

The effect of cold plasma by Nano titanium in cathode on the shelf life and quality characteristics of strawberry fruits

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Abstract

Different post-harvest diseases in fruits and vegetables cause heavy economic losses worldwide. Strawberry fruit is extremely corruptible and prone to mechanical damage, rotting, and physiological bruising in postharvest period. Nowadays, one of the essential issues in societies is to reduce postharvest losses of fresh crops to increase food security and prevent loss of capital. In this study, cold plasma was used to reduce degradation rate of it during 7 days of storage and increase shelf life. Samples of strawberry were treated with cold plasma jet using helium gas for 5 min and color indicators were measured immediately after the plasma application. The results indicated no significant difference between the indicators in control and treated samples. According to the results of sensory evaluation after 7 days of storage, the texture, color, and general acceptance (acceptability) of plasma-treated samples were significantly better than those of control samples, but no significant difference was observed in terms of the odor. In this context, it may be concluded that cold plasma may be considered a novel approach to increase shelf life of strawberry fruits.

Keywords: Cold plasma, strawberry, sensory evaluation, postharvest, shelf life

1. INTRODUCTION

Strawberry (*Fragaria ananassa*) is a relatively new fruit. As a matter of fact, it did not exist 250-300 years ago in the form it is today (Harooni and Abbasi, 2011). It is rich in phenolic compounds such as anthocyanins providing the fruit's bright red. On the other hand, strawberry is grown both naturally and garden plant (Kavoosi, 2013). It is non-climacteric with high corruptibility which should be harvested when it is fully ripened to have the highest quality in terms of appearance, texture, flavor, and nutrient content (Hernandez-Munoz *et al.* 2008). Freshly harvested strawberries are very susceptible to mechanical damage, dehydration, rotting, and physiological degradation. Postharvest spoilage of strawberries may mainly be attributed to yeast development and mold growth. In a research carried out by Emamifar (2014), a strawberry loss of 30% was estimated from harvest to table.

As mentioned above, most fresh or processed food products are prone to microbial contamination, which necessitates seeking solutions to prevent and control such infections.

Use of chemical disinfection or physical treatment is not only often associated with consumer unacceptability, but also low efficiency. Chlorine-based wash is widely used to disinfect fresh crops. However, use of chlorine for washing fresh products or fruit slices is prohibited in some European countries, including the Netherlands, Switzerland, and Belgium. Consequently, both consumer demands and drawbacks of existing technologies have reasoned development of alternative, in particular non-thermal, methods (Misra *et al.*, 2014). Thus, development of effective methods for removal of microbial contamination in fresh products is of particular importance (Baier, *et al.*, 2014). Novel non-thermal methods including high hydrostatic pressure processing (HPP) and pulsed electrical fields (PEF) have been examined in many studies with good results. However, expensive equipment is required for the development of the HPP method (Misra *et al.*, 2014).

Non-thermal gas plasma is a new technique for reduction of microbial load in fresh fruits and vegetables (Baier, *et al.*, 2014). Plasma technology is one of the modern technologies with many applications in various industries including food industry. In fact, plasma is referred to as the fourth state of matter, i.e. an electrically neutral gas consisting of molecules, atoms, ions, and free electrons, which can be used for the sterilization of medical equipment, food industry equipment, and sterilization of food products (Harooni and Abbasi, 2011; Misra *et al.*, 2014). By applying energy to a gas (e.g. in an electric field), some of its electrons leave its atoms and become positively charged ions, called ionization. Indeed, plasma is referred to as an ionized gas all or a considerable part of its atoms have lost one or more electrons, turning into positively charged ions. Plasma comprises positive ions, electrons, atoms and/or neutral gases, ultraviolet waves, free radicals, and excited atoms and molecules (Mazloom *et al.*, 2013).

Application of an electric field to a neutral gas is the most common method for production and stabilization of an atmospheric cold plasma for technical and technological uses. Free charge carriers (FCCs) are accelerated by applying an electric field and **now (now or new?)** FCCs are produced when these FCCs collide with atoms and molecules in gas or on surface of electrodes, which usually produces a cascade of charged particles, ultimately leading to the formation of a stable plasma by the loss of some FCCs and reaching a balance.

All man-made plasmas can be classified into two classes, namely hot (local thermodynamic equilibrium) and cold (non-equilibrium local thermodynamic) plasmas, with the former produced by electric arcs, nuclear reactions, laser stimulation, flame, and microwaves. In hot plasma, degree of ionization is about 100% and electrons, atomic components, and other particles are at an extreme, identical temperature. Cold plasma is not actually cold and its electrons even reach 100 °C; in this type, however, only a small part of particles are ionized close to 1%. For this reason, the frequency of elastic collisions between electrons and atoms is low and electrons do not have much opportunity to transfer their energy to the gas, being unable to effectively warm up the heavy species. Therefore, background gas remains at ambient temperature or close to it, resulting in a very higher temperature of electrons than that of the gas followed by a local heat imbalance, a process appropriate for heat-sensitive

materials (Abdi and Niakowsari, 2013; Mazloom et al., 2013). Accordingly, cold plasma is a new non-thermal technology used for biological disinfection and sterilization of surfaces, medical instruments, water, air, food, living issues, and the surface of fresh products. In addition to the antimicrobial property, plasma has non-chemical advantages, no need for water, and usability in the atmospheric pressure and room temperature (Lacombe *et al.*, 2015). Cold plasma is produced using electricity and a carrier gas, such as the air, oxygen, nitrogen, or helium, and can reportedly inactivate microorganisms in blueberries and be optimized to improve the product safety and quality (Lacombe *et al.*, 2015). In a research, hazelnut, pistachio, and peanut products were artificially infected with a fungus and inoculated samples were exposed to low-pressure cold plasma (LPCP) for different durations. The results indicated that 20 min was an optimal time to reduce the fungus. The LPCP was also introduced as a rapid elimination method to eradicate an aflatoxin-producing fungus from nutshells and as a suitable disinfection method (Basaran *et al.*, 2008). Cold plasma treatment was also tested as a tool to improve the microbiological safety of fresh vegetables and dry fruits (Lee *et al.*, 2015).

This study is to aim to apply cold plasma jet to increase shelf life of strawberry and evaluate degradation rate of strawberry quality characteristics such as texture, color, and acceptance during storage. To this end, the texture, color, and general acceptance (acceptability) indicators of samples are evaluated under the plasma treatment.

2. MATERIAL AND METHOD

Fresh strawberry samples were obtained from a local market in Karaj city. The samples were selected equally based on the color, size, free of apparent spoilage, and without visible mechanical damage (Han *et al.*, 2014). The experiments were carried out by being applied plasma and control treatments for two groups of strawberries with equal characteristics. The cold atmospheric plasma jet (CAPJ) was produced using a device consisting of a high-voltage power supply, a helium gas capsule, and a jet probe, with a maximum transition voltage of 12 kW and a power of 30 W. Then, strawberry samples were exposed separately to the plasma gas using the helium gas, at a frequency of 6 kHz. Immediately after the plasma application, the color indicators ($L^*a^*b^*$) were determined for the control and treated samples by a colorimeter for the first group for 5 min in laboratory conditions. Experiments were done in the laboratory of the Agricultural Engineering Department, the Iranian Research Organization for Science and Technology.... The strawberry samples of the second group (including the control and samples treated for 5 min) were placed in individual packages and refrigerated at 6-8 °C for 7 days. All the tests were performed in triplicate. The second group was subjected to sensory evaluation test on the 7th day of storage, in which the color, odor, texture (Which texture), and general acceptance of samples were evaluated through five-point hedonic scale with combined quality scoring and ranking. Scores were in range of 5 (very good), 4 (good), 3 (moderate), 2 (poor), and 1 (very poor) (Emamifar, 2014). Collected data were introduced to the EXCEL software (as the database) and then, analyzed based on research hypotheses in a completely randomized design format by the SPSS (2016) software.

Results and discussion

According to statistical results, study of color indicators in surfaces of strawberries in the first group revealed no significant differences between the control samples and plasma treated samples for 5 min by plasma. This means that application of system had no negative effects on the color of tested strawberries. Table 1 and Figure 1 show the results of the t-test and comparison of means, respectively. In a research carried out by Hertwig *et al.*, (2014), microbial load of spices of medicinal plants was reduced using nano titanium plasma and examination of quality characteristics showed that product quality and color were not affected before and after plasma application.

Results of data evaluation effect on the color, texture, and general acceptance (acceptability) of samples in control and plasma treatments after the 7-day storage revealed a significant effect on the second group at 5% level (Table 2). However, control and plasma treatments were not significantly different in terms of odor indicator, as shown in Table 1. Application of plasma had a significant effect on shelf life of strawberries so that samples in plasma treatments were marketable after the 7-day storage. However, control samples displayed degraded texture (which texture), with fully evident mold growth and bruising and dehydration effects. It may be concluded that this trend may result from surface damage and cell wall rupture in microorganisms bombarded strongly with the plasma due to presence of charged electron and ion particles, UV radiation, free radicals, and chemically active species. Hence, those cells cannot rapidly repair the rapture completely and mostly die for this reason.

In a previous research carried out by Hong *et al.* (2009), electron microscopy images demonstrated morphological changes in plasma-treated *E. coli* cells for 2 min. Assessment of the images disclosed harsh cytoplasmic deformations and bacterial chromosome leakage in the treated cells. Accordingly, the increased shelf life declined quality degradation rate, and better appearance of the plasma-treated strawberries can be attributed to the elimination of surface microorganisms ____?. It is noteworthy that plasma has a superficial effect, meaning that it does not penetrate the product hence changes occur only on the surface of the product.

Table 1. Comparison of color indicators in the control and plasma-treated strawberries (immediately after the plasma application) using the t-test

<i>t</i>			
<i>C</i> *	<i>b</i> *	<i>l</i> *	df
-0.362	-0.282	-0.023	4

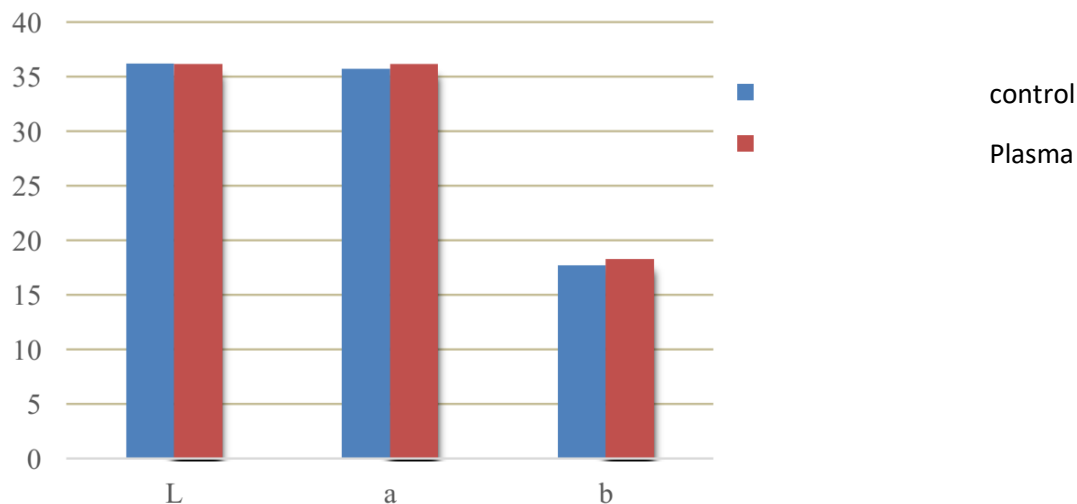


Figure 1. Comparison of color indicators in the control and plasma-treated strawberries (immediately after the plasma application)

Control Plasma-treatment

Table 2. Comparison of sensory evaluation results in the control and plasma-treated strawberries using the t-test

<i>t</i>				
Color	Texture (Which one)		Odor	df
Acceptability				
-2.236*	-3.13	-0.647	-2.907*	10

Color Texture Odor Acceptability

Mean scores by sensory evaluators

Figure 2. Comparison of mean scores by sensory evaluators for the control and plasma-treated strawberries after 7 days of the storage

Conclusion

The effects of non-thermal plasma on the food nutritional and chemical properties are not well recognized due to scarce studies on the use of cold plasma technology in food processing, which necessitates the assessment of plasma effects on product quality and safety. According to the findings of this study concerning the effects of the CAPJ on the shelf life and quality characteristics (texture, color, and acceptability) of strawberries, it is concluded that the cold plasma can be considered a novel approach to increase the shelf life of strawberries.

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