consists of copper scraps as high voltage electrode covered by dielectric barrier which was made of quartz. The cold plasma is created at atmospheric pressure between barrier and figs. Figure 1 presents a schematic diagram of the plasma generator system.

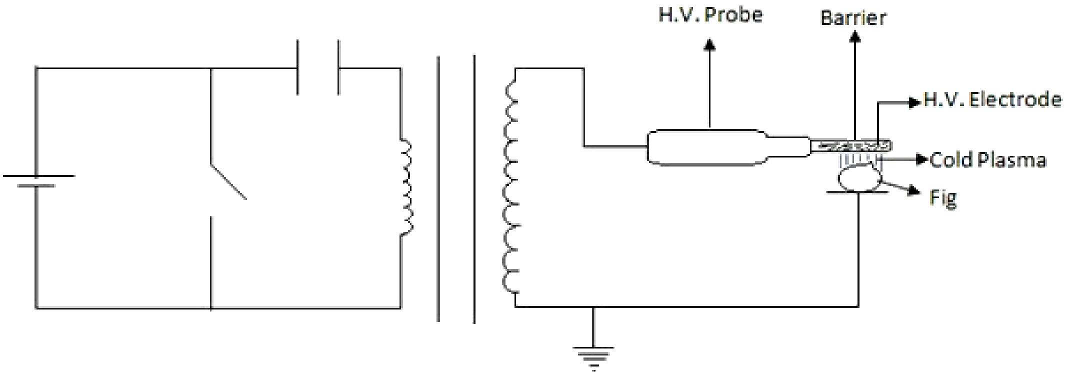

Fig. 1. Schematic diagram of the plasma generator system

Pre-tests were carried out to select suitable durations for plasma application in main experiments, because of lack of study about cold plasma utilization for fresh fig. In this step, three treatment times (0, 1 and 5 minutes) were used. Then sensorial quality of figs was evaluated after 10 days by seven panelists. It included color, texture, odor, appearance and overall acceptance. Figs were scored on a scale of 1–5.

The time durations of main experiments were selected based on pre-test results. Plasma exposure times were 0, 30, 90 and 180s. Cold plasma was applied to fruits directly and also in-package. Directly treated samples were kept in package after plasma application while in-package treatment was done for previously sealed-packaged figs. The package which was plastic zip lock bag had dimensions of 18×14 cm. Each experiment was repeated three times. Fruits were stored at approximately 3°C. After 11 days samples quality was assessed with subjective and objective methods. Figs were sensory evaluated similar to pre-tests based on 1-5 hedonic scale.

Then color was determined using Hunter L*, a* and b* scale using a color meter (TES-135A; TES Electric Electronic Corp., Taiwan). Fig's color was measured at three individual points of samples and the average was calculated for each color space value. Flesh firmness of the figs was estimated by a digital penetrometer of fruit (GY-4, China). It was equipped by a medium cylinder (diameter: 3mm, height: 16mm). The test was repeated on three points for each fig. Total soluble solids were determined using a handheld refractometer in terms of Brix degrees. pH of the figs was also measured by a handheld pH-meter (3100, Ohaus, USA).

The statistical analysis of sensorial data was conducted based on completely randomized block design. Each evaluator was considered as a block (Yazdi et al., 2007). Completely randomized design was also used for objective experiments. Each treatment was replicated three times. Exposure time and the existence or absence of packaging was considered as independent factors. ANOVA was performed on the data and Duncan's test was applied to compare the means. This analysis was carried out by SPSS software (version 16.0).

Results and discussion

The pre-experimental results are presented in Fig 2. Two plasma treatments with different exposure times, 1 and 5 min, caused better results than the control. A 67% increase was observed, on average, in sensory scores of figs treated for one min. Main treatments were chosen for around one min exposure time because of its averages which were more than five min treatment and also its time efficiency.

The Variance analysis of collected data from main sensory evaluations showed significant effects of treatments on panelist's preference (Table 1).

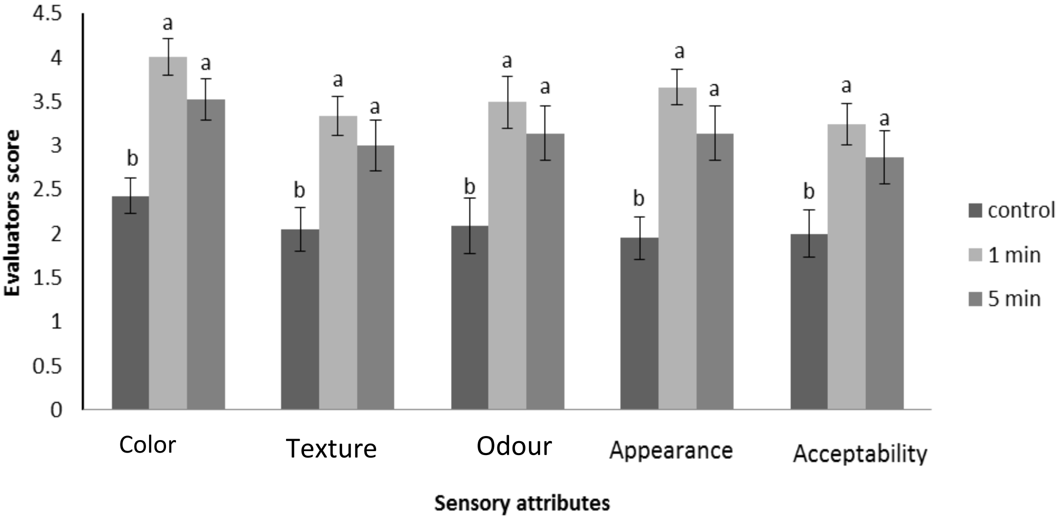

Fig. 2. Sensory evaluation of plasma pretest treatments and control (columns with the same letter are not significantly different)

Table 1. ANOVA results on the effect of cold plasma application on sensorial quality of fresh fig (Main tests)

Source	Variable	Sum of Squares	df	Mean Square	F	p-value
Block	Color	115.020	6	19.170	15.634	.000
	Firmness	84.898	6	14.150	11.212	.000
	Odour	28.327	6	4.721	2.872	.012
	Appearance	74.993	6	12.499	9.654	.000
	Acceptability	69.986	6	11.664	9.092	.000
Treatment	Color	73.211	6	12.202	9.951	.000
	Firmness	103.755	6	17.293	13.703	.000
	Odour	128.993	6	21.499	13.080	.000
	Appearance	112.517	6	18.753	14.485	.000
	Acceptability	109.415	6	18.236	14.214	.000
Error	Color	164.313	134	1.226		
	Firmness	169.102	134	1.262		
	Odour	220.245	134	1.644		
	Appearance	173.483	134	1.295		
	Acceptability	171.918	134	1.283		
Total	Color	352.544	146			
	Firmness	357.755	146			
	Odour	377.565	146			
	Appearance	360.993	146			
	Acceptability	351.320	146			

Mean sensory scores of fig samples obtained in main experiments are shown in Fig 3 to 7. Fresh figs were affected by non-thermal plasma. All plasma treatments were significantly better than the control. Direct application of plasma for 90 s and in-package plasma treatment for 30 s yields the highest quality among treatments after storage period.

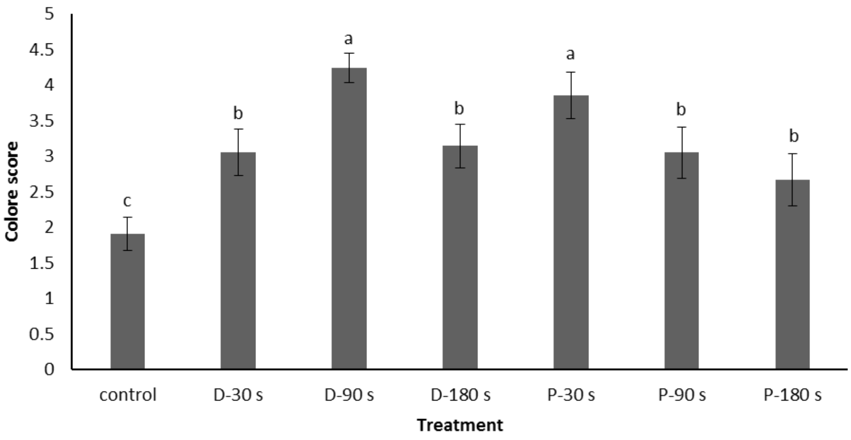

Fig. 3. **Mean sensory score of color for figs treated by cold plasma at the end of storage (Direct: D, In-package: P) (columns with the same letter are not significantly different)**

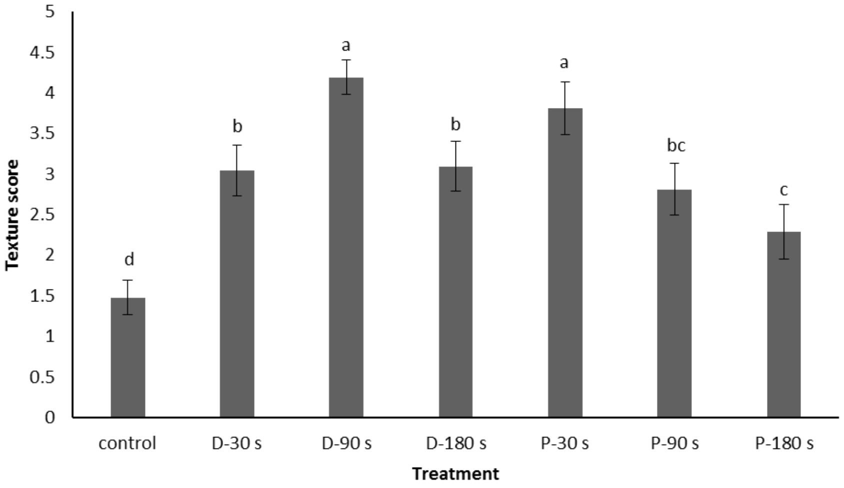

Fig. 4. **Mean sensory score of texture for figs treated by cold plasma at the end of storage (Direct: D, In-package: P) (columns with the same letter are not significantly different)**

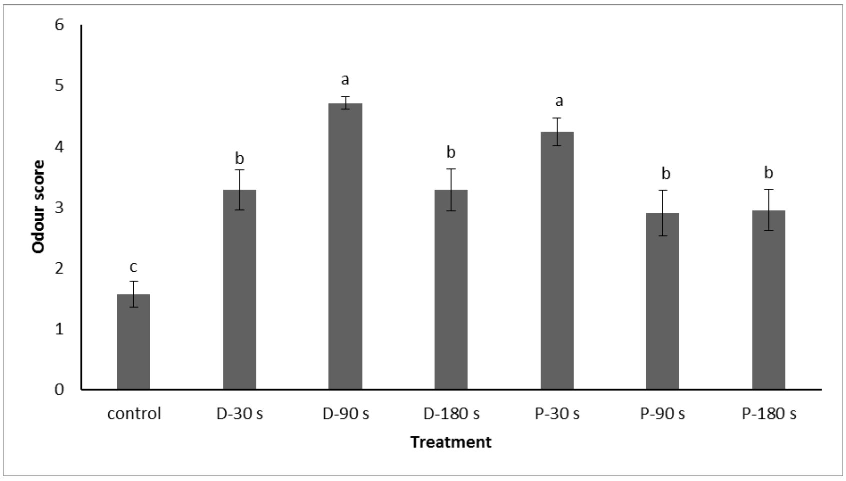

Fig. 5. **Mean sensory score of odour for figs treated by cold plasma at the end of storage (Direct: D, In-package: P) (columns with the same letter are not significantly different)**

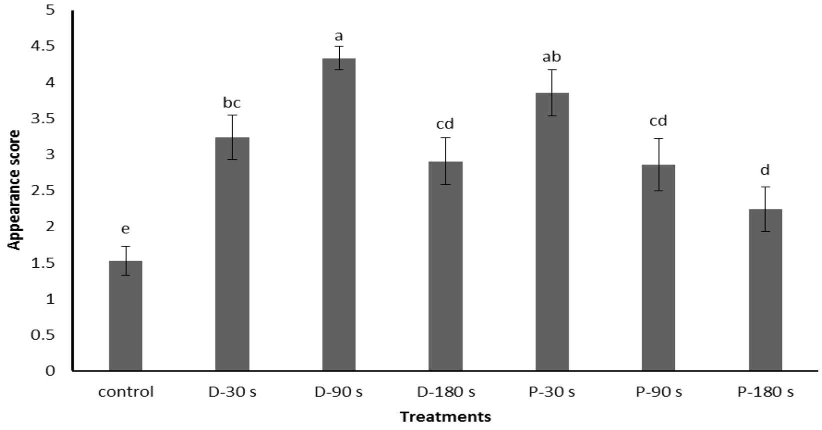

Fig. 6. Mean sensory score of appearance for figs treated by cold plasma at the end of storage (Direct: D, In-package: P) (columns with the same letter are not significantly different)

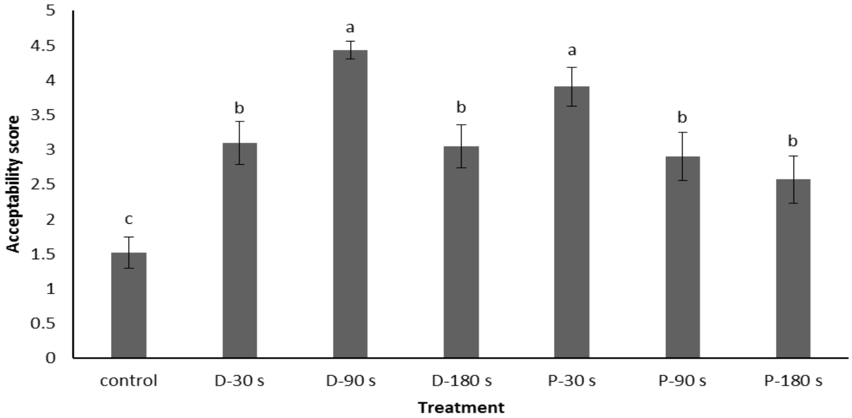

Fig. 7. Mean sensory score of acceptability for figs treated by cold plasma at the end of storage (Direct: D, In-package: P) (columns with the same letter are not significantly different)

Application of cold plasma requires finding optimum dose. As shown in figures, increasing the treatment time did not necessarily improve the quality attributes. This may be due to the effect of the plasma on the destruction of the cell wall of fig surface and long-term exposure caused the leakage of their moisture and consequently provided the conditions for fruit deterioration. In an experiment on carrots, plasma treatments for 2.5–10 min resulted in surface browning of all carrots without differences between treatment times and an associated exudation of some milliliters of orange-colored liquid. Hence treatment durations below 2.5 min or change of the plasma source are necessary to obtain a potential feasibility (Baier et al., 2015).

It also seems that the treatment accelerated plasma influence because of accumulation of generated ozone in the packaged figs. Fig is a climacteric fruit which generate ethylene and ozonation treatment is one of methods used for ethylene removing. Ozone has been also known to have disinfectant effect. In-package decontamination of fresh fruits is interesting way to minimize the possibility of post-processing contamination. It reduced background microflora of strawberries without significant effect on color and firmness through low temperature plasma (Mirsa et al., 2014).

Table 2 shows ANOVA results on the effect of cold plasma application on quality of fresh fig. Despite the lack of significant effects of treatments, Duncan's test was performed (Yazdi et al., 2007) and it presented the differences among treatments for two attributes.

Effects of applied plasma treatments on some quality attribute of fresh fig are shown in Table 3. Although some traits showed lower values for control samples compared to untreated ones, most of characteristics were not significantly changed. Control pH value was statistically lower than figs directly treated for 30 and 90 s. Lowest value of pH was detected for untreated samples (4.63) and the highest pH was 1.17. Reduction of acidity postponed fig souring. The a* value was also different for one of treatments. Generally any side-effects of cold plasma was not observed for measured attributes except for the pH and a* which are not undesired. However, it is necessary to study other quality indices of fig under plasma treatment.

TSS and firmness were not significantly changed in response to applied plasma. The average values were 12.9 °Brix and 3.5 kg for TSS and firmness, respectively.

Table 2. ANOVA results on the effect of cold plasma application on quality of fresh fig

		Sum of Squares	df	Mean Square	F	p-value
Firmness	Treatments	18.515	6	3.086	.698	.656
	Error	61.918	14	4.423		
	Total	80.432	20			
TSS	Treatments	13.338	6	2.223	.209	.968
	Error	149.040	14	10.646		
	Total	162.378	20			
pH	Treatments	3.266	6	.544	2.505	.074
	Error	3.043	14	.217		
	Total	6.309	20			
L	Treatments	152.423	6	25.404	.546	.765
	Error	651.451	14	46.532		
	Total	803.873	20			
a	Treatments	133.618	6	22.270	1.954	.142
	Error	159.577	14	11.398		
	Total	293.196	20			
b	Treatments	108.051	6	18.008	1.177	.372
	Error	214.189	14	15.299		
	Total	322.240	20			

Table 3. Comparison of quality characteristics of fresh figs treated by cold plasma

Treatment	pH	TSS (°Brix)	Firmness (kg)	L*	a*	b*
Control	4.63^{b}	13.7^{a}	2.9^{a}	23.932^{a}	2.413^{b}	1.860^{a}
Direct-30 s	5.68^{a}	12.8^{a}	4.3^{a}	29.162^{a}	10.976^{a}	2.340^{a}
Direct-90 s	5.80^{a}	11.7^{a}	4.7^{a}	30.982^{a}	3.322^{b}	-0.179^{a}
Direct-180 s	5.66^{b}	13.6^{a}	2.0^{a}	27.986^{a}	5.874^{ab}	4.790^{a}
In-package-30 s	5.03^{ab}	11.6^{a}	4.6^{a}	32.746^{a}	5.254^{ab}	-0.660^{a}
In-package-90s	5.11^{ab}	13.4^{a}	3.4^{a}	31.557^{a}	5.919^{ab}	0.206^{a}
In-package-180s	5.23^{ab}	12.9^{a}	3.1^{a}	28.629^{a}	5.720^{ab}	6.006^{a}

Means with the same letter in each column are not significantly different

Fig's skin is thin and its surface can be favorite place for many microorganisms which are the cause of fruit decay. In addition, figs are usually harvested by hand in several regions and this is another possible contamination factor. Shelf life of fresh fig fruit was prolonged which was probably because of inactivation of fungus and bacteria by cold plasma. It seems this effect is due to components of plasma such as ultraviolet (UV). Combination of infrared radiation heating with ultraviolet irradiation was studied on fig fruit and it was found that figs affected by growth of mold and yeast. Therefore, it was hypothesized that the DNA damage was occurred (Hamanaka et al., 2011). Various anti-microbial mechanisms have been presented for non-thermal plasma. Reactive species has effective role in sterilization of surfaces. Cold plasma can influence permeabilization of the cell wall and damage the intracellular contents and also inactivate some enzymes (Stoica et al., 2014).

Skin extract of Siyah fig cultivar has high antioxidant activity (Maghsoudlou et al., 2017). In the other hand, interaction of cold plasma reactive species with fruit component may cause physical and chemical variations (Pankaj et al., 2018). Therefore antioxidant activity of fig skin can help against negative effects of plasma on fruit properties.

Integration of non-thermal plasma and other technique is another way to develop beneficial applications of this progressing method. Atmospheric cold plasma and green tea extract in combination extended the shelf life of fresh-cut dragon fruit while it did not have negative effect on the sensorial quality and nutritional value of fruit (Matan et al., 2015). The quality preservation of fig fruit can be improved through interactions between the plasma and chemical methods such as calcium chloride (Irfan et al., 2013) or physical methods such as infrared heating and ultraviolet irradiation (Hamanaka et al., 2011). These combinations are a novel approach for reducing unfavorable effects of chemical and thermal methods. However, the potential for plasma treatment as a sanitation technique for fresh fruit is closely linked with retention of quality indices. Considerable differences in shape, size, and physical characteristics activate the need to test its feasibility for every type of produce. Effective microbial decontamination needs to be performed within the limits of postharvest quality retention.

Conclusion

In this study, a non-thermal technique was applied to packed and unpacked fresh fig fruits. The findings have identified, for the first time, the potential of cold plasma technology to preserve fresh fig quality. Positive effect of non-thermal atmospheric plasma on sensorial quality of fig fruit was observed and undesired quality change was not found. It is suggested to perform microbiological and nutritional experiments and also study of packaging materials influence. Cold plasma technique can be considered as an approach for prolonging shelf life of fresh figs. It is free of water and chemical materials but commercial-scale of plasma application to packed or unpacked figs needs further investigation. Considering the practical aspects, in-package processing of figs for 30 s is recommended. The next step should be to use the results of this feasibility study to get indications to set up and develop a more complete and exhaustive set of experiments by considering very important aspects of product shelf-life, such as metabolic and enzymatic activity and microbiological characteristics.

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