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Role of a corona field application in the physicochemical properties of stored strawberries

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Abstract: Grey mould disease caused by the fungus *Botrytis cinerea* Pers is widely distributed on strawberries as the dominant postharvest disease. Therefore, fruits have been treated using a pin-to-plate corona electrical field at a high voltage electric field (HVEF) intensity of 3.61, 4.56, and 5.13 kV·cm^{-1} for 60 minutes. The result revealed that the corona discharge demolished the *B. cinerea* growth using 20 kV·cm^{-1} for 10 min in the Petri dishes. In addition, the treated strawberries at 4.56 kV·cm^{-1} had an average infection rate of 23.33% compared with non-treated samples rate of 45.33%. The HVEF-treated samples showed significantly lower mass losses. The analysis of variance showed that the HVEF did not significantly affect the total soluble solids content, pH, titratable acidity, and softness; however, the lower acidity affected the *Botrytis cinerea* growth. No significant differences were observed among the mean values in the colour change parameters and colour difference for 4.56 kV·cm^{-1} compared with the control, while the lightness was significantly higher. The result show that the corona electrical field was able to demolish the *B. cinerea* growth, and an electric field intensity at 4.56 kV·cm^{-1} was found to extend the strawberries' cold storage and to lead to a lower mass loss.

Keywords: shelf life; *Botrytis cinerea*; high voltage; decay

The strawberry (*Fragaria ananassa*) is a perishable fruit with a high physiological postharvest activity among agricultural products. This fruit is susceptible to mechanical injuries and bruising due to its soft texture and lack of a protective layer, making its marketing a challenge; fresh whole strawberries last for 5 to 7 days (Han et al. 2004). Several methods have been developed to extend the shelf life of strawberries. Rapid cooling after harvest and low-temperature storage at 3 to 10 °C with a high relative humidity at 65 to 95% are the most common approaches for preserving the quality, controlling the decay, and extending the shelf life of strawberries (Ghaouth et al. 1991). The drawbacks of these methods, however, are high costs and low efficiency. In addition, hot water treatments, UV applications, and chemical treatments have been used to enhance the storage period of strawberries (Sallato et al. 2007). To control the grey mould growth caused by the *Botrytis cinerea* pathogen, the preharvest or postharvest spraying of Dicarboxyamide and Benzimidazole fungicides is commonly used. The continued use of chemical fungicides should be curtailed due to the increased fungal resistance and concerns about human health and environmental hazards. Alternative methods to demolish the grey mould includes photochemical treatments, heat treatments, and UV irradiation. Using plasma on strawberries demolished many aerobic bacteria, yeasts, and moulds while their colour and texture were negligibly changed (Misra et al. 2014). Therefore, finding a new method to increase the storage period and reduce the senescence may be useful for strawberry postharvest technologies.

A high-voltage electric field (HVEF) causes gas ionisation at room temperature and atmospheric pressure, so it is a nonthermal treatment useful in extending the shelf life of fruits (Bajgai et al. 2006). The air around the electrodes of the HVEF is ionised and moved toward the opposite electrode at a high

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velocity which makes a corona wind. Many studies indicate that HVEF can produce ozone, influence enzyme activity, inhibit microbial action and extend the preservation period of food, vegetables, fruits, fruit juices, and grains. There is a review comprehensively analysing the appropriate ozone concentrations and exposure times and discusses various factors that affect the food products' quality and safety during ozonation (Pandiselvam et al. 2019). The acoustic field's cavitation bubbles generate robust micro streaming, and a high shear leads to enzyme inactivation (Raviyan et al. 2005). Kuldiloke and Eshtiaghi (2008) stated that the ion pressure along the foods' surface by high-voltage electric fields which causes the ionising water molecules to attach to hydroxyl free radicals, making it reliable oxidants quickly react with amino acids like microorganisms. Ozone and nitrous oxide are produced during the corona electrical field (Hashinaga et al. 1999). Ozone can demolish pathogenic microbes and reduce decay in fresh products. Not to mention, the demolition of ethylene and the elimination of airborne fungal spores using ozone could be useful for the shelf life extension of fruit (Pandiselvam et al. 2019). A corona electrical field might help reduce decay and spore production in stored materials. HVEF-treated cranberries enhanced the fruits' shelf life (Palanimuthu et al. 2009). Kharel and Hashinaga (1996) applied an external electric field to observe a reduction in the strawberries' decay rate. In another study, a high-voltage electric field was found to improve the sweet pepper's freshness and shelf life (Kharel et al. 1996). Yeom et al. (2002) employed an electric field treatment to induce pectin methylesterase in orange juice. Pectin methylesterase is an enzyme that adversely affects the fruit texture. A corona wind produces the same enzyme inactivation effect, as does the application of an acoustic field make.

However, comprehensive studies are needed to shed light on different aspects of a pin-to-plate corona electrical field application as a non-thermal and non-destructive method to enhance the strawberries' postharvest life. It seems that using an air-blower with a chamber could be a possible application to treat fruits commercially. The aim of the present study was to investigate a corona electrical field's effectiveness on *B. cinerea* and to determine the physicochemical indices of strawberries. In addition, the mass loss, total soluble solids content, pH, titratable acidity, softness, colour parameters, and grey mould growth was measured to evaluate the HVEF treatments to prolong the strawberries storage period.

MATERIAL AND METHODS

Strawberries (*Fragaria ananassa* cv. selva) were obtained from the Research Greenhouse of Isfahan University of Technology the day before the experiments were conducted and stored in polyethylene containers at 6 °C in a refrigerator. The fruits were selected based on their uniformity in size, with a surface redness of 70% (using a digital camera, SONY-CyberShot, DSC-P72, Japan), an absence of physical damage, and no apparent fungal infection. The samples were sanitised after removing their calyx by immersing them in a 2% sodium hypochlorite solution to ensure disinfection for 2 min (Gol et al. 2013). Then, we washed with distilled water. They were allowed to surface dry for 2 h under ambient conditions (20 °C, relative humidity of 50%). The thus prepared fruit samples were weighed using an electronic digital balance (accuracy 0.01 g, GF-400, AND, Japan). In addition, to evaluate the effects of the corona electrical field on the *B. cinerea* growth, purified fungal samples were obtained from the Plant Pathology Laboratory of Isfahan University of Technology. The fungus was then grown on a potato dextrose agar (PDA), in a Petri culture medium. The cultures were incubated at 24 ± 2 °C, and the radial growth of *B. cinerea* was measured daily by MATLAB software (version 7.6) for seven days.

A pin-to-plate corona electrical field was accomplished on the rotational fruits with three replications using a positive electrical field electrode with 108 slim pins and an aluminium plate used as the grounded cathode according to Figur 1 (Esehaghbeygi et al. 2014). A high-voltage power supply was used to produce a corona wind of ions with a maximum voltage of 40 kV at 50 Hz using 5 mA (PNC 4000-5, Heinzinger Electric GmbH, Germany). Different polarities show that the positive corona electrical field was more efficacious than the negative one at lower applied voltages (Balcer and Lai 2004). A hexagonal arrangement was used to obtain equal distances among the electrode's pins. An electric field intensity was created under three levels of 3.61, 4.56, and 5.13 $kV \cdot cm^{-1}$ for 1 h based on a preliminary study and the limitation of the corona discharge setup configuration, the electrode gaps were set to 2, 3, and 4 cm for the applied voltages of 10.26, 13.68, and 14.44 kV, respectively.

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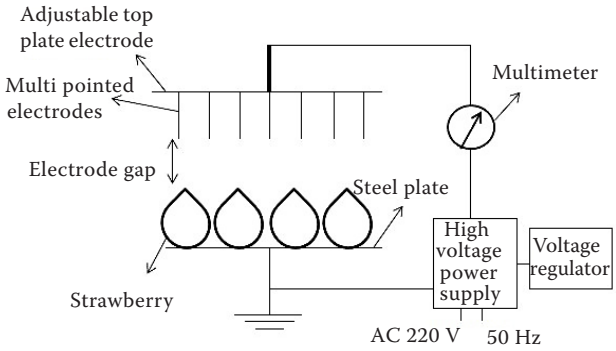

Figure 1. A schematic of the multiple pin-to-plate electrodes used in the high-voltage electric field setup

The strawberries were inspected visually for the grey mould growth after 1, 2, 3, and 4 days during the cold storage at 6 °C (Gol et al. 2013). The samples showing visible grey mould (at least one-third of the damaged surface) or black spots were considered decayed (Hernandez Munoz et al. 2006). The mass loss of the treated strawberries stored at 6 °C was calculated as the percentage loss of the initial mass (Olivas et al. 2007). A compression test using a Universal Testing Machine (model STM-20, Santam Co., Iran) was used to measure the fruit softness. The test was conducted using a 5 mm in diameter flat probe at a forward speed of 5 mm·s^{-1} and a penetration depth of 5 mm on the fruit's half concave-slice (Hernandez Munoz et al. 2006). A digital refractometer (Atago Co., Japan) was used to determine the total soluble solids content (TSS) of the juice of the filtered strawberries to express the Brix (Palanimuthu et al. 2009). For this purpose, the fruits were initially homogenised in a blender (MX-J110P, Panasonic, China), and 6 g of the ground strawberry mix was suspended in 100 mL of distilled water before being filtered. The pH was assessed using a pH meter (pH, 7110, WTW inoLab, Germany) in solvation titrated to a pH of 8.1 using 0.1 mol·L^{-1} NaOH. The titratable acidity (TA) was expressed as the mass of the citric acid per 100 g of fresh mass (Hernandez Munoz et al. 2006).

The apparent strawberries' surface colour was assessed using a digital camera (DSC-P72 CyberShot, SONY, Japan) in an especially designed chamber that housed the camera and the lighting equipment. Illumination was provided by four lamps, each of which contained two fluorescent tubes. Antireflective material was used on the chamber's interior side to avoid bright spots that could affect the colour measurement accuracy. The camera was placed vertically at a distance of 20 cm from the top of the samples. The angle between the lens' axis and the illumination sources was fixed at about 45 ° since diffuse reflection occurs at this angle (Hutchings et al. 2002). In addition, the calibration of the camera was accomplished using standard coloured papers. The photos were analysed using Adobe Photoshop software (version CS6), and the values of L^* (lightness), a^* (redness), and b^* (yellowness) were determined. Equation (1) was used to determine a colour difference, ΔE^* of HVEF-treated strawberries, and the control's initial colour had already been determined before storage (Palanimuthu et al. 2009).

$$\Delta E^* = \left(\Delta a^* + \Delta b^* + \Delta L^*\right)^{\frac{1}{2}} \quad (1)$$

where: $\Delta a^* = a^* - a^*_0$; $\Delta b^* = b^* - b^*_0$; $\Delta L^* = L^* - L^*_0$.

The statistical analysis was performed using a general linear model (GLM) under a complete randomised design with three replications, and the means were compared using the least significant difference (LSD test $P < 0.05$). SAS statistical software (version 9.1) was used.

RESULTS AND DISCUSSION

Fungal growth. The experiments' results investigating the effects of the pin-to-plate corona electrical field on the *B. cinerea* growth showed that the corona electrical field was able to demolish the *B. cinerea* growth in the Petri dishes using 20 kV·cm^{-1} for 10 minutes. It seems that the free radical of oxygen in the electric field is highly capable of not only oxidising microbes, bacteria, and fungi, but also demolishing their nutrition source, leading to the pathogens' inactivation (Pandiselvam et al. 2019). Figure 2 and Table 1 show the strawberries with the visible fungal infection growth versus the storage time duration and the intensity levels. Significant differences in the grey mould growths were observed between the HVEF at 4.56 kV·cm^{-1} and the control ($P < 0.05$). Initial signs of the grey mould were observed on day 2 for 4.56 kV·cm^{-1}. Infections were detected in 93% of the control fruits, whereas they were detected in only 63% of the treated samples. The HVEF-treated at 4.56 kV·cm^{-1} exhibited visual decay at the end of their storage period after 4 days. The treated samples at 3.61 kV·cm^{-1} showed fungal growth one day after storage. The lower electric field intensity was associated with higher rotting rates

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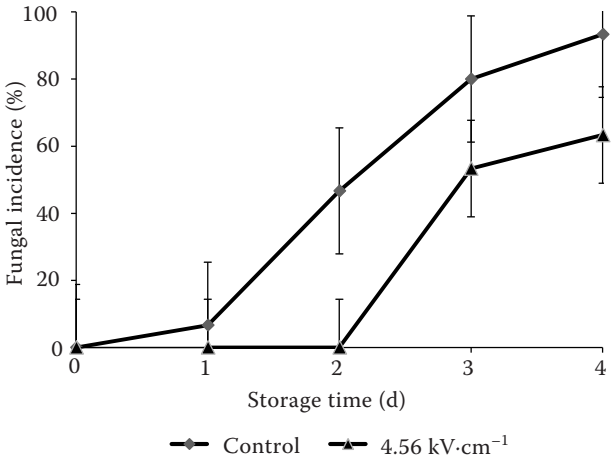

Figure 2. The grey mould growth on the strawberries during cold storage at 6 °C
Vertical bars show standard error

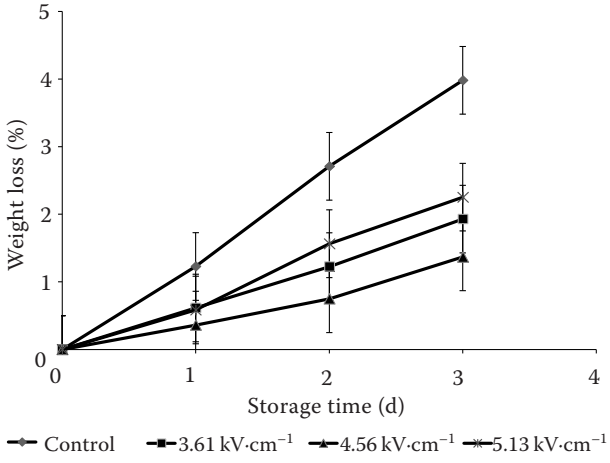

Figure 3. The mass loss of the strawberries treated by the electric field during cold storage at 6 °C
Vertical bars show standard error

Table 1. The grey mould growth and mass loss percentage of the strawberries at various electrical field intensities

	Day	Electrical field intensity (kV·cm^{-1})			
		0	3.61	4.56	5.13
The grey mould growth (%)	0	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}
	1	6.66^{a}	10.00^{a}	0.00^{a}	0.00^{a}
	2	46.66^{a}	40.00^{a}	0.00^{b}	20.00^{c}
	3	80.00^{a}	70.00^{a}	53.33^{b}	70.00^{a}
	4	93.33^{a}	80.00^{b}	63.33^{c}	80.00^{b}
Mass loss (%)	0	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}
	1	1.23^{a}	0.61^{b}	0.36^{b}	0.58^{b}
	2	2.71^{a}	1.22^{b}	0.75^{c}	1.56^{d}
	3	3.98^{a}	1.93^{b}	1.36^{c}	2.25^{d}

The average values of 3 replicates during cold storage at 6 °C

(Kharel and Hashinaga 1996). Hernandez Munoz et al. (2006) reported 91% of untreated strawberries stored at 20 °C showed visual mould infections after four days of storage. In addition, the corona electrical field led to the breakdown of the ethylene molecules to CO_2 and H_2O during the HVEF treatment (Duft et al. 2003).

Mass loss during storage. The strawberries' mass loss during the cold storage was observed in all the treatments (Figure 3). Significant differences were observed between the HVEF-treated samples and the control ($P < 0.05$). The mass loss for the treated samples at a 4.56 kV·cm^{-1} electric field was 1.36%, while it was 3.98% for the control at the end of the storage time. Significant differences in the mass loss were also detected daily among the treated-samples according to the treatment results of 3.61 kV·cm^{-1} and 5.13 kV·cm^{-1} as shown in Table 1. In other words, a stronger HVEF leads to the better preservation of the fruit moisture and freshness. Bajgai et al. (2006) studied the efficacy of 4.3 kV·cm^{-1} and a direct current of high electric fields in extending the fruits' shelf life at 20 °C. Their results showed the physiological loss of the mass was lower during the shelf life using the HVEF-treated samples than the control, mainly when the HVEF was applied (Kharel et al.1996; Palanimuthu et al. 2009).

Chemical effects. No significant differences were observed for the total soluble solids content between the HVEF treated and untreated fruits ($P > 0.05$). The total soluble solids of the control samples decreased progressively with the duration of the storage and the intensity levels (Figure 4 and Table 2). The mass loss has been reported to enhance the

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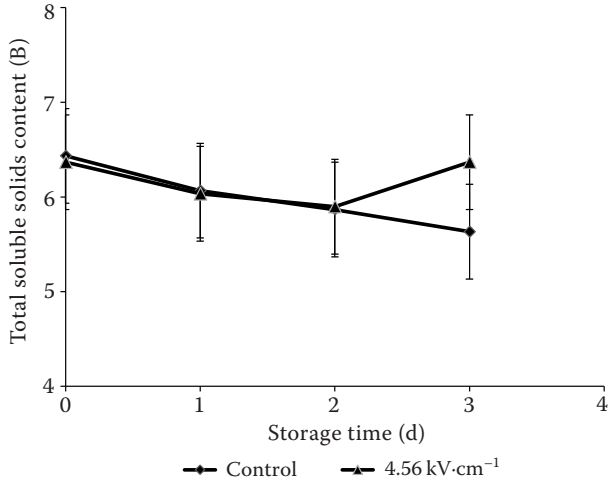

Figure 4. Total soluble solid contents of the strawberries during cold storage at 6 °C

Vertical bars show standard error

Table 2. The titratable acidity of the strawberries at different electrical field intensities

HVEF (kV·cm^{-1})	Titratable acidity
0	0.67^{a}
3.61	0.73^{a}
4.56	0.72^{a}
5.13	0.70^{a}
CV (%)	14.60

means with different superscripts in the same column are significantly different at $P < 0.05$ as determined by the LSD test; the average values of 4 days and three replicates during cold storage at 6 °C; HVEF – high voltage electric field; CV – coefficient of variations

enzymatic activity, leading to decreased TSS during cold storage (Garcia et al. 1998). The effect of HVEF on the pH was not significant. The HVEF-treated fruits exhibited a reduced pH level on day four of the storage period. At the same time duration, the control showed a gradual increase in the pH throughout the storage because of the lower TSS of the control samples. This finding agrees with the results reported by Hernandez Munoz et al. (2006) for untreated strawberries stored at 20 °C. Table 3 shows variations in the pH, and the grey mould growth rate in the examined fruits. It clearly shows that the grey mould growth rate decreased with an increasing pH. The titratable acidity declined slightly at the end of the storage period in all the treatments. Our results agree well with Garcia et al. (1998), who reported low titratable acidity levels in their HVEF-treated samples. Their strawberries matured during cold storage, which was a significant reason for the observed reduced titratable acidity. In the present study, no significant differences were observed in the titratable acidity between the HVEF-treated and the control samples (Table 2).

Table 3. The grey mould growth and the pH of the strawberries at different electrical field intensities

HVEF (kV·cm^{-1})	The grey mould growth (%)	pH
0	45.33^{a}	3.60^{a}
3.61	39.33^{ab}	3.65^{b}
4.56	23.33^{c}	3.69^{b}
5.13	34.00^{b}	3.68^{b}
CV (%)	22.04	2.15
RMSE	7.82	0.07

means with different superscripts in the same column are significantly different at $P < 0.05$ as determined by the LSD test; the average values of 4 days and three replicates during cold storage at 6 °C; HVEF – high voltage electric field; CV – coefficient of variations; RMSE – root-mean-square error

No significant differences were observed for the softness between the treated samples at 4.56 kV·cm^{-1} and the control after four days ($P > 0.05$). Degradation of the middle lamella of the cell walls, wall strength, cell to cell contact, and cellular turgor are some of the leading causes claimed to be responsible for the softening, ripening, and the quality demotion of fruits during storage (Perkins-Veazie 1995; Harker et al. 1997). In other words, HVEF did not have any action on the degradation of the middle lamella caused by the pectin solubility (Koh and Melton 2002). Palanimuthu et al. (2009) reported that HVEF in the range of 2 to 8 kV·cm^{-1} for 30 to 120 min did not affect such mechanical properties in cranberries.

Apparent colour. $L^*a^*b^*$ is a three-dimensional colour space in which the L^* axis ranges from zero for black to 100 for white; axis a^* has positive values for red and negative values for green and axis b^* have positive values for yellow and negative values for blue. In this study, the $L^*a^*b^*$ values of the fruits were calculated by photographing the strawberries and using Matlab 2016 software. Table 4 shows the changes in the surface colour of the strawberries stored at 6 °C for four days. It clearly shows no significant differences were observed between the HVEF-treated samples and the control in their a^* and b^* values. These results agree with those reported by Palanimuthu et al. (2009) for cranberries.

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Table 4. The CIELAB colour values (L^*, a^*, b^*) and colour difference (ΔE^*) of the HVEF treated strawberries

HVEF (kV·cm^{-1})	L^*	a^*	b^*	ΔE^*
0	39.61^{bc}	35.51^{a}	31.88^{a}	3.58^{a}
3.61	39.29^{c}	35.29^{a}	31.88^{a}	3.64^{a}
4.56	40.32^{a}	35.09^{a}	31.14^{a}	3.41^{a}
5.13	40.01^{ab}	35.03^{a}	31.61^{a}	3.19^{a}
CV (%)	0.74	0.54	1.15	10.11
RMSE	0.29	0.19	0.36	0.34

means with different superscripts in the same column are significantly different at $P < 0.05$ as determined by the LSD test; he average values of 4 days and three replicates during cold storage at 6 °C; HVEF – high voltage electric field; CV – coefficient of variations; RMSE – root-mean-square error; L^* – lightness; a^* – redness; b^* – yellowness; ΔE^* – colour difference

The strawberries darkening (L^*) in all the treatments was reduced for the time duration, and a significant difference was observed in this regard between the samples treated at 4.56 kV·cm^{-1} and the control. ΔE^* did not show any significant differences in the colour difference value, indicating our experiments did not reveal any additional effects on delaying the colour surface changes in strawberries.

CONCLUSION

The pin-to-plate corona electric filed at 20 kV·cm^{-1} for 10 min could demolish the *B. cinerea* growth in the Petri dishes. The high-voltage electric field at 4.56 kV·cm^{-1} led to a lower mass loss in the strawberries' cold storage. The HVEF at 4.56 kV·cm^{-1} was also found capable of controlling fungal infections in the treated strawberries and conserving the fruits' moisture content and freshness during the cold storage.

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