

ORIGINAL ARTICLE

Treatment of onion skin waste using dielectric barrier discharge cold plasma processing

Berna Senguler^{1,2} | Celale Kirkin¹  | Hilal Donmez¹ | Senanur Unal¹¹Department of Food Engineering,
Faculty of Chemical and Metallurgical
Engineering, Istanbul Technical University,
Maslak, Istanbul, Turkey²Department of Gastronomy and Culinary
Arts, Faculty of Applied Sciences, Istanbul
Gelism University, Avcilar, Istanbul,
Turkey

Correspondence

Celale Kirkin, Department of Food
Engineering, Faculty of Chemical and
Metallurgical Engineering, Istanbul
Technical University, Maslak, 34469
Istanbul, Türkiye.
Email: kirkin@itu.edu.tr

Funding information

Bilimsel Araştırma Projeleri Birimi, İstanbul
Teknik Üniversitesi, Grant/Award Number:
MAB-2021-43242

Abstract

Onion skin constitutes a major part of industrial food waste, and cold plasma technology can be employed in the treatment of onion skin. Onion skin waste was ground and exposed to dielectric barrier discharge cold plasma (DBDCP) at 40kV for 10 or 20min. Samples that were not DBDCP treated were used as the control. The changes in the color, microbial load, total phenolic content (TPC), and antioxidant activity of the onion skin waste upon treatment were evaluated. An increase in the b^* and C^* values of the onion skin powder (OSP) was obtained after the DBDCP treatment. The DBDCP process also decreased the total mesophilic aerobic bacteria and yeast-mold counts of the OSP by up to 0.92 and 0.97 log cfu/g (colony-forming units per gram), respectively. In addition, the TPC and antioxidant activity, as determined by 2,2-diphenyl-2-picrylhydrazyl (DPPH) scavenging activity and ferric-reducing antioxidant power (FRAP) methods, were increased for up to 59% and 28%, respectively, depending on the treatment time. In conclusion, the findings of the study show that using DBDCP processing in the treatment of onion skin waste can reduce microbial count while enhancing TPC and antioxidant activity.

KEYWORDS

antioxidant activity, cold plasma, color, microbial quality, onion skin, total phenolic content

1 | INTRODUCTION

Onion (*Allium cepa* L.) is an agricultural product that is widely cultivated and consumed in the world (Bello et al., 2013; Benítez et al., 2011). In addition, the generation of onion waste has been increasing with the increase in its production while threatening the environment (Benítez et al., 2011; Choi et al., 2015). The majority of onion waste is composed of onion skin, which has high antioxidant and antimicrobial properties and good fiber content (Benítez et al., 2011; Downes et al., 2009; Jaime et al., 2002; Škerget et al., 2009). Thus, onion skin can be employed as an ingredient in many culinary preparations (Gawlik-Dziki et al., 2013; Kirkin et al., 2021; Kurt

et al., 2019; Michalak-Majewska, Teterycz, et al., 2020; Michalak-Majewska, Złotek, et al., 2020; Sagar & Pareek, 2020, 2021). On the other hand, the microbial load of onion skin can be quite high and may also contain mycotoxins and pesticide residues (Katip, 2019; Zohri et al., 1992). Therefore, microbial safety must be controlled before the utilization of onion skin in food production.

Cold plasma processing has been one of the recent techniques that can be practiced in decontamination and pretreatment of food products (Elcik & Kirkin, 2024; Laroque et al., 2022; Niemira, 2012). Cold plasma can be created using various systems. In dielectric barrier discharge cold plasma (DBDCP) systems, the plasma is delivered between two electrodes when one or both of them are coupled with

a material with dielectric properties (Kumar et al., 2023; Mandal et al., 2018; Niemira, 2012). It can enable microbial decontamination by inducing reactions between the plasma-generated material and the membrane and damaging the membrane and cell components by ultraviolet (UV) irradiation produced during the treatment (Niemira, 2012). It has facilitated pathogenic and spoilage microorganism inactivation in several studies (Ahangari et al., 2021; Charoux et al., 2020; Chizoba Ekezie et al., 2017; Hemmati et al., 2021; Kashfi et al., 2020). Cold plasma technology can also be utilized in the oxidation and removal of gaseous pollutants (Veerapandian et al., 2019; Xie et al., 2024).

Furthermore, cold plasma can enhance bioactive compound extraction from plant material by disrupting the surface and improve the total phenolic content (TPC) and antioxidant activities (Bao et al., 2020; Farias et al., 2022; Heydari et al., 2023). Besides, cold plasma can negatively affect TPC and antioxidant properties depending on several parameters that are used in processing, such as treatment time, voltage, gas, etc. (Kumar et al., 2023). Thus, the conduction of further studies is needed to better comprehend the role of cold plasma process parameters in the TPC and antioxidant capacity of food products and to optimize the process.

No previous studies have examined the treatment of onion skin waste using cold plasma processing to the best of our knowledge. To evaluate the changes in the color values, microbial count, total phenolic content, and antioxidant activity of onion skin waste upon DBDCP was the objective of this study.

2 | MATERIAL AND METHODS

2.1 | Preparation and cold plasma treatment of the samples

The outer skins of yellow onion (*Allium cepa* L.) bulbs were collected as a waste after culinary class activity at Istanbul Gelisim University. Then, the onion skin waste was washed three times under tap water followed by 24-h air-drying on blotting paper to reach a moisture content of approximately 18% on a dry basis. Then, the onion skins were pulverized using a coffee grinder (Bosch, Türkiye) in order to have samples with uniform particle size (212–450 µm).

Three grams of onion skin powder (OSP) was placed in a glass petri dish (diameter: 10 cm, thickness: 1.5 mm). Then the petri dish was placed between two parallel electrodes (stainless steel, diameter: 12 cm, thickness: 4 mm) of the cold plasma reactor that was connected to a pulsed direct current (DC) power supply (Asentek, Ankara, Türkiye). The top electrode was connected to a glass plate (thickness: 2 mm), and the gap between the petri dish and the top glass barrier was 2 cm. The samples were treated with DBDCP at 40 kV (0.1 mA, 56 kHz) for 0 (control), 10, or 20 min. These parameters were selected according to the preliminary studies on different foods and surfaces. Each treatment was replicated three times.

2.2 | Color measurement

The CIE color values (L^* , a^* , and b^*) of the onion skin powder samples were determined using a color meter (CR-400, Konica Minolta, Japan). A white plate was used to calibrate the device before the measurements. Three different measurements were averaged for each sample. Also, the Chroma (C^*) and hue angle (h°) were calculated using the following formula:

$$C^* = \sqrt{a^{*2} + b^{*2}}$$

$$h^\circ = \arctan\left(\frac{b^*}{a^*}\right)$$

2.3 | Microbial analysis

One gram of onion skin powder was diluted in buffered peptone water and spread on plate count agar (PCA) or dichloran rose bengal chloramphenicol agar (DRBC) for the total mesophilic aerobic bacteria (TMAB) count and total yeast-mold count, respectively. The plates for the TMAB and yeast-mold count were incubated for 48 h at 37°C and 3–5 days at 25°C, respectively.

2.4 | Extraction of the samples

One gram of the OSP samples was added with 25 mL methanol (80%, v/v) and incubated at 40°C for 2 h in an ultrasonic bath (Isolab, Germany) and centrifuged at 4000 rpm (revolutions per minute) for 20 min (Universal 320R, Hettich, Germany). Then, the aliquots were separated and stored at –18°C.

2.5 | Total phenolic content (TPC)

The TPC of the OSP samples was evaluated by the Folin-Ciocalteu method, as described before (Viuda-Martos et al., 2010). Three hundred µL of OSP extract was added with 2.5 mL of Folin-Ciocalteu reagent (0.2 M) and 2 mL of sodium carbonate (Na_2CO_3) (7.5% in water, w/v) after diluting 8 times in methanol. Then, the mixtures were incubated at 50°C for 5 min, and the absorbance values were read at 760 nm using a spectrophotometer (T80 UV/VIS, PG Instruments, UK). Results were expressed as milligrams (mg) of gallic acid equivalents per gram (mg GAE/g) using a standard calibration curve.

2.6 | Antioxidant activity

The 2,2-diphenyl-2-picrylhydrazyl (DPPH) radical scavenging activity and ferric-reducing antioxidant power (FRAP) assays were utilized to assess the antioxidant properties of the OSP samples (Viuda-Martos et al., 2010). Fifty µL of extracts diluted in methanol was mixed with 2 mL of 6×10^{-5} M DPPH solution (in methanol) and

incubated for 1 h at room temperature for the DPPH assay. Then, the absorbance of the mixtures was obtained at 517 nm. For the FRAP assay, one mL of OSP extract (diluted in methanol) was added with 2.5 mL of sodium phosphate (NaH_2PO_4) buffer (0.2 M, pH 6.6) and 2.5 mL of potassium ferricyanide (1%, w/v). A 2.5 mL of trichloroacetic acid (TCA) was added to the mixture after incubating for 20 min at 50°C. Then, a 2.5 mL of the mixture was mixed with 2.5 mL of distilled water and 0.5 mL of iron (III) chloride (1%, w/v), prior to incubation at room temperature for 30 min. Then, the absorbance was noted at 700 nm. The results obtained by both methods were expressed as milligrams (mg) of Trolox equivalents per gram (mg TE/g) using a standard calibration curve.

2.7 | Statistical analysis

A full factorial design with three levels of DBDCP treatment and three replications was employed in the study. Data were assessed using statistical software (Minitab 16, Minitab, USA) by analysis of variance (ANOVA), Pearson's correlation, and Fisher's least significant difference (LSD) tests.

3 | RESULTS AND DISCUSSION

3.1 | Color

The changes in the color values of OSP, as affected by the DBDCP treatment, are given in Table 1. The C^* values of the samples increased after DBDCP processing and with increasing treatment time ($p < .05$). Also, the b^* value was higher after the DBDCP treatment for 20 min compared to other samples ($p < .05$), while no changes were observed in the other color values (L^* , a^* , and h°) of the samples ($p > .05$).

In the present study, cold plasma-induced changes were only observed on the b^* and C^* values. The increase in the b^* - and C^* -values can be regarded as a desired effect of the cold plasma treatment for onion skins, as b^* and C^* values are related to yellowness and color saturation, respectively. It has been known that the major pigments in onion skins are quercetin and quercetin derivatives, which are known to have good antimicrobial and antioxidant properties (Choi et al., 2015; Lee, Patil, & Yoo, 2015; Ly et al., 2005; Osojnik Črnivec et al., 2021; Ramos et al., 2006; Yang et al., 2015). The b^* and C^* values positively correlated with the DPPH radical scavenging activity

($p < .05$). In addition, these values negatively correlated with the load of total yeast and mold ($p < .05$). Therefore, the increase in the antioxidant properties and the decrease in the fungal count can be related to the change in the color values. Moreover, color change occurred after cold plasma processing of several food products was reported in various studies. For instance, Rezaei et al. (2020) observed cold plasma-induced significant color changes in hyssop leaves depending on the voltage and treatment time. Also, Darvish et al. (2022) stated that the color values (L^* , a^* , b^* , C^* , h° , and total color difference) of saffron increased after cold plasma processing. Moreover, cold plasma treatment of dried peppermint resulted in decreased L^* , b^* , and C^* values and increased a^* value and total color difference, as reported by Kashfi et al. (2020).

3.2 | Microbial count

The differences in the TMAB and total yeast and mold counts on the onion skins after the treatments are shown in Table 2. A decrease (up to 0.92 log cfu/g) in the TMAB count was observed after DBDCP treatment compared to the control ($p < .5$). Also, the total yeast and mold count of the 20-min DBDCP-treated samples was significantly lower than that of the control and 10-min treated samples ($p < .05$).

The decreases in the TMAB and total yeast and mold counts were similar to the findings of Ahangari et al. (2021), and they stated that the total viable and mold count on dried walnut kernel was decreased by 1.09 and 0.89 log cfu/g, respectively, after cold plasma processing. Also, the total aerobic bacteria count on brown rice decreased with prolonged cold plasma exposure (Lee et al., 2016). The reduction in the fungal count on OSP after the DBDCP treatment was limited in the present study. This could be associated with the low water content of the samples, as the water in foods can be converted to free radicals (hydroxyl (OH), hydrogen ion (H^+), and hydrogen peroxide (H_2O_2)) during plasma processing and improve the efficacy of the treatment (Bermudez-Aguirre, 2020). The antimicrobial activity of cold plasma is lower for products with low water content (Bourke et al., 2017; Thirumdas et al., 2015). For instance, Lee, Kim, et al. (2015) observed that cold plasma-induced reduction of pathogens on dried figs was lower than that on cabbage, and the efficacy of utilizing cold plasma was higher when the water activity was higher. It should also be added that the effect of cold plasma against foodborne microorganisms can be determined by many factors, such as the employed device, type of plasma, gas flow rate, gas

TABLE 1 Color values of the OSP samples as affected by the DBDCP treatment.

Treatment time (min)	L^*	a^*	b^*	h°	C^*
0	60.93 ± 0.32^a	12.90 ± 0.18^a	22.23 ± 0.08^b	1.05 ± 0.01^a	25.70 ± 0.02^c
10	61.12 ± 0.66^a	12.93 ± 0.13^a	22.55 ± 0.13^b	1.05 ± 0.01^a	26.00 ± 0.06^b
20	61.82 ± 0.42^a	13.03 ± 0.06^a	23.08 ± 0.14^a	1.06 ± 0.00^a	26.50 ± 0.09^a

Note: Values are mean $\pm$ standard deviation of three replications and significantly different from those labeled with different superscript letters in the same column ($p < .05$).

TABLE 2 Microbial count of the OSP samples as affected by the DBDCP treatment.

Treatment time (min)	Total viable (log cfu/g)	Yeast-mold (log cfu/g)
0	4.35 ± 0.05 ^a	4.45 ± 0.18 ^a
10	3.43 ± 0.13 ^b	4.27 ± 0.01 ^a
20	3.76 ± 0.04 ^b	3.48 ± 0.18 ^b

Note: Values are mean ± standard deviation of three replications and significantly different from those labeled with different superscript letters in the same column ($p < .05$).

composition, voltage, frequency, time, water content, surface, microorganism, etc. (Bourke et al., 2017; Mao et al., 2021; Misra et al., 2011; Niemira, 2012; Surowsky et al., 2015). The effectiveness of cold plasma increased with increasing exposure time, as claimed by several scholars (Darvish et al., 2022; Lee et al., 2016; Tappi et al., 2016). Thus, it could be possible to improve the reduction of microorganisms on OSP by changing the cold plasma processing parameters.

3.3 | Total phenolic content

The DBDCP treatment significantly increased the TPC of onion skin waste ($p < .05$) as demonstrated in Table 3, while no difference was noted between the 10 and 20-min treatments ($p > .05$).

Cold plasma processing improved the TPC of onion skin waste in the present study. Several other studies also reported a similar finding. For instance, Bao et al. (2020) reported that 5- and 15-min cold plasma treatments of grape pomace increased the TPC compared to control, while 10-min treatment did not lead to a difference. In addition, an increase in the TPC of haskap after cold plasma treatment depending on the power was reported (Li et al., 2023). Moreover, Keshavarzi et al. (2020) reported that nitrogen (N_2)-cold plasma application at 15 W for 15 min augmented the TPC of green tea leaves, while air cold plasma (5–15 W, 5–15 min) caused the TPC to decrease. On the contrary, no changes in the TPC of black pepper grains were observed upon 3- and 5-min cold plasma treatments at 15 and 30 kV (Charoux et al., 2020). The TPC of fresh and dried walnuts did not change after cold plasma exposure at 15 kV for up to 11 min (Sasireka et al., 2021). Furthermore, a previous study reported that the TPC value of ground dandelion root increased after 20-min DBDCP treatment at 40 kV compared to control, while that of the unground roots decreased after 10-min treatment (Elcik & Kirkin, 2024). In addition, Hemmati et al. (2021) claimed that increasing power and treatment time decreased the TPC of green tea powder. Also, a reduction in the TPC of red chili powder upon radio-frequency cold plasma treatment was observed (Sasireka et al., 2021).

Cold plasma can disrupt the surface of plants, improve the extraction yield, and facilitate the release of bioactive compounds with the aid of plasma-generated reactive species (Heydari et al., 2023).

TABLE 3 Total phenolic content of the OSP samples as affected by the DBDCP treatment.

Treatment time (min)	TPC (mg GAE/g)
0	5.47 ± 0.58 ^b
10	12.02 ± 0.39 ^a
20	10.12 ± 0.69 ^a

Note: Values are mean ± standard deviation of three replications and significantly different from those labeled with different superscript letters in the same column ($p < .05$).

TABLE 4 2,2-diphenyl-2-picrylhydrazyl (DPPH) and ferric-reducing antioxidant power (FRAP) values of the OSP samples as affected by the DBDCP treatment.

Treatment time (min)	DPPH (mg TE/g)	FRAP (mg TE/g)
0	6.67 ± 0.45 ^b	30.58 ± 3.53 ^b
10	7.46 ± 0.61 ^b	39.20 ± 2.04 ^a
20	10.61 ± 0.45 ^a	37.19 ± 1.86 ^a

Note: Values are mean ± standard deviation of three replications and significantly different from those labeled with different superscript letters in the same column ($p < .05$).

However, plasma-generated reactive species can also reduce the amount of phenolics and antioxidant properties (Muhammad et al., 2018). These changes generally depended on the equipment setup, processing parameters, gasses, and food matrix (Muhammad et al., 2018). Thus, the conflicting findings reported previously could be related to the different cold plasma equipment, processing parameters employed, and the food matrix.

3.4 | Antioxidant activity

The DBDCP-induced differences in the antioxidant activity are exhibited in Table 4. The DPPH radical scavenging activity of the OSP samples was boosted by the DBDCP treatment for 20 min compared to the other samples ($p < .05$). The DPPH values of the 20-min-treated samples were greater than that of the control by 59%. The FRAP of the DBDCP-treated samples was greater, by approximately 28% after the 10-min treatment, than that of the control ($p < .05$).

Similar to the increase in the TPC, the DBDCP processing increased the antioxidant activity of the onion waste depending on the cold plasma exposure time and assessment method. Likewise, cold plasma process enhanced the DPPH scavenging activity of haskap powder, as reported by Li et al. (2023). Also, the DPPH scavenging activity of green coffee bean extract was improved by increasing treatment time up to 35 min, while a decrease was observed upon 60-min treatment (Kungsuwan et al., 2023). The authors added that the FRAP of the green coffee bean extracts was not influenced by the 35-min treatment. Similarly, the DPPH and FRAP values of peppermint extract increased upon cold plasma treatment at 50 W but decreased after 60-W treatment (Kashfi et al., 2020). Furthermore,

the DPPH and FRAP of ground dandelion root increased after 20-min DBDCP treatment at 40kV, but a decrease upon 10-min treatment was noted in unground samples (Elcik & Kirkin, 2024).

4 | CONCLUSIONS

The treatment of onion skin waste using DBDCP affected the color, microbial load, TPC, and antioxidant activity. The B^* and C^* values were increased after the treatment, and the highest values were obtained upon the treatment for 20min. The DBDCP led to a reduction in the TMAB and yeast-mold counts. Furthermore, the DBDCP treatment improved the TPC, DPPH scavenging activity, and FRAP of the OSP. In conclusion, DBDCP processing can be used in onion skin waste treatment while improving the TPC and antioxidant properties and reducing the microbial load. However, it is worth adding that the effects of different cold plasma processing parameters (voltage, frequency, treatment time, feed gas, etc.) on the microbial inactivation and antioxidant and antimicrobial capacity of onion skin waste still need to be evaluated. The valorization of cold plasma-treated onion skin waste as an ingredient in different food recipes will be assessed in further studies. It is also important that the mycotoxin levels and pesticide residues on onion skin waste are decreased before it is added to foods, and the influences of cold plasma on them still need to be determined.

AUTHOR CONTRIBUTIONS

Berna Senguler: Formal analysis (equal); investigation (equal); methodology (equal); writing – original draft (equal). **Celale Kirkin:** Conceptualization (equal); methodology (equal); project administration (equal); supervision (equal). **Hilal Donmez:** Formal analysis (equal); investigation (equal). **Senanur Unal:** Formal analysis (equal); investigation (equal).

ACKNOWLEDGMENTS

Istanbul Technical University Scientific Research Projects Department is acknowledged for financially supporting the study (project number: MAB-2021-43242).

FUNDING INFORMATION

This study was supported by the Scientific Research Projects Department of Istanbul Technical University (project number: MAB-2021-43242).

CONFLICT OF INTEREST STATEMENT

The authors declare that there are no conflicts of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

ETHICS STATEMENT

This study does not involve any human or animal testing.

ORCID

Celale Kirkin  <https://orcid.org/0000-0003-0736-4213>

REFERENCES

- 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.
- Bao, Y., Reddivari, L., & Huang, J. Y. (2020). Enhancement of phenolic compounds extraction from grape pomace by high voltage atmospheric cold plasma. *LWT*, 133, 109970.
- Bello, M. O., Olabanji, I. O., Abdul-Hammed, M., & Okunade, T. D. (2013). Characterization of domestic onion wastes and bulb (*Allium cepa* L.): Fatty acids and metal contents. *International Food Research Journal*, 20(5), 2153–2158.
- Benítez, V., Mollá, E., Martín-Cabrejas, M. A., Aguilera, Y., López-Andréu, F. J., Cools, K., Terry, L. A., & Esteban, R. M. (2011). Characterization of industrial onion wastes (*Allium cepa* L.): Dietary fibre and bioactive compounds. *Plant Foods for Human Nutrition*, 66(1), 48–57.
- Bermudez-Aguirre, D. (2020). Disinfection of high-moisture food using cold plasma. In D. Bermudez-Aguirre (Ed.), *Advances in cold plasma applications for food safety and preservation* (pp. 147–183). Elsevier.
- Bourke, P., Ziuzina, D., Han, L., Cullen, P. J., & Gilmore, B. F. (2017). Microbiological interactions with cold plasma. *Journal of Applied Microbiology*, 123(2), 308–324.
- Charoux, C. M. G., Free, L., Hinds, L. M., Vijayaraghavan, R. K., Daniels, S., O'Donnell, C. P., & Tiwari, B. K. (2020). Effect of non-thermal plasma technology on microbial inactivation and total phenolic content of a model liquid food system and black pepper grains. *LWT*, 118, 108716.
- Chizoba Ekezie, F.-G., Sun, D.-W., & Cheng, J.-H. (2017). A review on recent advances in cold plasma technology for the food industry: Current applications and future trends. *Trends in Food Science & Technology*, 69, 46–58.
- Choi, I. S., Cho, E. J., Moon, J.-H., & Bae, H. J. (2015). Onion skin waste as a valorization resource for the by-products quercetin and biosugar. *Food Chemistry*, 188, 537–542.
- Darvish, H., Ramezan, Y., Khani, M. R., & Kamkari, A. (2022). Effect of low-pressure cold plasma processing on decontamination and quality attributes of saffron (*Crocus sativus* L.). *Food Science & Nutrition*, 10(6), 2082–2090.
- Downes, K., Chope, G. A., & Terry, L. A. (2009). Effect of curing at different temperatures on biochemical composition of onion (*Allium cepa* L.) skin from three freshly cured and cold stored UK-grown onion cultivars. *Postharvest Biology and Technology*, 54(2), 80–86.
- Elcik, B. E., & Kirkin, C. (2024). Quality and antioxidant activity of dandelion root infusions as affected by cold plasma pretreatment. *Food Science & Nutrition*, 12(1), 526–533.
- Farias, T. R. B., Rodrigues, S., & Fernandes, F. A. N. (2022). Comparative study of two cold plasma technologies on apple juice antioxidant capacity, phenolic contents, and enzymatic activity. *Journal of Food Processing and Preservation*, 46(10), e16871.
- Gawlik-Dziki, U., Świeca, M., Dziki, D., Baraniak, B., Tomiło, J., & Czyż, J. (2013). Quality and antioxidant properties of breads enriched with dry onion (*Allium cepa* L.) skin. *Food Chemistry*, 138(2–3), 1621–1628. <https://doi.org/10.1016/j.foodchem.2012.09.151>
- 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, and sensory quality of green tea powder. *Food Bioscience*, 44, 101348.

- Heydari, M., Carbone, K., Gervasi, F., Parandi, E., Rouhi, M., Rostami, O., Abedi-Firoozjah, R., Kolahdouz-Nasiri, A., Garavand, F., & Mohammadi, R. (2023). Cold plasma-assisted extraction of phytochemicals: A review. *Food*, 12(17), 3181.
- Jaime, L., Mollá, E., Fernández, A., Martín-Cabrejas, M. A., López-Andréu, F. J., & Esteban, R. M. (2002). Structural carbohydrate differences and potential source of dietary fiber of onion (*Allium cepa* L.) tissues. *Journal of Agricultural and Food Chemistry*, 50(1), 122–128.
- 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.
- Katip, A. (2019). Bursa ili tarımsal pestisit kullanımının değerlendirilmesi. *Bitlis Eren Üniversitesi Fen Bilimleri Dergisi*, 8(1), 197–205.
- Keshavarzi, M., Najafi, G., Ahmadi Gavlighi, H., Seyfi, P., & Ghomi, H. (2020). Enhancement of polyphenolic content extraction rate with maximal antioxidant activity from green tea leaves by cold plasma. *Journal of Food Science*, 85(10), 3415–3422. <https://doi.org/10.1111/1750-3841.15448>
- Kirkin, C., Cinar, M., Derindere, B., Erikman, K., & Onural, N. (2021). Sensory properties of chocolate truffles and peanut butter as affected by onion skin powder addition. *Journal of Gastronomy and Tourism Studies*, 9(3), 1547–1553.
- Kumar, S., Pipliya, S., & Srivastav, P. P. (2023). Effect of cold plasma on different polyphenol compounds: A review. *Journal of Food Process Engineering*, 46(1), e14203.
- Kungsuwan, K., Sawangrat, C., Ounjaijean, S., Chaipoot, S., Phongphisutthinant, R., & Wiriyacharee, P. (2023). Enhancing bioactivity and conjugation in green coffee bean (*Coffea arabica*) extract through cold plasma treatment: Insights into antioxidant activity and phenolic-protein conjugates. *Molecules*, 28(20), 7066.
- Kurt, S., Ceylan, H. G., & Akkoc, A. (2019). The effects of onion skin powder on the quality of cooked chicken meat patties during refrigerated storage. *Acta Alimentaria*, 48(4), 423–430.
- Laroque, D. A., Seó, S. T., Valencia, G. A., Laurindo, J. B., & Carciofi, B. A. M. (2022). Cold plasma in food processing: Design, mechanisms, and application. *Journal of Food Engineering*, 312, 110748.
- Lee, E. J., Patil, B. S., & Yoo, K. S. (2015). Antioxidants of 15 onions with white, yellow, and red colors and their relationship with pungency, anthocyanin, and quercetin. *LWT - Food Science and Technology*, 63(1), 108–114.
- Lee, H., Kim, J. E., Chung, M.-S., & Min, S. C. (2015). Cold plasma treatment for the microbiological safety of cabbage, lettuce, and dried figs. *Food Microbiology*, 51, 74–80.
- 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.
- Li, J., Li, Z., Ma, Q., & Zhou, Y. (2023). Enhancement of anthocyanins extraction from haskap by cold plasma pretreatment. *Innovative Food Science & Emerging Technologies*, 84, 103294.
- Ly, T. N., Hazama, C., Shimoyamada, M., Ando, H., Kato, K., & Yamauchi, R. (2005). Antioxidative compounds from the outer scales of onion. *Journal of Agricultural and Food Chemistry*, 53(21), 8183–8189.
- Mandal, R., Singh, A., & Pratap Singh, A. (2018). Recent developments in cold plasma decontamination technology in the food industry. *Trends in Food Science & Technology*, 80, 93–103.
- Mao, L., Mhaske, P., Zing, X., Kasapis, S., Majzoobi, M., & Farahnaky, A. (2021). Cold plasma: Microbial inactivation and effects on quality attributes of fresh and minimally processed fruits and ready-to-eat vegetables. *Trends in Food Science & Technology*, 116, 146–175.
- Michalak-Majewska, M., Teterycz, D., Muszyński, S., Radzki, W., & Sykut-Domańska, E. (2020). Influence of onion skin powder on nutritional and quality attributes of wheat pasta. *PLoS One*, 15(1), e0227942.
- Michalak-Majewska, M., Złotek, U., Szymanowska, U., Szwajgier, D., Stanikowski, P., Matysek, M., & Sobota, A. (2020). Antioxidant and potentially anti-inflammatory properties in pasta fortified with onion skin. *Applied Sciences*, 10(22), 8164.
- Misra, N. N., Tiwari, B. K., Raghavarao, K. S. M. S., & Cullen, P. J. (2011). Nonthermal plasma inactivation of food-borne pathogens. *Food Engineering Reviews*, 3(3–4), 159–170.
- Muhammad, A. I., Liao, X., Cullen, P. J., Liu, D., Xiang, Q., Wang, J., Chen, S., Ye, X., & Ding, T. (2018). Effects of nonthermal plasma technology on functional food components. *Comprehensive Reviews in Food Science and Food Safety*, 17(5), 1379–1394.
- Niemira, B. A. (2012). Cold plasma decontamination of foods. *Annual Review of Food Science and Technology*, 3(1), 125–142.
- Osojnik Črnivec, I. G., Skrt, M., Šeremet, D., Sterniša, M., Farčnik, D., Štrumbelj, E., Poljanšek, A., Cebin, N., Pogačnik, L., Smole Možina, S., Humar, M., Komes, D., & Poklar Ulrih, N. (2021). Waste streams in onion production: Bioactive compounds, quercetin and use of antimicrobial and antioxidative properties. *Waste Management*, 126, 476–486.
- Ramos, F. A., Takaishi, Y., Shirotori, M., Kawaguchi, Y., Tsuchiya, K., Shibata, H., Higuti, T., Tadokoro, T., & Takeuchi, M. (2006). Antibacterial and antioxidant activities of quercetin oxidation products from yellow onion (*Allium cepa*) skin. *Journal of Agricultural and Food Chemistry*, 54(10), 3551–3557.
- Rezaei, S., Ghobadian, B., Ebadi, M., Jangi, F., & Ghomi, H. (2020). Effects of cold plasma on the color parameters of Hyssop (*Hyssopus officinalis* L.) using color imaging instrumentation and spectrophotometer. *Color Research & Application*, 45(1), 29–39. <https://doi.org/10.1002/col.22433>
- Sagar, N. A., & Pareek, S. (2020). Dough rheology, antioxidants, textural, physicochemical characteristics, and sensory quality of pizza base enriched with onion (*Allium cepa* L.) skin powder. *Scientific Reports*, 10(1), 1–11.
- Sagar, N. A., & Pareek, S. (2021). Fortification of multigrain flour with onion skin powder as a natural preservative: Effect on quality and shelf life of the bread. *Food Bioscience*, 41, 100992.
- Sasireka, R., Amponsah, A. G., Mallikarjunan, K., & Shunmugam, G. (2021). Effect of radio frequency low pressure cold plasma on total phenol, antioxidant activity and colour degradation kinetics of red chilli pepper powder. *Journal of Agricultural Engineering (India)*, 58(3), 241–249. <https://doi.org/10.52151/jae2021581.1748>
- Škerget, M., Majhenič, L., Bezjak, M., & Knez, Ž. (2009). Antioxidant, radical scavenging and antimicrobial activities of red onion (*Allium cepa* L.) skin and edible part extracts. *Chemical and Biochemical Engineering Quarterly*, 23(4), 435–444.
- Surowsky, B., Schlüter, O., & Knorr, D. (2015). Interactions of non-thermal atmospheric pressure plasma with solid and liquid food systems: A review. *Food Engineering Reviews*, 7(2), 82–108.
- 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.
- Thirumdas, R., Sarangapani, C., & Annapure, U. S. (2015). Cold plasma: A novel non-thermal technology for food processing. *Food Biophysics*, 10(1), 1–11.
- Veerapandian, S. K. P., De Geyter, N., Giraudon, J. M., Lamonier, J. F., & Morent, R. (2019). The use of zeolites for VOCs abatement by combining non-thermal plasma, adsorption, and/or catalysis: A review. *Catalysts*, 9(1), 98.
- Viuda-Martos, M., Ruiz Navajas, Y., Sánchez Zapata, E., Fernández-López, J., & Pérez-Álvarez, J. A. (2010). Antioxidant activity of essential oils of five spice plants widely used in a Mediterranean diet. *Flavour and Fragrance Journal*, 25(1), 13–19.
- Xie, W., Zhu, T., Yuan, B., Fu, S., Mao, Z., Ye, Z., Zhu, Z., & Zhang, X. (2024). Plasma-catalyzed combined dynamic wave scrubbing: A

- novel method for highly efficient removal of multiple pollutants from flue gas at low temperatures. *Journal of Hazardous Materials*, 461, 132518.
- Yang, X. N., Park, M. J., Ha, I. J., Moon, J. S., & Kang, Y. H. (2015). Functional components and antioxidant effects of colored onions. *Current Research on Agriculture and Life Sciences*, 33(2), 69–73.
- Zohri, A. A., Sabah, A. M., & Abdel-Gawad, K. M. (1992). Fungal flora and mycotoxins associated with onion (*Allium cepa* L.) in Egypt. *The Korean Journal of Mycology*, 20(4), 302–308.

How to cite this article: Senguler, B., Kirkin, C., Donmez, H., & Unal, S. (2024). Treatment of onion skin waste using dielectric barrier discharge cold plasma processing. *Food Science & Nutrition*, 12, 8387–8393. <https://doi.org/10.1002/fsn3.4448>