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Effect of Ethanol Vapor and Perforations in Polyethylene Bags on the Postharvest and Antioxidant Qualities of 'Thai Round Green' Eggplant Fruit

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Abstract

Eggplant is a horticulturally important crop that is highly perishable. To delay the deterioration of eggplant fruit quality, the use of packaging with different perforations and ethanol vapor was evaluated. Treatments included polyethylene bag (PEB) (0.04 mm) with 12 or 18 perforations (0.5 mm) and with or without ethanol vapor releasing sachet (0 or 0.3 g). 'Thai Round Green' eggplants stored at 13 °C were evaluated every four days for 12 days. Total phenolic content (TPC); 2,2-diphenyl-1-picrylhydrazyl (DPPH) radical scavenging activity; browning index; and vitamin C were analyzed. Weight loss was reduced in eggplant packed in PEB with 12 perforations at four and eight days with addition of ethanol vapor. The use of PEB with 12 perforations and ethanol vapor reduced the fungal contamination in sample eggplants. The vitamin C content of eggplant did not vary in both treatments. The use of PEB with 18 perforations decreased the TPC while addition of ethanol vapor increased browning of fruit at four days. Addition of ethanol in PEB with 12 perforations increased the TPC of pedicel and DPPH of fruit both at four days while it increased the browning at 12 days. Respiration of eggplant was initially higher in PEB with 12 perforations but it decreased at eight days of storage. The use of PEB with 12 perforations and 0.3 g ethanol vapor releasing sachet showed potential in maintaining the quality of 'Thai Round Green' eggplant at low temperature (13 °C) for four to eight days.

***Keywords**:* antioxidant content, 'Thai Round Green' eggplant, ethanol vapor, perforations in film bags

1. Introduction

Eggplant (*Solanum melongena* L.) is a horticulturally important solanaceous crop widely grown in the world. It is believed to have originated in India with more than 90% of the world's eggplant production coming from Asia (Islam *et al*., 2014). Eggplant fruit comes in varying colors, shapes and sizes, depending on the cultivar, with lengths of 4 to 45 cm, widths of 2 to 35 cm and weights of 15 to 1500 g (Swarup, 1995).

Eggplant is known for its high nutritive values. It is rich in vitamins B1 (thiamine), B2, B5 (pantothenic acid), B6, C, K, niacin, and minerals like magnesium, potassium, manganese and copper (Alam *et al*., 2006). It contains phenolic compounds and flavonoids (Singh *et al*., 2009), which has beneficial effects on human health. The presence of phenolic compounds and glycoalkaloids are common in the solanaceous family (Salunkhe and Kadam, 1998). It also contains polyphenol oxidase (PPO) which causes browning of tissues of eggplant fruit when cut and exposed to air (Salunkhe and Kadam, 1998).

Like many fruits and vegetables, eggplant is a highly perishable crop and cannot be stored long in ambient conditions. Proper postharvest treatments are critical to reduce postharvest losses and maintain good quality of fresh produce. Appropriate technologies help reduce the deterioration of fresh produce and maintain its nutritive quality. Some methods to delay produce deterioration include the use of modified atmosphere packaging, storage at low temperature, use of ethylene absorbents and application of chemicals that can control decay and ripening. Appropriate semi-permeable film packaging lessens respiration rate of fresh produce thereby maintaining its quality and increasing its shelf life. Proper ventilation through perforations is crucial in avoiding the build-up of carbon dioxide and heat that promotes faster deterioration of fruit in non-perforated or passive modified atmosphere packaging (Ngure *et al*., 2009). Storage of African eggplant in transparent perforated polyethylene bags resulted in lowest weight loss and longest shelf life compared to those stored closed in paper boxes and on-bench storage (Majubwa *et al*., 2015). In addition, the use of perforated polyethylene bag on eggplant stored at 13 °C for 15 days alleviated chilling injury and slightly increased the phenolic compounds content (Barragán *et al*., 2019).

On the other hand, one of the methods in controlling the deterioration of fruit is the use of ethanol vapor as postharvest treatment. Ethanol is known for its antifungal effect which can be applied in food as vapor. Ethanol vapor in sachet uses a carrier or a release pad that is usually a porous adsorbent with a high specific surface area that is not readily exposed (Utto, 2014). The use of ethanol in sachets offers an advantage over the dipping method as it can be safely incorporated in the packaging of food to provide an extended protection against latent infection during storage (Lurie *et al*., 2006). Ethanol vapor is widely known for its antimycotic effect in food, especially in bakery products (Daifas *et al*., 2000). There is an increasing interest on the application of ethanol vapor not only in bakery products but also in fresh produce. It has been reported to reduce decay development in horticultural crops such as in grapefruit, guava and sweet melon (Lurie *et al*., 2006; Jin *et al*., 2013; Ponzo *et al*., 2018). In tomato, ethanol vapor has shown to prolong shelf life by inhibiting the ripening process (Roy *et al*., 2017). In Chinese bayberry, ethanol vapor reduced decay development and maintained fruit quality because of an increased accumulation of anthocyanins (Zhang *et al*., 2007).

The combination of appropriate packaging and ethanol vapor can potentially help to maintain the quality of fresh produce. The use of ethanol in packaging of fruit is a recent interest in the development of active packaging for horticultural products (Utto, 2014). In eggplant, there is little information on the effect of ethanol vapor on its antioxidant and postharvest qualities. Hu *et al*. (2010) reported on the positive effect of ethanol on the physiological and quality attributes of fresh-cut eggplant when exposed to ethanol vapor (5 mL kg^{-1}) in a sealed container for 5 h at 20 °C. In this study, the effects of polyethylene bag with different perforations and ethanol vapor, generally recognized as safe compound (Jin *et al*., 2013), on the postharvest and antioxidant qualities of whole eggplant fruit were evaluated.

2. Methodology

The study was conducted in the Postharvest Laboratory of the School of Bioresources and Technology in King Mongkut's University of Technology Thonburi, Bangkhunthian, Bangkok, Thailand. Fifty kilograms of commercially mature 'Thai Round Green' eggplants were used in the study. Fruit were sorted according to quality. Fruit with uniform good quality were washed with water and air dried before treatment.

Treatments included polyethylene bags (0.04 mm thick; 22.9 cm L x 15.2 cm W) with 12 or 18 perforations (5 mm diameter, 6 or 9 perforations each side of the packaging) and with or without ethanol vapor releasing sachet (Antimold®, Japan) (0 or 0.3 g). There were four treatment combinations: (a) 12 perforations without ethanol vapor; (b) 12 perforations with ethanol vapor sachet (0.3 g); (c) 18 perforations without ethanol vapor; (d) 18 perforations with ethanol vapor sachet (0.3 g). Each pack was composed of six to nine eggplants with average weight per pack of 250.7±3.2 g. Fruit were stored at low temperature (13°C) and evaluated at four, eight and 12 days after storage.

2.1 Evaluation of Postharvest and Antioxidant Qualities of Eggplant Weight Loss

Weight of eight sample packs of eggplant in each treatment was initially obtained and weighed at a four-day interval for 12 days. Percentage of weight loss was calculated using the formula (Equation 1).

$$Weight\ loss\ (\%) = \frac{Initial\ weight - Final\ weight}{Initial\ weight} \times 100 \qquad (1)$$

2.2 Fungal Contamination

The degree of fungal development on the pedicel, calyx, and fruit, was regularly assessed for each package. The degree of fungal development was assessed using the rating scale of 0 to 5: 0 = no fungi; 1= < 5% of surface area with fungal development; 2 = < 10% of surface area; 3 = < 15% of surface area; 4 = < 20% of surface area; and 5 = >25% of surface area.

2.3 Vitamin C

Samples for vitamin C in eggplant were obtained from fruit excluding the pedicel and calyx. The method of Kapur *et al*. (2012) was used to determine the vitamin C in eggplant. Eggplant sample (2.5 g) was mixed and homogenized with 10 mL of 5% metaphosphoric acid. The extract was centrifuged at 12,000 × g at 4 °C for 10 min. Next, 0.4 mL of the supernatant was mixed with 0.2 mL of 0.2% indophenol, 0.4 mL of 2% thiourea and 0.2 mL of 2% 2,4-dinitrophenol (DNP). The solution was incubated at 37 °C for 3 h after which 1 mL of 85% sulfuric acid (H_2SO_4) was added. Next, the solution was incubated at room temperature for 30 min. The absorbance was recorded at 540 nm with ascorbic acid as the standard. The results were expressed as mg/100 g of fresh weight.

2.4 Total Phenolic Content (TPC)

The TPC was determined following the method of Singleton *et al*. (1999). Eggplant samples (2.5 g) were extracted with 10 mL of 80% ethanol. The extract was centrifuged at 8,000 × g at 4 °C for 20 min. From the supernatant, each sample of 0.02 mL was added with 1.6 mL distilled water, 0.1 mL of 100% Folin-Ciocalteu reagent and 0.2 mL of 20% sodium carbonate (Na_2CO_3). The solution was incubated at 40 °C for 30 min. The absorbance was recorded at 765 nm with gallic acid as the standard. The results were expressed as gallic acid equivalents (GAE)/100 g of fresh weight.

2.5 DPPH (2,2-diphenyl-1-picrylhydrazyl) Radical Scavenging Activity

The DPPH radical scavenging activity was determined using the method of Cavin *et al*. (1998). The working solution was prepared daily by mixing 2,2-diphenyl-1-picrylhydrazyl and 95% ethanol in a ratio of 1:5 (v/v). Eggplant samples (2.5 g) were extracted with 15 mL of 80% ethanol. The extract was centrifuged at 8,000 × g at 4 °C for 20 min; after which, 0.15 mL of the extract was mixed with 2.85 mL of the DPPH working solution. The solution was incubated at room temperature and was kept in a dark condition for 30 min. The absorbance was recorded at 515 nm. The DPPH radical scavenging activity was calculated using the formula (Equation 2).

$$DPPH\ radical\ scavenging\ activity\ (\%) = \frac{Absorbance\ of\ working\ solution - Absorbance\ of\ sample}{Absorbance\ of\ working\ solution} \times 100 \qquad (2)$$

2.6 Browning Index

The method used in assessing the browning of eggplant fruit and pedicel was modified from Supapvanich *et al*. (2011) where 2.5 g of eggplant samples were extracted with 80% ethanol. The extracted sample (0.4 mL) was diluted with 1.6 mL distilled water. The absorbance was recorded at 420 nm. The browning index described by the absorbance value in which the higher the value, the higher the browning (Sun *et al*., 2015).

2.7 Respiration

Four fruit from each sample pack were used to determine the respiration rate. Fruit were placed in a 400 mL air-tight plastic container and incubated at 13°C room temperature for 1 h. A 1 mL gas sample was withdrawn from the headspace and injected in a gas chromatograph (Shimadzu, Japan) equipped with a thermal conductivity detector (TCD). Nitrogen gas was used as a carrier.

2.8 Experimental Design

The experiment was a factorial experiment arranged in completely randomized design (CRD). Data were analyzed through analysis of variance (ANOVA). The least significant difference (LSD) at $p < 0.05$ was used to compare treatment means. Per evaluation period, eight packs of eggplant were used per treatment for physical quality assessment while four packs were used for respiration and chemical assessment with a pack as a replication.

3. Results and Discussion

3.1 Perforations in the Polyethylene Bag (PEB) Affected % Weight Loss

Weight loss did not vary with ethanol vapor treatments, but it differed at four and eight days of storage with the different perforations of the PEB (Table 1). At eight days, weight loss was lower (0.83%) in the package with 12 perforations. However, at 12 days, lower weight loss at 1.15% was recorded in the package with 18 perforations.

Table 1. Percentage weight loss of 'Thai Round Green' eggplant fruit packed in perforated polyethylene bags at two ethanol vapor concentrations during low temperature storage at 13°C

No. of perforations	Ethanol vapor concentration (g)		Mean
	0	0.3	
	Day 4		
12	0.78±0.14 ^{aA}	0.88±0.36 ^{aA}	0.83±0.27^{b}
18	1.03±0.19 ^{aA}	1.10 ±0.10^{aA}	1.58±0.15^{a}
Mean	0.91±0.20^{A}	0.99±0.28^{A}	
	Day 8		
12	1.36±0.22^{aA}	1.19±0.16^{aB}	1.28±0.21^{a}
18	1.07±0.05^{bB}	1.22±0.05^{aA}	1.15±0.10^{b}
Mean	1.22±0.91^{A}	1.21±0.120^{A}	
	Day 12		
12	2.03±0.16^{bB}	3.02±0.54^{aA}	2.53±0.58^{a}
18	3.06±038^{aA}	2.60±0.68^{aA}	2.83±0.64^{a}
Mean	2.46±0.60^{A}	2.81±0.63^{A}	

Per sampling day, means per column ^{ab} and per row ^{AB} with same letters are not significantly different at 5% level of significance using LSD.

Significant interaction between perforation in the package and ethanol vapor treatment was observed at eight and 12 days of storage (Table 7). At eight days, addition of 0.3 g of ethanol vapor releasing sachet decreased the weight loss of eggplant in PEB with 12 perforations but it hastened weight loss when the number of perforations was increased to 18. At 12 days of storage, fruit packed in PEB with 12 perforations resulted in lower weight loss but addition of 0.3 g ethanol vapor increased it. In all treatments, weight loss was minimal during storage as fruit was stored at low temperature (13°C).

In banana, 0.3 g ethanol vapor releasing pad showed lower weight loss compared to the untreated control and 0.6 g ethanol vapor releasing pad (Duerme *et al.*, 2019). Likewise, ethanol vapor reduced the weight loss of tomato by slowing down its respiration (Roy *et al*., 2017). Ethanol vapor also reduced the weight loss in fresh cut eggplant due to the higher water retention ability of the ethanol treatment (Hu *et al.*, 2010). The presence of ethanol was reported to influence the structure of cellular membrane in which the equivalent pore radius in the membrane became narrower and the membrane more hydrophobic (Kiyosawa *et al.*, 1975; Li *et al.*, 2018). This probably slowed down the water loss resulting in lower weight changes of eggplant. In a modified atmosphere packaging, respiration rate is lessened resulting in a slightly slow consumption of carbohydrate, thereby reducing weight loss in produce (Zenoozian, 2011). However, increasing the number of perforations results in higher permeability of packaging which influences the respiration and transpiration rates (Panta and Khanal, 2018). In the present study, PEB with 12 perforations only reduced the weight loss at four days of storage but addition of ethanol vapor reduced the weight loss at eight days. The interaction between ethanol vapor and perforations in packaging on the weight loss might have been due to both retention of water and slower respiration process.

3.2 Ethanol Vapor Reduced Fungal Contamination in the Perforated Package

As early as four days, fungi observed in eggplant were commonly found in the pedicel and calyx. At eight days, lesser fungal contamination was observed in 0.3 g ethanol vapor releasing sachet than in packaging without ethanol vapor (Table 2). However, at 12 days, ethanol vapor was no longer able to reduce the fungal contamination in eggplants. Lesser fungal contamination was observed in eggplant packed in PEB (with 12 perforations) than those in PEB with more perforations.

Table 2. Degree of fungi contamination of 'Thai Round Green' eggplant fruit packed in perforated polyethylene bags at two ethanol vapor concentrations during low temperature storage at 13 °C

No. of perforations	Ethanol vapor concentration (g) 0	0.3	Mean
	Day 4		
12	0.25±0.46[aA]	0.38±0.52[aA]	0.32±0.48[a]
18	0.25±0.46[aA]	0.38±0.52[aA]	0.32±0.48[a]
Mean	0.25±0.46[A]	0.38±0.50[A]	
	Day 8		
12	1.50±0.76[aA]	1.07±0.64[aA]	1.29±0.66[a]
18	1.68±0.89[aA]	0.75±0.71[aA]	1.22±0.77[a]
Mean	1.59±0.83[A]	0.91±0.58[A]	
	Day 12		
12	3.13±0.83[aA]	3.02±0.46[bB]	3.08±0.66[a]
18	3.06±0.89[bB]	3.4±0.714[aA]	3.25±0.77[a]
Mean	3.01±0.83[A]	3.23±0.58[A]	

Per sampling day, means per column [ab] and per row [AB] with same letter are not significantly different at 5% level of significance using LSD.

A significant interaction between ethanol and perforations in PEB was observed at 12 days (Table 7). Addition of ethanol vapor in PEB with 12 perforations reduced the fungal contamination in eggplants compared to PEB with 18 perforations and ethanol vapor releasing sachet.

Ethanol acts as a stress agent targeting the cell membrane of fungal cells that also denature the protein and inhibit the uptake of nutrients (Dao and Dantigny, 2011). This antifungal effect of ethanol vapor was shown in the present study up to eight days of storage and at 12 days in PEB with 12 perforations. The present study also showed that the efficacy of ethanol vapor varied between PEB with different perforations. In other horticultural crops, ethanol vapor was able to control microbial contaminants which reduced the decay incidence of fruits such as banana (de Franca *et al.*, 2018), mulberry (Choosung *et al.*, 2019), Chinese bayberry (Zhang *et al.*, 2007) and table grapes (Chervin *et al.*, 2005).

In a perforated film bag, ethanol at 3 g of alcohol powder accumulated in the atmosphere of the PEB in which the concentration increased and remained steady during five days of storage (Suzuki *et al.*, 2004). The concentration of ethanol was not measured in the present study. However, the antimycotic effect of ethanol vapor was observed at four days of storage, within the period in which the concentration of ethanol may have been more compared to a package without it. In loquat fruit, ethanol vapor controlled the decay due to inhibition of pathogen growth and disease resistance induction in the fruit tissue through increase in H_2O_2 content, and activities of defense-related enzymes such as phenylalanine ammonia lyase, peroxidase and polyphenol oxidase (Wang *et al*., 2015).

3.3 Vitamin C was not Affected by Ethanol Vapor and Perforations in PEB

The vitamin C content of eggplant ranged from 6.37 mg/100 g of fresh weight at the initial stage of storage to 3.72 mg/100 g of fresh weight at 12 days. There was no consistent trend in vitamin C content of eggplant in all treatments. Also, no significant interaction was observed between the package perforations and ethanol vapor from four to 12 days of storage (Table 7). The initial vitamin C content of the Thai eggplant used in this study was within the values reported by Niño-Medina *et al*. (2014) at 7.4±2.9 (mg/100 g of fresh sample) although this decreased during storage.

Opio *et al*. (2015) reported that ethanol vapor at a higher concentration of 0.6 g was able to maintain the vitamin C content of lime fruit. Compared with the concentration used in the present study, a higher concentration of ethanol vapor on broccoli inhibited some metabolic activity and senescence through the suppression of ethylene production (Suzuki *et al*., 2004). Ethanol concentration and produce type are factors that influence the vitamin C content of produce treated with ethanol vapor. The lower concentration of ethanol vapor used in the study may not have been enough to influence the vitamin C content of eggplant.

3.4 Ethanol Vapor in PEB with 12 Perforations Increased the TPC of Pedicel and Calyx

Higher TPC was recorded in fruit than in pedicel and calyx (Table 3). Eggplant fruit had higher TPC which decreased during storage from 89.27 to 48.84 GAE/100g of fresh weight. However, TPC in fruit was not affected by the number of perforations in PEB and ethanol vapor. On the other hand, TPC varied in the eggplant pedicel and calyx at four days and significant interaction was observed (Table 7). Higher TPC was recorded in eggplant packed in PEB with 12 perforations. Addition of ethanol vapor in PEB with 12 perforations increased the TPC. At 12 days of storage, TPC was not measured due to increasing fungal contamination on the sample.

Table 3. Pedicel TPC (GAE/100g of fresh weight) of 'Thai Round Green' eggplant packed in perforated polyethylene bags at two ethanol vapor concentrations during low temperature storage at 13 °C

No. of perforations	Ethanol vapor concentration (g)		Mean
	0	0.3	
	Day 4		
12	7.82±0.06^{aB}	11.22±0.09^{aA}	9.52±0.08^{a}
18	6.14±0.03^{aA}	5.00±0.04^{bA}	5.57±0.03^{a}
Mean	6.98±0.06^{A}	8.11±0.07^{A}	
	Day 8		
12	7.63±0.06^{aA}	9.52±0.03^{aA}	8.56±0.04^{a}
18	6.16±0.03^{aA}	8.03±0.02^{aA}	7.10±0.03^{a}
Mean	6.90±0.05^{A}	8.78±0.03^{A}	

Per sampling day, means per column ^{ab} and per row ^{AB} with same letter are not significantly different at 5% level of significance using LSD.

Phenolic acids are present in free, conjugated and insoluble-bound forms that act as an antioxidant by scavenging hydroxyl radical, superoxide radical anion, several organic radicals, peroxyl radical, peroxynitrite and singlet oxygen (Chandrasekara, 2019). The reduction of phenolic content during storage is attributed to phenols as substrate for polyphenol oxidase enzyme (Mir *et al*., 2018). The enzyme catalyzes the oxidation of phenolics which result in undesirable browning of fruit (Utami *et al*., 2018). A reduction in the total phenolic content was reported in tomato exposed to ethanol vapor (Tzortzakis and Economakis, 2007). In contrast, an increase of TPC was reported in cut eggplant (Hu *et al*., 2010) and broccoli florets treated with ethanol (Xu *et al*., 2012). The high phenolic content in ethanol-treated cut eggplant could prevent other reactions and maintain the quality during storage as high phenolic content is responsible for the high antioxidant capacity (Hu *et al*., 2010). This increase of phenolic content was also observed in the present study in the pedicel and calyx of eggplant fruit treated with ethanol packed in PEB with 12 perforations.

It has been suggested that the action of ethanol was through modification of membrane structure and permeability. It can lower the membrane breakage and maintain the integrity of the membrane in eggplant (Hu *et al*., 2010). However, an excessively high concentration of ethanol was reported to hasten the softening and weight loss which could be related to the rupture of plasma membrane in tissue (Li *et al*., 2018). Ethanol in wampee fruit showed positive effect on membrane integrity by regulating phenol metabolism in which it maintained higher phenolic content and enhanced the antioxidant systems (Shao *et al*., 2020).

3.5 Ethanol Vapor in PEB with 12 Perforations Increased % DPPH Radical Scavenging Activity in the Early Stage of Storage

The DPPH of pedicel and calyx was not affected by both ethanol vapor and perforations of PEB. Also, the DPPH radical scavenging activity of fruit was not affected by perforations and ethanol vapor (Table 4) but a significant interaction effect of the treatments was observed at four days of storage (Table 4). A lower DPPH radical scavenging activity was observed in PEB with 12 perforations but it increased with the addition of 0.3 g ethanol. On the other hand, packaging of eggplant in PEB with 18 perforations without ethanol resulted in higher DPPH radical scavenging activity.

Table 4. Percentage of DPPH radical scavenging activity of 'Thai Round Green' eggplant fruit packed in perforated polyethylene bags at two ethanol vapor concentrations during low temperature storage at 13 °C

No. of perforations	Ethanol vapor concentration (g)		Mean
	0	0.3	
	Day 4		
12	35.44±17.65^{bB}	52.78±5.38^{aA}	44.11±15.22^{a}
18	53.36±3.47^{aA}	47.48±9.57^{aA}	50.42±7.37^{a}
Mean	44.4±15.18^{A}	50.13±12.08^{A}	
	Day 8		
12	50.53±13.16 ^{aA}	60.69±14.97^{aA}	55.61±14.13^{a}
18	63.20±10.98^{aA}	63.29±11.78^{aA}	63.25±9.98^{a}
Mean	56.87+/-13.10	61.99±13.37^{A}	

Per sampling day, means per column ^{ab} and per row ^{AB} with same letter are not significantly different at 5% level of significance using LSD.

DPPH is a free radical compound that is widely used to measure the antioxidant capacity through free scavenging activity (Nisha *et al*., 2009). Eggplant has a high oxygen radical absorbance capacity due to its phenolics content (Singh *et al*., 2009). In fresh cut strawberry, the ethanol vapor treatment increased the DPPH radical-scavenging activity at 17 % in five days of storage (Li *et al*., 2018). Likewise, in the present study, at four days, an increase of DPPH radical-scavenging activity in eggplant treated with ethanol packed in PEB with 12 perforations was observed. In the study of Li *et al*. (2018), ethanol vapor increased the production of O_2^- and H_2O_2 content resulting in an increased activity of antioxidant enzymes like catalase (CAT), ascorbate peroxidase (APX) and superoxide dismutase (SOD) by up regulating the expression of antioxidant genes. Likewise, higher level of H_2O_2 and activities of SOD, CAT and APX were reported in loquat fruit treated with ethanol vapor which all played crucial roles in inducing disease resistance in fruit (Wang *et al*., 2015). The higher non-enzymatic antioxidants in ethanol-treated wampee fruit scavenged or reduced the accumulation of reactive oxygen species (ROS) which stabilized the membrane systems and consequently reduced the pericarp browning in fruit (Shao *et al.*, 2020).

A strong positive linear correlation between total phenolic and antioxidant capacity was reported in eggplant (Wu *et al.*, 2004). Phenolic compounds in most fruits and vegetables are known to be highly effective free radical scavengers and antioxidants (Wu *et al*., 2004). In the present study, both TPC and % DPPH radical scavenging activity increased with the addition of ethanol in PEB with12 perforations in the early stage of storage.

3.6 Ethanol Vapor in Perforated PEB tended to Increase the Browning Index

There was no significant difference in browning index of fruit (Table 5). However, a significant interaction was observed in browning of fruit at eight and 12 days of storage (Table 5). A higher browning index was observed in eggplants packed in PEB with 12 perforations without ethanol vapor at eight days than those in PEB with 18 perforations alone. At 12 days, browning of fruit packed in PEB with 12 perforations was lower but addition of 0.3 g ethanol vapor releasing sachet resulted in higher absorbance value indicating higher degree of browning.

Table 5. Browning index of 'Thai Round Green' eggplant fruit packed in perforated polyethylene bags at two ethanol vapor concentrations during low temperature storage at 13 °C

No. of perforations	Ethanol vapor concentration (g) 0	0.3	Mean
	Day 4		
12	$0.12{\pm}0.04^{aA}$	$0.14{\pm}0.02^{aA}$	$0.13{\pm}0.03^{a}$
18	$0.15{\pm}0.02^{aA}$	$0.15{\pm}0.01^{aA}$	$0.15{\pm}0.02^{a}$
Mean	$0.14{\pm}0.03^{A}$	$0.45{\pm}0.02^{A}$	
	Day 8		
12	$0.19{\pm}0.01^{aA}$	$0.18{\pm}0.02^{aA}$	$0.18{\pm}0.08^{a}$
18	$0.16{\pm}0.03^{aB}$	$0.20{\pm}0.02^{aA}$	$0.18{\pm}0.08^{a}$
Mean	$0.18{\pm}0.02^{A}$	$0.19{\pm}0.02^{A}$	
	Day 12		
12	$0.17{\pm}0.03^{aB}$	$0.29{\pm}0.09^{aA}$	$0.23{\pm}0.08^{a}$
18	$0.20{\pm}0.02^{aA}$	$0.16{\pm}0.02^{bA}$	$0.18{\pm}0.02^{a}$
Mean	$0.19{\pm}0.03^{A}$	$0.23{\pm}0.09^{A}$	

Per sampling day, means per column ^{ab} and per row ^{AB} with same letter are not significantly different at 5% level of significance using LSD.

The enzymatic browning in sample can be measured using the absorbance values of the browning soluble pigment at 420 nm. A high absorbance at 420 nm of the sample means an increase of browning soluble pigment showing high browning susceptibility in fresh cut produce (Supapvanich *et al.*, 2011). On the other hand, browning can also be measured by measuring the activities of enzymes involved in browning reaction. Polyphenol oxidase (PPO) catalyzes the oxidation of polyphenols which results in browning such as exhibited in lettuce (Yan *et al*., 2015). Ethanol treatment in lettuce controlled the enzymatic browning which is in contrast to the results of the present study. On the other, peroxidase (POD) – another important enzyme that is almost present in plants – also catalyzes browning reactions in fresh cut eggplant (Hu *et al*., 2010). However, both the PPO and POD activities in fresh cut eggplant were lower in ethanol treatment resulting in lower degree of browning. The higher browning in 'Thai Round Green' eggplant packed with the ethanol vapor sachet could be due to phenolic content which increased with ethanol treatment.

3.7 Slightly Higher Respiration Rate in Eggplant Fruit Packed with Ethanol Vapor in the Early Stage of Storage

Respiration of fruit was assessed in terms of CO_2 production. The initial respiration rate of eggplant was 3.38 mg CO_2/kg.hr which decreased during storage at less than 2 mg CO_2/kg.hr. No trend in respiration rate was shown by the number of PEB perforations. During the early stage of storage, a slightly higher respiration rate was recorded in fruit treated with 0.3 g ethanol vapor releasing sachet. Eggplants in the package with 18 perforations showed lower CO_2 production rate at four days (Table 6). No significant interaction was observed between number of perforations and ethanol vapor concentration.

Table 6. CO_2 production rate (mg CO_2/kg.hr) of 'Thai Round Green' eggplant fruit packed in perforated polyethylene bags at two ethanol vapor concentrations during low temperature storage at 13°C

No. of perforations	Ethanol vapor concentration (g)		Mean
	0	0.3	
	Day 4		
12	2.10 ± 0.07^{aA}	2.59 ± 0.16^{aA}	2.35 ± 0.28^{a}
18	1.99 ± 0.22^{aA}	2.37 ± 0.07^{aA}	2.18 ± 0.25^{b}
Mean	2.05 ± 0.17^{B}	2.48 ± 0.17^{A}	
	Day 8		
12	1.77 ± 0.07^{aA}	1.46 ± 0.52^{aA}	1.62 ± 0.39^{b}
18	2.00 ± 0.18^{aA}	1.88 ± 0.13^{aA}	1.94 ± 0.16^{a}
Mean	1.89 ± 0.18^{A}	1.67 ± 0.42^{A}	

Per sampling day, means per column ^{ab} and per row ^{AB} with same letter are not significantly different at 5% level of significance using LSD.

Compared with the initial rate, the respiration rate generally decreased during storage of eggplant in the present study. The rise in respiration was only temporary in ethanol-treated eggplants as it decreased in the succeeding sampling day. In honeydew melon, an increase of respiration rate was detected which leveled out after two days (Ritenour *et al*., 1997). However, treatment of ethanol in honeydew melon did not increase respiration after 13 days of storage with continuous ethanol vapor exposure. There was also no increase of respiration in tomato exposed to ethanol vapor indicating that anaerobic respiration and fermentation did not occur (Atta-ala *et al*., 1999). In treated broccoli, no climacteric-like respiratory increase was observed which possibly indicate that ethanol vapor treatments may result in the inhibition of some metabolic activity and suppression of ethylene production (Suzuki *et al*., 2004). On the other hand, ethanol vapor was not very effective in reducing respiration in apple (Weber *et al*., 2016) while it did not influence respiration in banana (de Franca *et al*., 2018). In fresh cut eggplant, ethanol vapor reduced the respiration rate up to eight days of storage. The differences on the effect of ethanol vapor on respiration maybe attributed to differences in fruit sample, cultivar, exposure and duration of ethanol treatment. To ensure that aerobic respiration still occurred in the perforated packaging with ethanol, it is recommended to measure the level of in-package CO_2, O_2, ethanol; and the accumulation of ethanol in fruit.

Table 7. The interaction effect between ethanol vapor and PEB perforations postharvest and antioxidant qualities of eggplant

Quality Parameter	Days of Storage Pr(> F)			
	0	4	8	12
Percentage weight loss	-	ns	0.0020	0.0002
Degree of fungi contamination	-	ns	ns	0.0039
Vitamin C	ns	ns	ns	ns
Total Phenolic Content (TPC)	ns	0.0139	ns	-

4. Conclusion

To delay the deterioration of quality, the use of PEB packaging with different perforations (12 or 18) and ethanol vapor releasing sachet (0 or 0.3 g) in ‘Thai Round Green’ eggplants was evaluated in this study. The use of PEB packaging with 12 perforations seemed to reduce weight loss but addition of ethanol vapor was not consistent in reducing the weight loss. The antifungal action of ethanol vapor was demonstrated in 0.3 g ethanol vapor treatment and in PEB with 12 perforations as it reduced the degree of fungal contamination. However, the ethanol vapor concentration may not be enough to influence the vitamin C as it did not vary among treatments. The high TPC and enhanced antioxidant capacity in eggplant packed in PEB with 12 perforations and the addition of ethanol at 0.3 g showed a positive effect on the maintenance of fruit quality as it slowed down the development of browning and diseases. On the other hand, the use of packaging with 18 perforations seemed to lessen the TPC and browning of eggplant but addition of 0.3 g ethanol sachet in the packaging did not further contribute in maintaining better quality of fruit. The addition of 0.3 g ethanol sachet in the PEB with 12 perforations temporarily increased the respiration but decreased it thereafter. This may indicate that the modified atmosphere in perforated PEB with ethanol did not lead to anaerobic conditions. However, there is a need to specifically measure the levels of fruit ethanol as well as in-package ethanol, CO_2 and O_2 levels. The present results indicated that ethanol vapor releasing sachets and PEB with 12 perforations showed potential in maintaining the quality of ‘Thai Round Green’ eggplant at low temperature (13°C) for four to eight days.

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