http://isae.in/journal-of-agricultural-engineering-JAE

Journal of Agricultural Engineering

Vol. 58 (3): July-September, 2021

doi: 10.52151/jae2021581.1748

Effect of Radio Frequency Low Pressure Cold Plasma on Total Phenol, Antioxidant Activity and Colour Degradation Kinetics of Red Chilli Pepper Powder

Sasireka Rajendran[1], George Amponsah Annor[2], Kumar Mallikarjunan[3]* and Ganapathy Shunmugam[4]*

[1]Ph.D. Scholar, Department of Food Process Engineering, Tamil Nadu Agricultural University, Coimbatore, India; [2]Assistant Professor, Department of Food Science and Nutrition, University of Minnesota, St. Paul, USA, [3]Professor, Department of Food Science and Nutrition, University of Minnesota, St. Paul, USA, [4]Professor, Department of Food Process Engineering, Tamil Nadu Agricultural University, Coimbatore, India. *Corresponding authors email addresses: kumarpm@umn.edu; ganapathy.s@tnau.ac.in

Article Info

Manuscript received:
October, 2020
Revised manuscript accepted:
June, 2021

***Keywords*:** Cold plasma, colour degradation, red chilli pepper, antioxidant activity, degradation kinetics

ABSTRACT

The study was aimed to analyse the effect of low pressure cold plasma treatment [operated at 60.8 kPa on the quality parameters of red chilli pepper powder (RCPP)]. The experiments were conducted at two radio frequency power levels (60 W, 120 W) over a time range from 0 to 10 min. Total phenols, antioxidant activity, colour, and moisture content were determined. Results showed that radio frequency operating power and treatment time had significant negative effects ($p < 0.05$) on the quality parameters analysed. Cold plasma treatment reduced the redness, total phenol content, moisture content, and increased the antioxidant activity of the RCPP. Changes in the quality of the treated samples, especially the colour degradation were significant after 4 min of treatment. Degradation kinetics was determined for parameters studied to ascertain their order of reaction during cold plasma treatment. The order of reaction was decided from best fit models with the highest R^2, minimum bias, and error sum of squares. Total phenol followed a zero-order, whereas antioxidant activity and colour followed first-order reactions. The study explored the possibilities and impact of using cold plasma for powdered food materials.

Red chilli pepper (*Capsicum annum* L.) is an economically important spice crop in tropical, subtropical, and temperate climatic regions of the world and is valued for its colour and pungency (Saengrayap *et al*., 2015). In 2018, the global production of dried red chilli pepper was 4.16 Mt, with India as the largest producer (1.23 Mt) followed by China and Thailand (FAO, 2018). Pre-harvest stress conditions, insufficient drying, and improper storage conditions result in the growth of pathogens, especially fungal species, in fresh and ripe chilli pepper. These pathogens are not decontaminated and, in most cases end up in red chilli pepper powder (RCPP). The presence of *Aspergillus flavus*, *Bacillus cereus*, *Clostridium* perfringens, and *Staphylococcus aureus* in RCPP has been reported (Aydin *et al*., 2007; Kim *et al*., 2014). Due to the heat sensitiveness of bioactive compounds in chilli pepper, there is a need to develop non-thermal processing methods to reduce the pathogenic microorganisms.

Cold plasma has been employed as a non-thermal processing method for food preservation and decontamination in recent times. Cold plasma is considered to be the fourth state of the matter comprising photons, electrons, positive and negative ions, excited and non-excited molecules, atoms, and free radicals (Baier *et al*., 2015; Thirumdas *et al*., 2017). The constant interactions of the molecules result in the release of energy in the form of visible and UV light (Niemira, 2012). Microbial decontamination is achieved through a non-thermal mode in cold plasma systems. The reactive oxygen species (ROS) present in plasma are the active components identified for the antimicrobial activity of cold plasma systems (Varilla *et al*., 2020). ROS attacks the cell envelope and intracellular components leading to microbial destruction through cell leakage (Sarangapani *et al*., 2018). Ample amount of ROS contained in the plasma makes it highly advantageous for microbial decontamination of food compared to other thermal and non-thermal methods (Chizoba Ekezie *et al*., 2017). Numerous types of plasma systems have evolved over the years based on the source of plasma generation, operating pressure conditions, and position of samples with respect to cold plasma being generated.

Atmospheric pressure jet plasma, atmospheric double barrier discharge plasma, low pressure radio frequency plasma, and microwave-powered cold plasma system are some of the commonly used cold plasma systems in food processing and decontamination. The efficiency of various cold plasma systems for microbial decontamination has been tested and reported for several food products and food powders such as apple juice, paprika, black pepper, red pepper powder, and legumes (Selcuk *et al*., 2008; Kim *et al*., 2014; Surowsky *et al*., 2014; Hertwig *et al*., 2015; Go *et al*., 2019; Misra *et al*., 2019; Tanino *et al*., 2019).

Cold plasma treatment for microbial decontamination of in-package red pepper powder using the microwave-powered system has been reported (Kim *et al*., 2014). To successfully employ cold plasma for the commercial decontamination applications of RCPP, it is important to understand the effects of different cold plasma operating parameters and the mechanism behind the degradation of chemical components. To the best of the authors' knowledge, the effect of low pressure radio frequency plasma on RCCP has not been studied. Thus, this research was focused to study the effects of cold plasma on the chemical characteristics of RCPP. The objectives of this study were to investigate the impact of radio frequency cold plasma and establishing cold plasma degradation kinetics on selected quality parameters of RCPP.

MATERIALS AND METHODS

Materials

RCPP (7.2 %, w.b.) was procured from a local market in 2019 from Coimbatore, Tamil Nadu, India. The samples were stored in resealable plastic pouches (Model: Ziploc®, SC Johnson & Son, Inc., Racine, WI) at refrigerated conditions (4°C) until used for cold plasma treatment. Folin-Ciocalteu reagent, sodium carbonate, and methanol were purchased from Sigma-Aldrich (St. Louis, MO, USA). Trolox, DPPH (2.2-diphenyl-1-picrylhydrazyl), and ethanol were purchased from EMD Millipore (San Diego, CA, USA), Santa Cruz Biotech (Dallas, TX, USA) and Fisher Chemicals (NJ, USA), respectively. All chemicals and reagents were of analytical grade. Carbon dioxide and argon gases were obtained from Matheson, Minnesota, USA.

Cold Plasma Treatment of RCPP

Cold plasma treatment of RCPP was carried out using a benchtop plasma system (Model: PE-25, Plasma Etch Industries, Carson City, Nevada, USA), located at the Department of Food Science and Nutrition, University of Minnesota, USA. The cold plasma set-up consisted of a radio frequency generator operating at 13.56 MHz (electrode dimensions: 88.9 mm by 177.8 mm) with power of 0-125 W, vacuum pump, temperature control unit, gas flow controller, and treatment chamber. The set up was controlled with the Plasma Etch Inc.'s software (version 2.1.0). The gases used for the cold plasma generation were carbon dioxide (CO_2) and argon (Ar).

Ten grams of RCPP was evenly spread in a glass petri dish (150 mm inner diameter) to obtain a thin layer, and placed inside the treatment chamber (Held *et al*., 2019). The gas flow rate of both CO_2 as well as Ar were maintained at 25 standard cubic centimetres per minute (sccm) in all experiments. The temperature during the experiment was maintained at 25°C. Samples were treated at two different power levels of 60W and 120W at five different time levels (1, 2, 4, 6, and 10 min) in duplicates. The treatment conditions were finalized based on the preliminary test conducted based on visual and sensory tests (data not reported). The samples were taken out and stirred halfway during the treatment to achieve uniform exposure to cold plasma. Once the treatment conditions were set, the cold plasma generation started after the vacuum had reached the pre-set level (60.8 kPa).

Analysis of Moisture Content

Moisture content of the samples in terms of percentage wet basis was measured using a moisture analyser (Model: Ohaus MB45, Ohaus corporation, NJ, USA, temperature range: 50 - 200ºC, repeatability: 0.00015 g, readability: 1 mg/0.01 % moisture content) located in the University of Minnesota, St. Paul, USA. The system specifications include. Heating was performed with an infrared halogen heating element in the moisture analyser system until a constant weight was attained without charring the samples.

Preparation of RCPP Extract for Total Phenol and Antioxidant Activity

One gram of plasma treated RCPP was mixed with 10 ml of 80 % ethanol. About twenty-one samples were placed in a rotary shaker (temperature range: 0 to 60°C, shaking speed: 10 to 250 rpm) at a speed of 30 rpm for 24 h at the room temperature of 20 ± 2°C. The samples were then centrifuged at 3500 rpm for 10 min at 4°C. The supernatants were filtered using Fisherbrand™ filter paper number P5. The filtrates were collected in 15 ml falcon tubes and stored at (-) 20°C. These extracts were used to measure the total phenol content and antioxidant property of plasma-treated samples.

Total Phenol Content

The total phenol content of a sample was determined using the Folin-Ciocalteu method (Shaimaa *et al*., 2016). About 125 μL of the extract was added to 0.5 ml Folin-Ciocalteu reagent, and 1 ml of 7.5 % sodium carbonate. The volume of the mixtures was made up to 10 ml with distilled water. The solution mixtures were incubated at room temperature (≈ 25°C) for 45 min, and the absorbance was measured at 765 nm using a UV visible spectrophotometer (Model: UV-1800, Shimadzu Corp., Kyoto, Japan). The technical specifications for the spectrophotometer are: bandwith 1 nm, wavelength range: 190 to 1100 nm, wavelength accuracy: 0.1 nm, wavelength reproducibility: 0.1 nm and photometric drift: <0.0003 A/hr. Gallic acid at different levels (0 to 150 $mg.L^{-1}$) was used to obtain the standard curve (R^2 = 0.9995). The total phenol content in the RCPP was expressed as mg Gallic Acid Equivalents (GAE) / g dry weight (DW) of the sample.

Antioxidant Activity

DPPH (2.2-diphenyl-1-picrylhydrazyl) radical scavenging assay method was used to determine the antioxidant activity of the RCPP extracts. DPPH was measure as described by Budaraju *et al*. (2018). One hundred micro-litre of RCPP extract was added with 3.9 ml of 60 μM of DPPH. The glasswares used were covered with aluminium foil to prevent the light degradation of DPPH. The solutions were vortexed (Model: Vortex-Genie 1, Scientific Industries Inc., Bohemia, NY, USA) thoroughly and incubated at room temperature (≈ 25°C) in dark for 1 h. The vortex system had operational speed of 3200 rpm. After the incubation period, the absorbance was measured at 515 nm against methanol as blank. DPPH radical scavenging activity was calculated using the given Eq. (1). The antioxidant activity was measured from the trolox standard curve (R^2 = 1.0) obtained at different concentrations (0 to 500 μM). The antioxidant activity was expressed in μM of trolox equivalents antioxidant activity (TEAC) using the IC50 obtained from the DPPH radical scavenging assay.

$$\%\ DPPH\ Inhibition = \frac{Absorbance_{control} - Absorbance_{sample}}{Absorbance_{control}} \times 100 \qquad ...(1)$$

Colour Measurement

Colour of RCPP in terms of L* (lightness), a* (redness and greenness), and b* (yellowness and blueness) co-ordinates were measured using a chromo meter (Model: CR-300, Konica Minolta, Ramsey, NJ, USA). The instrument was calibrated against standard white tile before measuring the samples (observer: 2°, L* = 92.89, a* = 0.3176, b* = 0.3344). Treated samples were taken in disposable petri dishes and placed above the light source.

Particle Size

The particle size of RCPP sample was measured using a laser scattering particle size distribution analyser (Model: Partica LA-960, Horiba Scientific, IL, USA). The technical specification of the particle size analyser are as follows: measurement range of 0.01 to 5000 μm, detector: silicon photo diode, measurement time: 1 min from dispersion liquid filling to measurement and rinse, operating temperature: 15 to 35°C, operating humidity: 85 %. Five grams of sample was placed in the feed auger provided in the analyser and the particle size was measured using the Method Expert software.

Kinetics of Selected Chemical Properties

The rate of changes of total phenol, antioxidant activity, and colour were determined using the general kinetics equation (Saxena *et al*., 2012) defined as:

$$\frac{dC}{dt} = \pm\, kC^n \qquad ...(2)$$

Where,

C = Concentration of the component, mg $equivalents.g^{-1}$ sample dry weight,

k = Rate constant, $mg.min^{-1}$ or min^{-1},

t = Treatment time, min, and
n = Order of the reaction.

Numerous studies on the kinetics of food quality parameters on thermal and non-thermal processing reported that the reaction rate followed either zero-order or first-order kinetics.

The above Eq. (2) was solved to attain the zero-order and first-order equations for the selected quality parameters as following:

$$C = C_o + kt \quad \text{…(3)}$$

$$C = C_o\, e^{-kt} \quad \text{…(4)}$$

The best-fit equation for each component studied was selected based on coefficient of determination (R^2), error sum of squares (SSE), and bias factor (Bf).

Statistical Analysis

Two-way ANOVA was performed to statistically analyse the results with a confidence interval of 95 per cent. The sample means were compared using Tukey's honestly significant difference test. The tests were performed using the statistical software Minitab 19 (Minitab Inc, State College, PA, USA). The degradation kinetics were analysed and fitted in selected models using a spreadsheet (Excel 365 Pro Plus, Microsoft Corp., Seattle, WA, USA). All analyses for the quality properties were done in replicates and averaged.

RESULTS AND DISCUSSION

Effect of Low Pressure Plasma on Total Phenol Content and Antioxidant Activity of RCPP

Low pressure plasma was found to have a significant effect on the total phenol and antioxidant activity of the RCPP (Table 1). The total phenol content in the RCPP decreased with the treatment time. The MEAN total phenol content in the untreated samples was estimated as 102.89 mg.GAE.g^{-1} DW. Total phenol content decreased by 12.6 % and 17.6 % when treated for 10 min at a 60 W and 120 W power, respectively (Table 1). Of the two process parameters (treatment time, power) considered for the study, only treatment time had a significant effect ($p < 0.05$) on the total phenol content.

The antioxidant property of a food delays and protects the oxidation of substrates. DPPH activity and trolox equivalents antioxidant activity (TEAC) of the control sample was found to be 84.81 % and 74.55 μM TE.g^{-1} dry weight. As the treatment time increased, DPPH activity and TEAC of the RCPP increased significantly ($p < 0.05$). However, as observed with the total phenol content, the power did not have any significant effect on the DPPH activity and TEAC. Maximum DPPH activity of 89.60 % was observed at 120 W power and 10 min treatment time. The results were in accordance with Zhang *et al*. (2019), who reported an increase in

Table 1. Effect of low pressure plasma on total phenol, antioxidant activity, colour, and moisture content of RCPP

Power, W	Time, min	Total phenol, mg GAE.g^{-1} chilli DW	AA, μM TEAC	DPPH activity, %	L*	a*	b*	Moisture content, %
60	1	102.60^{a}	75.61^{ab}	87.40^{bc}	47.71^{e}	19.73^{a}	25.33^{e}	4.64^{a}
	2	97.66^{bcd}	75.70^{ab}	87.69^{bc}	49.84^{de}	17.83^{b}	28.50^{cd}	4.32^{ab}
	4	96.10^{bcd}	76.05^{ab}	88.13^{ab}	53.21^{c}	14.84^{c}	30.81^{ab}	4.1^{bc}
	6	93.89^{d}	75.85^{ab}	88.20^{ab}	55.60^{b}	12.53^{de}	30.97^{ab}	3.74^{cd}
	10	89.88^{e}	76.58^{a}	89.02^{ab}	56.84^{ab}	10.68^{f}	29.72^{bc}	3.46^{de}
120	1	101.97^{a}	74.15^{b}	86.14^{c}	48.59^{de}	18.97^{ab}	26.62^{de}	4.67^{a}
	2	99.86^{ab}	75.50^{ab}	87.54^{bc}	50.82^{d}	17.64^{b}	29.33^{bc}	4.28^{abc}
	4	97.99^{bc}	76.29^{a}	88.50^{ab}	55.10^{bc}	13.40^{cd}	32.11^{a}	3.85^{bcd}
	6	94.20^{cd}	76.42^{a}	88.79^{ab}	56.46^{ab}	11.18^{ef}	31.16^{ab}	3.58^{de}
	10	84.76^{f}	76.83^{a}	89.60^{a}	57.97^{a}	9.88^{f}	30.65^{abc}	2.9^{e}

Note: $^{a\text{-}f}$Mean with the different superscript letters show significant differences in RCPP for the interactive effect of treatment time and power

DPPH activity with treatment time in an atmospheric air plasma system.

In the case of low pressure plasma produced from CO_2 gas, the free radicals would mostly contain O_2^+, O_2^-, O, and O_3 reactive species (Georgescu *et al*., 2010). The chemical structure of the phenolic compounds aids in acting as an antioxidant by arresting these free oxygen radicals from the plasma (Naczk and Shahidi, 2004) and by donating the hydrogen atom to the free radicals. This behaviour resulted in degradation of the phenolic compounds (Grzegorzewski *et al*., 2011) in RCPP after cold plasma treatment. To understand the antioxidant activity of the phenolics present in chilli, Pearson correlation was determined. Pearson correlation value between the DPPH activity and total phenol content in the RCPP at 60 W and 120 W power was found to be (-) 0.82 and (-) 0.87, respectively. The results indicated a strong negative correlation between DPPH activity and total phenol content. Several studies have also confirmed this negative correlation between total phenol content and antioxidant activities (Ramazzina *et al*., 2015; Amini and Ghoranneviss, 2016; Herceg *et al*., 2016)antioxidant activity, and inhibition of microbial growth in dried and fresh walnut cultivars during storage. In this study four walnut cultivars named Mazandaran, Toyeserkan, Taleghan and Shahmirzad was used for comparison. The results indicated that, although 11 min of plasma jet treatment caused complete elimination of Aspergillus flavus that had been inoculated onto fresh walnut cultivars, the amount of decrease on the inoculated walnuts was different for different cultivars. This difference may be caused by the differing volumes and thickness of the walnut cultivars. In addition, 10 min of plasma jet treatment eliminated Aspergillus flavus from the dried walnuts. After 15 and 30 d of storage (4 °C. The total phenols acting as an antioxidant impose two main functions. One as a primary antioxidant by donating an electron or hydrogen to the free radicals, and the other as a secondary antioxidant which acts as an aidant in the recovery of primary antioxidants (Gordon, 1990). The increase in antioxidant activity is due to the stability of the phenolic radicals after losing the proton from single oxidized forms (Alavi *et al*., 2010; Zargoosh *et al*., 2019). Thus, considering the chemical interactions (such as antagonism) of phenolic compounds (Zielinski *et al*., 2014) and the complexity of compounds (Zargoosh *et al*., 2019), the radical-scavenging capacities and phenolic contents are not always linearly correlated (Moreno-Ramírez *et al*., 2018).

Effect of Low Pressure Plasma on Colour and Moisture Content of RCPP

Colour

The impact of cold plasma on the colour of agricultural produce has always been a topic of interest in many studies (Selcuk *et al*., 2008; Wang *et al*., 2012; Kim *et al*., 2014; Misra *et al*., 2014; Hertwig *et al*., 2015; Go *et al*., 2019; Zhang *et al*., 2019). It is important to preserve the red colour of chilli peppers during the postharvest operations as it is the direct evaluation factor for consumers (Lee *et al*., 2004; Zhang *et al*., 2019; Idrees *et al.*, 2020). In this study, low pressure plasma had a significant effect ($p < 0.05$) on the colour of RCPP. The L*, a*, and b* of the control were found to be 46.7, 20.35, and 23.83, respectively. The oxidation property of the cold plasma molecules made the products more susceptible to colour degradation. There was a decrease in redness and increase in lightness with treatment time. Change in colour was highly noticeable after the treatment time of 4 min (Fig. 1). Among the three quality parameters measured, the colour of the RCPP was highly affected and resulted in a visibly distinct product as compared to the control.

Several studies showed that cold plasma treatment conditions did not significantly affect the colour value of the food materials such as whole black pepper, cherry tomatoes, and apples (Misra *et al*., 2014; Hertwig *et al*., 2015; Pankaj *et al*., 2018; Zhang *et al*., 2019). A study on microbial decontamination of red pepper powder using cold plasma revealed that there was no significant effect of plasma on the colour (Kim *et al*., 2014). The contradiction of results from our study could be attributed to the different cold plasma methods used and mode of sample exposure. Furthermore, in the present study, the RCPP was directly treated with plasma without the use of any packaging material. The previous study had used the RCPP packed in the stomacher bags and then exposed to the cold plasma. This prevented the direct interaction of plasma with the RCPP, thereby resulting in better retention of colour. The interactions of the free radicals present in plasma had a greater influence over the colour of the product. The presence of such reactive oxygen species resulted in the etching of surface molecules (Grzegorzewski *et al*., 2011) causing degradation of red colour pigments in RCPP. This loss in the quality of food due to increased concentration of oxygen in the working gas was reported in previous studies (Wang *et al*., 2012; Amini *et al*., 2017). Thus, for better retention of the quality parameters in RCPP it is suggested to having product that has lesser surface area of exposure (coarse

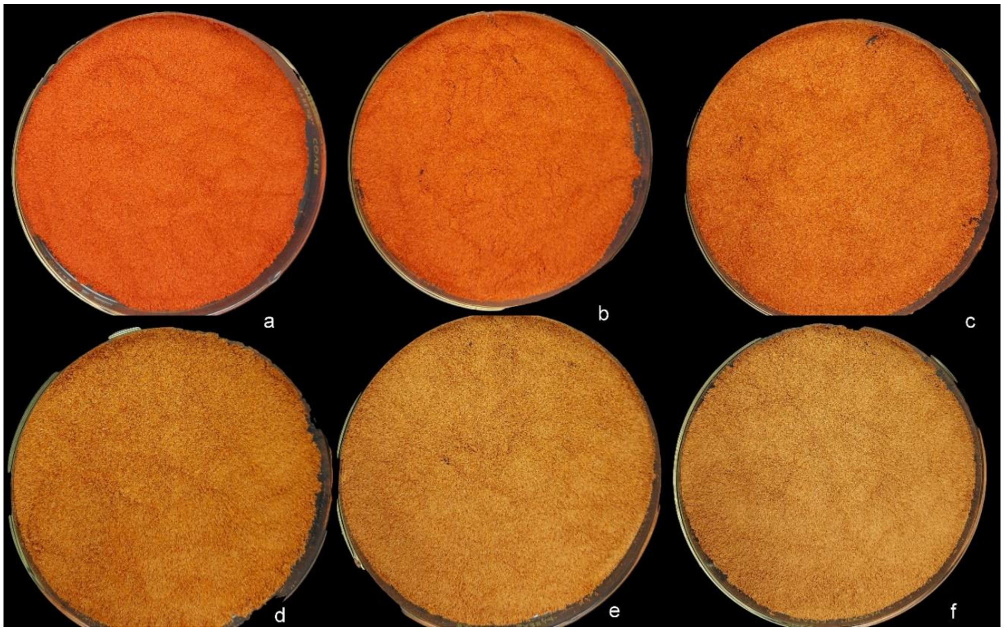

Fig. 1: Changes in visual colour appearance of RCPP treated with cold plasma 120 W with exposure time of (a) control, (b) 1 min, (c) 2 min, (d) 4 min, (e) 6 min, (f) 10 min

particles), packing the material before the treatment, and preventing the formation of oxygen radicals by avoiding atmospheric air into the treatment chamber.

Moisture Content

Cold plasma treatment time and power had a significant effect on the moisture content ($p < 0.05$). Moisture content of the control samples was found to be 7.2 % (w.b.). Moisture content of RCPP decreased (from 7.2 % to 3.46 % at 60 W, and to 2.9 % at 120 W) with treatment time. In the present study, the particle size of RCPP ranged between 0.27 mm and 0.38 mm, which resulted in higher surface exposure to the plasma particles leading to higher surface etching. This erosion of the epidermal layer resulting in higher moisture loss was also reported by Grzegorzewski *et al*. (2011). The vacuum in the low pressure RF setup also contributed to a significant effect on the moisture content reduction in RCPP (Sarangapani *et al*., 2015, 2017; Thirumdas *et al*., 2016).

Degradation Kinetics

Kinetic modelling is important in understanding the process of cold plasma effect on the quality parameters. Estimating the rate constant of the chemical reaction helps in understanding the impact of cold plasma on RCPP, and aids in predicting the time at which the quality changes. The kinetics equations were fitted to understand the order of the reaction. The values of control samples were taken as initial concentrations for determining the degradation kinetics. Most of the food compounds, including pigment and colour degradation, follow either zero-order or first-order kinetics (Maity *et al*., 2012; Saxena *et al*., 2012; Demiray and Tulek, 2015). The model that obtained better coefficient values was selected to explain the order of reaction of the component. The order of reaction with rate constant, bias factor, coefficient of determination (R^2), and error sum of squares (SSE) is presented in Table 2. Antioxidant activity and colour values (L*, a*, b*, ΔE) followed the first-order kinetics, whereas total phenol followed the zero-order kinetics reaction. Kinetics helps in providing added information on the impact of cold plasma technology on the quality of RCPP. The reaction rate constants (k) for first order degradation ranged from 0.0015 to 0.0022, 0.0094 to 0.0098, (-) 0.0334 to (-) 0.0296, 0.0098 to 0.0099 and 0.0694 to 0.0729 for antioxidant activity, L*, a*, b* and ΔE degradation kinetics, respectively. Similarly, k for the zero-order degradation ranged from (-) 1.7913 to (-) 1.1318 for total phenol degradation kinetics. Total phenol and a* value had better fitting models with regression coefficient value above 0.93.

With an increase in power of the treatment, rate constant of the reaction increased indicating that cold plasma power level over time had a significant effect on the total phenol and a* value of the RCPP over the treatment time taken. Attaining a distinctly coloured

Table 2. Degradation kinetics of selected components during cold plasma treatment

SI. No.	Property	Order of reaction	Power level, W	Rate Constant, k	R^2	Bias Factor	SSE
1.	Total phenol	Zero order	60	(-) 1.1318[a]	0.932	1.0000	8.6272
			120	(-) 1.7913[a]	0.976	1.0001	5.3715
2.	DPPH activity	First order	60	0.0015	0.62	0.9998	0.0001
			120	0.0022	0.805	1.0002	0.0001
3.	L*	First order	60	0.0094	0.889	1.0005	0.0008
			120	0.0098	0.848	0.9999	0.0012
4.	a*	First order	60	(-) 0.0296[a]	0.969	0.9998	0.0019
			120	(-) 0.0334[a]	0.938	1.0000	0.0051
5.	b*	First order	60	0.0098	0.527	0.9995	0.006
			120	0.0099	0.491	0.9995	0.0071
6.	Del E	First order	60	0.0729	0.688	1.0684	25.4248
			120	0.0694	0.68	1.0634	0.1163

Note: [a]significant at 5% level

product compared to the control could be attributed to this significant effect of power on the a* (redness) value. However, though there was an increase in the rate constant for other quality parameters, it was not significantly affected by the power level. The degradation kinetics of quality parameters followed first-order kinetics as in accordance with different thermal processing experiments in other produces (Ahmed *et al*., 2002; Ahmed *et al*., 2004; Demiray and Tulek, 2015; Dini *et al*., 2019; Kardile *et al*., 2020)a and b values. For future studies, the established rate constant values can be compared with other cold plasma treatment methods to understand the impact of different processing methods on the quality of RCPP.

CONCLUSIONS

Cold plasma treatment significantly affected the total phenol content, antioxidant activity, and colour of RCPP. The operating conditions of the cold plasma system play a major role in maintaining the product quality. The degradation of total phenol was less than 17.6 %, and antioxidant activity of the RCPP increased by 4.02 per cent. The established cold plasma degradation kinetics data on RCPP could be used to compare the cold plasma effect with other thermal and non-thermal technologies. Results from the present study showed the limitations such as oxidizing and vacuum effect in using low pressure cold plasma for treatment of RCPP as standalone RCPP considering the distinct colour changes. However, this method could be used to decontaminate and treat contaminated RCPP, which could be further used with spice powders and ready-to-cook products. Further studies on the effect of different gases for the generation of plasma, mode of generation of plasma (microwave or radio frequency), operating pressures (low pressure systems or atmospheric systems) on microbial and chemical safety of RCPP as well as whole red chilli pepper can help in understanding the mechanism of degradation and effectiveness of cold plasma for chilli pepper treatment.

ACKNOWLEDGEMENT

This research was funded by the Scheme for Promotion of Academic and Research Collaboration, Ministry of Human Resource Development, Government of India, Project Grant Ref. No. SPARC/2018-2019/P655/SL dated 15.03.2019. The authors thank the Department of Food Science and Nutrition, University of Minnesota for providing research facilities.

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