

# Effects of pre- and post-harvest treatments with hexanal formulations on time to ripening and shelf life of papaya (*Carica papaya* L.) fruits

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Papaya (*Carica papaya* L.) cv. Red lady is used as ripened fresh fruit as well as in the unripe state in many processed products. Therefore, for uses other than fresh fruit consumption, maintenance of fruit in the unripe state is extremely important for viable commercial applications. The application of 2% enhanced freshness formulation (EFF) with hexanal as the main active ingredient, has been shown to delay the onset of ripening in several subtropical fruits. This investigation was done to determine its effect on ripening and senescence in papaya fruits. Trials were conducted using 2% EFF applied as a pre-harvest spray and as a post-harvest dip alone or in combination with the pre-harvest spray. Pre-harvest treatments were applied at two week intervals beginning 30-days before expected harvest maturity. For post-harvest treatments, fruits were completely immersed in the dip solution for ten minutes and allowed to air dry at room temperature before storage. Fruits on trees sprayed pre-harvest with 2% EFF developed first colour stripe approximately 75 days after second spraying while fruits on trees sprayed with the control solution developed first colour stripe 15 days after application of the second spray. This was as expected since the pre-harvest applications were timed to be begin within 30 days of expected harvest. Thus, pre-harvest treatment with 2% EFF resulted in a 60 day delay in the onset of ripening in fruits on treated trees. Fruits were harvested on development of the first colour stripe, indicative of the onset of ripening. Following the delayed onset of ripening, fruits harvested from trees sprayed pre-harvest with 2% EFF ripened to full colour change in 15-18 days during storage at 20-22°C / 90-95% RH. Fruits harvested from trees sprayed with the control solution ripened to full colour change in 8-10 days when stored under the same conditions. At full colour change, fruits from trees treated pre-harvest with 2% EFF had a lower incidence of post-harvest diseases than fruits from control trees. The application of 2% EFF as a pre-harvest treatment and as a postharvest dip can be used to increase the time to onset of ripening of papaya fruit in the field, delay the development of full colour change in fruits after harvest, maintain postharvest quality of fruits during storage at 20-22°C / 90-95% RH and reduce the incidence of post-harvest diseases.

Keywords: Hexanal, papaya, pre-harvest, post-harvest

The Red Lady cultivar of papaya (*Carica papaya* L.) is widely cultivated in Trinidad and Tobago as a processing variety and for fresh fruit consumption. The fruit is characteristically large in size with a bright orange to red pulp colour when ripe. It is generally firm and has a shelf life of about seven days under ambient tropical conditions (25-30°C; 80-95% RH) (An and Paull 1990). At full maturity the fruit has a °Brix value of 10-13. Fruit set normally occurs three months after flower set for this variety and fruits are harvested when there is an initial colour change from green to yellow, appearing as stripes at the distal end on the surface of the fruit. This colour change is usually noticeable

approximately four months after fruit set. Ripening begins on the inside, at the distal end of the fruit, progressing upwards and outwards (Plate 1) until the fruit is fully ripe. The fruit is considered fully ripened when the external colour change is complete. Fruits are generally harvested when one or two colour stripes are evident (Paull et al. 1997; Kader 2006) and fruits harvested mature green have poor organoleptic qualities upon ripening (Akamine and Goo 1971). As a climacteric fruit, the presence of ethylene is associated with this colour development in the mesocarp and the concomitant rapid softening. This rapid softening severely limits available marketing time (An and Paull 1990).



Plate 1: Cut papaya fruit in the field showing interior flesh colour development and seed colour development as indicators of ripening and maturation of fruit on the tree

The rapid loss in firmness during ripening in papaya at tropical, ambient temperature is known to be associated with increases in the activity of phospholipase D, polygalacturonase, pectin methylesterase and  $\beta$ -galactosidase, as well as depolymerisation of cell wall pectins (Paull et al. 1999). One of the commonly used methods to extend post-harvest life of papaya is to store the fruit under modified atmosphere packaging to support low levels of ethylene production by the fruit, which, in turn, affects changes in colour and texture but not the levels of sugars and acids responsible for some of the flavour (Wills et al. 1989). Other methods used to reduce the rate of ripening were described by Lazan et al. (1990). They found that wrapping the fruit in polyethylene film resulted in a delay in ripening due to a concomitant decrease in internal ethylene concentration. However,

many of these methods are labour intensive and result in an increase in the price of the product to the consumer, while also limiting the availability of markets. Studies conducted on the use of hexanal to inhibit the activity of phospholipase D have shown that it is effective in improving the shelf life properties of fruits and vegetables (Paliyath et al. 1999; Paliyath and Murr 2007). Since papaya ripens from the inside out, reducing exposure to ethylene would be effective in reducing the rate of ripening of the mesocarp tissue nearer to the skin, that has not started to ripen.

The already well-softened mesocarp that is near to the seed cavity is not responsive to ethylene. Studies by Paull (1993) showed that ripening rate varied among cultivars, from 7 to 16 days from the colour break stage to full yellow. The rate of softening was also variable among cultivars and was affected by the rate of

respiration, ethylene production, skin de-greening and flesh colour development (Paull 1993).

In Trinidad and Tobago processors at cottage industries utilize Red Lady papaya mostly in its green immature stage. At this stage, the fruit is characterized by pale yellow to pale green pulp, white to grey coloured seeds and a firm pulp with full green skin colour. For most processing operations only the seeds are removed and the fruit is utilized with the skin intact.

It is important for agro-processors to have fruit that remain in the green immature stage for a reasonable period of time. This would ensure efficient use of the fruit, since fruits that show signs of ripening and senescence are unfit for processing. Therefore, it would be beneficial to farmers and agro-processors if the time to ripening and senescence in the field is increased to ensure that fruits remain in an unripe state for a period of time that would facilitate processing operations (Ali et al. 2011). Reduced rate of ripening and softening would also be beneficial since it would facilitate the trade in ripe fruits.

Papaya fruits have a high susceptibility to post-harvest diseases, usually as a result of poor post-harvest handling and storage, leading to high losses. Additionally, as senescence progresses with increased fruit softening, the incidence of post-harvest rots also increases. Treatment with hexanal has also been reported to cause reduction in post-harvest disease incidence.

This investigation was conducted to determine the efficacy of pre- and post-harvest applications of hexanal formulations, or a combination of both, on the time to onset of ripening of fruit on the trees, on the rate of ripening and senescence of harvested fruit, on fruit shelf life and the incidence of post-harvest diseases.

## Materials and methods

### Pre-harvest spray treatment

Papaya trees were selected for treatment from the field based on their similarity in stages of growth and fruit bearing. Trees with fruits that were expected to show first stripe within 30 days were selected for treatment. Fruits that showed any signs of colour changes on the surface were removed from the trees before treatment was applied. Random cut tests were also made on attached fruit to check the stages of maturation to ensure ripening was not initiated within the fruit prior to the application of 2% EFF pre-harvest spray treatment at the various application time intervals. Trees were sprayed with a 2% EFF at two-week intervals at approximately 30 days from the expected date of harvest as determined for the cultivar.

Two percent EFF consisted of 10 ml hexanal, 100 ml Tween and 100 ml ethanol made up to 50 litres and mixed with 1% calcium chloride. Trees were treated by drenching the fruits and leaves using a motorised spray can. Control trees were selected from a different area of the field, based on the same selection criteria as the treatment trees, and treated with the treatment solution minus the hexanal. Trees were observed to determine the effect of the treatment on harvest maturity as evidenced by development of first colour stripes.

### Post-harvest treatments

Post-harvest treatments were conducted on harvested fruits within 12 hours of removal from the field. Treatments were conducted in three replicates and fruits were stored at 20-22°C and 90-95% relative humidity for observation. Fruits showing one-stripe were harvested from control and pre-harvest treated trees for post-harvest treatments. Fruits harvested from control and pre-harvest treated trees were subjected to a 10-minute 2% EFF solution dip and allowed to air dry before being

placed in storage at 20-22°C / 90-95% RH. Fruits were monitored for rates of ripening indicated by the rate of colour development, and development of post-harvest diseases.

### Colour

Colour of the external surface of the fruits was measured visually as a percentage of the entire skin surface. Early signs of colour development, visible at the distal end of the fruit as a yellow stripe were recorded as onset of ripening. Full colour development was recorded when approximately 95 % of the skin colour had turned from green to yellow.

### Statistical design and analysis

A completely randomised experimental design was used in this study and involved the use of 10 tree replicates, randomly located in a field, for each treatment to be tested. One section of the field was treated to a pre-harvest spray treatment of 2% EFF at 15 and 30 days before harvest. Fruits were collected separately from each tree and individual samples from each tree were subject to a postharvest water dip (control) or a 2% EFF postharvest dip treatment. The fruits used during this study were subjected either to a pre-harvest spray treatment of 2% EFF only, a 2% EFF post-harvest dip treatment only or a combination of both pre-harvest and post-harvest treatments. These treated and untreated fruits were stored at 20-22°C and observed for quality changes until the 18th day after harvest. Statistical analysis was done using Statistical Package for Social Sciences software program version 24

(SPSS). For each experiment, the mean of three replicates from each treatment (200 in total) was calculated to produce the standard error and the sum of squares value. One-way analysis of variance was used to test if a statistical difference exists between the average amount of days it took for stripes to emerge on fruits between the treated fruits and control fruits.

## Results and discussion

Pre-harvest spray treatments, time to onset of ripening, rate of ripening and disease incidence

Fruits on trees sprayed pre-harvest with 2% EFF, developed first colour stripe 75 days after second spraying while fruits on trees sprayed with the control solution developed first colour stripe in 15 days after application of the second spray. The latter was as expected since the pre-harvest applications were timed to be begin within 30 days of expected harvest. Thus, pre-harvest treatment with 2% EFF resulted in a 60 day delay in the onset of ripening in fruits on treated trees. Fruits were harvested on development of the first colour stripe, indicative of the onset of ripening.

### Development of colour stripes on fruits

The average time to the development of colour stripes for the fruit treated with 2% EFF sprayed twice for a 30 day period was 61 days whereas the fruits used as the control group took an average of 14.5 days to first appearance of colour stripes (Table 1).

Table 1: Development of colour stripes in fruits treated with 2% EFF and control fruits

Independent Variable	Sub Categories	N	Mean	Std. Dev.
Treatment	Control	10	14.5	0.707
	2% EFF	10	61.0	1.333
$F = 9492.805; P = 0.000^{***}$				

\*\*\* p-value indicating less than 1% significance

The one way ANOVA model showed that a statistical difference was observed at a 1% significance level between the treatment and development of colour stripes ( $F = 9492.805$ ;  $P = 0.000$ ). Essentially, the results showed that the 2% EFF treatment will delay ripening as indicated by the development of colour stripes at the distal end of the fruits.

There was a delay in the rate of ripening after harvest for fruits treated with 2% EFF at the pre-harvest stage, when compared to control fruits and fruits treated with a post-harvest dip only. By day 10, most of the control fruits showed full colour change and the onset of post-harvest diseases. Post-harvest diseases were characterized by sunken areas on the surface of the fruit and subsequent evidence of growth. The results indicated that the presence of hexanal may have been responsible for cell membrane maintenance (Spotts et al. 2006) resulting in a firmer fruit at full colour change and the absence of sunken spots during ripening and senescence at 20-22°C / 90-95% RH for up to 18 days after harvest for fruits treated with 2% EFF as a pre-harvest treatment.

#### Post-harvest dip treatment, rate of ripening and post-harvest disease incidence

Pre-harvest treatments using 2% EFF were more effective in delaying ripening and extending shelf life than postharvest applications. For fruits treated with postharvest dips using 2% EFF, following pre-harvest treatment, full colour change occurred 15-18 days after harvest. There was no significant difference in the rate of full colour development in fruit treated by postharvest dipping in 2% EFF when compared to control fruits.

The study showed that fruits treated using a combination of both pre-harvest and post-harvest applications of 2% EFF had the

lowest incidence of post-harvest disease development by 18 days after harvest.

By day 18, all fruits showed full colour development regardless of treatment. 70% of fruits treated with 2% EFF post-harvest treatment developed post-harvest diseases by day 18 when compared to fruits treated pre-harvest with 2% EFF. By day 18, all control fruits showed signs of post-harvest microbial disease development. The incidence of disease development in fruits treated pre-harvest with 2% EFF was 31%. Fruits treated at both the pre-harvest and post-harvest stages had the lowest incidence of spoilage due to post-harvest disease development, i.e., 15% (Figure 1). As such, fruits subjected to both pre-harvest and post-harvest treatments were least susceptible to postharvest diseases. The post-harvest dip treatment using 2% EFF, had the least effect on decreasing the susceptibility of papaya fruits to developing post-harvest diseases.

Following the delayed onset of ripening, fruits harvested from trees sprayed pre-harvest with 2% EFF ripened to full colour change in 18 days during storage at 20-22°C / 90-95% RH. Fruits harvested from trees sprayed with the control solution ripened to full colour change in approximately 10 days when stored under the same conditions. Thus, while time to onset of ripening in the field was delayed, time to full ripening after harvest was also delayed, indicating that fruit from treated trees had a decreased rate of ripening and a longer shelf life as a result, especially since the incidence of post-harvest disease was also reduced in fruits from treated trees. Therefore, pre-harvest treatment with two per cent EFF resulted in an extended period in the unripe state of the fruit in the field and a longer shelf life through a reduced rate of ripening and enhanced postharvest quality.

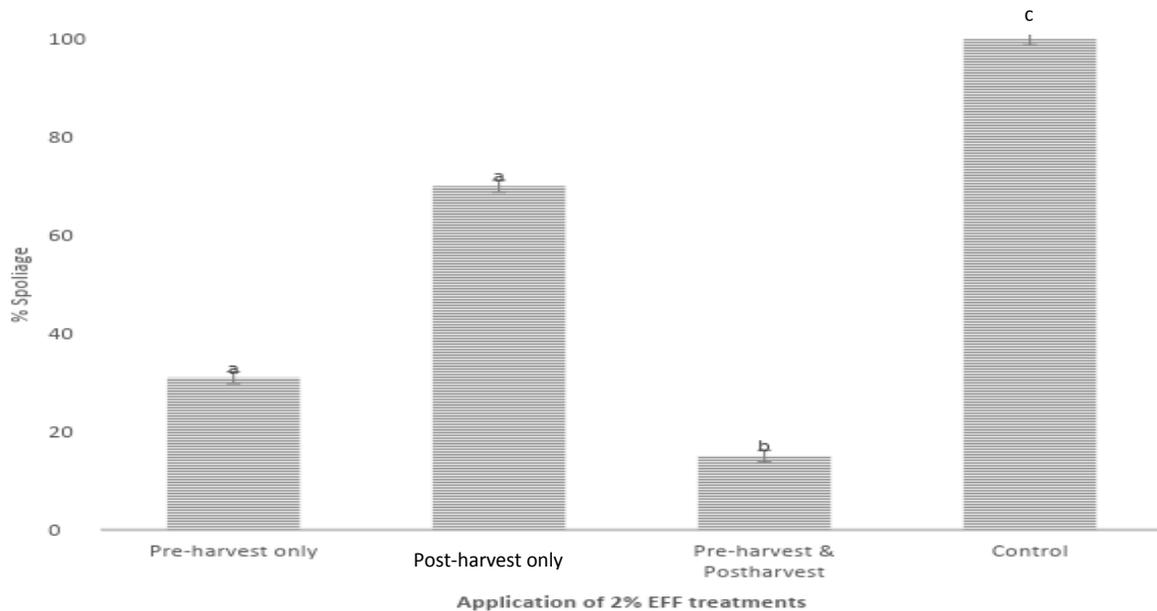


Figure 1: Percentage of papaya fruits showing signs of postharvest disease development by day 18 after application of 2% EFF treatments. Each point is the mean  $\pm$  SD of fifteen fruits. Values with the same letter suffix are not different according to the Tukey's test ( $p \leq 0.05$ ).

While pre-harvest treatment appeared to be more effective than post-harvest dipping for this cultivar, not all effects were positive; some fruit never ripened properly displaying a very long shelf life but progressing gradually to senescence without normal ripening changes, such as full colour development with concomitant fruit softening. Since for about 33 percent of fruit from treated trees, normal ripening never occurred, despite the development of the first colour stripe, further work is ongoing to determine the relationship between timing of spray application, stage of fruit maturation, delayed onset of ripening and rate of post-harvest ripening. This will allow for the development of more precise recommendations for optimal pre-harvest treatments.

In the meantime, pre-harvest treatment with 2% EFF appears ideal for papaya production for the unripe fruit market, including production of processed products.

## Conclusion

The results of the trials indicated that pre-harvest treatments with 2% EFF can delay the onset of fruit ripening, increase the time to full colour development and give better maintenance of post-harvest quality of papaya fruits. Pre-harvest treatment with 2% EFF can also reduce the incidence of post-harvest diseases.

Additionally, it was found that pre-harvest treatments using 2% EFF were more effective in delaying ripening and extending shelf life than post-harvest applications. This suggests that 2% EFF treatments applied as pre-harvest farm operations that are, in fact, less challenging for farmers to apply, are actually more effective than post-harvest dip treatments which are more suitable for pack house operations. Consequently, farmers stand to benefit more directly from the effects of this technology than other actors in the post-harvest chain since the effects such as delayed ripening and senescence, reduced incidence of post-harvest diseases and fruit quality maintenance, all translate into reduced post-harvest losses,

extended time for marketing of fruits and greater returns to the farmer.

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## References

- Akamine, E.K. and T. Goo. 1971. "Relationship between surface color development and total soluble solids in papaya." *HortScience* **6**:567–568.
- Ali, A., M.T.A. Muhammad, K. Sijam, and Y. Siddiqui. 2011. "Effect of chitosan coatings on the physicochemical characteristics of Eksotika II papaya (*Carica papaya* L.) fruit during cold storage." *Food Chemistry* **124**(2): 620–626.
- An, J.F. and R.E. Paull. 1990. "Storage temperature and ethylene influence on ripening of papaya fruit." *J. Amer. Soc. Hort. Sci.* **115**:949–953.
- Kader, A.A. 2006. "Papaya: Recommendations for maintaining postharvest quality." Postharvest Technology Research Information Center. Department of Plant Sciences, University of California p. 3.
- Lazan, H., Z.M. Ali, and W.C. Sim. 1990. "Retardation of ripening and development of water stress in papaya fruit seal-packaged with polyethylene film." *Acta. Hort.* **269**:345-358.
- Paliyath, G. and M.J. Droillard. 1992. "The mechanisms of membrane deterioration and disassembly during senescence." *Plant Physiol. Biochem.* **30**:789–812.
- Paliyath, G., and D.P. Murr., 2007. "Compositions for the preservation of fruits and vegetables." Google Scholar.
- Paliyath, G., R.G. Pinhero, R.Y. Yada, and D.P. Murr. 1999. "Effect of processing conditions on phospholipase D activity of corn kernel subcellular fractions." *J. Agric. Food Chem.* **47**:2579–2588.
- Paull R.E. 1993. "Pineapple and papaya." In *Biochemistry of fruit ripening*, edited by G.B. Seymour, J.E. Taylor and G.A. Tucker, 291-311. Chapman and Hall, New York, Tokyo.
- Paull, R.E., and W. Chen. 1997. "Minimal processing of papaya (*Carica papaya* L.) and the physiology of halved fruit." *Postharvest Biology and Technology* **12**(1): 93–99.
- Wills, R.B.H., W.B. McGlasson, D. Graham, T.H. Lee, and E.G. Hall. 1989. *Postharvest-An introduction to the physiology and handling of fruit and vegetables*, 3rd edn., New York, U.S.A., Van Nostrand Reinhold p. 46.