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1-MCP extends the storage and shelf life of mangosteen (*Garcinia mangostana* L.) fruit

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ABSTRACT

Mangosteen (*Garcinia mangostana* L.) fruit were harvested when the peel (pericarp) was light greenish yellow with scattered pinkish spots. Fruit were exposed to 1 μL L^{-1} 1-methylcyclopropene (1-MCP) for 6 h at 25 °C and were then stored at 25 °C (control) or 15 °C. The 1-MCP treatment only temporarily delayed softening of the fruit flesh, during storage. Storage life, defined as the time until the pericarp was dark purple, was much longer in fruit stored at 15 °C than in fruit stored at 25 °C. It was also longer in 1-MCP treated fruit (storage life at 15 °C: control 18 d, 1-MCP-treated fruit 27 d). The 1-MCP treatment also increased the length of shelf life, defined as the time until the pericarp turned blackish purple or showed calyx wilting, at 25 °C. 1-MCP treatment reduced ethylene production. It also reduced pericarp levels of 1-aminocyclopropane-1-carboxylic acid (ACC), and the pericarp activities of ACC synthase (ACS) and ACC oxidase (ACO). In the fruit flesh, in contrast, 1-MCP did not affect ACC levels and ACS activity, but the treatment reduced ACO activity. Taken together, both the storage life and the shelf life of the fruit were extended by the 1-MCP treatment. A decrease in ACO activity largely accounted for the effects of the 1-MCP on ethylene production in the pericarp.

1. Introduction

Mangosteen (*Garcinia mangostana* L.) is a tropical fruit with a high market value but with a relatively short storage and shelf life. The fruit rapidly changes its pericarp (peel) colour and shows shrinkage of both the attached stem end and sepals (calyx). The storage temperature cannot be lower than about 15 °C, as lower temperatures induce chilling injury: pericarp hardening, browning and shrinkage of both the stem end and calyx, browning of the fruit flesh, and an off-flavour (Choehom et al., 2003).

For the fresh fruit market, mangosteen fruit are ready to harvest when the pericarp is light greenish yellow scattered with pinkish spots. Harvested fruit at this stage of development will ripen normally (Tongdee and Suwanagul, 1989). Later on the fruit colour becomes a mix of red and purple, and still later, when it is ready to be sold, the fruit is deep purple. These colour changes occur both when the fruit is left on the tree and when the fruit is harvested at the early stage (light greenish yellow pericarp) stored at temperatures above 14 °C, and exposed to higher temperatures during shelf life. By the time the pericarp colour is dark purple the fruit flesh is soft and sweet enough for direct consumption.

Mangosteen might be a climacteric fruit as its respiration shows a transient increase (Noichinda, 1992). Inhibition of ethylene biosynthesis or ethylene action, therefore, may be effective in slowing down a number of ripening processes. We determined if treatment with 1-methylcyclopropene (1-MCP) could extend the storage and the shelf life of mangosteen fruit. 1-MCP is an effective inhibitor of ethylene action (Sisler and Serek, 1997; Blankenship and Dole, 2003; Watkins, 2006). We found a positive effect of this treatment. In order to further elucidate the 1-MCP effects we measured ethylene production, the levels of 1-aminocyclopropane-1-carboxylic acid (ACC) and the activities of ACC synthase (ACS) and ACC oxidase (ACO), both in the pericarp and in the fruit flesh.

2. Materials and methods

2.1. Plant material

Mangosteen (*G. mangostana* L.) fruit at the stage of light greenish yellow scattered with pinkish spots (stage 1 of postharvest development; Tongdee and Suwanagul, 1989), were obtained from a commercial orchard in Chanthaburi province, Eastern Thailand and

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transported at 15 °C to the laboratory, where they arrived within a day of harvest. Fruit were then selected for uniformity of colour and size for further experimentation.

2.2. Treatment with 1-MCP and storage

Batches of fruit were placed in a sealed plastic container (71 L) and treated with 1 μL L^{-1} 1-MCP (EthylBloc, Floralife Inc., USA) for 6 h at 25 °C. The control batch of fruit was placed in an identical plastic chamber without 1-MCP treatment. Following treatment, both treated and control fruit were placed into corrugated boxes and stored at 15 ± 0.5 °C (80–85% RH) and/or 25 ± 0.5 °C (80–85% RH).

2.3. Storage life, shelf life, eating quality

The storage life was terminated when the fruit colour was dark purple. Shelf life was determined at 25 °C and was defined as the time until the pericarp was uniformly blackish purple or showed calyx wilting. The softness of the fruit flesh and its taste were determined by three researchers, which used a score system based on five classes.

2.4. Total soluble solids, titratable acidity

At intervals, 20 fruit were taken from each treatment and assessed for colour, firmness, total soluble solids (TSS), titratable acidity (TA), ethylene production, ACC content and activities of ACC synthase (ACS) and ACC oxidase (ACO). The peel and fruit flesh were cut into 0.5 cm × 0.5 cm × 0.5 cm pieces, immediately frozen in liquid nitrogen and stored at −70 °C until use. The ACC content, ACS and ACO activities were determined in frozen samples.

Fruit colour was measured using a Minolta CR-300 chromameter (Minolta, Osaka, Japan) as L^*, a^*, b^* values. These three coordinates represent the lightness of the colour (L^* = 0 yields black and L^* = 100 indicates diffuse white), its position between red/magenta and green (a^*, negative values indicate green and positive values indicate magenta) and its position between yellow and blue (b^*, negative values indicate blue and positive values indicate yellow) and converted to hue angle by using the formula: h° = arctan (b/a) (colour wheel, with red-purple at an angle of 0, yellow at 90°, bluish-green at 180°). The colour readings were taken twice at the equatorial region of each fruit and averaged to give a value for each fruit.

Pericarp firmness was measured using a hand-held fruit firmness tester (Effegi, Alfonsine, Italy) equipped with a cylindrical plunger 0.5 cm in diameter. The plunger was inserted to a depth of 0.5 cm and the force recorded in newtons.

To measure soluble solids content (SSC) and titratable acidity (TA) of the flesh juice, the white flesh with the enclosed seeds was wrapped in cheesecloth and squeezed by hand to separate the juice from the seeds. The SSC was measured with a hand-held refractometer (Atago, Tokyo, Japan) and calibrated with distilled water. TA was determined from a 5 mL aliquot by titration with 0.1 M NaOH, using phenolphthalein as an indicator. Results are expressed as grams of citric acid per 100 mL.

2.5. Ethylene production

Ten fruit at stage 1 were individually weighed and placed into separate 0.8 L plastic containers with a flow of air with 100% RH at 125 mL min^{-1}. At daily intervals, 1 mL gas samples were withdrawn from the headspace and injected into a gas chromatograph equipped with a flame ionization detector (Shimadzu, Tokyo, Japan) for the detection of ethylene. Each data point consists of 10 replicate containers.

In addition, the ethylene production of fruit flesh and pericarp was also measured by placing samples into an airtight container for 20 min at 15 and 25 °C after dipping in 0.1 mM aminooxyacetric acid (AOA) to inhibit wound-induced ethylene biosynthesis. (Geballe and Galston, 1982).

2.6. ACC content; activities of ACS and ACO

The ACC content and ACS activity were measured using the method of Hoffman and Yang (1982). The protein level was determined using the Bradford (1976) method.

ACO activity was measured by modifying the method of Kato and Hyodo (1999). Samples were homogenized in a mortar with 1 mL of extraction buffer (2 mL g^{-1} for fruit flesh and 5 mL g^{-1} for pericarp) containing 0.1 M Tris-(hydroxymethyl)-aminomethane, 5 mM DTT, 30 mM L(+)-ascorbic acid sodium salt and 30% glycerol; pH 7.2 with HCl. The homogenate was centrifuged at 13,870 × g for 40 min in fruit flesh and 13,650 × g for 30 min in pericarp for 40 min and the supernatant was used for the ACO assay. The ACO activity was assayed by GC determination of the ethylene produced after incubation for 30 min at 30 °C in capped 12 mL vials containing 400 mL of reaction buffer (pH 7.2; 0.1 M Tris-(hydroxymethyl)-aminomethane, 30 mM Na-ascorbate, 30 mM $NaHCO_3$, 100 μM $FeSO_4$ and 30% glycerol) and 10 mM ACC (100 μL). The reaction was started by the addition of 500 μL of the above supernatant. The controls were reactions with or without boiled enzymes. In neither case was ethylene production detected. The protein concentration was determined following the standard Bradford method.

2.7. Statistical analysis

Visual assessment of colour, and measurement of firmness, total soluble solids (TSS), titratable acidity (TA), ethylene production, ACC content and the activities of ACC synthase (ACS) and ACC oxidase (ACO) were carried out using 20 fruit per treatment. Shelf life was determined using 12 fruit per treatment. Quantitative colour values (L^* and hue) were the average of three replications. The data were compared using analysis of variance and Duncan's new multiple range test (DMRT), at $P \leq 0.05$. All experiments were repeated at least once.

3. Results

3.1. Storage period, shelf life, and eating quality

Fruit were stored at 15 °C and 25 °C. Mangosteen fruit are usually marketed when dark purple. The fruit were taken out of storage

Table 1
Length of storage life and shelf life of mangosteen fruit, after treatment with 1-MCP and storage at 15 or 25 °C. Fruit were treated with 1 μL L^{-1} 1-MCP for 6 h at 25 °C before storage. The length of storage life was defined as the time until the pericarp had turned dark purple. Shelf life was determined at 25 °C. The length of shelf life was defined as the time until the pericarp colour was uniformly blackish purple or when calyx wilting occurred. Data are means of 12 fruit per treatment.

Storage temperature	Storage life (d)[a]	
	Control	1-MCP
15 °C	18.1 b	27.1 a
25 °C	2.1 d	5.2 c
Storage temperature	Shelf life after storage (d)[a]	
	Control	1-MCP
15 °C	3.1 b	4.1 a
25 °C	2.3 b	3.9 a

[a] Values within storage life and within shelf life, followed by different letters are significantly different at $P \leq 0.01$ (analysis of variance and DMRT).