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Effect of plasma activated water (PAW) on chlorpyrifos reduction in tomatoes

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Abstract

This study investigated the effect of plasma activated water (PAW) on chlorpyrifos reduction in tomatoes considering the changes in their color and texture. Oxidative species present in the PAW react with chlorpyrifos and degrade it. Tomatoes with different initial pesticide concentrations (0.6-0.8 mg/kg) were treated with PAW and distilled water (DW) at varying input voltages (100-200 V), treatment times (5-15 minutes) and flow rate (5 & 10 l/h). The concentration of chlorpyrifos, color, and the texture was assessed before and after treatments. Maximum of 51.97% reduction in the pesticide concentration was attained at 200 V, 15 minutes and 10 l/h with 0.8 mg/kg initial pesticide concentration while with DW for 15 minutes gave a maximum of 0.64% reduction. Tomato color index was increased significantly ($p<0.05$) with PAW while the texture was unaffected. Thus, PAW could be a feasible and effective non-thermal method for pesticide reduction in tomatoes.

Keywords: Plasma activated water, chlorpyrifos, pesticide, color, texture, tomato

1. Introduction

In the growing population of the world, demand for sustainable agricultural production is increasing in order to feed the world. This imposes the use of agrochemicals like insecticides, pesticides, herbicides, and fertilizers to increase the production of agricultural crops. Though these agrochemicals support cultivation, consuming the agricultural commodities having the traces of chemical residues will cause severe health problems which majorly involve the chronic diseases like cardiovascular diseases (CVDs), various cancers, pulmonary diseases like asthma, diabetes mellitus, arthritis, reproductive and neural disorders (Mostafalou & Abdollahi, 2013) [24] in humans. This fact cannot be evaded lightly as the presence of the residual pesticide in the consumables was encountered in a global extent (Blasco, Font, & Pico, 2006) [4] (Iqbal, Maqbool, Perveez, Farooq, & Asi, 2009) [18] (Wang, Wang, Zhang, Wang, & Guo, 2013) [38]. Specifically, pesticide residues in fruits and vegetables which are often preferred to be eaten either raw or partially cooked have to be addressed with serious concern.

In this regard, reducing pesticide in tomato, the third largest consumed (De Vos, Hall, & Moing, 2018) [10] as well as one of the most pesticide encountered fruits (Witczak, Pohoryło, Abdel-Gawad, & Cybulski, 2018) [39] (Amrollahi, Pazoki, & Imani, 2018) [2] in the world is substantial. Investigations on domestic (Kumari, 2008) [21], as well as commercial (Uysal-pala & Bilisli, 2006) [36] unit operations for pesticide reduction on tomatoes, were found to give noticeable results. Yet their ability to reduce pesticides in whole tomato fruits was indeterminate. Also, the high temperature involving operations tend to affect the nutritional profile of the fruits (Chavarri, Herrera, & Arino, 2005) [7]. The intervention of non-thermal methods like high-pressure processing (Iizuka, Maeda, & Shimizu, 2013) [17], gamma irradiation (Chowdhury, *et al*., 2014) [8], pulsed electric field (Delsart, *et al*., 2016) [11], and UV irradiation (Khoobdel, *et al*., 2010) [19] granted conspicuous reduction in pesticide content with better freshness retention. However, the feasibility was insignificant to implement these methods on a large-scale level. This increases the demand for a simple, feasible as well as an intensified non-thermal technique for pesticide reduction.

Washing tomatoes with sanitizers containing oxidants like hydrogen peroxide, chlorine and ozone were found to cause effective pesticide reduction (Cengiz & Certel, 2014) [16]. But then again, the inclusion of chemical sanitizers will increase the risks of allergic and respiratory disorders (Cardador & Gallego, 2012) [5].

Thus, washing pretreatments with innate oxidized species from water molecules would be effective as well as safer. Plasma activated water comprises of highly energized oxidative free radicals and non-radical species such as hydroxyl radical, ozone, oxygen singlet, nitric acid, nitrogen dioxide, nitrous oxide, and other potential oxidants (Traylor, *et al*., 2011) [35] generated via an in-situ or ex-situ excitation of molecules. The presence of these oxidants enables effective mineralization of organic pesticides present in fruits and vegetables (Lozowicka, Jankowska, Hrynko, & Kaczynski, 2016) [22].

Chlorpyrifos, an organophosphorus (OP) pesticide was encountered above the maximum permissible limit (MRLs) in many pesticide outbreak instances in the world (Fenske, Kedan, Lu, Fisker-Andersen, & Curl, 2002) [16] (Mukherjee, 2003) [25] (Amoah, Drechsel, Abaidoo, & Ntow, 2006) [1]. Also, it is one of the highly stable OP (Climent, *et al*., 2018) [9] pesticides with sparing solubility in water which makes it impossible to reduce by simple washing pretreatment. But the dense reactive species produced in plasma were determined to incur higher pesticide reduction (Feng, *et al*., 2019) [15]. However, the PAW treatment is simple and economic like a washing pre-treatment which makes it very flexible and feasible for large scale applications. Thus, in the present study, it is aimed to investigate the effect of plasma activated water on percentage reduction of chlorpyrifos and the two major physicochemical attributes color and texture of tomatoes.

2. Materials and Methods

2.1 Pesticide application in tomato

In order to investigate the effect of plasma activated water on chlorpyrifos reduction in tomatoes, tomatoes were initially spiked with the known concentrations of pesticides. Tomatoes of uniform size were procured from the Thanjavur local markets and washed with distilled water for eliminating any external impurities. The washed tomatoes were air dried to remove the surface moisture. The purchased ccommercial chlorpyrifos (TRICEL 20% EC) pesticide was dissolved into distilled water to prepare stock pesticide solutions of concentration 0.6 – 0.8 mg/kg. The surface dried tomatoes were then immersed for 5 minutes into three different pesticide stock solutions (Iizuka, Maeda, & Shimizu, 2013) [17]. After 5 minutes, the pesticide applied tomatoes were again surface dried and then used for further investigations. The representative tomatoes were examined for pesticide concentration before the pesticide reduction treatments in order to determine the initial concentration of pesticide applied.

2.2 Plasma Activated Water treatment

The Dielectric Barrier Discharge (DBD) system used for the production of Plasma Activated Water (PAW) comprised of the following components namely (given in figure 1); the plasma chamber having an active electrode wire surrounded by the hollow cylindrical ground electrode, a step up transformer for converting the given input voltage to higher levels required for plasma generation, voltage regulator to adjust the range of input voltage and an air pump to provide the source of plasma i.e. the atmospheric air into the plasma chamber at varying flow rates. Plasma species generated inside the system were drawn out and bubbled into the known volume of distilled water. These species on collision with the water molecules produce the required Plasma Activated Water (PAW). In the present study, the tomatoes of three different initial pesticide concentrations (0.6-0.8 mg/kg) were immersed into PAW produced with the varying plasma input voltages (100, 150, 200 V) for the exposure time of (5-15 minutes). The flow rate of atmospheric air was also varied as 5l/h and 10l/h. Tomatoes immersed into the same volume of distilled water without plasma bubbling were considered as control. Both the control and plasma treated tomatoes were analyzed further for the pesticide concentration.

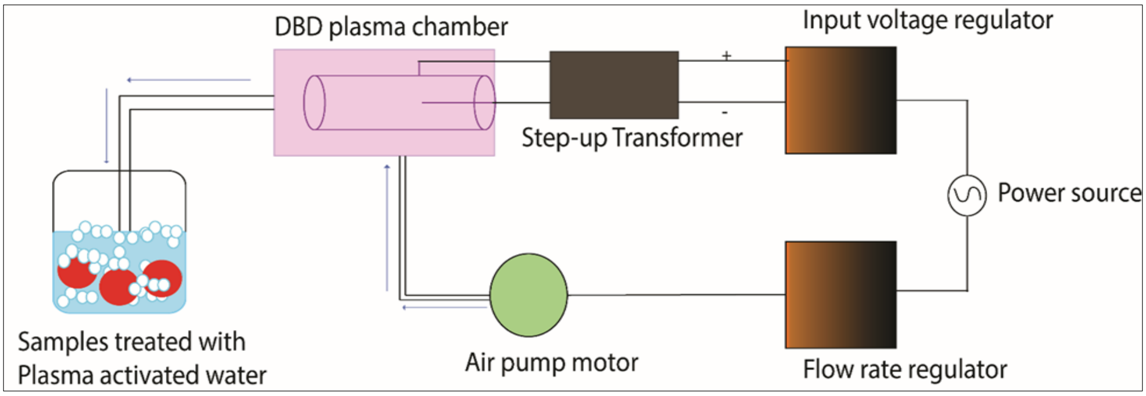

Fig 1: Experimental set up used in the study

2.3 Pesticide quantification by colorimetric method

The pesticide concentrations in the PAW treated and control tomatoes were quantified using a UV- calorimetric method (Rokade & Mali, 2013) [31]. The tomatoes were homogenized with 20 ml of a solvent mixture of isopropanol and water (in the ratio of 1:1) and filtered using Whatman 42-grade filter paper for overnight. The filtrate consist of the dissolved pesticide chlorpyrifos was read in the UV spectrophotometer at 290 nm (UV-1700 spectrophotometer, Shimadzu) with isopropanol as blank. The obtained absorbance of the filtrate was correlated with the standard curve. Priorly, the standard curve was drawn with the absorbance of pesticide standards of known concentrations ranging from 0.01-0.1 mg/l. The linear regression equation of the standards curve was used to determine the concentration of the pesticide (Zalat, Elsayed, Fayed, & Abd El Megid, 2014) in the samples. The percentage of pesticide reduction after the treatment was calculated using the following equation (eq.1)

$$\%\text{ of pesticide reduction} = \frac{C_0 - C_t}{C_0} \times 100 \qquad \text{……….(eq.1)}$$

Where, C_0 and C_t stands for the concentration of pesticide before and after the treatment in mg/kg.

2.4 Determination of physicochemical attributes of tomato (color & texture)

In order to study the effect of PAW on the physicochemical attributes of tomato, two major properties such as color and texture were determined before and after the treatments. Hunter lab colorimeter (Colourflex EZ model: 45/0 LAV) was used to determine the color of the tomatoes as L* a* b* values (where L*-lightness (+) / darkness (-); a*-redness (+)/ greenness (-) ; b*-yellowness (+) / blueness (-)). From these values, tomato color index (TI) i.e. the ratio of a* and b* values (a*/b*) (Misra, Keener, Bourke, Mosnier, & Cullen, 2014) [26] was calculated. Before measuring the color values, the colorimeter was calibrated with the standard white (X = 80.06; Y = 85.06; Z = 89.63) and black tiles. The firmness and bioyield point of the tomatoes were determined with the help of texture profile analyzer (TA HD Plus: Stable Microsystems). P/35 probe was used to cause 25 % strain by single compression on the tomatoes. The speed of compression was fixed at 5 mm/min and a 5 kg load cell was used for the analysis. The maximum force required to produce the given strain in the fruit was considered as the firmness and the minimum force causing microstructure disruption in the fruit was considered as the bio yield point (Tangwongchai, Ledward, & Ames, 2000) [33].

2.5 Statistical analysis

Statistical analysis of the data was performed using SPSS statistical software (SPSS Inc, Chicago, USA, Version 20.0). Significant changes in the pesticide reduction percentage and textural attributes with respect to the process parameters were analyzed using multivariate ANOVA with Tukey-Honesty test at 95% confidence level. Paired student t-test was employed to analyze the significant changes ($p<0.05$) in the tomato color index after the pesticide reduction treatments. All the experiments were done in triplicates.

3. Results & Discussion

3.1 Effect of PAW process voltage and treatment time on pesticide reduction

The input plasma voltage and the treatment time of PAW significantly influenced the percentage of pesticide reduction compared with the control i.e. distilled water treatment as given in figure 2 and 3. The pesticide reduction percentage, after distilled water immersion was very less in the range of about 0.12 - 0.64% which was due to the water insolubility of chlorpyrifos (Climent, *et al*., 2018) [9]. While the percentage of pesticide reduction increases from 2.19% to the maximum of 51.97% with an increase in plasma input voltage and treatment time irrespective of the initial pesticide concentration considering both the flow rates 5l/h and 10 l/h. This clearly distinguishes the capability of plasma activated water to react with chlorpyrifos and degrade it to result in a noticeable reduction in its concentration. Similar results were observed by (Kiris & Velioglu, 2016) [20] The oxidative species produced in plasma-activated water such as ozone, hydroxyl radicals, and other reactive species interact with chlorpyrifos and metabolize it to less toxic molecules of 3,5,6 trichloro pyridinol (TCP) (Devi, Murthy, & Kumar, 2009) [12] (El Masri, Al Rashidi, Laversin, Chakir, & Roth, 2014). At higher input voltages and treatment times, the possibility of denser production of ROS (Ramanan, Sarumathi, & Mahendran, 2018) [29] and prolonged reaction time increase the percentage of reduction.

3.2 Effect of PAW flow rate on pesticide reduction

The flow rate of plasma for the production of PAW significantly ($p<0.05$) influences the percentage of pesticide reduction as given in figure 2 and 3. The maximum percentage of chlorpyrifos reduction attained with 5 l/h plasma flow rate at 200 V input voltage for 15 mins treatment time was 24.89%, whereas with 10 l/h plasma flow rate, the nearer of 26.16% reduction was attained at the input voltage of 200 V for 5 mins treatment time itself. Also, at 10 l/h plasma flow rate, the highest percentage of reduction of 51.97% was observed at 200 V for 15 mins. Increase in the flow rate increases the number of molecules passing through the plasma chamber which in turn increases the number of energized plasma species produced per unit time. Higher the number of plasma species, greater will be the reaction between the pesticide molecules and plasma species. This would be the reason behind the increased percentage of reduction at higher flow rates. These findings were strongly in correlation with (Bai, Chen, Mu, Zhang, & Li, 2009) [3]. Nonetheless, in some studies (Phan, *et al*., 2018) (Feng, *et al*., 2019) [15], extremely higher flow rates more than the optimum would reduce the degradation of pesticides as the generated plasma species and free radicals collide with the other species and get stabilized which terminates the cascade of reactions (Porter, Caldwell, & Mills, 1995) [28]. This necessitates further study on optimization of PAW process parameters to yield 100% reduction in pesticide concentration.

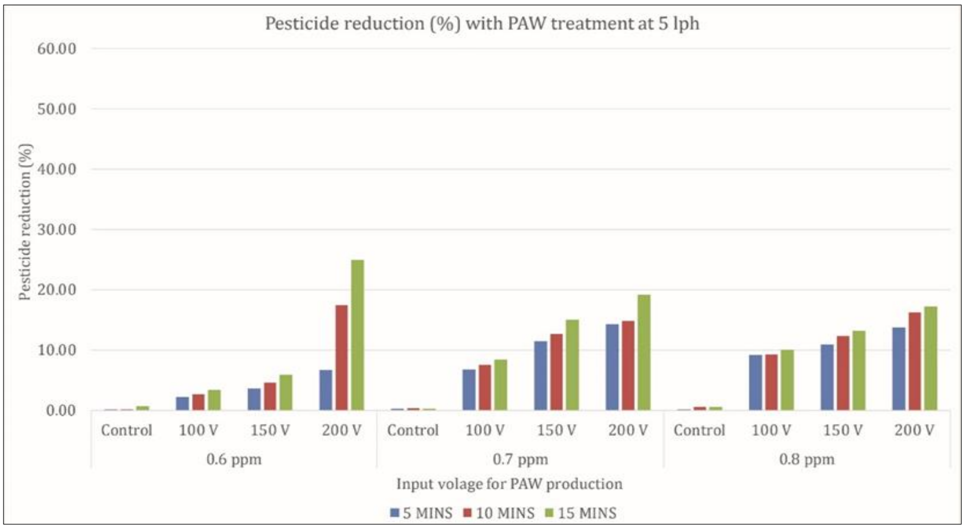

Fig 1: Effect of PAW on pesticide reduction at 5 l/h flow rate

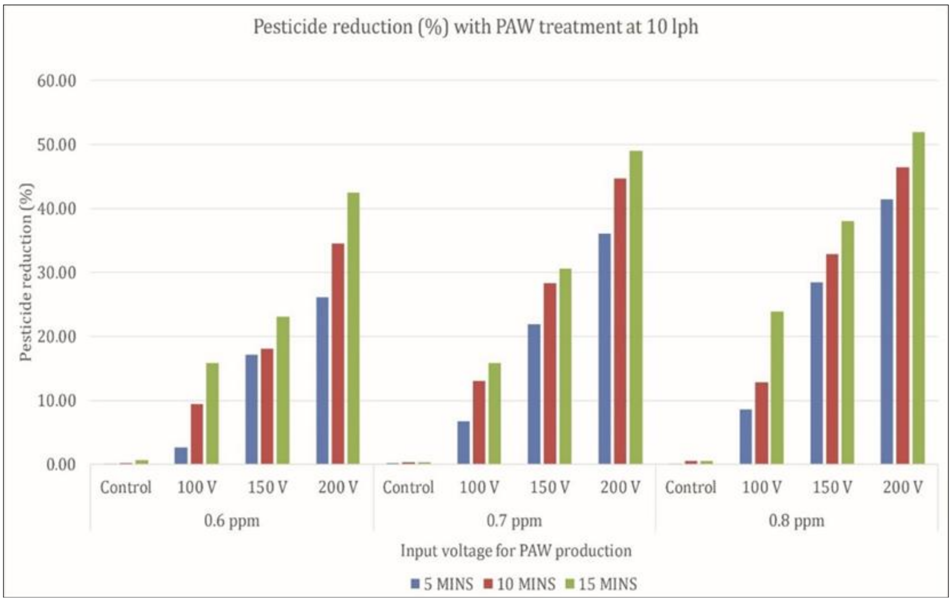

Fig 3: Effect of PAW on pesticide reduction at 10 l/h flow rate

3.3 Effect of PAW treatment on the color index of tomato (TI)

Change in the tomato color index after the pesticide reduction treatments were given in table 1. The tomato color index was significantly (p<0.05) increased with PAW treatment but in a non-linear pattern while there were no changes observed after distilled water treatment. Increase in color index implicitly represents either an increase in redness value or a decrease in yellowness value. The principal components responsible for the redness and yellowness of the tomato are the carotenoids namely lycopene and beta-carotene (Tiziani, Schwartz, & Vodovotz, 2006) [34]. These pigments because of their innate nature to scavenge free radicals and oxidative species, interact with the plasma species and get altered (Ramazzina, *et al*., 2015) [30] in structure to yield secondary plant metabolites. Yet, the increase in TI was one of the desired changes which help in enhancing consumer attraction towards the commodity. Besides, the lesser stability of reactive oxygen species in water (Sadło, *et al*., 2017) [32] assures retention of biochemical components without prominent variations.

3.4 Effect of PAW treatment on the texture of tomato

The influence of PAW treatment on the textural attributes of tomato was given in table 2 and 3 in terms of firmness and bio yield point respectively. It was observed that the firmness and bio yield point of tomatoes were not affected significantly (p<0.05) after both DW and PAW treatment. The reaction of oxidative species with the structural polysaccharides of the fruit might degrade them to cause structural disruption which could further diminish the firmness of the fruit (Duan & Kasper, 2010) [13]. In the present study, no such changes were observed which would be owing to the superiority of the treatment. However, the non-linear decrease and increase in firmness would be attributed to the intrinsic quality of the analyzed tomatoes. Though there were no significant changes, the bio yield point of the tomatoes was reduced considerably after PAW treatments. Similar results were observed by (Wang, Feng, & Luo, 2004) [37]. On a contrary, the oxidative plasma species would also cause retardation in the activity of enzymes influencing fruit texture such as pectin methylesterase, polygalacturonase and poly oxidase (Pankaj, Misra, & Cullen, 2013) [23] thereby prevents fruit softening. This implies that PAW treatment promises textural retainment of tomatoes in addition to pesticide reduction.

Table 1: Effect PAW on tomato color index

Plasma input voltage	**Flow rate (l/h)**		**5**			**10**		
	Time (mins)	**Initial pesticide concentration**	**0.6 ppm**	**0.7 ppm**	**0.8 ppm**	**0.6 ppm**	**0.7 ppm**	**0.8 ppm**
Distilled Water treatment	5	Before	1.26 ± 0.07 ^{a}	1.12 ± 0.06 ^{a}	1.12 ± 0.04 ^{a}	1.23 ± 0.07 ^{a}	1.20 ± 0.06 ^{a}	1.25 ± 0.09 ^{a}
		After	1.25 ± 0.09 ^{a}	1.12 ± 0.08 ^{a}	1.12 ± 0.05 ^{a}	1.24 ± 0.08 ^{a}	1.20 ± 0.06 ^{a}	1.29 ± 0.08 ^{a}
	10	Before	1.27 ± 0.08 ^{a}	1.26 ± 0.14 ^{a}	1.01 ± 0.13 ^{a}	1.35 ± 0.07 ^{a}	1.28 ± 0.11 ^{a}	1.27 ± 0.09 ^{a}
		After	1.27 ± 0.09 ^{a}	1.24 ± 0.15 ^{a}	1.04 ± 0.16 ^{a}	1.34 ± 0.05 ^{a}	1.25 ± 0.12 ^{a}	1.17 ± 0.01 ^{a}
	15	Before	1.23 ± 0.10 ^{a}	1.17 ± 0.08 ^{a}	1.05 ± 0.04 ^{a}	1.26 ± 0.05 ^{a}	1.19 ± 0.09 ^{a}	1.23 ± 0.11 ^{a}
		After	1.23 ± 0.11 ^{a}	1.18 ± 0.08 ^{a}	1.04 ± 0.05 ^{a}	1.27 ± 0.04 ^{a}	1.21 ± 0.09 ^{a}	1.25 ± 0.11 ^{a}
100 V	5	Before	1.27 ± 0.06 ^{a}	1.12 ± 0.06 ^{a}	1.15 ± 0.11 ^{a}	1.28 ± 0.05 ^{a}	1.25 ± 0.03 ^{a}	1.34 ± 0.05 ^{a}
		After	1.34 ± 0.05 ^{b}	1.31 ± 0.07 ^{b}	1.23 ± 0.09 ^{b}	1.38 ± 0.06 ^{b}	1.31 ± 0.05 ^{b}	1.39 ± 0.12 ^{a}
	10	Before	1.28 ± 0.14 ^{a}	1.21 ± 0.11 ^{a}	1.08 ± 0.22 ^{a}	1.26 ± 0.11 ^{a}	1.27 ± 0.02 ^{a}	1.32 ± 0.13 ^{a}
		After	1.32 ± 0.01 ^{a}	1.39 ± 0.10 ^{b}	1.35 ± 0.04 ^{b}	1.37 ± 0.03 ^{b}	1.33 ± 0.09 ^{b}	1.33 ± 0.06 ^{a}
	15	Before	1.29 ± 0.13 ^{a}	1.16 ± 0.02 ^{a}	1.11 ± 0.11 ^{a}	1.24 ± 0.12 ^{a}	1.21 ± 0.08 ^{a}	1.34 ± 0.12 ^{a}
		After	1.34 ± 0.12 ^{a}	1.29 ± 0.10 ^{b}	1.26 ± 0.16 ^{b}	1.39 ± 0.13 ^{b}	1.27 ± 0.10 ^{b}	1.41 ± 0.08 ^{b}
150 V	5	Before	1.11 ± 0.08 ^{a}	1.20 ± 0.11 ^{a}	0.94 ± 0.17 ^{a}	1.14 ± 0.07 ^{a}	1.27 ± 0.08 ^{a}	1.32 ± 0.09 ^{a}
		After	1.32 ± 0.09 ^{b}	1.45 ± 0.07 ^{b}	1.21 ± 0.02 ^{b}	1.35 ± 0.11 ^{b}	1.36 ± 0.01 ^{b}	1.46 ± 0.02 ^{b}
	10	Before	1.19 ± 0.11 ^{a}	1.23 ± 0.04 ^{a}	0.97 ± 0.11 ^{a}	1.26 ± 0.13 ^{a}	1.20 ± 0.04 ^{a}	1.37 ± 0.12 ^{a}
		After	1.37 ± 0.12 ^{b}	1.33 ± 0.09 ^{b}	1.03 ± 0.02 ^{a}	1.39 ± 0.10 ^{b}	1.25 ± 0.07 ^{a}	1.37 ± 0.08 ^{a}

	15	Before	1.13 ± 0.08^{a}	1.15 ± 0.11^{a}	0.99 ± 0.12^{a}	1.20 ± 0.13^{a}	1.27 ± 0.08^{a}	1.18 ± 0.08^{a}
		After	1.18 ± 0.08^{a}	1.41 ± 0.03^{b}	1.34 ± 0.07^{b}	1.36 ± 0.18^{b}	1.39 ± 0.03^{b}	1.24 ± 0.06^{b}
200 V	5	Before	1.11 ± 0.08^{a}	1.21 ± 0.06^{a}	0.92 ± 0.09^{a}	1.19 ± 0.03^{a}	1.20 ± 0.11^{a}	1.25 ± 0.02^{a}
		After	1.25 ± 0.02^{b}	1.37 ± 0.07^{b}	1.12 ± 0.03^{b}	1.28 ± 0.04^{b}	1.38 ± 0.03^{b}	1.34 ± 0.06^{b}
	10	Before	1.31 ± 0.09^{a}	1.27 ± 0.11^{a}	1.03 ± 0.02^{a}	1.24 ± 0.11^{a}	1.17 ± 0.09^{a}	1.35 ± 0.11^{a}
		After	1.34 ± 0.11^{a}	1.32 ± 0.12^{a}	1.27 ± 0.02^{b}	1.34 ± 0.14^{b}	1.30 ± 0.12^{b}	1.36 ± 0.09^{a}
	15	Before	1.22 ± 0.03^{a}	1.19 ± 0.10^{a}	1.03 ± 0.11^{a}	1.21 ± 0.03^{a}	1.18 ± 0.15^{a}	1.28 ± 0.01^{a}
		After	1.28 ± 0.01^{b}	1.36 ± 0.14^{b}	1.35 ± 0.10^{b}	1.30 ± 0.03^{b}	1.27 ± 0.16^{b}	1.35 ± 0.10^{b}

Values are denoted as mean ± standard deviation. Values having varying alphabets (a, b, c) in the superscripts are significantly different (*p*<0.05) as analyzed by paired student t-test.

Table 2: Effect of PAW on firmness (kg) of tomatoes

Plasma input voltage	**Flow rate (l/h)**	**5**			**10**		
	Initial pesticide concentration (mg/kg)	**0.6 ppm**	**0.7 ppm**	**0.8 ppm**	**0.6 ppm**	**0.7 ppm**	**0.8 ppm**
	Treatment time						
	No treatments	2.83 ± 0.98	3.39 ± 0.33	2.87 ± 0.49	2.83 ± 0.98	3.39 ± 0.33	2.87 ± 0.49
Distilled water treatment	5 mins	2.88 ± 0.24	2.99 ± 0.33	2.74 ± 0.46	2.88 ± 0.24	2.99 ± 0.33	2.74 ± 0.46
	10 mins	2.44 ± 0.20	2.50 ± 0.21	3.04 ± 0.49	2.44 ± 0.20	2.50 ± 0.21	3.04 ± 0.49
	15 mins	2.59 ± 0.18	2.61 ± 0.23	2.73 ± 0.50	2.59 ± 0.18	2.61 ± 0.23	2.73 ± 0.50
100 V	5 mins	2.46 ± 0.31	2.97 ± 0.41	2.69 ± 0.57	3.08 ± 0.37	2.90 ± 0.14	2.20 ± 0.31
	10 mins	2.62 ± 0.25	2.64 ± 0.38	2.89 ± 0.14	2.68 ± 0.35	2.80 ± 0.10	2.56 ± 0.25
	15 mins	2.34 ± 0.45	2.47 ± 0.22	2.66 ± 0.84	2.41 ± 0.17	2.48 ± 0.49	2.62 ± 0.39
150 V	5 mins	2.79 ± 0.44	2.92 ± 0.17	2.65 ± 0.11	3.09 ± 0.35	2.71 ± 0.17	2.73 ± 0.44
	10 mins	2.74 ± 0.18	2.75 ± 0.10	2.39 ± 0.07	2.62 ± 0.20	2.83 ± 0.63	2.68 ± 0.18
	15 mins	2.61 ± 0.35	2.43 ± 0.19	2.97 ± 0.44	2.37 ± 0.35	2.82 ± 0.47	2.55 ± 0.35
200 V	5 mins	2.78 ± 0.43	3.02 ± 0.21	2.69 ± 0.25	2.92 ± 0.51	2.70 ± 0.57	2.72 ± 0.43
	10 mins	2.68 ± 0.37	2.82 ± 0.10	2.63 ± 0.24	2.83 ± 0.27	2.68 ± 0.30	2.62 ± 0.37
	15 mins	2.59 ± 0.23	2.77 ± 0.41	2.13 ± 0.11	2.67 ± 0.29	2.86 ± 0.70	2.53 ± 0.23

Values are denoted as mean ± standard deviation.

Table 3: Effect of PAW on bio yield point (kg) of tomatoes

Plasma input voltage	**Flow rate (l/h)**	**5**			**10**		
	Initial pesticide concentration (mg/kg)	**0.6 ppm**	**0.7 ppm**	**0.8 ppm**	**0.6 ppm**	**0.7 ppm**	**0.8 ppm**
	Treatment time						
	No treatments	8.57 ± 1.26	7.96 ± 0.62	8.48 ± 0.01	8.57 ± 1.26	7.96 ± 0.62	8.48 ± 0.01
Distilled water treatment	5 mins	6.33 ± 0.48	7.31 ± 0.71	6.36 ± 0.48	7.22 ± 0.80	7.97 ± 0.46	6.36 ± 0.48
	10 mins	6.55 ± 0.42	6.62 ± 0.21	6.65 ± 0.21	6.88 ± 0.35	7.46 ± 1.00	6.58 ± 0.42
	15 mins	6.20 ± 0.53	6.07 ± 0.67	7.57 ± 1.69	5.95 ± 1.09	7.98 ± 0.51	6.23 ± 0.53
100 V	5 mins	6.02 ± 0.80	7.75 ± 0.29	7.15 ± 1.26	7.54 ± 0.94	6.97 ± 0.27	6.05 ± 0.80
	10 mins	6.00 ± 0.84	7.37 ± 1.05	7.20 ± 0.80	5.63 ± 0.11	7.28 ± 0.56	6.03 ± 0.84
	15 mins	5.51 ± 0.22	6.29 ± 0.40	5.94 ± 0.86	5.95 ± 1.08	5.84 ± 0.41	5.55 ± 0.22
150 V	5 mins	7.87 ± 0.77	7.00 ± 0.63	7.81 ± 0.64	6.50 ± 0.70	7.85 ± 0.94	7.90 ± 0.77
	10 mins	6.68 ± 0.32	6.54 ± 0.43	7.41 ± 1.03	7.09 ± 0.42	6.41 ± 0.43	6.72 ± 0.32
	15 mins	6.45 ± 0.19	6.40 ± 1.51	7.38 ± 0.92	5.83 ± 0.72	7.69 ± 1.61	6.48 ± 0.19
200 V	5 mins	6.95 ± 1.38	7.16 ± 0.03	6.56 ± 0.32	6.76 ± 1.26	8.01 ± 0.49	6.98 ± 1.38
	10 mins	6.95 ± 0.44	7.16 ± 0.66	6.56 ± 0.73	6.76 ± 1.63	7.25 ± 0.78	6.02 ± 0.44
	15 mins	6.22 ± 0.69	5.26 ± 0.70	5.81 ± 0.23	5.90 ± 0.59	6.35 ± 0.73	6.25 ± 0.69

Values are denoted as mean ± standard deviation. Values having * in the superscripts are significantly different (*p*<0.05).

4. Conclusion

This study explains the influence of plasma activated water on chlorpyrifos reduction in tomatoes without causing major changes in the color and textural attributes. Maximum of 51.97% reduction in the pesticide concentration was occurred after immersing the tomatoes in PAW produced with the input voltage of 200 V for 15 minutes with the flow rate 10 l/h. All the process parameters such as plasma input voltage, treatment time and air flow rate were significantly (*p*<0.05) affecting the pesticide reduction percentage while the initial concentration of pesticide in the tomatoes had no significant effect. The tomato color index was increased considerably though not in a linear way. But the PAW had not influenced the texture of the tomatoes both in terms of firmness and bio yield point. These findings evince that PAW treatment could be a promising alternative for the chemical washing of fruits and vegetables to assure safe commodity for consumption. Furthermore, the practicability of the technology enables large scale application of the same in primary and secondary processing lines. However, a detailed study on the influence of PAW on the other physicochemical properties of tomato for complete pesticide reduction is required for further understanding of the process.

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