Responses of ‘Carabao’ Mango to Various Ripening Agents

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Calcium carbide (CaC₂) reacts with moisture in the air to produce acetylene (C₂H₂) gas, an analog of ethylene (C₂H₄). Commercial sources of CaC₂ may be contaminated with arsenic and phosphorous, which are also released during a chemical reaction. This constitutes a potentially serious health risk to ripeners and may contaminate the product. Although banned in many countries, CaC₂ is still used in the Philippines because equally inexpensive and effective alternatives are lacking. This study investigated the relative efficacy of alternatives for ripening ‘Carabao’ mango. Fruit harvested at 107 d after flower induction were treated with CaC₂ (2.5, 5.0, or 7.5 g kg⁻¹); ethephon (500, 1000, or 1500 μL L⁻¹); Gliricidia sepium leaves (20% w/w); or ‘Cardava’ banana fruit (10% w/w) for 72 h. Mangoes were then held under ambient room conditions [29.9 ± 3.1°C, 77.74 ± 2.9% relative humidity (RH)] for 7 d. Assessments of peel color, firmness, and total soluble solids showed that fruit treated with higher concentrations of ethephon (1000 or 1500 μL L⁻¹) exhibited similar ripening responses as those treated with CaC₂. Application of 500 μL L⁻¹ ethephon and the bioethylene sources G. sepium and ‘Cardava’ banana did not effectively ripen ‘Carabao’ mango as compared to the other treatments. The effectiveness of CaC₂ did not vary between the concentrations tested. Just 2.5 g kg⁻¹ was needed to ripen the fruit, which is considerably less than the commercial practice of using 10 g kg⁻¹. Weight loss was highest in mangoes treated with CaC₂ or ethephon. Similar to CaC₂, ethephon treatment (1000 or 1500 μL L⁻¹) reduced the time to reach saleability to 3–4 d as compared to 6 d for untreated mangoes. Accordingly, 1000 μL L⁻¹ ethephon could be a relatively safer alternative to CaC₂ in ripening ‘Carabao’ mango. Moreover, the benefits of using ethephon over conventional CaC₂ include lower cost and higher profit.

Keywords: bioethylene, calcium carbide, ‘Carabao’ mango, ethephon, ripening agent

INTRODUCTION
‘Carabao’ mango is known internationally as the ‘Philippine Super Mango’ and is the country’s most economically important mango (Mangifera indica) variety. It is considered one of the world’s best varieties due to its characteristically attractive taste and aroma. Accordingly, it is in strong demand in both local and international markets. ‘Carabao’ mango is a high-value crop in the Philippines, where it ranks third among fruit crops after banana and pineapple (Rodeo 2016). In 2016, its production reached 814,055 MT – of which 14,343 MT was exported (PSA 2018).
Being a climacteric fruit, mango is harvested at a firm green mature stage. The fruit can subsequently be ripened through artificial methods to make it saleable sooner and to improve fruit-to-fruit uniformity. Ripening dessert mango fruit undergoes many physicochemical changes that result in favorable taste, aroma, and texture when ripe. Depending on harvest maturity, it typically takes five to ten days for mango fruit to become fully edible ripe after harvest.

In the Philippines, mangoes are ripened using pieces (chunks) of CaC$_2$. CaC$_2$ releases C$_2$H$_4$ gas in the presence of moisture. It acts as an analog of ethylene, effectively triggering natural fruit ripening (Medlicott et al. 1987). CaC$_2$ is commonly used as a ripening agent in tropical fruit. It is currently being used by wholesalers and retailers in the Philippines at 8–10 g CaC$_2$ per kg of mango fruit.

Commercial CaC$_2$ powder contains traces of arsenic and phosphorus (Lakade et al. 2018). Chandel (2014) reported that CaC$_2$, whether in sachet or solution, contained 0.03 - 0.08 mg kg$^{-1}$ arsenic and 129.9–135.4 mg kg$^{-1}$ phosphorus residues. These potentially toxic residues can be released to contaminate fruit with materials harmful to human health (Sy and Wainwright 1990). That is, arsine (AsH$_3$) and phosphine (PH$_3$) gases are released when CaC$_2$ reacts with moisture and become residues that may contaminate the artificially ripened fruit (Chandel et al. 2017). The highest health risks are to individuals involved in fruit ripening and handling through inhalation and ingestion of these contaminants. A study by Essein et al. (2018) on Wistar rats suggested that consumption of fruit ripened with CaC$_2$ could lower the body’s resistance to infection in weakening the immune system and may also affect hormonal balance that could lead to infertility.

Given the abovementioned potential risks of this ‘traditional’ method, safer alternatives should be explored for ripening mangoes. Ethephon (2-chloroethylphosphonic acid) breaks down to liberate C$_2$H$_4$ within the fruit. It is commonly used to promote fruit ripening and other plant physiological responses (Tan et al. 2014). The application of ethephon in pre- and postharvest stages stimulates and coordinates ripening in ‘Uba’ mango (Silva et al. 2011), banana (Tan et al. 2014), pear (Dhillon and Mahajan 2011), apple, peach, prune, fig, and cranberry (Beaudry and Kays 1988). However, ethephon has the potential to cause severe skin and eye irritation (Toxicity Category I) but is otherwise moderately acutely toxic. As an organophosphate pesticide, it also has the potential to cause neurotoxic effects due to cholinesterase inhibition (US EPA 1995). Personal protective equipment including chemical-resistant gloves and protective eyewear is required for handlers.

An even safer option is to utilize C$_2$H$_4$ produced from biological sources, also known as bioethylene. C$_2$H$_4$ from sources such as ‘kakawate’ (Glricticida sepium Steud) leaves can ripen ‘Saba’ banana (Musa, BBB group) (Acedo and Bautista 1991) and tomato (Tirtosoktojo and Bautista 1984). G. sepium produced more C$_2$H$_4$ than did the leaves of Averrhoa carambola, Bauhinia monandra, Calopogonium mucunoides, Leucaena leucocephala, and Sesbania grandiflora (Bautista et al. 1990). Fruits can also serve as bioethylene sources for ripening, such as climacteric banana, avocado, mango, and tomato (Sjaifullah and Bautista 1984). Increased C$_2$H$_4$ production is observed at different stages of these fruits’ ripening. Increased C$_2$H$_4$ production by ‘Saba’ banana occurred between breaker to fully ripe stages (Cua et al. 1984). C$_2$H$_4$ produced by fruit during the climacteric rise may be utilized to trigger ripening of ‘Carabao’ mango fruit.

This study was conducted to evaluate ethephon and the bioethylene sources G. sepium leaves and ‘Cardava’ banana fruit as potential alternatives to the hazardous ripening agent CaC$_2$.

MATERIALS AND METHODS

Plant Material Preparation and Treatment
A total of 90 kg mature green ‘Carabao’ mango fruit was harvested at 107 days after flower induction from a farm in Malandag, Malungon, Sarangani Province, Philippines. The fruit were transported to the Postharvest Biology Laboratory at the University of the Philippines Mindanao in an air-conditioned vehicle. They were weighed, sanitized in 200 µL L$^{-1}$ NaOCl solution for 3 min, and air-dried. They were then treated with CaC$_2$ (2.5, 5.0, or 7.5 g kg$^{-1}$); ethephon (500, 1000, or 1500 µL L$^{-1}$); G. sepium leaves (20% w/w); or ‘Cardava’ banana (10% w/w) at breaker stage (i.e., more green than yellow peel color). Untreated control ‘Carabao’ mango fruit were stored under ambient room conditions.

Ethephon was applied by soaking the fruit in the different concentrations for 3 min, followed by air-drying under ambient conditions. CaC$_2$ application was based on the conventional practice of wholesalers in the market. Different amounts of CaC$_2$ were carefully wrapped in two layers of newspaper and placed at the bottom-center section of bamboo baskets lined with newspaper. The amounts of G. sepium leaves (20% w/w) and ‘Cardava’ banana fruit (10% w/w) were calculated based on the total weight of the fruit samples in a basket. The G. sepium leaves and banana fruit were placed at the bottom-center of the basket together with the mangoes. The mango fruit were arranged in layers inside the baskets lined
with newspaper then tightly covered with two sheets of newspaper secured in place with polypropylene twine.

Temperature and RH inside the baskets were monitored by inserting probes of a UX120-014M 4-Channel Thermocouple Logger (HOBQ Data Loggers, USA) into respective baskets during treatment for 72 h. Ambient temperature and RH during storage were also recorded (28.60 ± 0.58 °C, 68.06 ± 3.57% RH). Mango fruit quality was evaluated on the day of opening after 72 h treatment and 4, 7, and 10 days after harvest (DAH).

**Quality Evaluation**

Mango fruit quality was assessed as weight loss (%); firmness (N); total soluble solids (TSS, % Brix); peel color (subjective index, L*, a*, b*, chroma); visual quality; severity of stem-end rot and anthracnose; days to saleability; saleable days; and shelf life. Percentage of weight loss was calculated as the proportional difference of final weight from the initial. Fruit firmness was measured using a Fruit Tester FT 327 pressure tester (Wagner Instruments, USA). TSS was determined using a refractometer (HI 96801, Hanna Instruments, Romania). Peel color was subjectively assessed using the index: 1 = green; 2 = breaker, a trace of yellow at the stem-end; 3 = turning, more green than yellow; 4 = more yellow than green; 5 = yellow with traces of green; and 6 = fully yellow (Ekman *et al.* 2018). The color was also objectively measured using a color meter (Chroma Meter CR-400, Konica Minolta Optics, Inc., Japan). Color meter values were expressed as CIE L*, a*, b*, and chroma. Visual quality was assessed using the scale: 1 = excellent, no symptoms of deterioration; 2 = good, minor symptoms of deterioration that are not objectionable; 3 = fair, evident deterioration but not serious, limit of saleability; 4 = poor, serious deterioration, limit of usability; and, 5 = extremely poor, unusable (Ekman *et al.* 2018). Severity of stem-end rot and anthracnose was evaluated using the scale: 1 = no discoloration at the stem-end or visible spots on the surface; 2 = slight infection, 1–5% of the surface; 3 = moderate infection, 6–10%; 4 = moderately severe infection, 11–25%; and 5 = severe infection, > 25% (Ekman *et al.* 2018). Days to saleability indicates the time for mangoes to reach a saleable stage of ripeness (i.e., peel color index of ≥ 5, a visual quality rating of ≤ 3, and no diseases). Saleable days refer to when the fruit was judged marketable (i.e., the time when the fruit was deemed ripe until the end of shelf life). Shelf life is defined as the length of time from the day of harvest until it goes beyond the limit of saleability (i.e., a visual quality rating of > 3 and presence of disease). The experiment was arranged in a completely randomized design, with three replications for each treatment. Each replicate had 10 fruit samples. Data were analyzed using analysis of variance and differences between means were detected using Tukey’s honest significant difference (HSD) Test at the 5% level of significance using Statistical Tool for Agricultural Research (STAR 2.0.1).

After the experiment, a cost-benefit analysis was conducted to evaluate the impact of using a safer alternative ripening treatment against the conventional use of CaC₂.

**RESULTS**

**Temperature during Treatment**

The temperature during ripening is important. High temperatures accelerate fruit ripening but can also reduce quality and increase disease (Ahmad *et al.* 2001). The temperature within baskets during treatment was maximum for ‘Carabao’ mango fruit treated with the highest concentration of CaC₂ (7.5 g kg⁻¹). The lowest temperature was in fruit treated with ‘Cardava’ banana. The order of descending temperatures within baskets as influenced by treatments was: 7.5 g kg⁻¹ CaC₂ (36.6 °C) > G. sepium (33.1 °C) > 5 g kg⁻¹ CaC₂ (32.3 °C) > 2.5 g kg⁻¹ CaC₂ (32.2 °C) > ‘Cardava’ banana (27.3 °C). Ambient room temperature where untreated and ethephon-treated mangoes were held at 29.9 ± 3.1 °C.

**Weight Loss**

After 72 h of treatment, weight loss was lower in mangoes treated with G. sepium leaves and ‘Cardava’ banana (3.1% and 2.5%, respectively) than those treated with different concentrations of CaC₂ (4.2–4.4%), ethephon (4.0–4.3%), and the untreated fruit (4.0%, Figure 1A). This trend continued throughout storage under ambient room conditions of 29.9 ± 3.1 °C and 77.7 ± 2.9% RH. At the end of storage, mango fruit from all treatments exhibited a similar weight loss of 12.8 ± 0.5%.

**Fruit Firmness**

‘Carabao’ mangoes treated with ethephon (1000 and 1500 μL L⁻¹) had softened after 72 h of treatment. This was similar to fruit treated with CaC₂ (2.5, 5.0, and 7.5 g kg⁻¹; Figure 1B). Fruit treated with 500 μL L⁻¹ ethephon had similar firmness (12.6 N) to those treated with G. sepium leaves (12.4 N). Mango fruit exposed to ‘Cardava’ banana were still firm (29.4 N) similar to untreated control fruit (22.7 N). Firmness in all fruit reduced with storage time. Mangoes treated with CaC₂ and ethephon were less firm than those treated with G. sepium leaves, ‘Cardava’ banana fruit, and the untreated control.

**Total Soluble Solids**

Upon opening of baskets or at 3 d from treatment,
‘Carabao’ mango fruit treated with 5.0 or 7.5 g kg$^{-1}$ CaC$_2$ had lower TSS (7.9–8.4% Brix) than did all other treatments (12–13.7% Brix; Figure 1C). However, mangoes started to develop a similar level of sweetness at 4 DAH, which was between 12.9% and 15.5% Brix.

**Visual Quality and Diseases**

All ‘Carabao’ mangoes had excellent visual quality after 72 h of treatment and until 4 DAH (Figure 1D). All mango fruit stored for 7 d (viz., 10 DAH) under ambient room conditions had visual quality ratings of very good (2) to good (3) at the end of storage. Anthracnose and stem-end rot disease intensity did not vary among treatments (Figure 1E and F).

**Peel Color**

As apparent from changes in peel color, treatment with ethephon (500, 1000, or 1500 µL L$^{-1}$) or CaC$_2$ (2.5, 5.0, or 7.5 g kg$^{-1}$) induced faster ‘Carabao’ fruit ripening as compared to control, 20% *G. sepium* leaves, and 10% ‘Cardava’ banana treatments (Figures 2 and 3A). On the day of basket opening, mango peel color appeared
Figure 2. Appearance of ‘Carabao’ mango fruit after 72 h treatment with various ripening agents: CaC\(_2\) (2.5, 5.0, or 7.5 g kg\(^{-1}\)); ethephon (500, 1000, 1500 µL L\(^{-1}\)); Gliricidia sepium leaves (20% w/w); and ‘Cardava’ banana fruit (10% w/w).

Figure 3. Color index (A), \(L^*\) (B), \(a^*\) (C), \(b^*\) (D), and chroma (E) of ‘Carabao’ mango fruit during storage under ambient room conditions (29.9 ± 3.05 °C, 77.7 ± 2.90% RH) as influenced by various ripening agents: CaC\(_2\) (2.5, 5.0, or 7.5 g kg\(^{-1}\)); ethephon (500, 1000, 1500 µL L\(^{-1}\)); Gliricidia sepium leaves (20% w/w); and ‘Cardava’ banana fruit (10% w/w). Asterisks indicate where there is a significant difference among the treatments using Tukey’s HSD at \(P \leq 0.05\).
relative lighter and more yellow in fruit treated with ethephon or CaC$_2$ (Figure 3B–D). Mangoes treated with G. sepium and ‘Cardava’ banana and also the untreated control delayed peel color change until 5 DAH. Between the two bioethylene sources, G. sepium seemed to initiate peel color change faster than did ‘Cardava’ banana. Moreover, ‘Cardava’ banana did not appear to affect the ripening of ‘Carabao’ mango since peel color development was similar to the control. Chroma was higher in fruit treated with CaC$_2$ or ethephon indicating they were more vivid as compared to those treated with G. sepium, ‘Cardava’ banana, and the control (Figure 3E). The fruit reached table ripe stage or the time of exhibiting ripeness attributes and palatability at 7–10 DAH.

**Saleability and Shelf Life**

In terms of days to reach saleability or time to attaining a peel color index of ≥ 5 with excellent to good visual quality, ‘Carabao’ mangoes treated with 1000 to 1500 µL L$^{-1}$ ethephon were comparable (3.9 DAH) to fruit treated with different concentrations of CaC$_2$ (3.6–4.7 DAH; Table 1). The effect of 500 µL L$^{-1}$ ethephon, G. sepium leaves, and ‘Cardava’ banana on the days to saleability – which ranged from 5.1 to 6.6 DAH – did not vary with the control at 6.7 DAH. The saleable days of 5.3–8.1 DAH and shelf life of 10.7–12.2 DAH of mangoes also did not vary among treatments.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Days to saleability</th>
<th>Saleable days$^\text{NS}$</th>
<th>Shelf life$^\text{NS}$ (d)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>6.7$^a$</td>
<td>5.3</td>
<td>12.0</td>
</tr>
<tr>
<td>CaC$_2$, 2.5 g kg$^{-1}$</td>
<td>4.7$^bc$</td>
<td>6.1</td>
<td>10.7</td>
</tr>
<tr>
<td>CaC$_2$, 5 g kg$^{-1}$</td>
<td>3.6$^a$</td>
<td>8.1</td>
<td>11.7</td>
</tr>
<tr>
<td>CaC$_2$, 7.5 g kg$^{-1}$</td>
<td>3.9$^a$</td>
<td>6.8</td>
<td>10.7</td>
</tr>
<tr>
<td>Ethenoph, 500 µL L$^{-1}$</td>
<td>5.1$^bc$</td>
<td>6.9</td>
<td>11.6</td>
</tr>
<tr>
<td>Ethenoph, 1000 µL L$^{-1}$</td>
<td>3.9$^a$</td>
<td>7.4</td>
<td>11.3</td>
</tr>
<tr>
<td>Ethenoph, 1500 µL L$^{-1}$</td>
<td>3.9$^bc$</td>
<td>7.1</td>
<td>11.0</td>
</tr>
<tr>
<td>Gliricidia sepium, 20% w/w</td>
<td>5.2$^b$</td>
<td>5.8</td>
<td>11.0</td>
</tr>
<tr>
<td>‘Cardava’ banana, 10% w/w</td>
<td>6.6$^a$</td>
<td>5.6</td>
<td>12.2</td>
</tr>
</tbody>
</table>

$^a$Means in a column with common letters are not significantly different by Tukey’s HSD at $P \leq 0.05$.

$^\text{NS}$Not significant

**Cost-benefit Analysis**

The potential impacts of using 1000 µL L$^{-1}$ ethephon as a safer alternative to the conventional use of CaC$_2$ was evaluated using cost-benefit analysis (Table 2). The use of CaC$_2$ costs more than the use of ethephon by 9.4% because CaC$_2$ requires more consumable materials such as CaC$_2$, old newspaper, and polypropylene twine than ethephon treatment. The use of 1000 µL L$^{-1}$ ethephon would only use 1.04 mL of commercial ethephon (48%) per L of water. Further, losses due to bruising were recorded in ‘Carabao’ mango but not in those treated with ethephon (Ekman et al. 2018). As a result, the profit of using ethephon in ripening ‘Carabao’ mango was higher by 28.9% than those earned by using CaC$_2$.

**DISCUSSION**

Ripening is a complex physiological process characterized by changes in skin and flesh color, firmness, taste, and aroma all making the fruit attractive and palatable. The plant hormone C$_2$H$_4$ coordinates most aspects of ripening in climacteric fruit (Pech et al. 2012). Stimulatory quantities of C$_2$H$_4$ accumulate prior to the onset of the climacteric rise in respiration (Burg and Burg 1962). The fruit then undergoes ripening through an autocatalytic process in which C$_2$H$_4$ stimulates its own biosynthesis.

Higher concentrations of ethephon (1000 or 1500 µL L$^{-1}$) effectively advanced ripening of ‘Carabao’ mango at a rate similar to that of the traditional ripening agent CaC$_2$ (2.5, 5.0, or 7.5 g kg$^{-1}$). Ethephon releases ethylene upon breakdown, with production being highly dependent on concentration (Dhall and Singh 2013). Ethephon has been reported to ripen banana (Tan et al. 2014), tomato (Dhall and Singh 2013), and pears (Dhillon and Mahajan 2011), among other fruits. Efficacious postharvest application of ethephon has also been reported for other mango cultivars – including ‘Haden,’ ‘Tommy Atkins,’ ‘Van Dyke,’ ‘Carrie,’ ‘Palmer’ and ‘Edwards’ (Barmore 1974), ‘Kensington Pride,’ (Singh and Janes 2001), ‘Langra’ (Gill et al. 2014), and ‘Dashehari’ (Jawandha et al. 2016). Singh and Janes (2001) used different concentrations of ethephon – including 250, 500, 1000, 1500, or 2000 µL L$^{-1}$ – together with modified atmosphere packaging in ‘Kensington Pride’ mangoes. They reported that the amount of ethylene during ripening increased with higher concentrations of applied ethephon. Similarly, ethephon treatment induced fruit ripening and reduced the time needed to ripen the fruit, especially at higher concentrations. Ethephon is deemed ‘generally regarded as safe’ by the US Food and Drug Administration if used for the purpose indicated and in accordance with a good manufacturing practice (Venkatesan 2016). Personal protective equipment (e.g., eye and face protection, gloves) should be used, and safety requirements followed by applicators and other handlers to avoid risk. The acceptable daily intake of ethephon is 0–0.05 mg kg$^{-1}$ body weight per day on the basis of a no-observed-adverse-effect in studies in humans (Wolterink et al. 2015).
**Table 2.** Cost-benefit analysis of conventional CaC\(_2\) treatment (250 g per basket of 25 kg fruit) or ethephon (1,000 µL L\(^{-1}\)) in 1000 kg ‘Carabao’ mango.

<table>
<thead>
<tr>
<th>Particulars</th>
<th>Value (Philippine Peso, PHP)</th>
<th>CaC(_2) (250 g 25 kg(^{-1}) fruit(^a))</th>
<th>Ethephon (1000 µL L(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>A. Cost</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Green mango</td>
<td>50.00/kg</td>
<td>50,000.00</td>
<td>50,000.00</td>
</tr>
<tr>
<td>Material cost</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bamboo basket(^b)</td>
<td>70.00/pc</td>
<td>2,800.00</td>
<td></td>
</tr>
<tr>
<td>Pail(^b)</td>
<td>300.00/pc</td>
<td>300.00</td>
<td></td>
</tr>
<tr>
<td>Glassware(^b)</td>
<td>110.00/pc</td>
<td>110.00</td>
<td></td>
</tr>
<tr>
<td>Consumables</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CaC(_2)</td>
<td>80.00/kg</td>
<td>800.00</td>
<td></td>
</tr>
<tr>
<td>Old newspaper</td>
<td>50.00/kg</td>
<td>500.00</td>
<td></td>
</tr>
<tr>
<td>Polypropylene twine</td>
<td>80.00/roll</td>
<td>80.00</td>
<td></td>
</tr>
<tr>
<td>Ethephon</td>
<td>850.00/ 500 mL</td>
<td>68.00</td>
<td></td>
</tr>
<tr>
<td>Tap water</td>
<td>22.16/m(^3) x 20 L</td>
<td>0.44</td>
<td></td>
</tr>
<tr>
<td>Safety apparel</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Safety goggles(^b)</td>
<td>150.00/pc</td>
<td>150.00</td>
<td>150.00</td>
</tr>
<tr>
<td>Particulate respiratory protection mask(^b)</td>
<td>900.00/box of 20 pcs</td>
<td>45.00</td>
<td>45.00</td>
</tr>
<tr>
<td>Gloves(^b)</td>
<td>100.00/pair</td>
<td>100.00</td>
<td>100.00</td>
</tr>
<tr>
<td>Labor cost</td>
<td>20.00/basket (CaC(_2)) or 300.00/ man-day (ethephon)</td>
<td>800.00</td>
<td>300.00</td>
</tr>
<tr>
<td><strong>Postharvest losses</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weight loss after 3 d ripening</td>
<td>4.42% (CaC(_2))</td>
<td>3,536.00</td>
<td>3,464.00</td>
</tr>
<tr>
<td>Low-quality mangoes sold at lower price after 8 d</td>
<td>4.33% (ethephon)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>22.22% at 50.00/kg</td>
<td>6,666.00</td>
<td>6,666.00</td>
<td></td>
</tr>
<tr>
<td>Losses due to bruising/bumps</td>
<td>9.09% (CaC(_2))</td>
<td>1,818.00</td>
<td>0</td>
</tr>
<tr>
<td>0% (ethephon)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total cost</strong></td>
<td>67,295.00</td>
<td>61,203.44</td>
<td></td>
</tr>
<tr>
<td><strong>B. Benefit</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ripe mango revenue</td>
<td>80.00/kg</td>
<td>80,000.00</td>
<td>80,000.00</td>
</tr>
<tr>
<td><strong>Other benefits</strong></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Safety</td>
<td></td>
<td>Hazardous</td>
<td>Relatively safe</td>
</tr>
<tr>
<td>Ripening time</td>
<td>3.9 d</td>
<td>3.9 d</td>
<td></td>
</tr>
<tr>
<td>Salaeable days</td>
<td>6.8 d</td>
<td>7.4 d</td>
<td></td>
</tr>
<tr>
<td>Shelf life</td>
<td>10.7 d</td>
<td>11.0 d</td>
<td></td>
</tr>
<tr>
<td><strong>C. Profit (revenue – cost)</strong></td>
<td>12,705.00</td>
<td>18,796.56</td>
<td></td>
</tr>
</tbody>
</table>

\(^a\)Rate used by ripeners in the Philippines
\(^b\)Reusable

1 USD = 52.15 PHP (as of May 2019)

CaC\(_2\) releases C\(_2\)H\(_2\), a C\(_2\)H\(_4\) analog, upon contact with water thereby triggering ripening. C\(_2\)H\(_2\) generated from CaC\(_2\) has been demonstrated with mangoes to induce their early and uniform ripening (Joon *et al.* 2001). Similarly, C\(_2\)H\(_2\) released from CaC\(_2\) increased respiration rates as well as starch and chlorophyll degradation in banana (Nogueira *et al.* 2007). In Bangladesh, Mahmud *et al.* (2015) reported that sprays of 10% CaC\(_2\) solution act rapidly on mangoes, ripening the fruit after 0.5 d as compared to the control which ripened after 5 d.
Despite its efficacy in ripening fruit, the use of CaC\textsubscript{2} poses some risk as it presents a potential hazard to human health. Chandel (2014) found relatively high arsenic and phosphorus residues in mango fruit ripened using more than 2 g CaC\textsubscript{2} kg\textsuperscript{-1} of fruit. The residues that attach to the fruit surface may come from AsH\textsubscript{3} and PH\textsubscript{3} produced from commercial formulations of CaC\textsubscript{2} when they react with water. The highest arsenic residue was found on the fruit surface followed by the peel and the pulp (Chandel \textit{et al.} 2017). Even the use of 2.5, 5.0, or 7.5 g kg\textsuperscript{-1} CaC\textsubscript{2}, which are significantly lower than the traditional application rate of up to 10 g kg\textsuperscript{-1} in the local market, could potentially yield high residues of arsenic and phosphorus. Higher amounts of arsenic residues from fruit collected from the market in India were observed by Chandel \textit{et al.} (2017). This suggests that traders use very high quantities of CaC\textsubscript{2} for ripening. Silva \textit{et al.} (2012) reported that the use of 20 g kg\textsuperscript{-1} CaC\textsubscript{2} had the same effect with the use of 50 µL L\textsuperscript{-1} C\textsubscript{2}H\textsubscript{4} and were both enough to accelerate a uniform ripening in ‘Uba’ mango. The present study showed that even the lowest rate of 2.5 g kg\textsuperscript{-1} CaC\textsubscript{2} could ripen mangoes similar to higher CaC\textsubscript{2} concentrations (5 and 7.5 g kg\textsuperscript{-1}). However, even the lower dose of CaC\textsubscript{2} may still potentially harm both ripeners and consumers because of the AsH\textsubscript{3} and PH\textsubscript{3} generated.

The high temperature generated from CaC\textsubscript{2} (32.2–36.6 °C) as compared to ‘Cardava’ banana (27.3 °C) inside the baskets likely contributed to the earlier ripening of the mangoes. In association with the increase in temperature, respiration rate and C\textsubscript{2}H\textsubscript{4} production were reported to increase (Ahmad \textit{et al.} 2001). According to Barmore (1974), temperature modifies the effectiveness of C\textsubscript{2}H\textsubscript{4} on ripening as lower temperatures during treatment result in less immediate ripening responses. The basket with mangoes ripened with bioethylene from \textit{G. sepium} had a higher temperature (33.1 °C) inside, but also did not ripen the fruit after 72 h of treatment. In this case, the increase in temperature in the basket was presumably contributed by the heat produced from the respiration of \textit{G. sepium} leaves. Too high temperature could also adversely affect the ripening fruit, such as by more weight loss and shriveling, and early onset of disease and senescence (Semple and Thompson 1988).

In relation to temperature, mangoes ripened with CaC\textsubscript{2} had higher weight loss than those treated with \textit{G. sepium} and ‘Cardava’ banana. The weight loss may be attributed to the high temperature inside baskets with CaC\textsubscript{2} that enhanced both transpiration and respiration during ripening resulting in moisture loss from the fruit (Mutton 1978). On the other hand, weight loss was also high in control and ethephon-treated mangoes because the fruit were held under ambient conditions (29.9 ± 3.1 °C, 77.7 ± 2.9% RH) during the 72 h treatment period.

This could have led to an increased rate of transpiration as compared to those contained in the basket.

In terms of firmness, mangoes treated with ethephon (1000 and 1500 µL L\textsuperscript{-1}) were similar to those treated with CaC\textsubscript{2} (2.5, 5.0, and 7.5 g kg\textsuperscript{-1}). As shown in Figure 1B, fruit firmness generally followed a declining trend – a characteristic of advancement in ripening. As the fruit ripens, it also softens due to the increasing solubility of cell wall pectin (Roe and Brummer 1981). Softening of the flesh in ripening mangoes is associated with degradation of α-1,4-linked galacturonic acid residues by elevated polygalacturonase activity (Abu-Sarra and Abu-Goukh 1992). Also involved is pectinesterase, which catalyzes de-esterification of methyl groups from acidic pectins (Roe and Brummer 1981). The use of 500 µL L\textsuperscript{-1} ethephon did not reduce the firmness of the fruit after 72 h treatment, suggesting that this concentration is not enough to ripen the fruit quickly. Dhall and Singh (2013) observed that firmness of tomato fruit decreased with increased concentration of ethephon during treatment.

Regarding TSS, mangoes treated with higher concentrations of CaC\textsubscript{2} (\(i.e.,\) 5.0 and 7.5 g kg\textsuperscript{-1}) were apparently less sweet than for other treatments and the control. In the case of CaC\textsubscript{2}, the heat generated from its reaction with water and the C\textsubscript{2}H\textsubscript{4} was produced as a result of faster ripening in terms of color change but not the pulp; thus, the lower TSS value, a probable case of asynchronous ripening for a time as TSS became similar thereafter. Ideally, TSS increases as ripening proceeds with the hydrolysis of starch to sugars (Sinha \textit{et al.} 1983). Silva \textit{et al.} (2011) also reported low TSS in ‘Uba’ mangoes treated with the pre-harvest ethephon application at a dose of 1000 µL L\textsuperscript{-1} compared to lower concentrations (500 and 750 µL L\textsuperscript{-1}).

The skin color of mango fruit is an important indicator of the level of ripeness and is crucial in marketing as it makes the commodity more visually saleable. The development of yellow peel color in mango is due to chlorophyll breakdown as part of the ripening process (Chesworth \textit{et al.} 1998). Bioethylene levels produced from 20% \textit{G. sepium} leaves and 10% ‘Cardava’ banana did not initiate color development as quickly as the effects of ethephon and CaC\textsubscript{2}. Mangoes ripened only slowly when treated with bioethylene from more green than yellow ‘Cardava’ banana. The slow ripening of mangoes using ‘Cardava’ banana was probably due to low C\textsubscript{2}H\textsubscript{4} production at the more green than yellow stage compared to the advanced stage of ripeness. Although these bioethylene sources were not as effective as CaC\textsubscript{2} or ethephon, an earlier study conducted by Acedo (1989) reported that \textit{G. sepium} leaves at 5% of fruit weight uniformly ripened ‘Saba’ banana 2 d after 24 h treatment.
In contrast, untreated banana fruit took 5–16 d to ripen. Also, Bautista et al. (1990) reported that the use of 10% G. sepium leaves produced high enough bioethylene for the acceleration of tomato ripening. In this study, only higher concentrations (1000 or 1500 μL L⁻¹) of ethephon had an equivalent effect as CaC₂ in ripening ‘Carabao’ mango. Mangos treated with CaC₂ or ethephon at 1000 or 1500 μL L⁻¹ ripened in 3–4 DAH as compared to the control fruit that ripened at 6 DAH.

Comparing the estimated costs and benefits of the conventional use of CaC₂ and 1000 μL L⁻¹ ethephon on ‘Carabao’ mango shows that the impact of ethephon does not only match the fast ripening benefits of CaC₂ but also results in higher profit. The use of CaC₂ would incur a higher cost as it requires more consumable materials such as CaC₂, old newspaper, and polypropylene twine while ethephon treatment only uses 1.04 mL of 48% commercial ethephon per L of water. CaC₂ treatment also requires higher labor cost because, for every basket so treated, one needs to pay 20.00 PHP (0.38 USD) whereas ethephon treatment pays on a fixed man-day rate (300.00 PHP or 5.75 USD). With this, ripening more mangoes with CaC₂ means greater labor cost than the use of ethephon. In mangoes treated with CaC₂, defects due to bruising and bumps result in 9.09% losses because of packing and tightly securing fruit in bamboo baskets with twine, while no bruising was observed in those treated with ethephon (Ekman et al. 2018). As a result, the profit of using ethephon in ripening ‘Carabao’ mango was higher by 28.9% than those earned by using CaC₂. In addition to the profit, the use of ethephon is relatively safer than CaC₂, thus minimizing the potential health hazards. However, ripeners of both treatments are still advised to wear personal protective equipment for safety.

CONCLUSION

This study showed that ethephon, as a safer treatment, was equally effective as CaC₂ and can thus be an alternative ripening agent for ‘Carabao’ mango. Higher concentrations of ethephon (1000 or 1500 μL L⁻¹) were at par with CaC₂ (2.5, 5.0, or 7.5 g kg⁻¹). The use of 500 μL L⁻¹ ethephon and the bioethylene sources G. sepium leaves and ‘Cardava’ bananas were not as effective in ripening ‘Carabao’ mango quickly. Ripening time was shortened by CaC₂ and ethephon (1000 or 1500 μL L⁻¹) at 3–4 d as compared to 6 d for the untreated mangoes. It is proposed that 1000 μL L⁻¹ ethephon be used in ripening ‘Carabao’ mango instead of CaC₂, with a view of reducing the risk of residual contamination to fruit as well as attendant health risks due to CaC₂ treatment. Moreover, the cost-benefit analysis showed that lower cost and higher profit will be gained when ripening with 1000 μL L⁻¹ ethephon than the conventional use of CaC₂. Ripeners are still encouraged to wear personal protective equipment when dealing with ethephon to avoid health hazards.

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