

## Effect of Non-thermal Plasma on Physicochemical Properties of Nam Dok Mai Mango

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**Abstract**— Mango is considered as a popular and economically important tropical fruit around the world because of its attractive color, favorable flavor, and high nutritional quality. Nowadays, more consumers consciously desire not only fresh and nutritious but also safe fruits with low or free of microorganisms and chemical contamination. Non-thermal plasma (NTP) is one of the emerging technologies that could potentially decontaminate the fresh food and food processing surfaces. Recently, NTP emerges as a new sanitizing method in the agro-industrial application, where the qualitative characteristics of the treated product could probably be modified by the reactive species as well as the residues of oxidation processes. This study evaluates the changes of physicochemical indexes of Nam Dok Mai mango treated with several NTP conditions. The NTP process was discharged in 0.05 % sodium bicarbonate solution under different voltage levels (800-1500 V) and various treatment durations (2-10 min). It was found that there were significant decreases ( $p < 0.05$ ) in titratable acidity and total phenolic content of NTP treated mango, while the total soluble solid showed a significant increase ( $p < 0.05$ ). The color and texture parameters of this fruit with NTP treatments were not significantly different ( $p > 0.05$ ). The results demonstrated that NTP had slight effect on the physicochemical properties of mango. Future work is required to investigate more comprehensive effect of NTP on the pesticides residues in the mango.

**Keywords**— non-thermal plasma; mango; color; texture; phenolic compound.

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### I. INTRODUCTION

Nowadays, health concerns on consumed fruits and vegetables prompt the need of safe, fresh and high nutritious products undergoing minimal processing with low or free of microbes and chemical contamination. Accordingly, novel non-thermal processes for decontamination chemical residues and microorganisms together with maintaining nutritional and sensory qualities of fruits are required [1]. Mango (*Mangifera indica* L.) is considered as a popular and economically important tropical fruit around the world because of its attractive color, favorable flavor, and high nutritional qualities [2]. Thailand is in the fourth rank of producing mango in the world (1.8 million tons production), with a 27% share of world market and an emphasis in Japan

and Europe [3]. The Nam Dok Mai mango is one of the most famous cultivars for consumption at the ripe stage in Thailand [4]. However, various microorganisms on this fruit lead to quality deterioration, lower market value, and sometimes the rejections of the fruit shipment at the destination countries.

Conventional postharvest washing treatments are not highly effective for eliminating pesticide residues as well as against the growth of mold and pathogens [1]. Chemical sanitizing methods which are commonly used in the food industry now, have increased public health concerns about the risk of carcinogenic by-products formation [5-7]. Other thermal treatments can ensure a safe toxic level for food, but they also have undesirable effects on the flavor, color and texture of products [8]. Non-thermal plasma (NTP) is one of

the emerging novel technologies that could potentially decontaminate fresh food and food processing surfaces.

Plasma is considered to be the fourth state of matter [9-11] and defined as a mixture of partially ionized gas [12-14] containing reactive species like electrons, charged ions, free radicals, gas atoms and photons [14-16]. NTPs are characterized by an electron temperature and do not present a local thermodynamic equilibrium, thus operating temperature of NTP is around 30-60 °C which is preferred by the food industry due to the low energy required for plasma generation [17]. NTP using a dielectric barrier discharge to degrade pesticide residues on strawberries had been successfully investigated [18]. By applying NTP, harmful bacteria and toxins in fruits, vegetables, and meat products can be eliminated effectively while the fresh taste, aroma, texture, wholesomeness, and nutritional content of them are still preserved [14, 19].

Nevertheless, there are still limited studies conducting on physicochemical or nutritional qualities of fresh fruits and vegetables in general, and those of mangoes in particular after plasma treatment. The presence of reactive species as well as the residues of oxidation processes could probably promote the modification of physicochemical and sensory characteristics of the plasma treated products [20]. The objective of this study was to quantify effects of different operating NTP conditions on color, texture, total soluble solid (TSS), titratable acidity (TA) and total phenolic content (TPC) of Nam Dok Mai mango.

## II. MATERIALS AND METHODS

### A. Materials

A number of Nam Dok Mai mango fruits were purchased from a company exporting mango. Fruits were packed in carton boxes, transported to the laboratory and stored in a closed refrigerated chamber at 4-5 °C until use (maximum 3 days of storage). Mangoes which had uniform size and appearance without mechanical injury were selected for the experiments. All chemicals used in this study were of analytical grade and were purchased from Sigma- Aldrich (St Louis, MO, USA) and ACI Labscan (Rd Pathumwan, Bangkok, Thailand).

### B. Plasma treatment of mango fruit

In this study, the non-thermal plasma system was developed from the method described by Deng et al. [21]. Four major parts including: (1) Non-thermal plasma discharge bath, (2) high-voltage power supply, (3) electrical parameter measurement and (4) control devices. Sodium bicarbonate (NaHCO<sub>3</sub>) solution (0.05 %) was prepared and filled as solution plasma for increasing electrical conductivity of solution (550 μS/cm). The high conductivity of solution is required for the discharge generation in liquid [22]. Plasma was generated in the solution by applying 426 ns wide of pulse and 50 kHz electric field with different voltage levels through the electrode. The plasma source utilized was a power systems DC generator (DCG-100E, ENI Power Systems). Temperature of plasma solution before and after plasma treatment was ranged from 28 to 45 °C. Increase of temperature was observed by either higher applied voltage or longer treatment duration.

Mango fruits were placed directly in the NTP bath (3 fruits per 3000 mL solution for each treatment), then different levels of high-voltage power (ranged from 800 to 1500 V) were supplied between 2 and 10 min as shown in Table 1. After NTP treatments, the mango samples were recovered and taken for physicochemical properties measurements. The control sample was mango fruit without any NTP treatment.

TABLE I  
DESCRIPTION OF NTP TREATMENTS

Simple description	Voltage level (V)	Treatment time (min)
D800_2 min	800	2
D1000_2 min	1000	2
D1200_2 min	1200	2
D1500_2 min	1500	2
D1200_4 min	1200	4
D1200_6 min	1200	6
D1200_10 min	1200	10

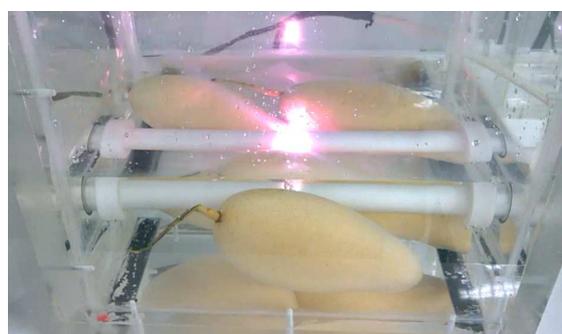


Fig. 1 Mango treated NTP discharged in NaHCO<sub>3</sub> solution

### C. Color measurement

The CIE (L\*, a\* and b\*) of skin color of mango was determined at selected points on both sides of the fruit control and after the plasma treatments using a colorimeter (CR-410, Konica-Minolta, Japan) with ten measurements per fruit. The overall mango color change was indicated by ΔE\* which calculated according to the following equation:

$$\Delta E^* = \sqrt{(L_c^* - L_t^*)^2 + (a_c^* - a_t^*)^2 + (b_c^* - b_t^*)^2}$$

where L<sub>c</sub>\*, a<sub>c</sub>\* and b<sub>c</sub>\* are the color values of control sample (mango fruits without any plasma treatment), and L<sub>t</sub>\*, a<sub>t</sub>\* and b<sub>t</sub>\* are the color values of fruits with plasma treatments [23, 24].

### D. Texture analysis

Mango samples were equilibrated to room temperature (28 °C) and cut into uniform cubes (1.5 x 1.5 x 1.5 cm<sup>3</sup>) before taking textural analysis. Texture of mango was evaluated by applying texture profile analysis (TPA) with a texture analyzer (TA-XTplus, Stable Micro Systems, USA) following the method of Banjongsinsiri et al. [25]. A cylindrical probe (50 mm diameter) was chosen to perform TPA tests. Samples were compressed in two consecutive cycles to get 25 % deformation from the initial sample height of 1.5 cm, at a speed of 2 mm s<sup>-1</sup>. The textural parameters determined were hardness, cohesiveness, springiness, gumminess and chewiness.

The first maximum force which is necessary to compress the mango cube sample is defined as the hardness and measured in newtons (N). The ratio of the area of work during the second compression divided by the area of work during the first compression is the cohesiveness. Springiness is the distance (mm) at which the sample was compressed by the peak force of second compression. The product of hardness and cohesive is the gumminess (N) while chewiness (N x mm) is calculated from gumminess and springiness. For each treatment, at least fifteen samples were analyzed.

#### E. Titratable acidity and total soluble solids measurement

Titratable acidity (TA) was determined by titration with NaOH 0.1 N and two to three drops of 0.1 % (w/v) phenolphthalein as an indicator [26]. The results were expressed as percent of citric acid (%).

Total soluble solids (TSS), expressed as °Brix, were measured with a refractometer (Atago, Tokyo, Japan) at 25 ± 1 °C [23].

#### F. Total phenolic content (TPC) measurement

Blended 2.5 g mango flesh were added into 20 mL of ethanol-acetone solution (ratio 7:3) and kept in ultrasonic bath for 1 h to extract followed by the centrifugation process at 10,000 rpm in 15 min. Supernatant was collected and analyzed of total phenolic content. Three replications were applied for each treatment [23]. Total phenolic content were determined following Siddiq et al. [23]. Taking 0.5 mL of standard or extracted sample and 0.5 mL of Foline-Ciocalteu reagent (diluted 10 times with distilled water) into small test tubes, the mixture was shaken well for 15 s. After 3 min, adding 1 mL of saturated sodium carbonate (about 75 g/L) and 1 mL of distilled water into these tubes. The mixture was incubated in the dark area for 2 h before its absorption was measured at 725 nm against de-ionized water by spectrophotometer (PerkinElmer Lambda 25, UV/Vis Spectrophotometer). The data were expressed in mg gallic acid equivalents (GAE)/ 100 g fresh weight (FW).

#### G. Statistical analysis

Completely randomized design (CRD) with three replications per treatment was done for the experiment. Data analysis was performed using SPSS statistical package 16.0 (SPSS Inc., USA). Mango quality attributes including color, texture, TSS, TA and TPC of the control and plasma treated

samples were tested for significance ( $p \leq 0.05$ ) by one-way analysis of variance (ANOVA) and Duncan's post hoc test.

### III. RESULTS AND DISCUSSION

#### A. Color of mango

Color is one of the most important quality attributes for the consumer's acceptability of fresh fruits [24]. The values of color parameters of mango treated plasma and the control were shown in Table 2. There was not significantly different ( $p > 0.05$ ) between  $L^*$ ,  $a^*$  and  $b^*$  values of control, D800\_2 min, D1000\_2 min, D1200\_2 min and D1200\_4 min. However, when compared with the control, the  $L^*$  and  $b^*$  values of D1200\_10 min slightly increased. D1200\_6 min also had the higher  $b^*$  value and  $a^*$  value than those of the control. Overall mango color change ( $\Delta E^*$ ) was not significantly different ( $p > 0.05$ ) among treatments. Alterations in color parameters of corn salad leaves [27] and bell peppers [28] which are treated NTP have been observed. However, color of strawberries and tomatoes applied NTP shows insignificant changes [18, 29].

#### B. Mango texture

Texture parameters of the control and samples treated plasma were not significantly different ( $p > 0.05$ ) (Table 3). There is also an insignificant difference in the firmness values of treated cold plasma tomatoes when comparing with the control [5]. Ma et al. [24, 30] found similarly that plasma activated water (PAW) could maintain the firmness of strawberries and bayberries. It might be said that the non-thermal plasma treatments would not affect a lot on texture quality of mango fruit.

#### C. TSS and TA values of fruit

The results of TSS and TA of the control and plasma treatments were displayed in Fig. 2. The TSS values ranged from 9.5 to 13 °Brix with the highest one found in D1000\_2 min. All plasma treatments had significantly higher TSS content ( $p \leq 0.05$ ) than the control. As the main substrates of respiratory metabolism, sugars and acids are consumed, causing corresponding changes in TSS of fruits. Higher contents of TSS in plasma treated mangoes may be due to the effect of NTP treatments on the respiratory rate of mango which consequently increased the consumption of sugars and acids of this fruit [30].

TABLE II  
COLOR PARAMETERS OF CONTROL AND MANGO TREATED PLASMA

Test ID	$L^*$	$a^*$	$b^*$	$\Delta E^*$
Control	71.97 <sup>a</sup> ± 1.61	-4.14 <sup>a</sup> ± 1.05	33.33 <sup>ab</sup> ± 2.69	
D800_2 min	72.21 <sup>ab</sup> ± 1.52	-4.38 <sup>a</sup> ± 0.76	32.72 <sup>a</sup> ± 1.95	3.24 <sup>a</sup> ± 1.76
D1000_2 min	72.01 <sup>a</sup> ± 1.38	-4.55 <sup>a</sup> ± 0.47	34.50 <sup>bcd</sup> ± 1.64	4.22 <sup>a</sup> ± 1.72
D1200_2 min	72.23 <sup>ab</sup> ± 1.42	-4.30 <sup>a</sup> ± 0.91	33.98 <sup>abc</sup> ± 1.25	3.32 <sup>a</sup> ± 1.36
D1500_2 min	71.78 <sup>a</sup> ± 1.2	-4.55 <sup>a</sup> ± 0.47	35.52 <sup>d</sup> ± 1.32	4.08 <sup>a</sup> ± 1.41
D1200_4 min	71.62 <sup>a</sup> ± 1.26	-4.07 <sup>a</sup> ± 1.16	33.65 <sup>ab</sup> ± 0.78	3.31 <sup>a</sup> ± 1.44
D1200_6 min	72.50 <sup>ab</sup> ± 1.55	-3.27 <sup>b</sup> ± 0.88	35.36 <sup>d</sup> ± 2.25	3.92 <sup>a</sup> ± 1.39
D1200_10 min	73.21 <sup>b</sup> ± 1.11	-3.92 <sup>a</sup> ± 0.95	35.15 <sup>cd</sup> ± 1.08	4.14 <sup>a</sup> ± 1.67

Means values with different letters in the same column are significantly different ( $p \leq 0.05$ )

TABLE III  
TEXTURE PROFILE ANALYSIS OF THE CONTROL AND MANGO TREATED PLASMA

Test ID	Hardness <sup>ns</sup> (N)	Cohesiveness <sup>ns</sup> (unitless)	Springiness <sup>ns</sup> (mm)	Gumminess <sup>ns</sup> (N)	Chewiness <sup>ns</sup> (N.mm)
Control	2.39 ± 0.82	0.21 ± 0.02	0.54 ± 0.05	0.43 ± 0.1	0.23 ± 0.06
D800_2 min	2.20 ± 0.8	0.22 ± 0.02	0.52 ± 0.09	0.43 ± 0.15	0.23 ± 0.09
D1000_2 min	2.15 ± 0.94	0.21 ± 0.03	0.51 ± 0.07	0.41 ± 0.08	0.24 ± 0.03
D1200_2 min	2.39 ± 0.68	0.23 ± 0.02	0.51 ± 0.08	0.45 ± 0.1	0.25 ± 0.07
D1500_2 min	2.22 ± 0.87	0.21 ± 0.02	0.52 ± 0.07	0.42 ± 0.07	0.26 ± 0.09
D1200_4 min	2.19 ± 0.8	0.22 ± 0.01	0.51 ± 0.08	0.44 ± 0.12	0.24 ± 0.08
D1200_6 min	2.38 ± 0.61	0.21 ± 0.04	0.56 ± 0.05	0.42 ± 0.08	0.25 ± 0.04
D1200_10 min	2.12 ± 0.6	0.20 ± 0.02	0.54 ± 0.08	0.44 ± 0.07	0.24 ± 0.07

<sup>ns</sup> indicates no significantly different ( $p > 0.05$ )

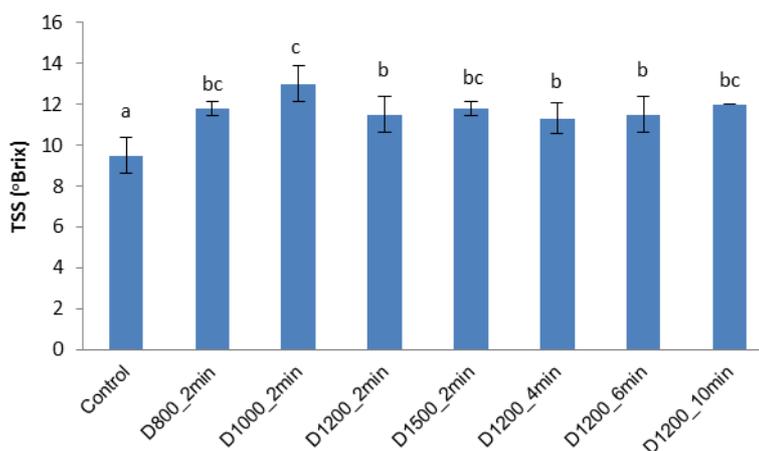


Fig. 2 Total soluble solid (TSS) of mango flesh of control and NTP treatments  
Mean values with different letters are significantly different ( $p \leq 0.05$ )

TA is an essential parameter used to evaluate storage characteristics of fruits. High decrease in value of TA reflects the senescence of fruits [2]. In this study, TA percentage of mangoes decreased significantly ( $p \leq 0.05$ ) with all NTP treatments when comparing with this of the controlled sample (Fig. 3). The maximum TA reduction was observed in D1500\_2min. Titratable acidity decrease with advancing fruit ripening [2] and NTP plasma with temperature between 28 and 45 °C may cause some effects supporting the faster maturity of mango. Moreover, the reaction of fruit's cells with reactive oxygen species generated by plasma chemistry could be used to explain the loss of fruit quality during processing [31].

#### D. Total phenolic content

Phenolic contents in mangoes have been reported to vary from 15.3 to 266 mg GAE/100 g FW [32, 33]. The higher phenolic contents can potentially contribute to improved antioxidant activity [34]. For this research, the phenolic content of the control was 144.91 mg GAE/100 g FW while treated NTP samples had significantly lower contents ( $p \leq 0.05$ ) from 84.68 to 138.54 mg GAE/100 g FW (Fig. 4). Among various treatment conditions, the lowest phenolic content was observed in D1200\_2 min sample. Scavenging free radicals is known as the ability of phenolic compound leading to cleavage of the central heterocyclic in

polyphenolic skeleton as well as oligomerization subsequently [35]. Grzegorzewski et al. [36] found that the degradation of phenolic compounds in lamb's lettuce was not made by photo- or thermodesorption processes at the surface but by the combined interaction of various reactive species of plasma. The interactions with charged ions and reactive species like  $\bullet\text{OH}$ ,  $\text{O}$  and  $\text{O}_2$  may cause an erosion of epidermal tissue layers of this vegetable from that flavonoids and other compounds stored in the central vacuoles of guard cells as well as epidermal cells are released and degraded [36].

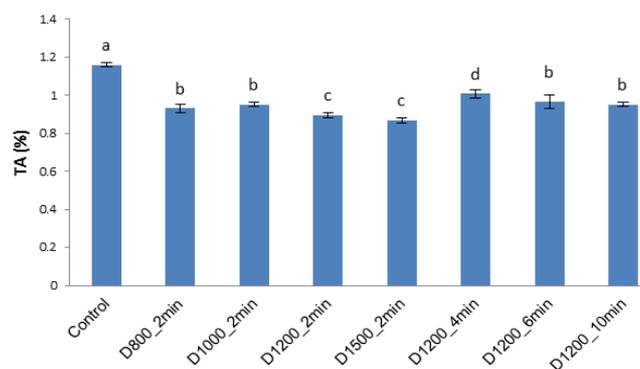


Fig 3 Titratable acidity (TA) of mango flesh of control and NTP treatments  
Mean values with different letters are significantly different ( $p \leq 0.05$ )

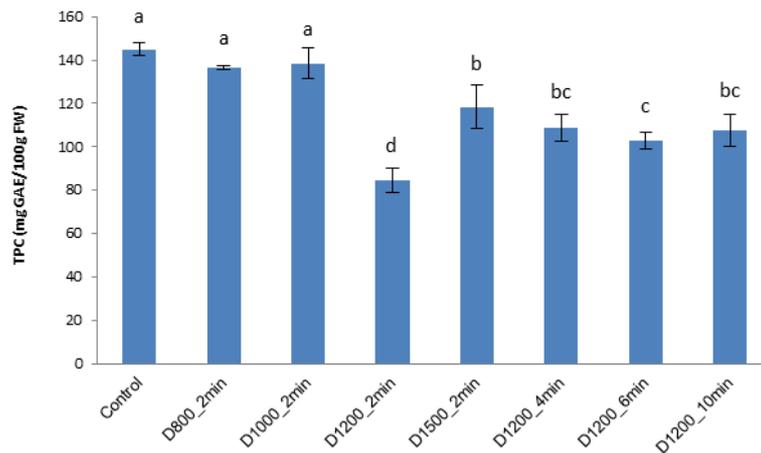


Fig. 4 Total phenolic content (TPC) of flesh of control and NTP treatments  
Mean values with different letters are significantly different ( $p \leq 0.05$ )

#### IV. CONCLUSIONS

NTP could cause some significant changes on the physicochemical indexes of mango including TSS, TA and TPC. There were also some minor alterations in color parameters but no significantly impact on mango texture when compared to the control. Although further investigations should be carried out to elucidate the chemical kinetics mechanisms of these effects, NTP still can be a new promising as an alternative sanitizing method to decontamination chemicals and pathogens from various types of fresh fruits and vegetables due to many advantages of it including high efficiency, low temperature, independence of chemicals together with openly and continuously operation.

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