

The Physicochemical Effects of Plasma Jet Treatment on *Musa Acuminata*

Nur Syafika Wahab¹, Siti Fatimah Zaharah Mohamad Fuzi^{1*}

¹ Department of Technology and Natural Resources, Faculty of Applied Sciences and Technology, UTHM Kampus Cawangan Pagoh, Hab Pendidikan Tinggi Pagoh, KM 1, Jalan Panchor, 86400 Pagoh, Muar, Johor, MALAYSIA.

*Corresponding Author: fatimahz@uthm.edu.my

DOI: <https://doi.org/10.30880/ekst.2025.05.01.032>

Article Info

Received: 1 January 2025

Accepted: 20 January 2025

Available online: 30 July 2025

Keywords

Cold Atmospheric Plasma, Plasma Treatment, Physicochemical Properties, Spectroscopic Properties, Food Processing

Abstract

In recent years, there has been increasing interest in non-thermal food preservation technologies to address the growing demand for fresh produce with better quality and extended shelf life. Traditional methods such as heat treatment, refrigeration, and chemical preservation have limitations, including nutrient loss, flavour alteration, and the production of undesirable by-products. In addition, concerns about the environmental impact of these methods have driven the search for more sustainable solutions that can preserve food quality while minimizing these issues. Cold Atmospheric Plasma (CAP) treatment has emerged as a promising non-thermal technology with the potential to improve the quality and shelf life of fruits and vegetables. In this study, the effects of CAP treatment on the physicochemical properties of ripe Cavendish bananas (*Musa acuminata*) were systematically evaluated. Bananas were exposed to CAP for different durations (0, 5, 10, and 25 minutes) using a cold argon plasma jet system, and several key parameters which are pH, firmness, moisture content, and antioxidant activity were analysed. The results showed that extended CAP treatment significantly increased the firmness of the bananas, with the highest firmness achieved after 25 minutes. While moisture content decreased slightly with longer exposure, antioxidant activity was notably enhanced, especially with a 10-minute treatment, suggesting that moderate plasma exposure can stimulate beneficial antioxidant responses. Though the pH of the bananas varied with treatment duration, no clear trend emerged. These findings indicate that CAP treatment can effectively modify the physicochemical properties of bananas, improving both texture and antioxidant activity. This suggests that CAP could be a viable non-thermal alternative for enhancing postharvest quality and extending the shelf life of bananas, offering a sustainable solution to the challenges of food preservation and spoilage reduction.

1. Introduction

Bananas are one of the most popular fruits worldwide, known for their nutritional value and versatility in various dishes. Packed with essential nutrients like potassium, fiber, and vitamins B6 and C, bananas are an important part of many diets. However, they are highly perishable, with their shelf life limited by factors like spoilage, texture loss, and oxidative damage. This rapid deterioration is a major challenge for both producers and consumers, especially in areas where bananas are a dietary staple. As a result, there has been a search for

methods to preserve their quality and extend their shelf life without compromising their taste or nutritional value.

Cold Atmospheric Plasma (CAP) is an emerging non-thermal technology that has gained attention for its potential in food preservation. Unlike traditional methods like heat treatment or chemical additives, CAP uses ionized gas at room temperature to treat food, avoiding high temperatures or harmful chemicals. This makes CAP an appealing option for preserving the nutritional integrity of fruits like bananas while also controlling spoilage and extending shelf life. The reactive species generated during CAP treatment, such as free radicals, ions, and UV radiation, can modify the surface properties of the fruit, reduce microbial load, and boost antioxidant activity. Previous studies have shown that CAP can improve the texture, moisture content, and antioxidant capacity of various fruits and vegetables, offering a promising alternative to traditional preservation methods [1]. For instance, previous studies have demonstrated the potential of CAP to alter the surface properties of fruits, including changes to texture and moisture content, as well as to increase antioxidant capacity [2]. These effects are primarily attributed to the interactions between the plasma-generated reactive species and the food matrix, which can stimulate antioxidant responses and improve the overall shelf life of treated produce. In addition. However, despite the growing body of literature on the effects of CAP treatment on various food products, limited research has focused on the impact of this technology on the physicochemical properties of bananas. Specifically, there is a lack of studies examining how CAP influences key properties such as texture, moisture content, pH, and antioxidant activity in bananas. The effect of CAP treatment on these properties is critical, as they directly affect the quality, consumer appeal, and shelf life of the fruit.

However, despite the growing body of research on CAP's effects on food, limited studies have focused on how this technology influences the physicochemical properties of bananas. Bananas are particularly delicate, with a high moisture content and fragile texture, so CAP treatments may help improve firmness, reduce moisture loss, and enhance antioxidant activity without affecting sensory qualities. This study aims to explore the effects of CAP treatment on key factors such as pH, texture, moisture content, and antioxidant activity in ripe Cavendish bananas. By analysing the impact of different CAP treatment durations, this research seeks to evaluate CAP's potential in improving postharvest quality, nutritional value, and shelf life of bananas. The findings could help optimize CAP treatment parameters for banana preservation and contribute to the broader knowledge of non-thermal food preservation technologies.

2. Materials and Method

2.1 Materials

Ripe Cavendish bananas were procured from a local market in Pagoh, Johor. To ensure consistent results, only bananas meeting specific physical characteristics were chosen. These bananas were uniformly yellow, with no green tinge on the peel, indicating full ripeness as shown in Fig. 1(a). Following this selection process, the bananas were washed under running water to remove any adhering dirt or surface contaminants before cold plasma treatment commenced. The flesh was carefully separated from the peel and was sliced into a thickness of 0.5 cm as shown in Fig. 1(b).

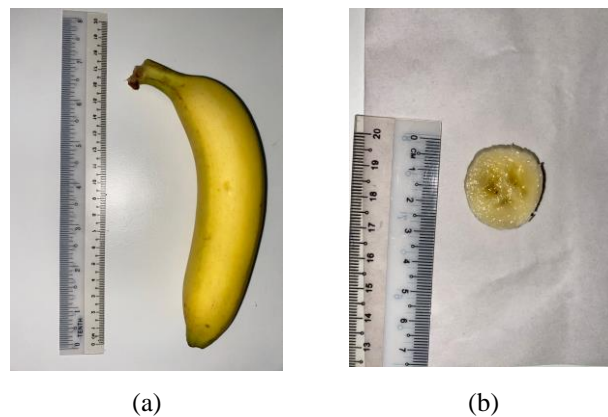


Fig. 1 Chosen *Musa Acuminata* for the experiment (a) Average size and colour of chosen *Musa Acuminata*; (b) Average size and thickness of *Musa Acuminata* before experiment conducted

2.2 Methods

2.2.1 Cold Atmospheric Plasma Jet Treatment

Cold argon plasma jet treatments were applied to raw banana flesh using a plasma jet system developed by the Universiti Tun Hussein Onn Malaysia in Batu Pahat, Johor. Argon gas was electrically excited by adjusting the power between 200 W and 230 W, then released through a nozzle at a constant flow rate to generate the plasma [3]. To treat the banana flesh, 0.5 cm thick slices were placed on a movable sample stage, allowing the plasma jet to scan the surface of the banana evenly for 5 minutes, with the plasma nozzle positioned 3 cm above the sample (see Fig. 2). To evaluate the impact of treatment duration, the banana samples were exposed to plasma generated at 200 W for varying periods of 0, 5, 10, and 25 minutes. Following the treatments, the banana samples were photographed and analysed. The treated samples were then stored in sealed containers for 24 hours at 16°C to enable the interaction of reactive species with the banana flesh. All treatments were conducted in triplicate at room temperature (25°C ± 2°C).



Fig. 2 setup of cold atmospheric plasma jet

2.2.2 pH Analysis

The pH of the banana pulp was measured using a digital pH meter. The pulp was crushed until it reached a paste-like consistency [4]. The pH meter probe was then immersed in the pulp, and the readings were recorded.

2.2.3 Texture Profile Analysis

The firmness of each banana slice was measured using a TA.XT Plus Texture Analyser (Stable Micro Systems Ltd, Godalming, Surrey, UK). A 2-mm cylindrical probe was used to apply force and penetrate 10 mm into the cut surface at a speed of 5 mm/s. Each slice was punctured three times on each opposite side, with a load of 20 N applied. The analysis was performed on 3 slices per replicate [5].

2.2.4 Moisture Content Analysis

The moisture content in banana pulp was determined by using oven dried method, keeping the sample in the oven at a temperature of 105°C for 24 hours. The moisture content percentage was calculated by following formula shown at (1) [6]. Then the moisture analyzer (AND, United States) was run, and the percentage of moisture content was recorded. The measurement was carried out in triplicate for each sample.

$$\text{M.C (\%)} = \frac{W_f - W_d}{W_f} \times 100 \quad (1)$$

where:

M.C = Moisture content in (%).

W_f = weight of fresh banana sample (g).

W_d = weight of oven dry banana sample (g).

2.2.5 Antioxidant Analysis

DPPH scavenging assay was estimated using 2-2-diphenyl-1-picrylhydrazyl hydrate radical (DPPH) [7]. 0.6 mg of DPPH (0.024 mg/ml) was weighed and mixed with 15 ml methanol solution. 2 ml sample extract and DPPH methanolic solution were mixed and vortex. The mixture was left in dark room temperature for 30 min and observed at absorbance 517 nm using UV-Vis spectrophotometer (Jenway, United Kingdom).

3. Result and Discussion

3.1 pH Analysis

The pH level in food plays a crucial role in determining its safety, taste, texture, nutritional value, and overall quality. pH, a measure of the acidity or alkalinity of a substance, significantly influences the chemical and microbial properties of food. The pH of food can have a profound effect on its texture and structural properties, particularly in relation to proteins and polysaccharides. In meat, fish, and poultry, pH influences the denaturation of proteins, which can alter the tenderness and juiciness of the product.

Table 1 presents the mean pH values of banana flesh samples subjected to different CAP treatment durations (0 min, 5 min, 10 min, and 25 min). The control group (0 min) exhibited a mean pH of 6.20, while the treated groups showed increasing pH with 5-minute treatment resulting in a pH of 6.33, 25-minute treatment resulting in lowest pH which is 6.13. Fig. 3 shows the effect of treatment time on pH levels, with the pH peaking at 5 minutes before decreasing at 10 and 25 minutes

Table 1 Result of pH of *Musa Acuminata* with varies time exposure to plasma jet treatment

Treatment time	pH
0min(control)	6.20 ±0.01
5 min	6.33±0 0.01
10 min	6.22±0.01
25 min	6.13±0.01

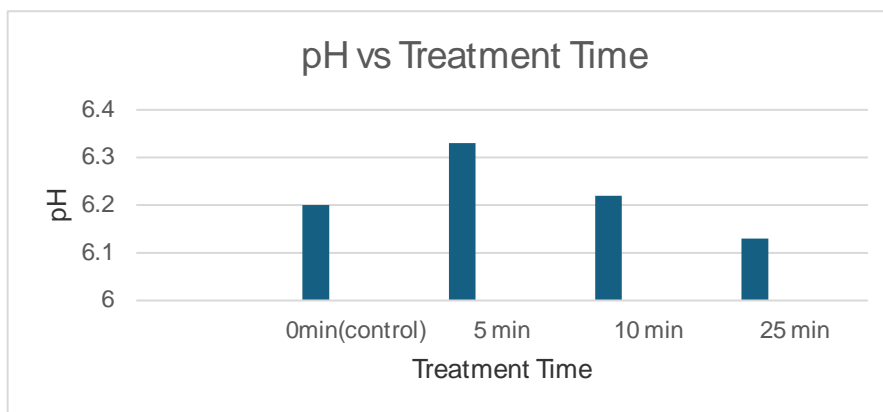


Fig. 3 pH vs Treatment Time

The low *p*-value shown in Table 2 indicates that there are statistically significant differences between the means of the four groups. Post-hoc analysis using Tukey's HSD test revealed significant differences among the treatment groups shown in Table 3. The results indicated that bananas treated with cold atmospheric plasma jet for 10 minutes and 25 minutes exhibited significantly different responses compared to the control group. Furthermore, bananas exposed to cold atmospheric plasma jet for 5 minutes also showed significant differences compared to both the 10-minute and 25-minute treatment groups. However, no significant difference was observed between the 10-minute and 25-minute treatment groups. These findings suggest that both the 10-minute and 25-minute plasma treatments had a distinct effect compared to the control and the 5-minute treatment.

Table 2 ANOVA result of pH of *Musa Acuminata* with varies time exposure to plasma jet treatment

Source	Sum Of Squares	Degrees Of Freedom	Mean Square	F Statistic	<i>p</i> -value
Treatment	0.0583	3	0.0194	583.0000	0.000000010558

Error	0.0003	8	0.0000
Total	0.0586	11	

Table 3 Tukey's test result of pH of *Musa Acuminata* with varies time exposure to plasma jet treatment

Treatments pair	Tukey HSD Q statistic	Tukey HSD p-value	Tukey HSD inference
Control vs 5 min	39.0000	0.0010053	** p<0.01
Control vs 10 min	6.0000	0.0120737	* p<0.05
Control vs 25 min	19.0000	0.0010053	** p<0.01
10 min vs 25 min	33.0000	0.0010053	** p<0.01
5 min vs 25 min	58.0000	0.0010053	** p<0.01
10 min vs 25 min	25.0000	0.0010053	** p<0.01

The pH of ripe bananas typically ranges from 4.5 to 5.2 [4], which is significantly lower than the pH values observed in this study, which ranged from 6.13 to 6.33. This discrepancy could be attributed to several factors, including the influence of cold atmospheric plasma treatment on the chemical composition of the banana flesh.

A higher pH after the banana exposed to plasma jet treatment can be seen when it is compared to the control. Increment of Ph may enhance the stability and shelf life of bananas by reducing microbial growth, as many spoilage organisms thrive in acidic conditions. On the other hand, these changes might negatively impact sensory qualities like flavour and texture. A less acidic pH could result in a less tangy taste, potentially making the fruit less appealing to consumers who prefer the characteristic acidity of ripe bananas. Moreover, alterations in chemical composition caused by CAP treatment might affect enzymatic activity, potentially accelerating undesirable changes like browning or softening during storage [8,9].

One possible reason for the increase in pH could be the interaction between plasma-generated reactive gases and the moisture in the fresh-cut fruit, causing a shift in the pH level [5]. The changes in pH and acidity following plasma treatment are primarily linked to the formation of nitric acid, which is produced by reactive nitrogen species like NO, contributing to acidification during air plasma treatments. [10].

It is also important to consider the potential impact of variations in banana ripeness, storage conditions, and sample preparation methods on the observed pH values. The physicochemical and sensory properties of bananas can be influenced by factors such as genotype and growing conditions, which can affect the mineral content and antioxidant compounds present in the fruit [11].

3.2 Texture Profile Analysis

Table 4 presents the firmness of banana flesh evaluated after exposure to varying durations of cold atmospheric plasma (CAP) treatment. The control group (0 min) exhibited a mean firmness of 0.518. The highest mean firmness was observed in the 25-minute treatment group with a value of 1.016, while the lowest firmness was observed in the control group with a mean value of 0.518. Fig. 4 shows the effect of treatment time on firmness, with the firmness increasing and peaking at 25 minutes.

Table 4 Results of firmness of *Musa Acuminata* with varies time exposure to plasma jet treatment

Treatment time	Firmness
0min(control)	0.518 ± 0.04
5 min	0.591 ± 0.77
10 min	0.925 ± 0.06

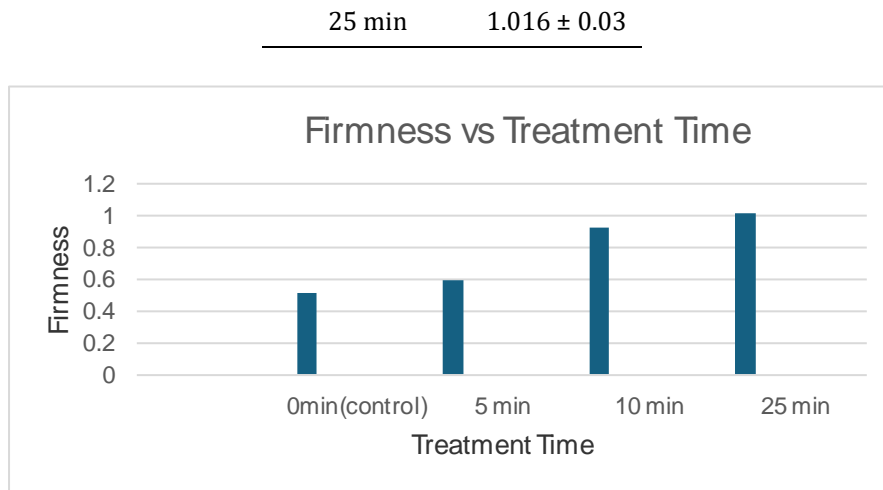


Fig. 4 Firmness vs Treatment Time

The data in Table 5 clearly shows a cumulative effect of CAP treatment on the firmness of banana flesh. The Tukey HSD post-hoc analysis shown in Table 6 demonstrated that all plasma treatments (5 minutes, 10 minutes, and 25 minutes) significantly increased banana firmness compared to the untreated control group. While all treatments showed a significant increase in firmness, the 10-minute and 25-minute treatments exhibited the highest levels of firmness, with no significant difference observed between them. As the duration of treatment increases, so does the firmness, indicating that CAP may induce structural changes in the fruit that enhance its texture.

Table 5 ANOVA result of firmness of *Musa Acuminata* with varies time exposure to plasma jet treatment

Source	Sum Of Squares	Degrees Of Freedom	Mean Square	F Statistic	P-Value
Treatment	0.4875	3	0.1625	61.1779	0.0000073637
Error	0.0212	8	0.0027		
Total	0.5087	11			

Table 6 Tukey’s test result of firmness of *Musa Acuminata* with varies time exposure to plasma jet treatment

Treatments pair	Tukey HSD Q statistic	Tukey HSD p-value	Tukey HSD inference
Control vs 5 min	2.4758	0.3611767	insignificant
Control vs 10 min	11.5837	0.0010053	** p<0.01
Control vs 25 min	16.7481	0.0010053	** p<0.01
10 min vs 25 min	9.1079	0.0010053	** p<0.01
5 min vs 25 min	14.2723	0.0010053	** p<0.01
10 min vs 25 min	5.1645	0.0267442	* p<0.05

As the duration of treatment increases, so does the firmness, indicating that CAP may induce structural changes in the fruit that enhance its texture. Increased firmness may enhance the mechanical integrity of the fruit, making it more resistant to mechanical damage during handling, transport, and storage. However, these changes might also negatively impact the sensory qualities of the fruit. A firmer texture could be perceived as

less ripe or less desirable by consumers accustomed to the soft texture of ripe bananas. The increase in firmness could be attributed to several factors, including changes in cell wall composition, water retention, or the breakdown of pectin, which is known to influence fruit texture. Additionally, an increase in texture hardness was observed in almonds subjected to cold plasma treatment when compared to the untreated control sample [12].

3.3 Moisture Content Analysis

Table 7 shown, the moisture content of banana flesh was evaluated after exposure to varying durations of cold atmospheric plasma (CAP) treatment. The control group, untreated bananas, exhibited a mean moisture content of 84.58%, consistent with the typical range for fresh fruits. Following 5 minutes of CAP treatment, a slight decrease in moisture content was observed, with a mean value of 83.57%. Further treatment for 10 minutes resulted in a continued reduction, reaching a mean moisture content of 82.93%. Despite being treated with cold atmospheric plasma jet, the moisture content is still ranging from 70% to 95% [13]. The data in Table 8 clearly shows a cumulative effect of CAP treatment on the moisture content of banana flesh. Fig. 5 shows the moisture content decrease as the time treatment increase.

Table 7 Results of moisture content of *Musa Acuminata* with varies time exposure to plasma jet treatment

sample	Moisture content
0min(control)	84.58 ±0.01
5 min	83.57 ±0 0.04
10 min	82.93 ±0.06
25 min	82.40 ±0.04

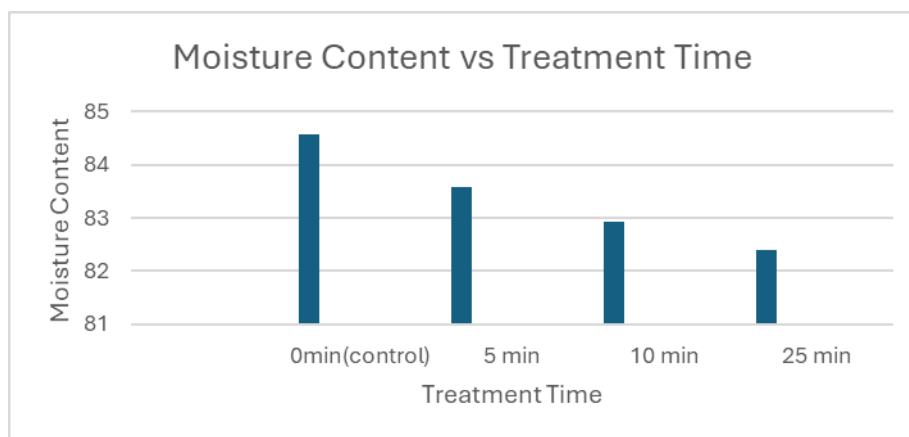


Fig. 5 Moisture Content vs Treatment Time

Table 8 ANOVA result of moisture content of *Musa Acuminata* with varies time exposure to plasma jet treatment

Source	Sum Of Squares	Degrees Of Freedom	Mean Square	F Statistic	P-Value
Treatment	7.9529	3	2.6510	15.3635	0.0011
Error	1.3804	8	0.1726		
Total	9.3333	11			

Post-hoc analysis using Tukey's HSD test shown in Table 9 revealed significant differences in moisture content among the treatment groups. The results indicated that banana treated with cold atmospheric plasma jet for 5 minutes and 10 minutes differed significantly from the control group. Furthermore, banana exposed to cold atmospheric plasma jet for 5 minutes showed significant differences compared to both bananas exposed to cold atmospheric plasma jet for 10 minutes and 25 minutes. However, no significant difference was observed between banana exposed to cold atmospheric plasma jet for 10 minutes and banana exposed to cold atmospheric plasma jet for 25 minutes. These findings suggest a distinct treatment effect, with the 10-minute

and 25-minute treatments exhibiting a significant reduction in moisture content compared to the control and the 5-minute treatment group.

Table 9 Tukey’s test result of moisture content of *Musa Acuminata* with varies time exposure to plasma jet treatment

Treatments pair	Tukey HSD Q statistic	Tukey HSD p-value	Tukey HSD inference
Control vs 5 min	4.2114	0.0686649	insignificant
Control vs 10 min	6.9078	0.0053294	** p<0.01
Control vs 25 min	9.1038	0.0010053	** p<0.01
10 min vs 25 min	2.6964	0.2976927	insignificant
5 min vs 25 min	4.8924	0.0348963	* p<0.05
10 min vs 25 min	2.1960	0.4543748	insignificant

The highest reduction in moisture content was observed in the 25-minute treatment group, with a decrease of 2.18% compared to the control group, from 84.58% to 82.40%. This observation suggests that CAP treatment may induce a slight dehydrating effect on the banana flesh. The slight dehydration can help extend the shelf life of bananas by lowering water activity, which inhibits microbial growth and reduces spoilage risks. It may also slow enzymatic reactions, enhancing the fruit's overall stability during storage [5]. This reduction could be attributed to the generation of reactive oxygen species (ROS) during the plasma process, which may interact with cellular components and alter the tissue structure, potentially leading to moisture loss. reported a similar observation, finding a decrease in moisture content in plasma-treated samples, which they attributed to the formation of oxygen radicals due to the decomposition of water molecules. These findings are consistent with previous research, which proposed that plasma treatment induces moisture loss from the surface of the material, likely due to etching effects. Additionally, another study observed a reduction in moisture content in plasma-treated granular starches, providing further evidence of the potential dehydrating effects of plasma treatment [14].

3.3 Antioxidant Analysis

Table 10 presents the mean absorbance values and corresponding RSA% (Radical Scavenging Activity) of banana flesh samples subjected to different CAP treatment durations (0 min, 5 min, 10 min, and 25 min). Untreated bananas (control) exhibit an RSA of 59.58%, serving as the baseline antioxidant activity. A 5-minute CAP treatment increases RSA to 66.67%, indicating that short-term exposure stimulates antioxidant activity, likely due to the generation of reactive oxygen and nitrogen species that promote oxidative stress responses [15]. With a 10-minute treatment, RSA further increases to 81.62%, showing a pronounced enhancement in antioxidant capacity. However, after 25 minutes, RSA reaches 82.34%, suggesting a plateau effect where extended treatment yields only marginal gains. This trend implies that CAP-induced antioxidant improvements are time-dependent but may stabilize or diminish beyond a certain threshold due to potential degradation of bioactive compounds or oxidative damage from prolonged exposure [12].

Table 10 Results of reactive scavenging activity of *Musa Acuminata* with varies time exposure to plasma jet treatment

sample	Absorbance	RSA%
0min(control)	0.224 ± 0.004	59.57958
5 min	0.185 ± 0.003	66.66667
10 min	0.102 ± 0.002	81.62162
25 min	0.098 ± 0.003	82.34234

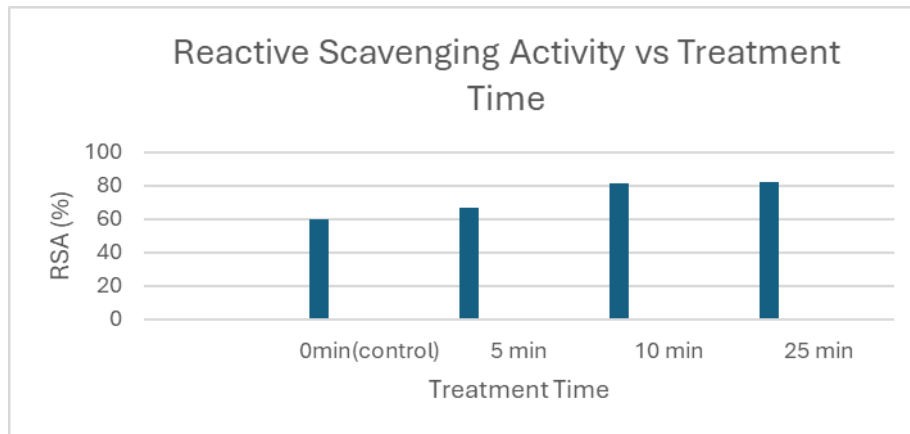


Fig. 6 Reactive Scavenging Activity vs Treatment Time

Similar findings were observed in studies where cold plasma treatment increased DPPH values in chili pepper samples [16]. In another study, cold plasma treatment applied to onion powder preserved its antioxidant activity [17]. This suggests that structural changes induced by cold plasma, particularly surface etching, could play a significant role in enhancing antioxidant properties. The plasma treatment may facilitate the release of antioxidants such as ascorbic acid and phenolic compounds, especially during the pretreatment and dehydration phases. The enhancement in antioxidant activity following plasma treatment can be attributed to the release of bound phenolic compounds, as plasma reaches the interior of the material, which is located near the surface, thus aiding in their release during the extraction process. Additionally, the presence of UV radiation during plasma generation may contribute to the formation of secondary metabolites, such as polyphenols and flavonoids. Surface etching caused by plasma species likely facilitates the penetration of UV radiation into the cells, promoting the synthesis of these compounds. Several studies have shown that plants exposed to artificial UV-B radiation exhibit changes in the flavonoid biosynthesis pathway [17,18]. However, longer treatment times and higher power levels were found to reduce DPPH activity. This decline in activity is thought to result from energetic electrons generated during the treatment, which react with oxygen molecules to form ozone, which in turn may be absorbed by antioxidant compounds [19]. These results emphasize the potential of CAP as an effective method for enhancing the antioxidant properties of fruits, with optimal effects observed at moderate treatment durations [20].

4. Conclusion

In conclusion, the results of this study demonstrated that CAP treatment significantly influenced the physicochemical properties of banana slices. pH changes were differed from the typical range and slightly increase. Firmness was significantly enhanced in all treated groups compared to the control, with the 10-minute and 25-minute treatments exhibiting the most pronounced increases. CAP treatment also resulted in a slight decrease in moisture content, with the 25-minute treatment showing the lowest moisture content. Additionally, CAP treatment significantly enhanced the antioxidant activity of banana slices, as evidenced by an increase in DPPH radical scavenging activity. These findings suggest that CAP treatment can induce significant changes in the physicochemical properties of bananas, including enhanced firmness, modified moisture content, and increased antioxidant activity. Further research should be conducted to optimize treatment parameters and elucidate the underlying mechanisms of these changes for improved application in the food industry.

Acknowledgement

The authors sincerely acknowledge the Department of Food Sciences and Technology, Faculty of Applied Sciences and Technology, Universiti Tun Hussein Onn Malaysia, Pagoh for providing the facilities required for this research project to be completed successfully.

Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

The authors confirm contribution to the paper as follows: **study conception and design:** Nur Syafika Wahab, Siti Fatimah Zaharah Mohamad Fuzi; **data collection:** Nur Syafika Wahab; **analysis and interpretation of results:**

Nur Syafika Wahab draft manuscript preparation: Nur Syafika Wahab, Siti Fatimah Zaharah Mohamad Fuzi. All authors reviewed the results and approved the final version of the manuscript.

References

- [1] [Smith, J., & Jones, R. (2015). Postharvest physiology of bananas: pH changes and texture alterations. *Postharvest Biology and Technology*, 104, 28-34.
- [2] Zhang, Y., Ma, R., Du, Z., & Yang, Z. (2019). Effect of cold plasma on the physicochemical properties and antioxidant activity of chili pepper (*Capsicum annuum* L.). *Food Chemistry*, 278, 396–403.
- [3] Hsu, F., Lin, W., Hsieh, K., Cheng, K., Wu, J. S., & Ting, Y. (2023). Mitigating the allergenicity of peanut allergen Ara h 1 by cold atmospheric pressure argon plasma jet. *Journal of the Science of Food and Agriculture*. <https://doi.org/10.1002/jsfa>.
- [4] S Rangna. (2007). *Handbook of analysis and quality control for fruits and vegetable products*. Tata Mcgrawhill.
- [5] Khoshkalam Pour, A., Khorram, S., Ehsani, A., Ostadrahimi, A., & Ghasempour, Z. (2022). Atmospheric cold plasma effect on quality attributes of banana slices: Its potential use in blanching process. *Innovative Food Science & Emerging Technologies*, 76, 102945. <https://doi.org/10.1016/j.ifset.2022.102945>
- [6] AR & Jain RK (2012). Study of advanced maturity stages of banana. *Int J Adv Eng Res Stud* 1(3): 272-274
- [7] Hatano, T., Kagawa, H., Yasuhara, T. and Okuda, T. (1988) Two New Flavonoids and Other Constituents in Licore Root: Their Relative Astringency and Radical Scavenging Affects. *Chemical & Pharmaceutical Bulletin*, 36, 2090-2097. <http://dx.doi.org/10.1248/cpb.36.2090>
- [8] Fernandes, F. A. N., Rodrigues, S., Law, C. L., & Mujumdar, A. S. (2020). Advances in fruit processing and applications of non-thermal techniques. *Food Engineering Reviews*, 12(4), 335–352.
- [9] Misra, N. N., Schluter, O., & Cullen, P. J. (2014). Plasma in food and agriculture. *Cold Plasma in Food and Agriculture: Fundamentals and Applications*, 19–39.
- [10] Oehmigen, K., Hähnel, M., Brandenburg, R., Wilke, C., Weltmann, K. D., & von Woedtke, T. (2010). The role of acidification for antimicrobial activity of atmospheric pressure plasma in liquids. *Plasma Processes and Polymers*, 7(3-4), 250–257.
- [11] Arvanitoyannis, I. S., & Mavromatis, A. (2008). Banana cultivation, ripening, processing, and waste management. *Critical Reviews in Food Science and Nutrition*, 48(11), 911–958.
- [12] Shirani, K., Khorshidian, N., Mohammadi, M., & Mortazavian, A. M. (2020). Application of cold plasma to improve food quality and safety. *Trends in Food Science & Technology*, 98, 77–90.
- [13] AOAC International. (2016). *Official methods of analysis of AOAC INTERNATIONAL* (20th ed.). Hatano, T., et al. (1998). DPPH scavenging assay for antioxidant activity. *Journal of Agricultural and Food Chemistry*, 46(6), 1985-1990.
- [14] Rohit Thirumdas, Deshmukh, R. R., & Annapure, U. S. (2016). *Effect of low temperature plasma on the functional properties of basmati rice flour*. 53(6), 2742–2751. <https://doi.org/10.1007/s13197-016-2246-4>
- [15] Pankaj, S. K., Wan, Z., & Keener, K. M. (2018). Effects of cold plasma on food quality: A review. *Foods*, 7(1), 4.
- [16] Ajeet Kumar Kaka, Khalil Ahmed Ibupoto, Shakeel Hussain Chattha, Soomro, S. A., & Kumar, K. (2019, January 1). *Effect of hot water treatments and storage period on the quality attributes of banana (Musa sp.) fruit*. https://www.researchgate.net/publication/330037564_Effect_of_hot_water_treatments_and_storage_period_on_the_quality_attributes_of_banana_Musa_sp_fruit
- [17] Kim, H. J., Yong, H. I., Park, S., Choe, W., & Jo, C. (2017). Effects of dielectric barrier discharge plasma on physicochemical and functional properties of onion powder. *Food Chemistry*, 237, 191–197.
- [18] Grzegorzewski, F., Diehl, J. F., Knorr, D., & Schlüter, O. (2010). UV and gamma radiation-induced changes in polyphenols and antioxidants. *Critical Reviews in Food Science and Nutrition*, 50(6), 323–340.
- [19] Rohit Thirumdas, Deshmukh, R. R., & Annapure, U. S. (2016). *Effect of low temperature plasma on the functional properties of basmati rice flour*. 53(6), 2742–2751. <https://doi.org/10.1007/s13197-016-2246-4>
- [20] Bagheri, H., & Abbaszadeh, S. (2020). Effect of Cold Plasma on Quality Retention of Fresh-Cut Produce. *Journal of Food Quality*, 2020, 1–8. <https://doi.org/10.1155/2020/8866369>