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FULL PAPER

The effects of heat treatment and modified atmosphere packaging on the storage stability of noni (*Morinda citrifolia* L.) fruit

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Abstract

Noni fruit (*Morinda citrifolia* L.) is a herbal remedy known for its therapeutic and nutritional value. However, it is perishable and subject to rapid postharvest deterioration that shortens its shelf life during storage. Therefore, this study investigated whether hot water dipping (HWD; 60°C, 1 min) and Modified Atmosphere Packaging (MAP; carbon dioxide and nitrogen) could prolong noni's shelf life. The noni physicochemical properties such as colour, firmness, weight loss, total soluble solids, titratable acidity and scopoletin content were monitored during six days of storage at room temperature. During storage, the noni skin colour changed from greenish-yellow to translucent yellow, but HWD storage was stopped on day 2 due to black spots' formation. The reduction of weight loss was significantly lowest in both MAP treatments (1.39–1.74%). Among these, N_2-based had a significantly higher scopoletin content (27.12 mg/g) and firmness (0.8 N) compared to CO_2-based, suggesting that it was the most effective postharvest treatment to efficiently prolong the shelf life and retained the quality and stability of noni during storage.

1. Introduction

Noni fruit (*Morinda citrifolia* L.) originates from tropical Asia and Australia and belongs to the Rubiaceae family. It is known as mengkudu in Malaysia, Indian mulberry, hog apple, great morinda and jo ban in other countries (Singh *et al*., 2020). Noni contains more than 150 types of nutraceuticals, minerals, vitamins, macro and micronutrients, and has been used effectively as a traditional medicine for the treatment of diarrhoea-intestinal parasites, diabetes, high blood pressure, kidney, menstrual cramps, skin problems and bone-related diseases (Macpherson *et al*., 2007; Rethinam and Sivaraman, 2007; Yahia, 2011). The physicochemical characteristics of noni have been quantified as follows: 90% moisture, pH 3.72, 9.87% dry matter, 8°Bx total soluble solids (TSS), 2.5% crude protein content, 0.15% crude lipid content, 11.97 g/L of glucose, 8.27 g/L of fructose, 3.9 g/L of potassium, 214 mg/L of sodium, 14 mg/L of magnesium, 28 mg/L of calcium and 155 mg/100 g of vitamin C (Chunhieng *et al*., 2005). Moreover, noni contains phenolic compounds such as scopoletin, damnacathal, morindone and aucubin (Wang and Su, 2001). Scopoletin can regulate serotonin levels and acts as an anti-inflammatory (Moon *et al*., 2007) and an anti-diabetic agent to aid in insulin resistance and as an anticoagulant (Chang *et al*., 2015).

Noni is commonly harvested for agricultural products and marketed in liquid form to produce a beverage or medicine. Singh *et al*. (2007) claimed that noni's shelf life could be up to 5 to 7 days in open conditions at room temperature of 25–30°C with a relative humidity of 70–75%. As the fruit matures, the skin changes colour from greenish-yellow to creamy yellow on day 3, turning white after five storage days. However, rapid deterioration of noni after harvesting affects the quality (Rosalizan *et al*., 2010), thus influence the stability and shelf life of the fruit. According to Wu *et al*. (2019), there are 4 different stages (0, 2, 4 and 6 days) that represent the physiology phases of postharvest noni fruit. For stage I, freshly harvested noni has greenish-white, hard and smooth surface. After being harvested for 2 days (stage II), it turns whiter and softer inside, yet the surface is still hard. After 4 days (stage III), the whole fruit including the surface become very soft. Noni enters stage IV after 6 days, at which it becomes extremely soft with water-like pulp. The flesh softens quickly within a few days, accompanied by a strong rancid-like odour (Yahia, 2011). In addition, the

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physicochemical properties of the fruit undergo changes after harvesting in terms of weight, texture, titratable acidity (TA), TSS and odour, which leads to difficulties during storage for further processing or transportation.

Hence, postharvest treatments of noni may lead to better quality attributes during storage. Heat treatment using hot water dipping (HWD) is effective in retaining the firmness of the fruits such as citrus (Zhou *et al*., 2014) and muskmelon (Yuan *et al*., 2013). Furthermore, HWD for 2–3 mins at 50–55°C can help prolong the stability of fruit by suppressing or killing fungal pathogen activities, and deactivate enzyme activity (Sui *et al*., 2016). Moreover, carbon dioxide (CO_2)-based, and nitrogen (N_2)-based Modified Atmosphere Packaging (MAP) may also increase the shelf life of the fruit (Koseki and Itoh, 2002). However, between HWD and MAP, none of these methods has been used on noni for postharvest treatment. We hypothesised that, even though HWD has a direct effect to inhibit the activity of fungal pathogens, it can also impact the fruit quality by enhancing ripening and senescence processes. Meanwhile, MAP will effectively preserve the fruit compared to HWD due to less exposure to the environment. Therefore, this study aims to investigate between control (untreated), HWD, CO_2-based and N_2-based MAP, which of these postharvest treatments could prolong noni's shelf life, retaining the quality and stability during storage.

2. Materials and methods

Noni was harvested from the farm at Universiti Putra Malaysia, Malaysia. The fruits had average size (10–12 cm length, 3–6 cm width), weighing 80–100 g and greenish-yellow skin. Sodium hydroxide (NaOH), ethyl acetate (99.8%), methanol (99.8%) and formic acid (95%) were chemical grade and purchased from Sigma-Aldrich, Germany.

2.1 Postharvest treatments

2.1.1 Control

Untreated noni (control) was placed in an open cardboard container at room temperature of 25±2°C and relative humidity of 70±5% up to 6 days. Four samples were taken out every day for analysis. Relative humidity was determined using a dry bulb and wet bulb temperature. The temperature difference was used to determine the percentage relative humidity according to a psychometric chart.

2.1.2 Hot water dipping

Hot water dipping (HWD) was performed by dipping four samples of noni for 1 min in a water bath at 60°C (Ranganna *et al*., 1998). After dipping, the fruits were wiped dry before storage. All samples were kept in a laboratory at room temperature of 25±2°C and relative humidity of 70±5% in open containers for up to 6 days. Four samples were analysed every day during storage (Grigio *et al*., 2015).

2.1.3 Modified atmosphere packaging

Each noni was packaged in 15×23 cm high-density polyethylene (HDPE) bags and vacuum packed to ensure the package was free of atmospheric gases. The package was injected with a needle connected to the gas tank containing CO_2 or N_2 and sealed with tape. This is followed by storage in the open container at room temperature (25±2°C) and relative humidity (70±5%) for up to 6 days. Four packages were analysed daily, with each package containing only one fruit.

2.2 Colour analysis

The skin and flesh colour of each sample was determined using a chromameter (CR-400 Chroma Meter, Konica Minolta, Osaka, Japan). The flesh colour was obtained by cutting the fruit in half to obtain a sample with an average diameter of 5 cm to fit the chromameter. The chromaticity planes were defined by the dimensions L^*, a^* and b^*; L^* indicates lightness, while a^* and b^* are the chromaticity coordinates in which $+a^*$ indicates redness, $-a^*$ greenness, $+b^*$ yellowness, and $-b^*$ blueness (Rosalizan *et al*., 2010; Azman *et al*., 2020). Ten replicates were measured for each fruit and the total colour difference (TCD) between four samples was calculated according to the following formula by Wrolstad and Smith (2017):

$$Total\ colour\ difference\ (TCD) = [(L^* - L_o)^2 + (a^* - a_o)^2 + (b^* - b_o)^2]^{1/2}$$

where, L_o, a_o, b_o = blank values of control samples after harvest on day 0

2.3 Determination of weight loss

The weight of fruit was obtained initially before treatment using an electronic mass balance, then recorded every day during storage. The results were expressed as the percentage loss using the following equation:

$$\%\ W_L = \frac{W_i - W_f}{W_i} \times 100$$

Where $\%W_L$ = percentage weight loss, W_i = initial fruit weight (g), W_f = final fruit weight (g) at the indicated period (Lopez-Castaneda *et al*., 2010).

2.4 Textural properties

The firmness of the fruits was analysed using a texture analyser (TA.XT.plus, Stable Micro System, UK) with a mechanical force-displacement using a 5 kg

loading cell and a 2 mm cylindrical flat head probe entering the noni flesh from the sagittal side. Each sample was compressed into three different sections. The force (N) was measured with the following instrument settings: test speed of 1.50 mm/s, post-test speed of 10.00 mm/s, auto force trigger of 25.0 g and distance of 10 mm (Giongo *et al*., 2013).

2.5 Determination of total soluble solids (TSS)

Noni was homogenised for two minutes in a blender (Masuko Sangyo Co., Ltd., Kawaguchi-city, Saitama-Pref., Japan) and filtered using thin cotton cloth (muslin) to obtain the juice. TSS was determined using a portable refractometer (N-1E, Brix 0–32%, ATAGO Co., Ltd., Tokyo, Japan). The analysis was a destructive technique as the fruits were prepared in juice extract and the results were expressed as °Bx (Grigio *et al*., 2015). The number of replicates for each treatment was four.

2.6 Determination of titratable acidity (TA)

By using the same juice extract for the TSS analysis, TA was measured by titration with an alkaline solution (0.1 N NaOH) until pH 8.1 (Askar and Treptow, 1993). Briefly, the sample (5 mL) was mixed with distilled water made up to 50 mL, filtered and titrated with NaOH. The total TA was expressed as a percentage of citric acid and four fruits were used for each treatment:

$$\%\ citric\ acid = \frac{V \times 64\ g \times V_m \times 100}{V_s \times W \times 1000}$$

Where V, N, V_m, W and V_s are mole of 0.1 N of NaOH used, normality, the quantity of volume made up, the weight of sample and volume of sample used, respectively (Thirukkumar *et al*., 2017).

2.7 Determination of scopoletin content by HPLC analysis

Approximately 100 g of noni was mashed and filtered through a Whatman No. 4 filter paper. Then, 10 mL of noni juice extract was accurately measured and extracted with a triple volume of ethyl acetate (30 mL). The organic phase was then combined and concentrated using a rotary evaporator at 60°C (Liu *et al*., 2005). The extracted residue was dissolved in 8 mL of methanol-H_2O (1:1, v/v) and filtered through a syringe nylon microfilter (0.22 µm pore size) and stored at -18°C for HPLC analysis.

The analysis was performed using Waters 2695 Alliance HPLC (Waters Corp., Milford, MA, USA) connected to a Waters 2414 refractive index (RI) detector, two Waters 515 HPLC pumps. A C18 column (250×4.6 mm, 5 µm) was used as the separation column and placed in a column oven at 40°C. An isocratic mixture of methanol and water (30:70) containing 0.1% (v/v) formic acid was used as the mobile phase, which was filtered through a vacuum pump and degassed by sonication for 15 min. The flow rate was adjusted to 1.0 mL/min, the auto-injection volume was 20 µL and the absorbance was measured at 366 nm (Vipul *et al*., 2013). Five different concentrations (0, 20, 40, 60, 80, 100 mg/mL) of scopoletin standard (Sigma-Aldrich) solution was injected into HPLC to obtain the calibration curve. Analysis was carried out in triplicate.

2.8 Statistical analysis

All physicochemical and chemical analyses were conducted by one-way analysis of variance (ANOVA) using Minitab V.16 (Minitab Inc., State College, Pennsylvania, USA). Tukey's test was used to determine the significant difference ($p<0.05$). Linear Pearson correlation was also used to evaluate correlations between colour properties, weight loss, textural properties, TSS, TA and scopoletin content.

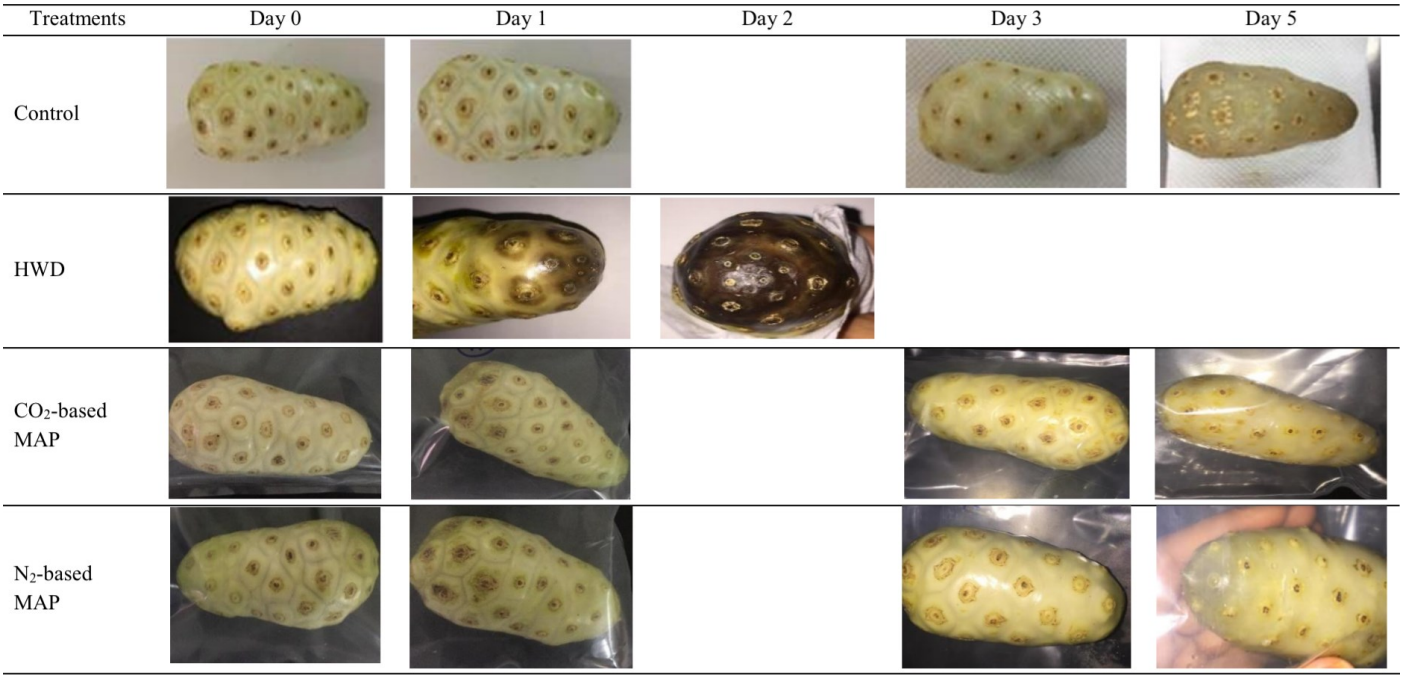
3. Results and discussion

3.1 Colour properties

Towards the end of storage, the noni skin changed colour, from greenish-yellow to translucent yellow, with dried patches observed around the seeds in all fruit (Figure 1). The fruits became a fully translucent yellow in the control treatment, while MAP only affected the colour of the bottom of the fruit. However, fruits under HWD treatment changed drastically in appearance, with black spots on the bottom of the fruit just after 2 days of storage. Subsequently, the storage of HWD fruits was stopped on day 2 to avoid any microbial growth and unpleasant odour. Kerbel *et al*. (1987) reported that the peel browning could be caused by heat damage either internally or externally of fruits. Also, polyphenol oxidase (PPO) activity triggered by the heat treatment can cause necrosis (Paull and Chen, 2000), as the high temperature disrupts the non-covalent bond sustaining the enzyme structure, causing the protein to unfold and activate PPO activity (Vieille and Zeikus, 2001; Kristjánsson and Ásgeirsson, 2002).

The colour analysis is an important indicator of fruit stability. Table 1 presents the changes of L^* (lightness), -a^* (greenness) and b^* (yellowness) values of noni skin and flesh. Overall, HWD caused the highest changes in L^*, a^* and b^*, followed by the control and MAP treatments. The lightness, greenness, and yellowness of noni skin after HWD changed significantly ($p<0.05$) on days 1 and 3 for the control treatment. In all treatments, L^* decreased from 71.0–74.5 on day 0 to 49.4–54.6 on day 6, indicating that the noni skin became darker. Most treatments resulted in an increment of a^* from negative towards positive and reduced b^* over time. However,

Figure 1. Images of postharvest treated Noni during storage. HWD: Hot water dipping; MAP: Modified atmosphere packaging; CO_2: Carbon dioxide gas; N_2: Nitrogen gas



there was a fluctuation in a^*, increasing trend in N_2-based MAP, which may be due to the different stages of noni's maturity on the specific tree (Nelson, 2003). Moreover, noni skin becomes translucent yellow as the fruit matures; thus, the skin becomes less yellow and darker in colour. There was a positive correlation between L^* and b^* values ($R = 0.747$, $p<0.05$), supporting the findings that a decrease in L^* also resulted in the decline of b^*.

The fruits subjected to HWD had the highest TCD (19.3±7.6) after day 2 compared to the control and MAP treatments. The TCD for MAP treatment started to rapidly increase ($p<0.05$) after day 4, with a significantly negative ($p<0.05$) coefficient between TCD and L^* ($R = -0.806$) and b^* ($R = -0.821$), proving that the reduction in L^* and b^* increased the TCD of Noni skins during storage. According to Singh *et al*. (2007), Noni changes colour from green to greenish-white, whitish, creamy, translucent, then brown and becomes softer in texture. As the fruit ripens, the colour turns white, which becomes darker, signalling senescence. Janick and Paull (2008) described that Noni would change to light green colour when unripe and whitish-yellow when ripe during the hard-white stage, becoming soft and translucent yellow after several days. The colour changes occur due to chlorophyll's breakdown during ripening, causing the fruit to change colour from green to yellow. Furthermore, Koseki and Itoh (2002) reported that packaging helps slow down the browning effect of fresh-cut vegetables. Browning can occur if the fruit is sliced, crushed, or aged due to PPO enzyme breakdown and oxygen contact in the air.

Regarding the noni flesh, the control treatment showed the highest TCD after 6 days in storage, followed by N_2-based and CO_2-based MAP. Notably, noni flesh from the HWD treatment had a lower TCD than the skin, suggesting that heat treatment affects the skin more than flesh. Moreover, L^* and b^* started to reduce significantly ($p<0.05$) after days 3 and 4, respectively for both control and MAP treatments. Amongst all treatments, the control sample had the significantly ($p<0.05$) highest decrease in L^* of flesh, from ~67.7 on day 0 to ~39.3 on day 6, indicating a reduction in lightness, followed by CO_2-based and N_2-based MAP with final L^* values of ~44.3 and ~43.5, respectively. The decrease in L^* significantly increased the TCD of noni flesh as indicated by the negative correlation ($R = -0.954$, $p<0.05$). The smaller changes in TCD suggest that MAP packaging efficiently preserved noni flesh's colour during storage compared to other treatments.

3.2 Weight loss

Figure 2 shows the weight loss which occurred during storage. The control, CO_2-based and N_2-based MAP were stored for 6 days and only 2 days for HWD treatment. Storage for HWD stopped on day 2 due to black spot formation and day 6 for other treatments due to the condition of the fruits that became translucent yellow with very fragile flesh. Fruits subjected to HWD had a rapid weight loss as early as day one of storage because heat treatment promoted the rearrangement of epicuticular layers that led to weight loss. Also, weight loss is caused by the loss of respiratory gases and water vapour from the fruits (Amin and Hossain, 2012.). The control treatment had the highest weight loss which started on day 2, while the CO_2-based and N_2-based

Table 1. Changes in *L**, *a**, *b** values and total colour difference (TCD) of Noni during different storage treatments.

Treatments	Storage time (days)						
	0	1	2	3	4	5	6
Skin							
L* value							
Control	71.0±1.1^{Ba}	73.8±1.7^{Aa}	74.5±0.7^{Aa}	65.6±2.0^{Ab}	59.0±1.7^{Ac}	54.8±1.9^{Ad}	54.6±1.0^{Ad}
HWD	74.5±1.2^{Aa}	60.0±0.8^{Bb}	57.0±6.5^{Cb}	-	-	-	-
CO_2-based MAP	71.0±1.1^{Ba}	70.6±2.5^{Aa}	65.9±3.2^{Bb}	62.9±2.0^{Aab}	55.0±8.2^{Abc}	50.8±2.1^{Ac}	49.4±3.6^{Bc}
N_2-based MAP	71.0±1.1^{Ba}	70.0±1.9^{Aa}	68.3±1.4^{ABa}	66.3±3.1^{Aab}	57.6±7.2^{Abc}	56.9±6.8^{Abc}	50.4±2.4^{ABc}
a* value							
Control	-0.6±1.1^{Ac}	-0.2±0.7^{ABbc}	-0.6±1.2^{ABc}	0.7±0.3^{Aabc}	1.2±0.8^{Aab}	2.0±0.5^{Aa}	2.3±0.2^{Aa}
HWD	-1.1±0.7^{Ab}	1.7±1.4^{Aa}	1.7±1.3^{Aa}	-	-	-	-
CO_2-based MAP	-0.6±1.1^{Aa}	-1.5±1.7^{BCa}	-1.6±1.1^{Ba}	-0.5±1.0^{Aa}	0.5±1.9^{Aa}	0.6±2.7^{Aa}	0.4±1.9^{Aa}
N_2-based MAP	-0.6±1.1^{Aa}	-3.4±1.7^{Ca}	-3.2±1.1^{Ba}	-0.1±0.6^{Aa}	3.8±7.6^{Aa}	-0.1±2.6^{Aa}	1.6±0.4^{Aa}
b* value							
Control	30.9±3.1^{Aa}	24.6±1.1^{Ab}	32.5±3.0^{Aa}	23.9±2.7^{Ab}	23.6±0.6^{Ab}	17.5±1.1^{Ac}	15.8±1.0^{Bc}
HWD	31.9±1.4^{Aa}	27.8±1.7^{Aab}	24.9±4.1^{Bb}	-	-	-	-
CO_2-based MAP	30.9±3.1^{Aa}	25.6±2.2^{Aab}	25.8±2.8^{Bab}	22.8±0.5^{Abc}	17.4±3.8^{Bc}	19.7±4.8^{Abc}	20.6±4.1^{Abc}
N_2-based MAP	30.9±3.1^{Aa}	29.0±3.5^{Aa}	26.6±2.3^{ABab}	21.3±1.0^{Abc}	19.0±3.5^{ABc}	19.7±4.4^{Ac}	16.3±0.5^{ABc}
TCD							
Control	-	7.1±2.6^{Bc}	4.4±0.2^{Bc}	10.1±2.3^{Abc}	14.4±3.0^{Ab}	21.3±3.3^{Aa}	22.6±3.0^{Aa}
HWD	-	15.5±2.2^{Aa}	19.3±7.6^{Aa}	-	-	-	-
CO_2-based MAP	-	6.3±2.3^{Bb}	8.4±4.3^{Bb}	11.7±2.3^{Ab}	21.5±7.1^{Aa}	23.5±3.3^{Aa}	24.6±2.8^{Aa}
N_2-based MAP	-	4.8±1.6^{Bc}	7.0±2.6^{Bc}	11.3±2.8^{Abc}	20.7±6.3^{Aab}	18.9±7.0^{Aab}	25.4±4.0^{Aa}
Flesh							
L* value							
Control	67.7±1.0^{Aa}	64.6±1.3^{Aab}	60.3±3.5^{Bbc}	59.9±0.8^{Ac}	55.3±1.8^{Ad}	40.3±2.0^{Ae}	39.3±1.1^{Be}
HWD	65.6±4.5^{Aa}	66.2±3.1^{Aa}	69.1±2.8^{Aa}	-	-	-	-
CO_2-based MAP	67.7±1.0^{Aa}	57.1±0.9^{Bb}	56.8±1.7^{BCb}	54.2±2.0^{Bb}	45.9±5.4^{Bc}	44.2±4.8^{Ac}	44.3±0.9^{Ac}
N_2-based MAP	67.7±1.0^{Aa}	57.2±1.2^{Bb}	54.5±1.8^{Cb}	54.2±2.1^{Bb}	47.3±3.4^{Bc}	46.8±4.4^{Ac}	43.5±1.1^{Ac}
a* value							
Control	2.1±0.6^{Aa}	2.6±0.5^{ABa}	2.4±0.4^{Ba}	0.7±0.2^{Bb}	1.2±0.2^{Bb}	2.2±0.3^{Aa}	2.4±0.1^{Ba}
HWD	2.5±0.1^{Ab}	3.5±0.4^{Aa}	3.2±0.3^{Aa}	-	-	-	-
CO_2-based MAP	2.1±0.6^{Abc}	2.3±0.5^{Babc}	2.6±0.4^{ABabc}	1.7±0.1^{Ac}	2.4±0.4^{Aabc}	2.7±0.4^{Aab}	3.0±0.3^{Aa}
N_2-based MAP	2.1±0.6^{Aa}	2.2±0.4^{Ba}	1.9±0.3^{Ba}	2.1±0.3^{Aa}	2.0±0.7^{ABa}	2.1±0.5^{Aa}	2.7±0.4^{ABa}
b* value							
Control	12.6±0.4^{Bb}	17.9±0.5^{Aa}	16.6±0.7^{Aa}	13.0±0.3^{Ab}	12.2±0.5^{Ab}	6.6±0.5^{Ac}	7.1±0.3^{Ac}
HWD	20.3±1.0^{Aa}	13.6±0.5^{Bb}	12.6±0.8^{Bb}	-	-	-	-
CO_2-based MAP	12.6±4.0^{Bab}	13.1±0.8^{Ba}	12.5±1.0^{Bab}	10.8±0.7^{Babc}	7.4±1.3^{Bc}	8.6±1.6^{Abc}	6.9±0.4^{ABc}
N_2-based MAP	12.6±4.0^{Ba}	12.8±1.2^{Ba}	11.7±1.0^{Bab}	9.6±0.9^{Babc}	7.9±1.6^{Bbc}	7.8±1.1^{Abc}	6.3±0.3^{Bc}
TCD							
Control	-	6.7±3.2^{Bc}	8.8±4.5^{Abc}	8.8±0.3^{Bbc}	13.1±1.8^{Bb}	28.3±3.0^{Aa}	29.1±2.5^{Aa}
HWD	-	8.0±1.5^{ABa}	9.1±2.2^{Aa}	-	-	-	-
CO_2-based MAP	-	11.1±1.2^{Ab}	11.7±1.7^{Ab}	14.3±2.0^{Ab}	22.8±4.5^{Aa}	24.2±3.4^{Aa}	24.3±2.3^{Ba}
N_2-based MAP	-	11.0±1.8^{ABb}	13.7±1.6^{Ab}	14.5±3.2^{Ab}	21.4±3.1^{Aa}	21.6±5.3^{Aa}	25.2±1.9^{ABa}

[a]HWD: Hot water dipping; MAP: Modified atmosphere packaging; CO_2: Carbon dioxide gas; N_2: Nitrogen gas. Figures in parentheses indicate the standard deviation. Values with the same lowercase superscript in each column or uppercase superscript in each row are not significantly different ($p>0.05$).

MAP showed the lowest weight loss beginning on day 4. Serdar and Usanmaz (2017) reported that MAP protects the fruit, reducing pomegranates' weight loss. Furthermore, MAP provides differences in the gas concentration within the packaging due to the fruit's dynamic interaction with the fruit's metabolic and biochemical processes. When the fruit respires, oxygen is consumed and CO_2, ethylene and water vapour are produced and regulated in the MAP system, thus preserve the fruit.

The reduction in weight of noni was related to the water loss. Migration of water occurs due to

transpiration, which then evaporates from the fruit's surface to the surroundings (Kader, 2002). These results are in agreement with Singh *et al*. (2007) and similar to those obtained for date palm by Hazbavi *et al*. (2015) as well as Park and Jung (1996) and Perez *et al*. (2004) who reported a rapid weight loss in citrus and avocado fruits, respectively upon exposure to heat treatments. However, Grigio *et al*. (2015) observed that camu-camu fruits without packaging had a higher weight loss (15%) than packaged fruits (8–9%), concluding that the packaging method help to retain the water in the fruit.

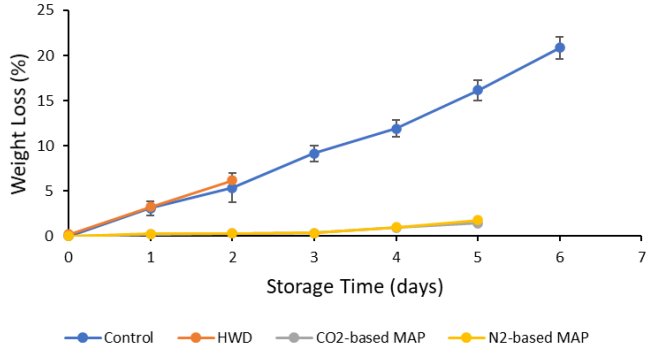


Figure 2. Weight loss (%) of Noni in different storage treatments. HWD: Hot water dipping; MAP: Modified atmosphere packaging; CO_2: Carbon dioxide gas; N_2: Nitrogen gas

3.3 Textural properties

Firmness is an indicator of immaturity or over-maturity of fruits and Table 2 presents the changes in firmness for each treatment during storage. HWD treated noni were removed on day 2 due to the spoilage and formation of black spots and had an 8.0 N reduction in the initial firmness, followed by control, N_2-based and CO_2-based MAP. Due to the spoilage condition of fruits from each treatment from Figure 1, storage was stopped on certain days even though the texture properties were acceptable. The appearance of fruits was considered an important factor that influences consumers' preferences. Grigio *et al*. (2015) mentioned that better-looking camu-camu fruits were stored for further analysis and fruits with loss of brightness and colouration were removed from the experiment even though the texture properties were acceptable.

The firmness of the control treatment started to rapidly ($p<0.05$) decrease after day 3, whereas MAP treatments caused a gradual reduction, with N_2-based MAP was found to have the highest firmness after 6 days in storage compared to CO_2-based MAP and control treatments. There was a negative correlation between firmness and TA ($R = -0.736$, $p<0.05$), suggesting that the decreased firmness produced significantly higher TA in noni. Also, strong negative correlations were detected between TCD of skin ($R = -0.819$, $p<0.05$) and flesh ($R = -0.804$, $p<0.05$), revealing that the decreased firmness also significantly changed the TCD of noni during storage. Arendse *et al*. (2014) also reported that pomegranate's firmness decreased significantly in all storage treatments at chilled and room temperature. Firmness is related to the softening promoting enzyme (polygalacturonase), which is responsible for the breakdown of pectin, resulting in a short storage period of HWD samples compared to the other treatments in this study.

3.4 Total soluble solid and titratable acidity

According to Table 2, noni subjected to HWD had higher total soluble solids (TSS) compared to other treatments on day 2. Thirukkumar *et al*. (2017) also stated that the TSS of noni significantly ($p<0.05$) increased up to 13.0°Bx as the blanching time increased. After 6 days, the TSS of the control treatment was maintained at ~9.6°Bx, while the readings in CO_2-based and N_2-based MAP treatments started to decrease after day 3 to 8.6 and 8.3°Bx, respectively. Grigio *et al*. (2015) findings regarding camu-camu fruit were in contrast with the control and HWD samples but in line with MAP treatments. They claimed that all treatments reduced the soluble solid content during storage days, due to compounds such as carbohydrates, organic acids, proteins, fat and mineral being used as an energy source for metabolic changes in plant tissues as the fruits progressed to senescence.

Also, TSS was affected by the concentration of sugar in the fruit. According to Grigio *et al*. (2015), the increase of soluble solids in unpackaged fruits was related to weight loss that increased the sugar concentration in the pulp. Hazbavi *et al*. (2015) reported that increasing soluble solids was due to water escape throughout storage and the enzymatic breakdown of larger polysaccharides to smaller sugar compounds. Gluconeogenesis is a metabolic process producing new glucose from non-carbohydrate carbon sources, which can occur in Noni stored in an open container. In contrast, the MAP treatments with a specific atmosphere decreased the TSS values due to metabolic changes. The packaging also caused water condensation that produced water vapour, which increased the amount of moisture, thus reducing the TSS. Linke and Geyer (2013) previously reported that fruit packaging promotes water condensation, leading to high humidity and reduced water loss. Furthermore, Hossain *et al*. (2014) observed that the TSS increased during the storage of mango due to the degradation of cell walls and hydrolysis of starch. TSS is directly proportional to the degree of fruit ripening, which positively relates to the percentage weight loss and storage period.

Table 2. Changes in the firmness, total soluble solids (TSS) and titratable acidity (TA) of Noni during different storage treatments.

Treatments	Storage time (days)						
	0	1	2	3	4	5	6
Firmness (N)							
Control	21.3±4.6^{Aa}	16.3±4.3^{Aab}	13.4±2.8^{Bb}	1.2±0.3^{Bc}	0.6±0.1^{Bc}	0.6±0.1^{Bc}	0.5±0.1^{Bc}
HWD	26.0±0.7^{Aa}	18.2±2.0^{Ab}	18.0±1.9^{Ab}	-	-	-	-
CO_2-based MAP	22.0±2.6^{Aa}	20.8±3.0^{Aa}	19.3±1.8^{Aa}	9.7±0.4^{Ab}	1.4±0.4^{ABc}	0.8±0.1^{Bc}	0.5±0.1^{Bc}
N_2-based MAP	21.3±3.0^{Aa}	19.0±4.7^{Aa}	14.8±0.3^{ABab}	9.3±0.5^{Abc}	4.3±2.0^{Acd}	1.9±0.1^{Ad}	0.8±0.1^{Ad}
TSS (°Brix)							
Control	9.7±0.6^{Abc}	10.3±0.5^{Aab}	9.6±0.5^{ABbcd}	8.4±0.5^{Bcd}	9.4±1.1^{Abcd}	8.3±0.2^{Ad}	9.6±0.5^{Abcd}
HWD	9.5±0.5^{Ab}	11.0±0.8^{Aa}	10.5±0.7^{Aab}	-	-	-	-
CO_2-based MAP	9.5±0.6^{Aab}	10.3±1.0^{Aa}	8.3±0.4^{BCc}	9.5±0.5^{Ab}	9.1±0.6^{Abc}	8.8±0.2^{Abc}	8.6±0.4^{Bbc}
N_2-based MAP	9.8±0.4^{Aa}	8.6±0.5^{Bab}	7.2±1.5^{Cb}	9.2±0.5^{ABa}	9.1±0.7^{Aa}	8.9±0.6^{Aab}	8.3±0.3^{Bab}
TA (%)							
Control	0.4±0.1^{Ac}	0.4±0.1^{ABc}	0.5±0.7^{Ac}	0.5±0.1^{Ac}	0.7±0.3^{Ab}	0.8±0.1^{Aab}	0.9±0.3^{Aab}
HWD	0.3±0.1^{Ab}	0.5±0.1^{Aa}	0.4±0.1^{Aa}	-	-	-	-
CO_2-based MAP	0.3±0.1^{Acd}	0.2±0.1^{Bd}	0.4±0.1^{Abc}	0.3±0.1^{Bcd}	0.5±0.1^{Bab}	0.5±0.1^{Bab}	0.7±0.1^{Ba}
N_2-based MAP	0.4±0.1^{Acd}	0.3±0.2^{Bd}	0.4±0.1^{Abcd}	0.5±0.1^{Aabc}	0.5±0.1^{Bab}	0.6±0.1^{Ba}	0.6±0.1^{Ba}

[a]HWD: Hot water dipping; MAP: Modified atmosphere packaging; CO_2: Carbon dioxide gas; N_2: Nitrogen gas. Figures in parentheses indicate the standard deviation. Values with the same lowercase superscript in each column or uppercase superscript in each row are not significantly different ($p>0.05$).

Furthermore, titratable acidity (TA) reflects the amount of acid as the fruit ripening and acid is responsible for the sweetness by transforming into sugar. As shown in Table 2, TA significantly increased ($p<0.05$) after day 1 for HWD and day 4 for control and MAP treatments. During day 6, the TA was highest in the control, followed by CO_2-based and N_2-based MAP treatments. HWD had a lower TA value on day 0 than other treatments, in line with a study by Shen *et al*. (2013) whereas fruit treated with high temperature had a lower TA due to leaching of the tenoplast membrane after heat treatment. However, Arendse *et al*. (2014) reported that lack of consistency in TA value could be because the moisture loss contributed to the high organic acids with increased temperature. Moreover, there was a positive correlation ($R = 0.714$, $p<0.05$) between TA and weight loss, demonstrating that the increase in weight loss also resulted in the higher TA in noni during storage.

Grigio *et al*. (2015) reported that TA for all treatments had a small increase at the beginning of storage due to moisture loss causing organic acids to be more concentrated, which later decreased due to the natural process of maturation and fruit senescence because organic acids acted as an energy source. Hossain *et al*. (2014) suggested that the significant decrease in the TA of mango during storage is due to their utilisation as substrates for respiration. In contrast, this study showed an increment in TA for each treatment over time, similar to a report by Rosalizan *et al*. (2010) of *Sambucus nigra* L., which suggested that the changes in TA during storage were due to the predominant free amino acids in fully developed fruits. Amino acids have been detected in noni's early and senescence stages, with leucine being the highest as the fruit matured (Golden and Lindsay, 2012), indicating an increase in TA. Also, the higher TA also significantly ($p<0.05$) increased the TCD of noni skin and flesh, as supported by the positive correlations, $R = 0.630$ and $R = 0.693$, respectively.

3.5 Scopoletin content

Scopoletin is known for its anti-fungal, anti-inflammatory, anti-allergy, and anti-angiogenesis effects (Li *et al*., 2015). The scopoletin content of noni depends on the maturity of the fruit and postharvest treatment. As mentioned by Moon *et al*. (2007), scopoletin helps to control the serotonin level in the body. According to a study by Deng *et al*. (2007), scopoletin content in noni juice extract as measured by HPLC ranged between 0.88 mg/g and 34.01 mg/g, suggesting that the results in this study (6.32–28.55 mg/g) were acceptable. Overall, the scopoletin content was higher on day 0, followed by a decrease, then increased towards the end of storage as quantified by HPLC (Table 3 and Figure 3). Notably, a significantly ($p<0.05$) lower scopoletin content was found in noni subjected to HWD on day 0 compared to other treatments, followed by a significant ($p<0.05$) decrease, then increase during day 1 and 2, respectively, yet the concentration was lower than day 0. In contrast, Basar *et al*. (2010) observed that HWD had a higher value on day 2 compared to day 0 due to heat concentration which increased the relative concentration of scopoletin. The control treatment had the highest

Table 3. Scopoletin concentrations (mg/g) in Noni as quantified by HPLC during different storage treatments.

Treatments	Scopoletin concentration (mg/g)				
	Storage time (days)				
	0	1	2	3	5
Control	28.55±0.03^{Aa}	15.10±0.03^{Ad}	-	18.64±0.03^{Ac}	18.53±0.02^{Cc}
HWD	11.08±0.04^{Ba}	6.32±0.11^{Dc}	9.50±0.02^{b}	-	-
CO_2-based MAP	27.55±0.05^{Aa}	14.82±0.05^{Ad}	-	15.27±0.01^{Cc}	22.02±0.08^{Bb}
N_2-based MAP	28.00±0.03^{Aa}	13.97±0.01^{Cd}	-	16.30±0.04^{Bc}	27.12±0.17^{Ab}

[a]HWD: Hot water dipping; MAP: Modified atmosphere packaging; CO_2: Carbon dioxide gas; N_2: Nitrogen gas. Figures in parentheses indicate the standard deviation. Values with the same lowercase superscript in each column or uppercase superscript in each row are not significantly different ($p>0.05$).

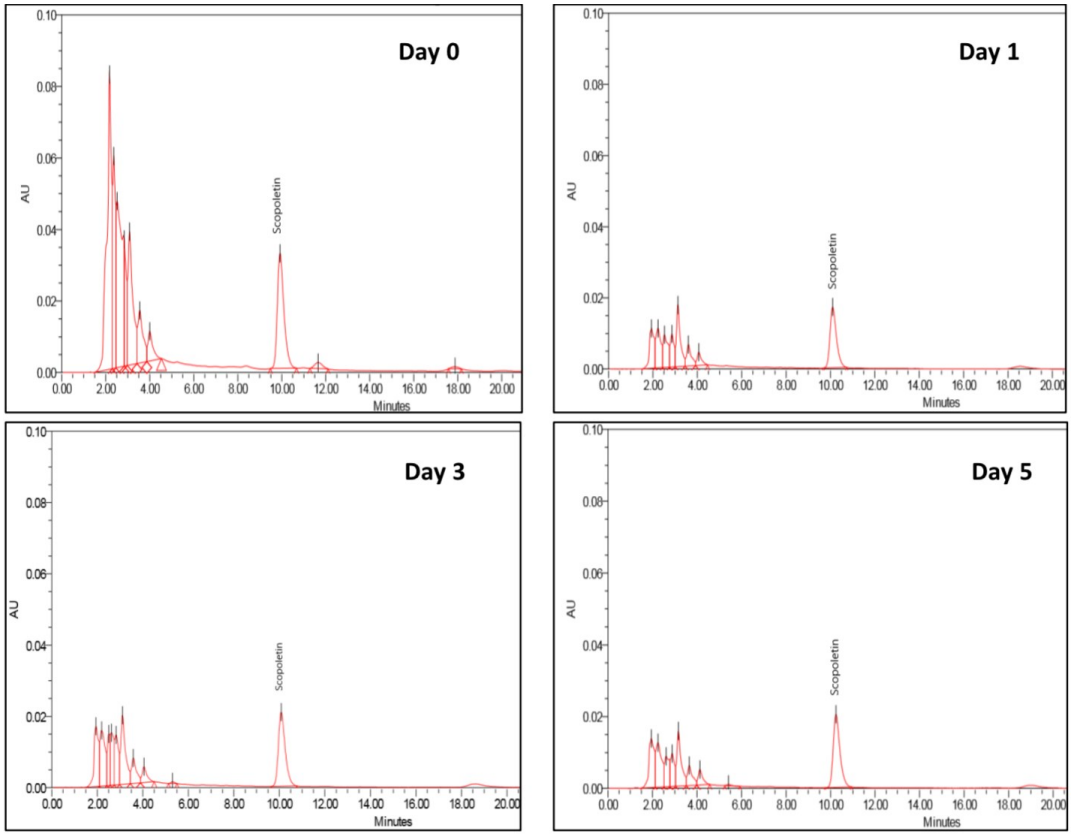


Figure 3. Typical HPLC chromatograms of scopoletin content in Noni during storage

concentration on day 0 and began to decrease and stagnant from day 3 to 5, in agreement with a study by Chan-Blanco *et al*. (2007). They reported that the scopoletin content increased as the fruit ripened, remaining constant during ageing. The maturity of noni varied with different nutritional values. Setyaningsih and Subekti (2019) claimed that noni fruit has the highest scopoletin content when the fruit is nearly ripe.

Interestingly, for both CO_2-based and N_2-based MAP treatments, scopoletin concentration decreased and increased significantly ($p<0.05$) after day 3 of storage. Both MAP treatments had a higher scopoletin content, as shown in Table 3, proving that the MAP method efficiently accumulated scopoletin compared to the control and HWD treatments. According to Dziedzic *et al*. (2020), MAP treated blue honeysuckle fruits had more bioactive compounds compared to those stored at room temperature. In addition, Khorshidi *et al*. (2011) reported that MAP increased the gas concentration in the system, leading to abiotic stress, causing the accumulation of secondary metabolites, including bioactive compounds in fruits. Similarly, Buschmann *et al*. (2000) reported that scopoletin in cassava roots was high directly after harvesting due to its response to harm. There was a decline in scopoletin content, followed by an increase after six days due to the defensive response towards microbial growth. Also, scopoletin acts as an anti-microbial agent at the infected part, with a ten-fold increase in the scopoletin content (Peterson *et al*., 2003). However, moderate negative correlations were recorded between the scopoletin content and a^* ($R = -0.481$, $p<0.05$) and b^* ($R = -0.499$, $p<0.05$), suggesting that the decrease in scopoletin content also reduced the greenness and yellowness of noni flesh.

4. Conclusion

This study reported the effect of different postharvest treatments on the physicochemical stability of noni.

According to the results, even though control treatment fruit had a longer shelf life than other treatments, the quality and stability of noni were not maintained. Heat treatment is a common technique used in industry; however, the HWD treatment used in this study affected the quality and shortened noni's shelf life. Interestingly, MAP treatments were found to efficiently preserve the Noni, with a lower weight loss, TSS, TA and TCD and higher firmness and scopoletin content observed during storage. Comparing the two MAP treatments, resulted in significantly ($p<0.05$) firmer fruit with a higher scopoletin content than the CO_2-based MAP, indicating that the N_2-based MAP postharvest treatment is best to efficiently maintain the stability and quality of noni during storage.

Conflict of interest

The authors declare no conflict of interest.

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