Enhanced Preservation of Fruits Using Nanotechnology –
A Canadian International Food Security Research Fund Project

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Yours sincerely

Julian Duncan
Editor in Chief/TA for this Special Issue

TROPICAL AGRICULTURE is pleased to receive and consider for publication, manuscripts of research papers, research notes* or reviews, in English on topics concerning tropical agriculture. The disciplines covered by the journal include: Soils, Environmental and Agro-Ecology; Crops; Livestock; Food Science; Agricultural Economics and Agribusiness; Food and Nutrition; Post-Harvest Technology; Geography; and Extension.

*The research note is not a full academic paper; it serves to advance a new idea, theoretical perspective, or methodological approach in a scientific study

Acknowledgement from the Research Team

We acknowledge the contribution of Ms. Siva Sikamani in coordinating the submission of manuscripts and tracking their progress and Ms. Carol Tinga for initial language editing of the manuscripts. We also thank IDRC personnel, especially Dr. Kevin Tiessen and Dr. Sara Ahmed, for encouraging us to take up this venture, which is a first for IDRC-funded projects.
Statement from Her Excellency Carla Hogan Rufelds
High Commissioner for Canada
Trinidad and Tobago

Food security continues to be a major challenge faced by countries around the world. The United Nations Sustainable Development Goal #2 – Zero Hunger – aims to end hunger, achieve food security and improved nutrition, and promote sustainable agriculture by 2030. In the wake of the 2008 global food price crisis, the Government of Canada developed an international assistance food security policy and dedicated funding for food security programming around the world. The Canadian International Food Security Research Fund (CIFSRF), jointly funded by IDRC and Global Affairs Canada, is one of the successful programs addressing the critical challenge of global hunger through applied research. Importantly, the research partnerships test and scale-up practical and innovative solutions, designed to address real-time food security challenges.

Researchers have used genetics and agronomy to efficiently improve food production. Equally important is the reduction of post-harvest losses, which range from 30-50% for various commodities, and occur at different stages in the journey from farm to fork. Fruits are notoriously perishable, but highly desirable, both for their taste and nutritional value. When the shelf-life of fruits is increased, farmers, retailers and fruit lovers benefit.

One of the successful CIFSRF initiatives is the ‘Enhanced Fruit Preservation using Nanotechnology’ project. Research at the University of Guelph in Canada led to the identification of a natural product, hexanal, which can keep fruits fresh longer. The effectiveness of this natural product has been taken around the world through the CIFSRF project. Interestingly, the research team used nanotechnology to deliver the hexanal more effectively. In general, nanotechnology research has served as a powerful revolutionary tool, from electronics to the health sector. The potential of nanotechnology in agriculture is just beginning to be realized. The CIFSRF group of researchers’ success in using nanotechnology to enhance the shelf-life of various fruits in different countries shows real promise.

I am delighted that the research conducted through this large multinational project has been brought together in a special issue of this research journal. Tropical Agriculture is a historically recognized journal from the University of the West Indies that highlights applied research in agriculture from tropical countries. I congratulate the authors from the six countries who have put together a compelling series of findings ranging from laboratory results to practical field experience to socio-economic impacts.

These research results, also available online, will help to decrease post-harvest wastage using hexanal and will be of great use to students, scientists, policy makers and entrepreneurs as we continue to work towards Zero Hunger.

Carla Hogan Rufelds
High Commissioner for Canada
Trinidad and Tobago
The University of the West Indies (The UWI) has benefited tremendously over the past decades from funding from international grant organizations. Specifically, The UWI School of Graduate Studies and Research has been the grateful recipient of funding for research and graduate programmes that has allowed the UWI to make meaningful contributions to the advancement of knowledge in areas relevant to the Caribbean Region, other tropical regions and the global environment.

This special issue of Tropical Agriculture comprises papers based on research findings from the project entitled: “Enhanced preservation of fruits using nanotechnology”. The project was a partnership among researchers at University of Guelph, Canada (Leader); Tamil Nadu Agricultural University, India; Industrial Technology Institute, Sri Lanka; University of Nairobi, Kenya; Sokoine University of Agriculture, Tanzania; and The University of the West Indies, Trinidad and Tobago.

Funding for the project was from the Canadian International Food Security Research Fund (CIFSRF), jointly funded by the International Development Research Centre (IDRC) and Global Affairs Canada. The UWI is grateful to the Government of Canada, for funding this project which allowed the collaboration of The UWI, through the Faculty of Food and Agriculture, with strategic partners. The UWI also wishes to express its gratitude to the University of Guelph, as the lead in the project, for its invitation to the Faculty of Food and Agriculture to partner with the other institutions.

The project demonstrated successful collaboration among researchers from diverse institutional backgrounds and with similarly varied resources, as they addressed a common research goal. It further demonstrated the importance of continuing scientific investigation in the area of plant physiology/post-harvest technology. Amidst increasing calls for the reduction in use of synthetic agro-chemicals, and where some may have mourned the loss of advantages gained such as increased crop production and extended shelf life, through their use, a natural product has been shown to be able to bring about positive changes that can be used to enhance shelf life, reducing postharvest losses and ultimately improving food and nutrition security. Most importantly, the potential of the research findings has been documented and the information has been released for future researchers to fine-tune the procedures as required for specific crops, cultivars and ecological zones.

The UWI is grateful for the selection of Tropical Agriculture for the publication of some of the research output from the project and for the funding of the publication of the Special Issue by the project. It is important to note that this issue is open access at the request of the funding agency - this is the first open access publication/issue of Tropical Agriculture and will mark the beginning of a new era for Tropical Agriculture as it seeks to achieve greater dissemination of research findings from tropical regions and to widen access to papers published in the Journal.

Dale Webber (Professor)
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(Musa acuminata cv. Grand Naine) in India

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A laboratory study was undertaken to determine the effects of a nano-emulsion carrying hexanal, an enhanced freshness formulation (EFF), as a post-harvest dip technology to minimize the post-harvest losses and to extend the shelf life of bananas. The banana fruits were harvested at three maturities (95%, 85%, and 75%), dipped or not dipped in the EFF, and studied under both ambient and reduced temperature storage conditions. During the experiments, the fruit’s physical, physiological, and biochemical parameters were periodically evaluated. The treated fruit had lower physiological loss of weight and higher firmness throughout the study period, regardless of maturity level at the start. Treated fruit had higher total soluble solids and total sugars, and less acidity indicating improved fruit quality during storage, in addition to an extended shelf life. High resolution imaging using scanning electron microscopy showed that EFF-treated fruit exhibited well maintained structural lenticels on the fruit skin and deposition of starch granules in the fruit pulp, regardless of maturity level at the start. Overall, the results clearly indicated that the EFF-treated banana fruit were delayed in the ripening process and had an extended shelf life of up to six days in ambient conditions and nine days in cold storage conditions. Post-harvest dipping using hexanal formulation is a potential technology that could be adopted in pack houses for domestic and export markets.

Keywords: Hexanal, shelf life, banana, storage, dip technology, enhanced freshness formulation, EFF, post-harvest technology

India is the largest producer of bananas in the world (30 million tonnes) produced from an area of 850,000 hectares (National Horticulture Board 2016). Among the many cultivars commercially grown, cv. Grand Naine is gaining popularity and may soon be the most preferred, due to its tolerance to biotic stresses, extended shelf life, uniform colour development during ripening, and export-quality bunches. In India, the magnitude of post-harvest losses for fruit is estimated at 30% to 35%, creating a huge economic drain on the country—in the order of 13,560 crores Indian rupees annually (Murthy et al. 2009). Such massive post-harvest losses in perishables are due to poor harvesting, handling, storage, transportation, and marketing practices. Although physiological and biochemical activities involved in fruit ripening are irreversible, many technologies have been developed targeting the pre-ripening stage to reduce post-harvest losses and extend the shelf life of fruit.

Bananas being a climacteric fruit, have a distinct ripening pattern with increased respiration and ethylene biosynthesis rates during ripening (Lelièvre et al. 1997), which limit their shelf life. Furthermore, biochemical and physiological changes during ripening take place within a short time. As the activities of these enzymes are mainly ethylene dependent (Lohani et al. 2004), it is necessary to understand the ripening process in banana to develop successful post-harvest technologies (Yanez et al. 2004). The
Post-harvest dip of enhanced freshness formulation to extend the shelf life of banana (Musa acuminata cv. Grand Naine) in India; Kanmani Venkatachalam et al.

softening of banana is caused by enzyme activities in cell walls, which involves polygalacturonase (PG), pectin methyl esterase (PME), pectatlyase (PL), and cellulases. The commercial application of 1-methylecyclopropene (1-MCP), a potent ethylene inhibitor (i.e. receptor blocker), has been successfully employed in climacteric fruit such as apple, plum, banana, strawberry, and pear for extending shelf life (Blankenship 2001; Zhu et al. 2015). European countries, particularly the United Kingdom, prohibit the direct use of 1-MCP in fruit preservation.

In order to improve the shelf life of fruit, various types of dip treatments have been adopted in several countries for different fruit. Several chemicals, such as combined solutions of calcium chloride, ascorbic acid, and cysteine (Bico et al. 2009), natural lysophospholipid along with soy lecithin (Ahmed and Palta 2016), salicylic acid (Srivastava and Dwivedi 2000), phenylurea [CPPU] and gibberellins [GA3] (Huang et al. 2014), 1-MCP (Blankenship 2001), nitrous oxide (N2O) (Palomer et al. 2005), potassium permanganate (KMnO4) (Hassan 2000), and oxalic acid (Huang et al. 2013), were found effective in minimizing the losses of fruit during storage and transport, and in extending the shelf life of fruit. In all cases, the chemicals inhibit ethylene production thus enabling the extension of shelf life of fruit. Despite the number of chemicals and technologies available for fruit preservation, the adoption of these technologies is very low due to practical difficulties, non-availability, and prohibitive costs. Non-invasive storage technologies, such as modified atmospheric storage, have been used to enhance the post-harvest shelf life of banana (Noomhorn and Poety 1993; Yahia 2009). The respiration rate of fruit is affected by the development stage and the respiration patterns (Nicolai et al. 2009), and the optimal storage temperature for banana appears to be 13°C to 14°C, with a relative humidity of 85% to 90% (Kader 2005). Although multiple options are available to extend the shelf life of fruit to some extent, various constraints make it necessary to introduce new formulations that are eco-friendly and economically feasible.

Hexanal, a naturally occurring, six-carbon aldehyde formed from linoleic acid via the lipoxygenase pathway in plants (Hildebrand 1989), is highly volatile and has antifungal properties against Alternaria alternate, Botrytis cinerea, and Penicillium expansum (Hamilton-Kemp et al. 1992; Song et al. 1998). Hexanal extends the shelf life of fruit when it is externally applied as a pre-harvest spray, post-harvest dip, or vapour. It is generally recognized as safe (GRAS), has been observed to be a strong inhibitor of phospholipase D, and so technologies for its application to enhance shelf life and the quality of fruit, vegetables, and flowers are currently under development (Paliyath et al. 1999, 2003; Paliyath and Murr 2007). Hexanal formulations applied as pre-harvest treatments, post-harvest dips, and vapour treatments were found to be effective in enhancing the shelf life of many fruit, such as apple, pear, peach, grape, sweet cherry, strawberry, mango (Paliyath et al. 1999; Paliyath and Murr 2007; Anusuya et al. 2006) and tomato (Utto et al. 2008). In addition to the antimicrobial activity of hexanal, its aroma volatiles increase the sensory attributes of ripe fruit (Archbold et al. 2000). It was also found to stimulate aroma production in Jonagold and Golden Delicious apple slices (Song et al. 1998). Hexanal formulations also prevented browning reactions for 16 days at 15°C when added under modified atmospheric conditions (Lanciotti et al. 1999). Despite hexanal formulations having been extensively studied in temperate fruit and vegetables, they have been rarely studied in tropical fruit. It is hypothesized that dipping of banana fruit in a hexanal formulation facilitates the inhibition of phospholipase D enzyme in the skin of the fruit and slowing down ethylene production; these two physiological processes enable the extension
of the shelf life of the fruit. Banana fruit is harvested at three distinct maturities to target domestic and export markets. This study focuses on the evaluation of the effectiveness of post-harvest dipping of fruit in an enhanced freshness formulation (EFF), a hexanal based formulation, at different levels of fruit maturity and under two distinct post-harvest storage conditions (ambient and reduced temperature storage) to extend shelf life.

Materials and methods

Fruit samples and treatments

The banana fruits were obtained from the Farm Fresh Banana, at Chinnamanur, Theni, Tamil Nadu, India. The fruits were harvested at three different stages of maturity (75, 85, and 95%) based on the number of days from shooting, using the nylon rope harvest method. However, only fruits harvested at 85% maturity are being discussed in this manuscript as this is the most common stage for commercial harvest for most practical purposes. The studies were undertaken from 2015 to 2016 at the Department of Fruit Crops, Horticultural College and Research Institute, Periyakulam and the Department of Nano Science and Technology, Tamil Nadu Agricultural University, Coimbatore, India. The banana fruit hands were cleaned carefully by washing with potable water and maximum efforts were made to select uniformly-sized fruit that were free from injuries and diseases. Fruits were treated with EFF for 5 minutes and then air-dried and washed once in clean water. Fruits dipped in water for 5 minutes and then air-dried served as control. Treated and untreated samples of fruits were stored under: (a) ambient (Temperature 28°C ± 2°C, RH 60 ± 10%) and (b) cold (14°C ± 2°C, RH 90 ± 5%). For each treatment, 100 kg of banana fruit were used. Fruits were sampled on predetermined dates between 10 a.m. and 11 a.m., frozen in liquid nitrogen, and stored at −80°C until analysis.

Shelf life

The time from the day of harvest, taken by fruit to reach the optimal, edible ripe stage was counted and reported in days.

Physiological and biochemical parameters

The physiological and biochemical traits were measured in 5 fruit sampled at three-day intervals, from each of treated and untreated banana fruit kept under ambient and reduced temperature storage conditions.

Physiological loss in weight (PLW)

The PLW was calculated by subtracting final weight from initial weight of the fruit and then expressed as per cent weight loss with reference to the initial weight as recommended by the Association of Office Analytical Chemists (2001) using the following formula: PLW (%) = Initial weight (g) − Final weight (g) / Initial weight (g) × 100. Ten fruits in each treatment were used for PLW estimation.

Respiration rate

One-kilogram of fruit of each batch, (EFF treated and control, ambient-stored and cold-stored) was placed in airtight plastic containers of 5L capacity with rubber septa placed in the top of the container lids. Changes in the O_2 and CO_2 levels inside the plastic containers were measured using Headspace Gas Analyzer (CheckMate 3 Dansensor) and measurements were made at 2-day intervals with three replicates for each treatment.
Post-harvest dip of enhanced freshness formulation to extend the shelf life of banana (Musa acuminata cv. Grand Naine) in India; Kanmani Venkatachalam et al.

Firmness

Fruit firmness was measured using a Texture Analyzer (TA-HDi, Stable Micro Systems, UK) fitted with a 4 mm cylindrical probe (P/4) by the method proposed by Camps et al. (2005). Textural values were obtained from a three-point slope (A to D measurements) for each banana and the average values were determined and recorded.

Fruit quality

Quality parameters such as titratable acidity and total sugars were determined using standard operational protocols in the same set of fruit that were used for the fruit firmness analysis. The titratable acidity was estimated by titration of the juice against 0.1 N KOH using phenolphthalein as an indicator and expressed as citric acid (Srivastava and Kumar 1993). The total sugars were determined colorimetrically by an Optima UV-VIS spectrophotometer (Model SP-3000) using anthrone reagent (Hedge and Hofreiter 1962). A standard graph was prepared using known concentrations of glucose solutions. The sample values were plotted on the standard graph for total sugars and total sugars were expressed as percentages. The ascorbic acid (vitamin C) content was determined using the 2,6-dichlorophenol-indophenol titration method described in Association of Official Analytical Chemists (2001). L-ascorbic acid was used to prepare a standard solution (1 mg/mL). The ascorbic acid concentration was calculated by comparing it with the standard and expressed as mg/100 g fresh weight.

Scanning Electron Microscope (SEM) Analysis

Fresh samples were collected from treated and untreated banana fruit after 12 days and 18 days under reduced temperature storage conditions. The fruit pulp and peel surface were cut into 2-3 mm long segments, processed as required for scanning electron microscopy and observed with a scanning electron microscope (SEM-FEI-Quanta 250, Netherlands).

Statistical analysis

A completely randomized factorial design was employed to understand the main effects of treatments on different maturities (75%, 85% and 95%) under ambient and reduced temperature storage conditions and their interactions for the different parameters examined in fruit samples in the laboratory. Mean comparisons were made after computing ANOVA and Least Significant Difference (LSD) at the \( P < 0.05 \) level. All the statistical analyses were performed utilizing the statistical analysis software AGRES.

Results

Only data from the 85% level of maturity are reported in the tables. There was no significant treatment by maturity interaction for any trait measured. The 85% level of maturity represents the stage of ripening at which most bananas would be harvested for the local markets. Any notable results for the 95% and 75% maturities are noted in the text.

Shelf life (days)

The shelf life of banana fruit dipped in EFF was 33 days under ambient conditions while the controls stayed fresh for 27 days only (Fig. 1). Under reduced temperature storage conditions, dipped fruit stayed fresh for 42 days, while control fruits were fresh for 36 days only. (Fig. 1). The results indicated that the shelf life was extended by 6 days (Fig. 2). However, the marketability of the treated fruits kept in reduced temperature storage improved by 18 days (15 days in control and 33 days in reduced temperature storage; Fig.2).
Post-harvest dip of enhanced freshness formulation to extend the shelf life of banana (*Musa acuminata* cv. Grand Naine) in India; Kanmani Venkatachalam et al.

Figure 1: Shelf-life of bananas in EFF treated and control bananas at 85% maturity under ambient and reduced temperature storage conditions with ± SD.

Figure 2: Shelf-life extension of banana fruits at 85% maturity in treated and control bananas under ambient (A) and reduced temperature storage (B) conditions. Yellow box shows the latest date of marketability and red box in control denotes unmarketable as they did not ripen normally.
Physiological loss in weight

The PLW values increased progressively with the advancement of storage, regardless of maturity, treatments, or storage conditions.

Table 1: Effect of enhanced freshness formulation on physiological loss in weight (PLW) % and fruit firmness of banana fruits

<table>
<thead>
<tr>
<th>Days</th>
<th>Physiological Loss of Weight</th>
<th>Firmness</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>28°C</td>
<td>4°C</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>T</td>
</tr>
<tr>
<td>3</td>
<td>2.09</td>
<td>1.67</td>
</tr>
<tr>
<td>6</td>
<td>3.23</td>
<td>2.24</td>
</tr>
<tr>
<td>9</td>
<td>4.21</td>
<td>3.42</td>
</tr>
<tr>
<td>12</td>
<td>5.12</td>
<td>4.25</td>
</tr>
<tr>
<td>15</td>
<td>6.83</td>
<td>5.78</td>
</tr>
<tr>
<td>18</td>
<td>8.23</td>
<td>6.32</td>
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<tr>
<td>21</td>
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<td>7.34</td>
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<tr>
<td>39</td>
<td>13.56</td>
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<tr>
<td>42</td>
<td>15.25</td>
<td>9.28</td>
</tr>
</tbody>
</table>

LSD* Least Significant Difference (P<0.05) used to compare means within a treatment (temperature)
C-Control; T-Treatment- dipped in EFF solution for 5 minutes

Firmness

The firmness of fruit decreased with the progression of storage duration. On the 18th day the treated fruit had higher firmness (15.56; 17.42 N/mm) than the control (14.12; 16.25 N/mm) under ambient or reduced temperature storage conditions, respectively (Table 1). In reduced temperature storage temperatures, the firmness of fruit was retained for a longer period of time (48 days). In general, the treated fruit had significantly (P ≤ 0.05) higher firmness than the control, regardless of storage conditions.

Total sugars

The total sugar content of banana fruit increased with the advancement of ripening in both control and treated fruit, as expected. However, the sugar content was significantly lower in the treated fruit compared to control at all days of observation (Table 2). This indicates that the ripening progressed normally due to EFF treatment, but at a reduced pace.
Table 2: Effect of enhanced freshness formulation on total sugars (per cent) of banana fruits

<table>
<thead>
<tr>
<th>Days</th>
<th>Total Sugars (per cent)</th>
<th>Ascorbic acid (mg/100g)</th>
<th>Respiration rate (mg kg(^{-1})h(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>28°C</td>
<td>4°C</td>
<td>28°C</td>
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<td></td>
<td>C</td>
<td>T</td>
<td>C</td>
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<tr>
<td>3</td>
<td>10.32</td>
<td>9.78</td>
<td>10.06</td>
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<td>11.98</td>
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<td>42</td>
<td>21.98</td>
<td>21.98</td>
<td>16.12</td>
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</tbody>
</table>

LSD\(^*\): Least Significant Difference (P<0.05) used to compare means within a treatment (temperature)
C-Control; T-Treatment- dipped in EFF solution for 5 minutes

Ascorbic acid

The ascorbic acid content increased during storage as expected. However, the ascorbic acid content in the EFF treated fruit was always significantly lower than control on any given day of measurement indicating the slowness of ripening due to EFF treatment (Table 2).

Respiration rate

The respiration rate of banana fruit declined gradually during storage, regardless of environmental conditions or treatments.

Although the respiration rate was higher in the treated fruit than control, the increase was not significant (Table 2).

Electron microscopy

The SEM images exhibited well-maintained structural lenticels on the fruit peel (Fig. 5) and the pulp cells had starch granules in the treated fruit, regardless of maturity (Fig. 3). Fruit skin was distorted and the pulp cells had fewer starch granules in the control fruit.
Post-harvest dip of enhanced freshness formulation to extend the shelf life of banana (*Musa acuminata* cv. Grand Naine) in India; Kanmani Venkatachalam et al.

**Figure 3:** Peel structure and starch granule deposition of banana fruit in control and EFF-treated fruits on 18th day as visualized with scanning electron microscopy at 1000 X magnification. The lenticels in the peel are intact and plump in treated against a dehydrated and flat appearance in the control. Similarly the starch granules are intact in the fruit indicating that it has not fully ripened while they have completely broken down in the control.

**Discussion**

Hexanal is a plant-derived compound that has been used to inhibit the phospholipase D enzyme in the skin of the fruit and it has been associated with the extension of shelf life of fruit in temperate (Paliyath and Subramanian 2008; Sharma et al. 2010) and tropical climates (Anusuya et al. 2016; Jincy et al. 2017). The banana fruit dipped in EFF maintained significantly lower PLW values throughout the experiments, regardless of maturity at harvest or storage conditions. This may be attributed to the thickening of the cell wall as a consequence of the inhibition of the lipoxygenase enzyme. Our data, in combination with that in the literature, provides a body of evidence that supports the hypothesis that hexanal formulations facilitate skin thickening, which contributes to the reduced PLW. Our EFF had a similar effect in all the maturities of harvest indicating that the dipping technology could be useful for both domestic and export markets.

It is well established that climacteric fruit, such as banana, continue to respire even after being harvested and this leads to fruit spoilage. Many post-harvest management strategies have been designed to minimize the respiration rate to extend the shelf life of fruit. Our results demonstrated that the EFF lowered the respiration rates, which corresponded closely with shelf life extension during storage, regardless of maturities. Kader (2005) reported that increasing the CO₂ concentration by 7-8% and lowering the oxygen to 1% in controlled atmospheric storage extended the shelf life of
banana fruit as a consequence of the reduced respiration rate. Furthermore, Paliyath and Subramanian (2008) extended the shelf life experimentally, of temperate fruit treated with hexanal formulation in combination with 1-MCP and have shown that hexanal has a unique advantage of slowing down the respiration naturally without ill effects. A potent ethylene blocker, 1-MCP has been used in various commercial applications to extend the shelf life of fruit, vegetables, and flowers (Blankenship and Dole 2003). The only constraint with 1-MCP application in certain fruit and vegetables is that it completely arrests the ripening process with no possibility of reversing the arrested reaction. Reversing the reaction, however, is necessary for certain fruit and vegetables after long distance transport and before reaching the market. Hexanal treatment offers several advantages over 1-MCP treatment as it does not impair colour nor flavour development but delays senescence in (at least) apples and tomato fruit (Kondo et al. 2005; Cliff et al. 2009). The EFF-dipped bananas maintained higher firmness compared to control fruit throughout our experiments. The fruit retained higher firmness due to the action of hexanal, which seems to have reduced the activities of enzymes promoting pectin and hemicellulose degradation. The delay in softening may also be due to the reduced biosynthesis of cell wall hydrolases in addition to ethylene inhibition. Most fruit soften during ripening and this is a major quality attribute that often dictates shelf life. Fruit softening could arise from one of the three mechanisms: loss of turgor, degradation of starch, or breakdown of the cell walls. Loss of turgor is largely a non-physiological process associated with the post-harvest dehydration of the fruit and it can become important during commercial storage. Degradation of starch probably results in a pronounced textural change, especially in those fruit like banana, where starch accounts for a high percentage of the fresh weight (Turner and Fortescue 2002). Our data clearly demonstrate that EFF-dipped fruit remain fresh for longer periods of time irrespective of maturity at harvest.

Sugars, soluble portions of starch, organic acids, soluble pectin, and vitamin C are the components of total soluble solids (TSS) of banana fruit pulp. Reis et al. (2004) reported that a chemical dip, calcium chloride plus ascorbic acid, and modified atmosphere storage increased the TSS of banana pulp. In our experiment, total sugars in banana fruit increased with the progression of ripening under both ambient and reduced temperature storage conditions. In general, total sugar content in treated fruit was lower compared to controls, regardless of storage condition, suggesting the reduction in pace of ripening due to hexanal. Similarly, the cold-stored fruit had lower total sugar content compared to ambient-stored fruit. Our result is in agreement with that of Blankenship and Dole (2003) who also found that sugar level was dependent on the storage conditions. The lower sugars seen under reduced temperature storage conditions may be due to the inhibition of acid metabolism and dehydration, which reduced soluble sugar concentrations in fruit (Duan et al. 2008).

Ascorbic acid is one of the most important qualitative traits, especially with respect to human nutrition. The observed increase in ascorbic acid content might be due to a catalytic influence of hexanal on ascorbic acid biosynthesis from its precursor glucose 6-phosphate, or inhibition of its conversion to dehydroascorbic acid by the enzyme ascorbic acid oxidase or both. That ascorbic acid content increase is in agreement with the reports of Khan et al. (1976) in litchi. Pinaki et al. (1997) carried out an experiment with mature and fully developed banana fruit of uniform size that were dipped in GA3 at 150 ppm and they found that GA3 -treated fruit retained a higher titratable acidity and had lower ascorbic acid content during storage. Selvaraj (1993) conducted an experiment on mango fruit and showed that the acidity increased during maturity, which is closely associated with the
production of higher amounts of anti-oxidants. Our study showed an increase in ascorbic acid content in treated fruit.

Banana is a typical climacteric fruit in which the respiration rate reaches a peak during ripening (Albert 1926). The transformation from starch to sugar accelerates during the sudden increase of respiration (Clendennen and May 1997; Chen and Ramaswamy 2002). However, after the climacteric respiration phase, the respiration rate decreases (Cordenunsi and Lajolo, 1995; Waliszewski et al. 2003). Our results clearly show that starch granules are well preserved in the treated fruit compared to the controls, regardless of maturity indices; that peel structures with clear lenticels were well retained; and that respiration rates were lower in the treated fruit compared to the control fruit (data not shown). All of these results indicate that the ripening-associated processes were delayed by EFF in the treated fruit compared to the control fruit.

**Conclusion**

Overall, the results indicated that dipping of banana fruits in EFF extended their shelf life. The treated fruits maintained lower PLW and higher firmness throughout the study period, regardless of maturities at the start. In addition, treated fruit had lower total sugars, and higher firmness indicating less decrease in quality of fruit during storage compared to the control. The structural integrity of skin cells and fruit pulp seen in the high-resolution images of the treated fruit clearly showed a delayed ripening process. Based on these data we conclude that banana fruit dipped in 2% EFF for 5 minutes experience an extended shelf life of up to 6 days under ambient conditions and 9 days under reduced temperature storage conditions with the added advantage of improved fruit quality.

**Acknowledgement**

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**References**


Post-harvest dip of enhanced freshness formulation to extend the shelf life of banana (Musa acuminata cv. Grand Naine) in India; Kanmani Venkatachalam et al.


Efficacy of hexanal application on the post-harvest shelf life and quality of banana fruits (*Musa acuminata*) in Kenya

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The study was conducted to determine the efficacy of hexanal applied either as pre-harvest spray or post-harvest dip in enhancing the shelf life of banana var. *Grand Nain*. The study was done in Meru County (high potential zone) and Machakos County (low potential zone) of Kenya. Two hexanal concentrations (2 % and 3 %) were sprayed either once (at 30 days) or twice (at 30 days and 15 days) before harvest. Observations of how long the fruits stayed on the tree between the treated and untreated ones, was based on the duration taken for 20 % of the fruits per bunch to ripen. Once ripe, the fruits were harvested and analysed. For the post-harvest dip treatment, fruits harvested at the mature green stage were dipped in 2 % hexanal, 3 % hexanal, or water (control) for 2.5 minutes or 5 minutes. The fruits were allowed to ripen at ambient room conditions (25 ± 1°C and RH 60 ± 5%). Physiological and physico-chemical parameters associated with fruit ripening were evaluated at 3-day intervals. An interaction between zone of production and mode of application had a significant effect (*p* < 0.05) on fruit retention. Hexanal applied twice as a spray significantly (*p* < 0.05) improved fruit retention by 12 days and 18 days in Machakos and Meru Counties, respectively. Post-harvest dip treatments enhanced fruit shelf life by 9 days (5-minute dip) and 6 days (2.5-minute dip) compared to 6 days for bananas sprayed twice. Respiration rate, ethylene production, and fruit softening were significantly (*p* < 0.05) delayed by hexanal treatment. Progression of other ripening-related changes including increases in total titratable acidity, *Brix*, and vitamin C were slower in fruits treated with hexanal. Overall, these findings indicate that hexanal applied either as a pre-harvest spray (30 days and 15 days before harvest) or a post-harvest dip (5 minutes) has the potential to enhance banana shelf life besides improving fruit retention on the tree by 12-18 days when applied as pre-harvest spray.

Keywords: hexanal, post-harvest dip, pre-harvest spray, banana, shelf life, quality

Huge post-harvest losses estimated at 40 % are a major constraint facing small-holder fruit farmers in developing countries such as Kenya. Losses are mostly attributed to the highly perishable nature of the produce and are further aggravated by failure to use appropriate post-harvest technologies. Banana is the most important fruit crop in Kenya. According to HCDA (2013), it is produced throughout the year in almost all the agro-ecological zones (AEZs). Commercially, banana is harvested at the mature green stage and then ripened before marketing. Once ripe, the fruits are very delicate and have a short shelf-life of 3-4 days which limits their marketability (Ahmed and Palta 2015). Being climacteric in nature, banana produces high levels of ethylene that triggers ripening and senescence. Ripening of banana is characterized by rapid softening which influences its shelf life considerably.

Over the years, several post-harvest technologies have been developed to address post-harvest losses in perishable commodities. Low temperature storage is one of the appropriate technologies for use by small-scale horticultural farmers. However, the majority of these farmers cannot afford the cold storage facilities; furthermore, banana is very sensitive to low temperatures with chilling injury a possible outcome (Pongprasert et al. 2006). Use of 1-methylcyclopropene (1-MCP) has been found effective in enhancing shelf life of several climacteric fruits such as mango (Ambuko et al. 2013) and avocado (Meyers et al. 2011). However, its adoption in
banana has been limited due to undesirable effects, such as abnormal colour biosynthesis resulting in blotchy ripening, softening, and inhibiting the production of essential volatiles and esters (Kondo et al. 2005; Tiwari and Paliyath 2011). Therefore, there is need to find an alternative technology to enhance the shelf life of banana fruits without compromising fruit quality.

Over the past few years, hexanal, a naturally occurring aldehyde produced through the lipoxygenase pathway after tissue damage, has been shown to enhance the shelf life and quality of some temperate fruits, such as strawberries, peaches, nectarines, and cherries (Sharma et al. 2010). Although hexanal’s mode of action is not clear, a previous study has suggested that it works by inhibiting the action of the enzyme phospholipase D which catalyzes hydrolysis of membrane phospholipids and initiates membrane deterioration and thus, fruit softening (Paliyath et al. 2008). Hexanal treatment results in cell membranes remaining intact and stable, causing fruits to remain firmer and fresher-looking for a longer period. A biochemical formulation of an artificially synthesized version of hexanal (Enhanced Freshness Formulation) which delays ripening of temperate fruits has been developed (Sharma et al. 2010). Although hexanal has shown promising results in Asian and North America countries, there is no published work on its efficacy in reducing post-harvest losses on tropical fruits grown in Africa. Therefore, the objective of this study was to evaluate the efficacy of hexanal, applied either as a pre-harvest spray or post-harvest dip, for enhancing the shelf life of banana fruit var. *Grand Nain* in Kenya.

**Materials and methods**

**Site description and experimental set up**

The study was conducted in two contrasting AEZs in Kenya on banana fruit var. *Grand Nain*. Meru County is a high potential AEZ II that lies at an elevation of 1,980–2,700 m above sea level and receives an annual average rainfall of 1,500 mm. Machakos County is a semi-arid AEZ IV that lies at an elevation of 1,000-1,600 m above sea level with an annual average rainfall of 600 mm. The experiment was conducted in 2016 and repeated in 2017.

For the pre-harvest spray mode of application, 60 banana trees at the flowering stage were randomly selected and tagged in the farmer’s field. Two concentrations of hexanal (2% and 3%) and a control (clean, plain water) were sprayed either once at 30 days, or twice at 30 and 15 days before harvest. Since hexanal is immiscible with water, Tween 20 and ethanol were added to increase its solubility (Tiwari and Paliyath 2011). Using a knapsack sprayer, the fruits were sprayed to the point of dripping with the solution. The fruits were left on the tree until approximately 20% per bunch had ripened. The fruits were then harvested and the middle hands only, were used in the post-harvest analysis.

For the post-harvest dip mode of application, fruits were harvested at the mature green stage based on degree of fullness of the fingers, as indicated by the disappearance of angularity and the number of days after anthesis (approximated at 104 days). Only the middle hands of each banana bunch (a cluster of fruits attached together at the stalk) were used in the analysis. The harvested fruits were packed in cushioned crates, covered with wet paper towels to reduce water loss, and immediately transported to the post-harvest laboratory.

**Sample preparation**

The fruits were cleaned, dried, and selected for uniformity and freedom from mechanical injuries. Pre-harvest spray-treated fruits were left to undergo normal ripening under ambient room conditions (25 ± 1°C and RH 60 ± 5%). Fruits for post-harvest treatment were dipped in one of the two hexanal concentrations (2%, 3%) or plain water (control) for either 2.5 minutes or 5 minutes. All the fruits were left...
to undergo normal ripening under ambient room conditions. Five banana hands from each treatment combination were randomly sampled at 3-day intervals to evaluate respiration rate, ethylene evolution rate, and cumulative weight loss. Three fruits were also randomly sampled to evaluate other ripening-related parameters (i.e., peel and pulp firmness, titratable acidity, ascorbic acid, and total soluble solids). Only the most effective treatments were analysed for the biochemical parameters.

Analysis of physical and physiological parameters

For pre-harvest spray treatment, fruit retention on the trees was monitored by observing how long the treated and untreated fruits took for 20% of the fruits per bunch to ripen. Peel colour was determined in the field using a NF-333-Color spectrophotometer (Nippon Denshoku Industries, Japan) on three fruits per bunch at 6-day intervals. The L*, a*, and b* coordinates were recorded and a* and b* values converted to hue angle (H°).

Rate of respiration was measured using a gas chromatograph model GC-8A, Shimadzu Corp., Kyoto, Japan, fitted with a thermal conductivity detector (TDC) and a Porapak N column. The detection temperature was 150°C while the initial and final column temperatures were 120°C. Ethylene production were determined using gas chromatographs Model GC-9A, Shimadzu Corp., Kyoto, Japan, fitted with a flame ionization detector (FID) and an activated alumina column. The detection temperature was 240°C, injection temperature was 220°C while the column temperature was 120°C. Peel and pulp firmness were measured at three different regions of the fruit using a penetrometer (CR-100D, Sun Scientific Co. Ltd, Japan) fitted with an 8 mm probe. Total soluble solids (TSS) content was determined using a digital refractometer (Model PAL-1, Atago, Tokyo, Japan) and expressed as °Brix, while ascorbic acid content was determined by the high performance liquid chromatography (HPLC) method. Total titratable acidity (TTA) was determined by titration with 0.1N NaOH in the presence of phenolphthalein indicator and expressed as per cent malic acid, the predominant organic acid in banana fruit.

Statistical analyses

The data were subjected to Analysis of Variance (ANOVA) using the Genstat statistical package (version 18) and means compared by Least Significance Difference (LSD) at $p \leq .05$.

Results

Fruit retention and shelf life

Hexanal-treated fruits were retained on the tree up to 54 days and 60 days in Machakos County and Meru County respectively compared to 42 days in the controls. The application of hexanal as a pre-harvest spray improved fruit retention on the tree (i.e., there was a delay in harvesting based on changes in peel colour) by 12-18 days though this varied with the number of sprays done and zone of production (Table 1, Figs. 1A and B). In Machakos County, hexanal improved fruit retention by 12 days in fruits sprayed twice (30 days and 15 days before harvest) and 6 days in those sprayed once (30 days before harvest), (Fig.1A). In Meru County, hexanal improved fruit retention by 18 days (fruits sprayed twice) and 6 days (fruits sprayed once). Shelf life was significantly ($p <0.05$) affected by the interaction between mode of hexanal application and treatment duration. Upon harvesting, sprayed fruits had a shelf life of 6 days and 3 days after double and single sprays, respectively, in Machakos County compared to 9 days for fruits treated by post-harvest dipping for 5 minutes in both zones.
Efficacy of hexanal application on the post-harvest shelf life and quality of banana fruits (*Musa* spp.) in Kenya: P.M. Yumbya et al.

Table 1: ANOVA for changes in peel colour in *Grand Nain* variety bananas in Meru County (AEZ II) and Machakos County (AEZ IV) sprayed with 2% or 3% hexanal either once at 30 days, or twice at 30 days and 15 days before harvest, and untreated controls

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>d.f.</th>
<th>s.s.</th>
<th>m.s.</th>
<th>v.r.</th>
<th>F pr.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concentration</td>
<td>2</td>
<td>1071.1</td>
<td>5355.6</td>
<td>222.1</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>No. of sprays</td>
<td>2</td>
<td>273.8</td>
<td>136.9</td>
<td>5.7</td>
<td>0.003</td>
</tr>
<tr>
<td>Location</td>
<td>1</td>
<td>326.3</td>
<td>326.3</td>
<td>13.5</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Days</td>
<td>9</td>
<td>29097.0</td>
<td>3233.0</td>
<td>134.1</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Concentration* Location</td>
<td>2</td>
<td>12.6</td>
<td>6.3</td>
<td>0.3</td>
<td>0.771</td>
</tr>
<tr>
<td>No. of sprays*Location</td>
<td>2</td>
<td>7.4</td>
<td>3.7</td>
<td>0.2</td>
<td>0.859</td>
</tr>
<tr>
<td>Concentration*Days</td>
<td>18</td>
<td>8852.9</td>
<td>491.8</td>
<td>20.4</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>No. of sprays*Days</td>
<td>18</td>
<td>368.5</td>
<td>20.5</td>
<td>0.9</td>
<td>0.641</td>
</tr>
<tr>
<td>Location*Days</td>
<td>9</td>
<td>1474.8</td>
<td>163.9</td>
<td>6.8</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Concentration<em>Location</em>Days</td>
<td>18</td>
<td>550.5</td>
<td>30.6</td>
<td>1.3</td>
<td>0.209</td>
</tr>
<tr>
<td>No. of sprays<em>Location</em>Days</td>
<td>18</td>
<td>99.5</td>
<td>5.5</td>
<td>0.2</td>
<td>1</td>
</tr>
<tr>
<td>Residual</td>
<td>258</td>
<td>6221.9</td>
<td>24.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>359</td>
<td>58194.0</td>
<td></td>
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</tr>
</tbody>
</table>

Figure 1: Effect of pre-harvest (*A, B*) application of hexanal on the peel color change in *Grand Nain* bananas from AEZ IV (Machakos County) and AEZ II (Meru County). Bars indicate least significant difference (LSD) between means at $p < 0.05$. 

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Ethylene production

The rate of ethylene production was significantly (p < 0.05) affected by the interaction between mode of application, treatment concentration, and zone of production. Fruits produced in Machakos County had a significantly higher rate of ethylene production compared to those produced in Meru County, irrespective of hexanal treatment. Generally, post-harvest dipped fruits (Figs. 2B and 2D) produced significantly (p < 0.05) higher levels of ethylene throughout storage compared to the pre-harvest spray-treated fruits (Figs. 2A and 2C).

In the control fruits, ethylene levels increased drastically to peak levels of 6 nL/kg/h (day 6) and 5.9 nL/kg/h (day 3) in Machakos and Meru Counties, respectively, for the pre-harvest spray treatment. On the other hand, the controls in the post-harvest dip treatment had significantly higher climacteric peaks of 12 nL/kg/h and 8.7 nL/kg/h at day 12 of storage in Machakos and Meru Counties, respectively. Although hexanal significantly delayed the climacteric peaks in both modes of application, a double spray in Meru County (Fig. 2C) delayed the peaks by 6 days compared to 3 days in Machakos County (Fig. 2A). In Machakos County, fruits sprayed with hexanal had significantly reduced climacteric peaks of 3.7 nL/kg/h and 4.2 nL/kg/h in fruits sprayed twice with 2 % and 3 % hexanal, respectively, compared to 8.5 nL/kg/h and 8.8 nL/kg/h in fruits dipped in hexanal for 5 minutes.
Respiration rate

The rate of respiration increased gradually to peak levels and then declined drastically until the end of storage in the hexanal-treated and control fruits. Hexanal treatment had a significant effect ($p < 0.05$) on the respiration rate with pre-harvest sprayed fruits (Figs. 3A and 3C) exhibiting higher levels of respiration compared to post-harvest dip treatment (Figs. 3B and 3D). For the pre-harvest spray mode of application, respiration rate in the untreated controls increased from initial values of 8 mg/kg/h and 6.8 mg/kg/h to peak levels of 52.6 mg/kg/h and 44.3 mg/kg/h at day 6 in Machakos and Meru Counties, respectively. In the post-harvest dip experiment, the untreated fruits had lower levels of respiration compared to the pre-harvest spray experiment with respiratory peaks of 34.8 mg/kg/h and 44.5 mg/kg/h in Machakos and Meru Counties, respectively, occurring 6 days later.

The duration of hexanal application significantly ($p < 0.05$) affected the rate of respiration: fruits sprayed twice (at 30 days and 15 days) before harvest or dipped for 5 minutes had lower rates of respiration compared to those sprayed once at 30 days, dipped for 2.5 minutes, and the controls. A significant interaction ($p < 0.05$) between zone of production and treatment was only observed for the pre-harvest spray treatment.
Efficacy of hexanal application on the post-harvest shelf life and quality of banana fruits (*Musa* spp.) in Kenya; P.M. Yumbuya et al.
Efficacy of hexanal application on the post-harvest shelf life and quality of banana fruits (Musa spp.) in Kenya; P.M. Yumbya et al.

Figure 3: Effect of pre-harvest (A, C) and post-harvest (B, D) application of hexanal on the rate of respiration in Grand Nain bananas from AEZ IV (Machakos County) and AEZ II (Meru County). Bars indicate least significant difference (LSD) between means at \( p < 0.05 \).
Efficacy of hexanal application on the post-harvest shelf life and quality of banana fruits (*Musa* spp.) in Kenya; *P.M. Yumbya et al.*

Peel firmness

Peel firmness was significantly ($p<0.05$) affected by the interaction between mode of treatment and zone of production. Generally, fruits produced in Machakos County softened faster compared to those from Meru County. Hexanal treatment applied either as a pre-harvest spray or post-harvest dip significantly delayed peel softening in both zones. However, the post-harvest dip mode of application (Figs. 4B and 4D) was more effective compared to the pre-harvest spray mode of application (Figs. 4A and 4C).

The control fruits softened very rapidly and by the end of storage (day 15) they had lost approximately 95% of their original firmness while the hexanal-treated fruit lost 90% of their firmness by day 24 (i.e. 9 days later). Fruits treated by pre-harvest spray maintained their peel firmness up to day 9 and day 12 for single and double sprays, respectively. Fruits sprayed once at 30 days had lost approximately 72% to 76.1% and 74% to 76% of their peel firmness in Meru and Machakos Counties, respectively, compared to only 64% to 67.8% and 59% to 67.4% of their peel firmness in the double-sprayed fruits, of Meru and Machakos respectively. Hexanal applied as a post-harvest dip significantly delayed peel softening by up to 15 days with the 5-minute dip being more effective compared to those dipped for 2.5 minutes, irrespective of the concentration. By day 15 of storage, fruits dipped for 2.5 minutes had lost about 62% to 68% and 62% to 65% of their peel firmness in Meru and Machakos Counties, respectively, compared to only 30% to 37% and 38% to 42% of their peel firmness in fruits dipped for 5 minutes, in the same counties, respectively.
Pulp firmness

Pulp firmness exhibited a similar trend to peel firmness with a gradual decrease in all the fruits during the storage period. Pulp firmness was significantly ($p < 0.05$) affected by the interaction between zone of production, mode of hexanal application, and treatment concentration. The post-harvest dip mode of application was more effective in delaying pulp softening in fruits harvested from Meru County compared to those from Machakos County and in fruits treated with pre-harvest sprays.

For the pre-harvest spray application, pulp firmness of control fruit declined by 94% and 95% in fruits produced in Meru and Machakos Counties, respectively, after 9 days of storage (Figs. 5A and 5C) compared to a decline of 91% in fruits treated by post-harvest dip application (Figs. 5B and 5D), after 15 days of storage. Pulp firmness was maintained up to day 15 and day 18 in Meru and Machakos Counties, respectively, in post-harvest dipped fruits compared to up to day 9 and day 6 in pre-harvest sprayed fruits in Meru and Machakos Counties, respectively. Fruits dipped in hexanal for 5 minutes lost approximately 46% to 50% and 32% to 38% of their pulp firmness by day 15 of storage in Meru and Machakos Counties, respectively, compared to 89% to 91% and 90% of their pulp firmness in doubled-sprayed fruits in Meru and Machakos Counties, respectively.
Efficacy of hexanal application on the post-harvest shelf life and quality of banana fruits (Musa spp.) in Kenya; P.M. Yumbya et al.
Figure 5: Effect of pre-harvest (A, C) and post-harvest (B, D) application of hexanal on pulp firmness in *Grand Nain* bananas from AEZ IV (Machakos County) and AEZ II (Meru County). Bars indicate least significant difference (LSD) between means at p < 0.05.
Total soluble solids (TSS)

 Levels of total soluble solids increased gradually with ripening in all the fruits (Figs. 6A, 6B, 6C, and 6D). The TSS levels were significantly ($p<0.05$) affected by the interaction between production zone and mode of application. Fruits from Machakos County had significantly higher TSS content compared to those from Meru County, irrespective of hexanal treatment. Increase in TSS levels was significantly affected by hexanal mode of application: the increase was greater and faster for the pre-harvest spray mode of application (Figs. 6A and 6C) compared to post-harvest dipping (Figs. 6B and 6D). The increase in TSS was less rapid in the hexanal-treated fruits, with a 5-minute dip being significantly ($p<0.05$) more effective compared to the sprayed fruits and those dipped for 2.5 minutes. In fruits dipped for 5 minutes, TSS levels increased from 0.96 °Brix and 0.63 °Brix to approximately 27.5 °Brix and 28.2 °Brix in Machakos and Meru Counties, respectively, at day 24 (the end of storage). In the fruits sprayed twice (at 30 days and 15 days) before storage (Figs. 6A and 6C), the TSS levels increased to peak levels of 27 °Brix–29 °Brix 14 days earlier than fruit dipped post-harvest for 5 minutes. Changes in TSS levels were more drastic in the pre-harvest sprayed fruits compared to the post-harvest dipped fruits.
Efficacy of hexanal application on the post-harvest shelf life and quality of banana fruits (*Musa* spp.) in Kenya; *P.M. Yumbya et al.*

Figure 6: Effect of pre-harvest (*A, C*) and post-harvest (*B, D*) application of hexanal on total soluble solids in *Grand Nain* bananas from AEZ IV (Machakos County) and AEZ II (Meru County). Bars indicate least significant difference (LSD) between means at *p* < 0.05.

**Total titratable acidity (TTA)**

Total titratable acidity levels increased gradually in all the banana fruits as ripening progressed (Figs. 7A, 7B, 7C, and 7D). However, the increase was less rapid in the hexanal-treated fruits in both zones. Mode of application had a significant effect (*p* <0.05) on TTA level, with pre-harvest spray-treated fruits (Figs. 7A and 7C) having high levels throughout storage compared to fruits from post-harvest dip treatment in both zones (Figs. 7B and 7D). The TTA was significantly (*p* < 0.05) affected by the interaction between zone of production and treatments with fruits from Machakos County (Figs. 7A and 7B) having high TTA levels compared to those from Meru County (Figs. 7C and 7D). Fruits dipped in hexanal for 5 minutes retained lower TTA levels of 0.49 %–0.51 % in Meru County and 0.52 %–0.6 % in Machakos County at the end of storage, which occurred 9 days later than the controls (Figs. 7B and 7D).
Efficacy of hexanal application on the post-harvest shelf life and quality of banana fruits (Musa spp.) in Kenya; P.M. Yumbya et al.
Figure 7: Effect of pre-harvest (A, C) and post-harvest (B, D) application of hexanal on total titratable acidity in *Grand Nain* bananas from AEZ IV (Machakos County) and AEZ II (Meru County). Bars indicate least significant difference (LSD) between means at $p < 0.05$. 
Ascorbic acid (vitamin C)

Vitamin C content was significantly ($p < 0.05$) affected by the interaction between zone of production and mode of hexanal application. Post-harvest dip treatment in fruits harvested from Meru County (Fig. 8D) had significantly ($p < 0.05$) higher vitamin C levels throughout storage compared to pre-harvest spray-treated fruits. Hexanal treatment significantly ($p < 0.05$) delayed the rate of vitamin C decrease in both zones, irrespective of the mode of application (Figs. 8A, 8B, 8C, and 8D). Vitamin C levels reduced drastically by 54% and 51% in Machakos and Meru Counties, respectively, by the end of storage (day 15) compared to 49% and 22% in the hexanal treated fruits in Machakos and Meru Counties respectively in the post harvest experiment. In fruits treated by dipping in hexanal for 5 minutes (Figs. 8B and 8D), vitamin C levels decreased from initial levels of 18 mg/100 g and 19 mg/100 g to an average of 9.35 mg/100 g and 8.5 mg/100 g in Machakos and Meru Counties, respectively, by the end of storage (day 24).
Efficacy of hexanal application on the post-harvest shelf life and quality of banana fruits (*Musa* spp.) in Kenya; P.M. Yumbya et al.

**Discussion**

The use of hexanal is a relatively new technology that has been found effective in enhancing the shelf life of several temperate fruits, such as apples, peaches, strawberries, and sweet cherries (Paliyath et al. 2008). Currently, several studies are being conducted to investigate the capability of hexanal-based technologies to enhance post-harvest characteristics of tropical fruits, such as bananas, papayas, and mangoes. In our study, two methods of hexanal application (pre-harvest spray and post-harvest dip) were evaluated on banana var. *Grand Nain* produced under two different AEZs in Kenya: Meru (a high potential AEZ II) and Machakos (a low potential AEZ IV). Hexanal, applied as a pre-harvest spray twice at 30 days and 15 days before harvest improved fruit retention by 18 days in Meru and 12 days in Machakos. Climactic differences between the two study sites might have caused the differences in retention time. Meru is relatively cool with a

Figure 8: Effect of pre-harvest (*A, C*) and post-harvest (*B, D*) application of hexanal on ascorbic acid (vitamin C) content in *Grand Nain* bananas from AEZ IV (Machakos County) and AEZ II (Meru County). Bars indicate least significant difference (LSD) between means at *p* < 0.05.
mean annual temperature ranging between 18°C and 21°C while Machakos is relatively hot with a mean annual temperature of 30°C. Cool temperatures in Meru could have led to the longer time taken for the fruits to ripen. Similar findings have been reported in sweet cherries (Sharma et al. 2010), apples (Paliyath et al. 2008) and tomatoes (Cheema et al. 2014).

The observed improvement on fruit retention in the hexanal-sprayed fruits could be attributed to the dilution of the abscission effect. According to Anusu ya et al. (2016), hexanal slows down the activities of peroxidase, RNA, and protein synthesis in the abscission zone and as a result, it extends fruit retention in hexanal-sprayed trees. Similar findings of improved fruit retention have been reported in tomatoes (Cheema et al. 2014), apples (Paliyath et al. 2008), and mangoes (Anusu ya et al. 2016). For hexanal to be effective, the stage of application is critical (Paliyath et al. 2008). In berry fruits, such as cherries, optimum results were obtained when hexanal was applied twice (at about 15 days and 7 days) before harvest (Sharma et al. 2010) whereas in tomatoes, optimum results were obtained when hexanal was applied at the mature green stage (Cheema et al. 2014). The hexanal is known to inhibit phospholipase D, the enzyme that initiates the degradation of the cell membrane that leads to loss of integrity and an accelerated senescence process (Tiwari and Paliyath 2011). In our study, optimum results were obtained when hexanal was applied twice (at 30 days and 15 days) before harvest. This might be due to the stage of development as it coincides with the temporal increase in phospholipase D activity that occurs during advancement in ripening as Pinhero et al. (2003) have suggested.

Hexanal enhanced shelf life by 9 days and 6 days in post-harvest dip treatments for 5 minutes and 2.5 minutes, respectively, irrespective of the concentration. Pre-harvest spray treatment enhanced shelf life by 6 days and 3 days in fruits sprayed twice and once, respectively. The reduced rates of ethylene production and respiration that were observed in the hexanal-treated fruits could partly explain the enhanced shelf life. An increase in respiration rate is known to contribute to post-harvest losses and enhance senescence of climacteric fruits. Banana has a thick and fibrous peel that will affect the penetration of hexanal solution, so the longer duration of exposure likely allowed sufficient penetration of the treatment solution. Similar findings have been reported in apples, strawberries, and cherries (Paliyath et al. 2008).

In the present study, the rate of ethylene production was significantly affected by the interaction between mode of application and zone of production. Fruits from Machakos (a drier zone) had a higher rate of ethylene production compared to those from Meru. This could be attributed to the high temperatures (above 30°C) in Machakos that accelerated the ripening process. Hexanal treatment slowed down the rate of ethylene evolution and delayed the climacteric peaks. Studies by Tiwari and Paliyath (2011) showed that hexanal treatment in tomato fruit can cause moderate reduction in ethylene evolution which might explain the observed low levels of ethylene in our study. Our results are in agreement with the observations of Tiwari and Paliyath (2011) in tomatoes. An increase in the rate of respiration is a main physiological parameter that changes during the ripening of climacteric fruits such as banana. Hexanal treatment significantly reduced the rate of respiration throughout the storage period in both modes of application in our experiments. A reduction in respiration rate leads to a reduction in utilization of substrates, such as free sugars that leads to enhanced post-harvest life (Saltveit 2004). The rate of respiration can therefore be used to gauge the rate of metabolism in a commodity, and in our study it correlated positively with other ripening changes.

Fruit softening is a main determinant of
ripening in banana and the rate of softening is rapid during the later stages of ripening (Mirshekar et al. 2015). A decline in banana firmness during ripening is largely the result of disassembly of the cell wall, deterioration of the cell membrane, and breakdown of starch into sugars (Mirshekar et al. 2015). Results of our study show that hexanal significantly delayed peel and pulp softening to different extents. This could be attributed to reduced rate of respiration observed in the hexanal-treated fruits as well as increased fruit cell wall biosynthesis and membrane preservation, as previously reported by Sharma et al. (2010). Similar results have been reported in tomatoes (Cheema et al. 2014), mangoes (Anusuya et al. 2016) and peaches (Paliyath et al. 2008). Fruits from the drier zone (Machakos) softened faster compared to those from the wet zone (Meru), irrespective of the treatment. This could be attributed to differences in temperatures and rainfall in both zones; both having been reported to affect fruit softening. Our findings are in agreement with the observations of Ambuko et al. (2006) who reported that banana fruits produced in drier zones and during the dry periods of the year, soften faster.

Results of our study have revealed that TTA in banana increased with the advancement of ripening. This is in agreement with Siriboon and Banlusilp (2004) who reported that the TTA levels of banana fruit increased with ripening. The observed increase in TTA during ripening may be due to the increase in malic acid. Malic acid content has been shown to rise from 1.8 meq/100 g to 6.2 meq/100 g during ripening in banana (John and Marchal 1995). In general, hexanal treatments significantly delayed the rate of TTA increase. This could be attributed to reduced activities of enzymes such as malate dehydrogenase, which influence the level of malic acid in banana. The observed increase in TSS during ripening may be associated with the breakdown of stored carbohydrates into simple sugars during ripening (Siddiqui and Dhua 2010). Further, the increased TSS levels in banana fruit could also be as a result of the partial breakdown of pectins and cellulose (De Lima, Melo and Lima 2001). The less rapid change in TSS level in hexanal-treated fruits in our study could be attributed to the reduced activity of the enzymes involved in the hydrolysis of stored carbohydrates into soluble sugars. Similar results were reported in tomato and mango fruits (Cheema et al. 2014; Anusuya et al. 2016). Generally, fruits from Machakos County had high TSS levels compared to those from Meru County, irrespective of treatments. This could be attributed to the longer periods of sunlight and higher temperatures found in semi-arid zones, such as Machakos County, that tend to favor photosynthetic activity and carbon accumulation. Similar findings have been reported in banana (Ambuko et al. 2006) and avocado fruits (Ferguson et al. 1999).

Ascorbic acid content decreased with storage time in all the fruits. However, the rate of degradation was slower in the hexanal treated fruits as compared to the controls. These findings are in agreement with Opara et al. (2012) who found ascorbic acid decreased with ripening in banana fruits because of its oxidative degradation during respiration or its transformation to other metabolites such as sugars and amino acids. This has been previously reported in tomatoes (Cheema et al. 2014) and sweet cherries (Sharma et al. 2010).

Therefore, the results of our study suggest that hexanal, applied at 2% and 3%, either as a pre-harvest spray or post-harvest dip, has the potential to enhance fruit shelf life by at least one week. The extended retention of fruits on the trees by hexanal for a period of 12-18 days that we saw, could be highly remunerative for the farmers as it gives them time to source better markets.

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References


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 β-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
Effects of pre- and post-harvest treatments with hexanal formulations on time to ripening and shelf life of papaya (Carica papaya L.) fruits; Nirmalla Debsingh et al.

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

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**

<table>
<thead>
<tr>
<th>Independent Variable</th>
<th>Sub Categories</th>
<th>N</th>
<th>Mean</th>
<th>Std. Dev.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treatment</td>
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<td>10</td>
<td>14.5</td>
<td>0.707</td>
</tr>
<tr>
<td></td>
<td>2% EFF</td>
<td>10</td>
<td>61.0</td>
<td>1.333</td>
</tr>
</tbody>
</table>

\[ F = 9492.805; P = 0.000*** \]

*** 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 postharvest 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.
Effects of pre- and post-harvest treatments with hexanal formulations on time to ripening and shelf life of papaya (*Carica papaya* L.) fruits; Nirmalla Debyasingh et al.

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 ± SD of fifteen fruits. Values with the same letter suffix are not different according to the Tukey’s test (p≤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


Effects of hexanal dip on the post-harvest shelf life and quality of papaya (Carica papaya L.) fruit

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The objective of this study was to evaluate the effects of hexanal on the post-harvest shelf life and quality of papaya (Carica papaya L.) in two agro-ecological zones (AEZs II and IV) among small-holder farmers in Kenya. Hexanal was tested at two concentrations, 1% and 2%, and applied as a dip for 2.5 minutes or 5 minutes on mature green Solo Sunrise and Mountain papaya cultivars. Water was used as control. The experiment was done in a randomized complete block design with three replications; means were compared by Analysis of Variance using GenStat Version 15. Untreated papaya fruits lasted for 9 days whereas papaya fruits dipped in 2% hexanal for 5 minutes lasted for 15 days with ethylene and respiratory peaks delayed by three days (p < 0.05). These hexanal-dipped fruits lost up to 19% of their cumulative physiological weight (p < 0.05) after the entire storage period of 15 days, whereas controls lost up to 35% of their physiological weight over the same period, and were firmer in texture by 37.4% (p < 0.05). Titratable acidity in papaya fruits gradually decreased with time during the ripening period with no significant difference between the treated and the untreated fruits (p < 0.05). Total soluble solids, however, increased as the fruit ripened and then declined with no significant differences between the treatments (p < 0.05). Dipping the papaya fruits in hexanal had no effect on beta-carotene content but decreased the rate of vitamin C decline with fruit ripening (p < 0.05). The results of this study indicate that the use of hexanal could be a novel and viable option for reducing post-harvest losses of papaya (Carica papaya L.) in Africa, benefitting small-scale farmers as well as large-scale farmers and traders through improved post-harvest maintenance of quality and longer shelf life.

Keywords: Post-harvest loss, Kenya, hexanal, papaya, shelf life, fruit quality

Among the Caricaceae family, papaya (Carica papaya L.) is the most important economic crop. It is widely cultivated for consumption as a fresh fruit and can be value-added to make jams, jellies, and pies. Papaya is also very popular due to its palatability, early fruiting, and versatility in usage (Aravind et al. 2013). Papaya is rich in vitamin C, carotenoids and riboflavin and is a fair source of iron, calcium, thiamine, niacin, pantothenic acid, vitamin B-6, and vitamin K (Saran et al. 2014). In Kenya, papaya is the fifth most economically important fruit crop in terms of volume and value of production (HCDA 2014). In the field, plantings can last up to 20 years under good irrigation and management but the average profitable commercial life span is only two to three years (Campostrini and Glenn 2007) depending on weather conditions, and biotic and abiotic stresses. The most popular varieties grown in Kenya include Mountain, Solo Sunrise, Honey dew, and Hawaii. Solo Sunrise and Kapoho Solo are hermaphrodites and may be produced following self-pollination or parthenocarpy (AFA 2015). All the Solo types of papaya are pear-shaped and are of adequate commercial size (300 g – 700 g) and quality (Pauli et al. 1997).

Papaya, containing about 89.7% water, is a highly perishable fruit (Mia et al. 2010). Huge post-harvest losses, estimated at over 50%, are one of the key challenges to the continued production and marketing of this thin-skinned fruit. Papaya ripens and softens over a very short period of time, usually three days, predisposing the fruit to physical damage and phyto-pathogen invasions. A typical papaya fruit has a thin, delicate exocarp that is less waxy than those of mango and banana fruits making it prone to mechanical injury. Wounds provide an avenue through which pathogens invade the fruit and also induce ethylene
production, further facilitating the ripening and softening of the fruit. Softened fruits provide an environment conducive to latent pathogen infections. Solute leakage around the wound has also been reported for various fruits (Prasanna et al. 2007) grown in extreme, hot climates. Such leakages encourage fungal growth. Overall, wounds shorten the post-harvest life of mature fruit.

Many technologies have been applied to manage the post-harvest life of papaya. The use of low temperature storage (Kays and Paull 2004) has been hampered by fruit sensitivity to chilling injury (Paull et al. 1990). Modified atmosphere packaging (MAP; Waghmare and Annapure 2013) and other technologies to manage ethylene (Ahmad et al. 2013; Bayogan et al. 2012) are unconventional and technology uptake by small-holder farmers in Africa has been very slow. Other additional technologies have been tested and the industry continues to evaluate emerging innovations that are naturally-occurring, environmentally friendly, cost effective, and easy to apply. Going forward, the technologies should also ensure that fruit colour, firmness, essential volatiles and esters are maintained and preserved after treatment (Fan and Mathias 1999).

Hexanal, a six-carbon aldehyde naturally found in fruits, is associated with the characteristic green flavour (Misran 2013). Hexanal has been reported to improve the shelf life of several temperate fruits including apples, plums, nectarines, peaches, pears (Tiwari and Paliyath 2011), and sweet cherries (Sharma et al. 2010). Recently, Anusuya et al. (2016) reported improved post-harvest shelf life of mangoes in India using hexanal as a pre-harvest spray. To our knowledge, no hexanal studies have been conducted in Kenya, a country that remains a strong player in the global fruit market and would benefit from this technology. The objective of our study was to investigate the effect of a hexanal dip on papaya fruits of two cultivars grown in two different agro-ecological zones (AEZs).

Materials and methods

Study area

Post-harvest dip treatments were carried out at the laboratory at Jomo Kenyatta University of Agriculture and Technology in Juja, Kenya for fruits obtained from the two different AEZs (AEZ II: Meru County, and AEZ IV: Machakos County). Solo Sunrise and Mountain papaya cultivars were obtained from each AEZ. Machakos County receives rainfall ranging from 600 mm to 1,100 mm annually and has an average temperature of 28°C while Meru County receives 1,000 mm to 1,600 mm rainfall per annum and has an average temperature of 21°C.

Sample collection

Solo Sunrise and Mountain fruits were harvested from Machakos and Meru early in the morning during the months of April and July from randomly selected farms, then packed in cartons according to variety and size. Fruits with visible physiological disorders and injuries were discarded. Used magazines dipped in clean chlorinated water (0.2–1 mg/litre of water) were spread over the cartons before wrapping the papaya fruits to minimize heat exposure in the field. The boxes were secured firmly and quickly transported to the laboratory. The samples were then thoroughly washed in clean chlorinated water, the 1 cm stalk left after harvesting was removed, and the sap from the fruits allowed to drip overnight from the point of stalk attachment, before the fruits were dipped the following day.

Experimental design and data analysis

The experiment was laid out in a randomized complete block design with the dip concentration as a main effect and with three replications within each season of data collection. The entire experiment was conducted within a 12-month period that
Effects of hexanal dip on the post-harvest shelf life and quality of papaya (*Carica papaya* L.) fruit; M. J. Hutchinson et al.

Data were subjected to an Analysis of Variance (ANOVA) using Genstat software (15th Edition) provided by the University of Nairobi. The main effects were from AEZ (or “location”), cultivar, dip time, storage time, and experiment (the latter standing for the three replications of the entire experiment). Three levels of interactions were studied between the main effects. Means were compared with Fishers protected Least Significant Difference set at $p < 0.05$.

**Firmness**

Firmness was measured along the equatorial portion of the whole papaya fruit using a penetrometer (CR-100D, Sun Scientific Co. Ltd, Japan) fitted with an 8 mm probe. The pointed probe was allowed to penetrate the fruit up to a depth of 10 mm and the penetration force was recorded. The force was expressed in Newtons according to Jiang et al. (1999).

**Peel colour**

Peel colour was read in three different points along the central portion of the fruit and repeated for three other fruits marked and monitored until the fruits’ end stages when the peel colour changes from a yellow hue (60°) to amber (50°). A Minolta colour difference meter (Model CR-200, Osaka, Japan) calibrated with a white and black standard tile was used. The “L*,” “a*,” and “b*” coordinates were recorded and a* and b* values were converted to hue angle (H°) according to McClellan et al. (1995).

**Percent physiological weight loss**

Physiological weight loss was calculated after using a digital weighing balance (Model CS 5000, Ohaus Corporation, USA) with a capacity of 5,000 g using three fruits chosen for each treatment combination of 1% or 2% dip, for 2.5 minutes or 5 minutes. The initial weight ($W_1$) of each fruit at day 0 and the new weight of the same fruit on the subsequent days ($W_2$) was recorded in kilograms and the per cent weight loss calculated using equation 1 below:

$$\text{Percentage weight loss (\%)} = 100 \times \frac{W_1 - W_2}{W_1}$$

**CO$_2$ and ethylene**

Three fruits were selected from each treatment and incubated at room temperature (25 °C) in airtight, transparent, ‘klip-lock’ plastic containers (1450 mL and 4500 mL) for Mountain and Solo Sunrise cultivars, respectively, and fitted with self-sealing rubber septa for gas sampling for one hour. Head-space gas samples were taken using an airtight, 1 mL, hypodermic syringe and injected into gas chromatographs, a model GC-9A (Shimadzu Corp., Kyoto, Japan) for analysis of ethylene production, and a model GC-14A (Shimadzu Corp., Kyoto, Japan) for analysis of CO$_2$ production. The GC-14A was fitted with a thermal conductivity detector and a Poropak N
column for CO₂, whereas the GC-9A was fitted with an activated alumina column and a flame ionization detector. The ethylene production rate was expressed as µL/kg/hr and CO₂ production (used to estimate respiration rate) was expressed as mL/kg/hr at standard atmospheric pressure.

Total titratable acidity (TTA)

The TTA was determined through titration. Five grams of fruit pulp were macerated and diluted with 20 mL distilled water. Ten mL of the diluted solution was mixed with 3 drops of phenolphthalein indicator (colourless in acid medium) for titration using 0.1 N NaOH with constant shaking until the appearance of a faint pink colour that persisted for at least 30 seconds. The results were expressed as per cent citric acid (titratable acidity) of fruit juice according to the method of Raganna (1986).

Total soluble solids (TSS)

Fruit pulp was obtained from the middle portion of unripe fruits by destructive sampling and 5 grams of juice extracted after crushing the fruit in a mortar with pestle. The same amount of juice was extracted from ripened fruits after the third day in storage. A Hanna digital hand held refractometer 0-85% Brix (Model HI 96801, USA) was used to determine the TSS. Data was repeated at 3-day intervals until the end of the 15-day study period.

Vitamin C

Vitamin C measurements were determined using the method described by Mamun et al. (2012) with a few modifications. Approximately 2 g to 3 g of papaya pulp were extracted using 0.8% meta-phosphoric acid (MPA) under subdued light conditions. This was diluted to 20 mL of juice with MPA. The juice was centrifuged at 100 rpm (Kokusan H-200, Tokyo, Japan) at 4°C for 10 minutes. The supernatant was filtered into vials using a 0.45 micro filter and samples set as a post-run in high performance liquid chromatography (HPLC) on the same day of extraction (20 µL was automatically injected into the machine). The HPLC analysis was done using a C18-4D column and a Shimadzu UV-VIS detector. Various concentrations of ascorbic acid (0, 10, 20, 40, 60, 80 and 100 ppm) were also made as standards to construct a calibration curve. The mobile phase was 0.8% metaphosphoric acid at a 1.2 mL/min flow rate, and a wavelength of 266.0 nm. The quantity of ascorbic acid was calculated using a (standard) vitamin C concentration regression curve obtained with the standards as shown in equation 2.

Equation 2. Ascorbic acid formula

\[
\text{Ascorbic acid} \left( \frac{mg}{100g} \right) = \left( \frac{\text{Peak area from graphs}}{y} \right) \frac{\text{Dilution volume}}{\text{sample volume (g)}} \frac{100}{1000}
\]

Where \( y = \) gradient of curve when y-intercept is zero.

Beta-carotene

Beta-carotene was analysed using UV spectrophotometry using the method described by Rodriguez-Amaya and Kimura (2004). A sample of approximately 2 g of the stored papaya pulp was transferred to a mortar and ground with acetone using a pestle: the extract was transferred to a 100 mL volumetric flask. This was repeated until the sample gave no colour in acetone. Partitioning was done using 25 mL of petroleum ether in a separating funnel. A small amount of distilled water was added to the mixture of acetone, extract, and petroleum ether to facilitate separation. The lower elute mixture of water and acetone was carefully channelled out to leave the upper layer mixture of carotenoids and petroleum ether. This mixture was then transferred to a 25 mL volumetric flask through a funnel and filter paper with anhydrous sodium
sulphate to remove water from the petroleum-carotene mixture. All extractions were done under subdued light conditions. Standards (0, 2, 4, 8, 10, 20, 40, 60, 80, and 100 ppm) were also made from freshly-prepared beta-carotene obtained from sigma Aldrich suppliers in Kenya (Kobian Kenya Ltd) and used to plot a calibration curve used to calculate beta-carotene amounts in the samples. Absorbance readings were done at 440 nm in a UV-spectrophotometry (Shimadzu model UV-1610 PC, Kyoto, Japan).

**Results**

**Firmness**

Hexanal application on papaya improved fruit firmness by up to 35% at 2% hexanal dip for 5 minutes in the two agro-ecological zones. The firmness of control fruits harvested from the warmer Machakos and cooler Meru decreased from over 55 N/cm to less than 10 N/cm in 3 days and 6 days, respectively (Figures 1A, 1B, 1C, and 1D). The decline in fruit firmness was more drastic in those from warmer Machakos than Meru. Dipping fruits in hexanal significantly delayed the softening of the fruits irrespective of location, with a 2% concentration and a 5-minute dip being the most effective. The control fruits lasted between 6 and 9 days while those dipped in different concentrations of hexanal were firmer up to day 12. However, beyond day 9, there was no significant ($p > 0.05$) difference between the firmness of treated and control fruits.
Effects of hexanal dip on the post-harvest shelf life and quality of papaya (*Carica papaya* L.) fruit; *M. J. Hutchinson et al.*

Peel colour

Hexanal treatment reduced the rate of peel colour break from green to yellow during the storage periods. The cultivars demonstrated differential responses to hexanal. Dipping at both concentrations showed significant differences (*p* < 0.05) in Solo Sunrise fruit compared to the controls but not in Mountain fruit (Figures 2A, 2B, 2C, and 2D). The interaction between agro-ecological zone and hexanal dipping was significantly different with higher hue means in papaya from Meru County. Fruits from Machakos had a relatively smaller change in hue angle (from 127° to 79°) in Solo Sunrise and from 124° to 75° in Mountain papaya compared to fruits from Meru County (121° to 56° in Solo Sunrise and 121° to 61° in Mountain varieties). The peel colour break changed from green (127°) to lime (101°) to yellow (90°) and finally to amber (< 60°). Fruits were completely yellow at a hue angle of 90°.

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*Figure 1:* Changes in fruit firmness (N/cm) in Solo sunrise (A&B) and Mountain (C&D) papaya varieties from Machakos County and Meru County, respectively, dipped in different concentrations of hexanal. Top bars are LSD values at *p*=.05.
Effects of hexanal dip on the post-harvest shelf life and quality of papaya (Carica papaya L.) fruit; M. J. Hutchinson et al.
Figure 2: Changes in peel colour in Solo sunrise (A&B) and Mountain (C&D) papaya varieties from Machakos County and Meru County, respectively, dipped in different concentrations of hexanal. Top bars are LSD values at $p=0.05$. 

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Pulp colour

Hexanal treatment slowed the rate of peel colour change without negatively affecting the overall red pulp colour intensity at full ripe stage (Hue angle 60°). The pulp colour change in treated papaya fruits was significantly ($p \leq 0.05$) slower than in the control fruits, irrespective of the AEZ although fruits from the warmer zone (Machakos) became yellow faster than those from cooler Meru (Figures 3A, 3B, 3C, and 3D). However, there was no difference in results between the concentrations of hexanal and the duration of dip in papaya from the different AEZs.
Effects of hexanal dip on the post-harvest shelf life and quality of papaya (*Carica papaya* L.) fruit; M. J. Hutchinson et al.

Figure 3: Changes in pulp colour in Solo sunrise (A&B) and Mountain (C&D) papaya varieties from Machakos County and Meru County, respectively, dipped in different concentrations of hexanal. Top bars are LSD values at *p*=.05.

Percent cumulative weight loss

There was a gradual increment in the cumulative weight loss across the 15 days of storage with a maximum value of 34.5% weight lost recorded for fruits from Meru County (Figures 4A, 4B, 4C, and 4D). An interaction between hexanal dip and the effect of agro-ecological zone had a significant (*p* ≤ 0.05) difference on percent cumulative weight loss. Fruits from the wetter AEZ II had a higher mean weight loss compared to those from the drier AEZ IV. The two varieties responded to the dip treatment differently, with Solo Sunrise maintaining 8.4% more weight and Mountain fruit maintaining 5.1% more weight compared to the control fruits. There was no difference between tested hexanal concentrations and duration of dip in weight loss among the two varieties of papaya.
Effects of hexanal dip on the post-harvest shelf life and quality of papaya (Carica papaya L.) fruit; M. J. Hutchinson et al.
Effects of hexanal dip on the post-harvest shelf life and quality of papaya (*Carica papaya* L.) fruit; *M. J. Hutchinson et al.*

Figure 4: Percent cumulative weight loss in Solo sunrise (A & B) and Mountain(C&D) papaya varieties from Machakos County and Meru County, respectively, dipped in different concentrations of hexanal. Top bars are LSD values at $p=.05$. 
Effects of hexanal dip on the post-harvest shelf life and quality of papaya (*Carica papaya* L.) fruit; *M. J. Hutchinson et al.*

Hexanal treatment delayed the respiratory peak and mildly reduced the amount of CO$_2$ evolved from the ripening fruits in ambient storage. Untreated papaya fruits from both AEZs had respiratory peaks on day 3 (Figure 5A, 5B, 5C, and 5D). Dipping fruits in hexanal delayed development of respiratory peaks, in papaya fruits, by 3 days. Respiration rates were higher in Solo Sunrise papaya compared to Mountain papaya during the 15 days in storage.
Effects of hexanal dip on the post-harvest shelf life and quality of papaya (*Carica papaya* L.) fruit; *M. J. Hutchinson et al.*

Figure 5: Changes in rate of CO₂ production in Solo sunrise (A & B) and Mountain (C & D) papaya varieties from Machakos County and Meru County, respectively, dipped in different concentrations of hexanal. Top bars are LSD values at $p=0.05$.

**Ethylene**

Ethylene peaks followed a similar pattern to the respiratory peaks (Figure 6A, 6B, 6C, and 6D). However, there was no significant ($p \leq 0.05$) difference in the rate of ethylene produced from papaya fruits treated at the two concentrations of hexanal. Control fruits and fruits treated with 1% hexanal for 2.5 minutes showed a similar behaviour with a slightly higher mean value of ethylene at $3.53\mu l/kg/hr$ in controls. Dip treatments for 5 minutes with 1% and 2% hexanal gave lower rates of ethylene evolution during ripening.
Effects of hexanal dip on the post-harvest shelf life and quality of papaya (*Carica papaya* L.) fruit; *M. J. Hutchinson et al.*
Effects of hexanal dip on the post-harvest shelf life and quality of papaya (*Carica papaya* L.) fruit; *M. J. Hutchinson et al.*

**Figure 6:** Changes in rate of ethylene production in Solo sunrise (A & B) and Mountain(C&D) papaya varieties from Machakos County and Meru County, respectively, dipped in different concentrations of hexanal. Top bars are LSD values at *p*=.05.

Percent total titratable acidity

Hexanal treatment did not show any significant (*p* ≥ 0.05) difference in the variation of TTA between the initial day and the third day in storage (Figures 7A, 7B, 7C, and 7D). However, between days 6 and 9, TTA was significantly high in papaya dipped in 1% and 2% hexanal for 5 minutes. Control fruits had lower levels of TTA with a consistent decline across the storage period, unlike the treated papaya fruits where TTA increased from 0.12% to 0.14% and 0.11% to 0.14% in Solo Sunrise and Mountain fruit, respectively, then declined to a low of 0.08% in both varieties. A high of 0.14% was recorded on day 6 in Solo Sunrise sample treated with 2% hexanal for 5 minutes. The percent TTA peak occurred when all the fruits were completely yellow at a *H*₀ < 90°.
Effects of hexanal dip on the post-harvest shelf life and quality of papaya (*Carica papaya* L.) fruit; *M. J. Hutchinson et al.*

**A-Machakos**

![Graph showing % Total Titratable Acidity over days after treatment for Solo sunrise and A-Machakos.]

**B-Meru**

![Graph showing % Total Titratable Acidity over days after treatment for Solo sunrise and B-Meru.]

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Figure 7: Changes in percent total titratable acidity in Solo sunrise (A&B) and Mountain (C&D) papaya varieties from Machakos County and Meru County, respectively, dipped in different concentrations of hexanal. Top bars are LSD values at $p=.05$. 
Total soluble solids (°Brix)

Hexanal treatment did not result in any significant effect in the levels of total soluble solids (TSS) in papaya fruit for the two varieties. However, TSS level increased continuously in the two varieties as fruit ripened from 8.7 °Brix to 13.1 °Brix in Mountain, and from 9.3 °Brix to 13.2 °Brix in Solo Sunrise fruits (Figures 8A, 8B, 8C, and 8D). However, there was no clear trend in the TSS levels in the two varieties of papaya for both hexanal treated and control fruits. The highest brix level (13.2 °Brix) was recorded in control fruits at the end stage. Papaya fruits from the hotter AEZ-IV had significantly higher mean TSS than fruits from AEZ-II.
Figure 8: Changes in total soluble solids (°Brix) in Solo sunrise (A&B) and Mountain(C&D) papaya varieties from Machakos County and Meru County, respectively, dipped in different concentrations of hexanal. Top bars are LSD values at $p=.05$. 

\[ \text{Effects of hexanal dip on the post-harvest shelf life and quality of papaya (Carica papaya L.) fruit; M. J. Hutchinson et al.} \]
Beta-carotene

Beta-carotene content increased consistently with ripening from 22.5 µg/100 g to 240.5 µg/100 g with no significant \((p > 0.05)\) difference in papaya fruits treated with hexanal at the two concentrations (Figures 9A, 9B, 9C, and 9D). Fruits of the Mountain cultivar had higher levels of beta-carotene during the 15-day storage period. The mean beta-carotene content was higher in fruits sourced from the warmer Machakos County compared to those from the cooler Meru County.
Effects of hexanal dip on the post-harvest shelf life and quality of papaya (*Carica papaya* L.) fruit; *M. J. Hutchinson et al.*

Figure 9: Changes in beta-carotene content in Solo sunrise and mountain papaya fruits from Machakos County (AEZ IV) and Meru County (AEZ II) in experiment I (A&B) and experiment II(C&D), respectively, dipped in different concentrations of hexanal. Top bars are LSD values at \( p = 0.05 \).

Vitamin C

Hexanal treatment gradually reduced the rate of Vitamin C decline as the fruits ripened from 70.12 mg/100 g to 26.11 mg/100 g, on average, for the two AEZs in the two seasons (Figures 10A, 10B, 10C, and 10D). The effects of location, variety, and hexanal dip revealed a significant \( (p \leq 0.05) \) difference in the level of ascorbic acid in papaya fruit with a slower rate of vitamin C decline in the treated fruits throughout the 15 days in storage.
Figure 10: Changes in vitamin C content in Solo Sunrise and Mountain papaya fruits from Machakos County (AEZ IV) and Meru County (AEZ II) in experiment I (A & B) and experiment II (C & D) respectively, dipped in different concentrations of hexanal. Top bars are LSD values at $p=0.05$. 
Discussion

Papaya fruits have a soft and thin skin with a resultant short shelf life after harvesting. Dipping harvested fruits from different AEZs in different concentrations of hexanal positively impacted selected post-harvest attributes. The rate of fruit softening increased drastically after CO$_2$ and ethylene peaked and then dropped to constant values when cellular integrity was completely lost. A difference of 38% in fruit firmness was gained from the best treatment concentration (i.e., 2% hexanal for 5 minutes). A gain of 38% firmness is significant to ensure extra protection against damages associated with softening. Hexanal works by inhibition of phospholipase D (Paliyath et al. 2003), which is responsible for membrane deterioration. Mirshekar et al. (2015) reported that the rate of softening is high during the last stage of ripening of fruits. Ripening and softening rates were rapid in control fruits between day 3 and day 6 in storage, contrary to the treated fruits that began softening between days 6 to 9 held in ambient temperature of 25±2˚C and relative humidity of 85±5%. This suggests that hexanal is capable of delaying the rapid rate of fruit softening associated with ripening.

Peel colour in hexanal treated fruits gradually changed from green to full yellow in 9 days and took only up to 6 days in untreated fruits. Colour change is caused by enzymatic degradation of chlorophyll (Ding et al. 2007) in the peel.

Cumulative weight loss is associated with moisture loss from the fruit surface during ripening and softening. Paull and Chen (2000) reported that a loss of approximately 8% of the initial weight renders papaya fruit un-saleable with low-gloss and shrivelled skin. In our study, weight loss surpassed 8% without affecting the fruits’ appearance at ambient room temperature 25±2˚C and relative humidity (RH) of 85±5%.

Respiration rate was determined through the amount of CO$_2$ evolution using gas chromatograph and expressed in ml/kg/hour. The amount of CO$_2$ increased with ripening up to day 6 and continued to drop after the climacteric peak. However, the untreated fruits shown a second rise in CO$_2$ evolved after day 6 in storage. The second increase in CO$_2$ in control fruits could be as a result of respiration from the fungus spores that were growing on the papaya peel. However, the treated fruits did not show any rise in CO$_2$ evolution after the respiratory peak. This suggests that hexanal potentially suppressed the growth of fungus associated with papaya fruit ripening. This result agrees with that from Lanciotti et al. (2003) who reported that hexanal application to apple fruit slices reduced microbial growth and enhanced storage life. The respiration pattern observed in papaya treated with hexanal also partially agrees with findings from Wills and Widjanarko (1995) who reported respiratory peaks in papaya after five days and an ethylene peak after one day in ambient storage. In our study, respiratory and climacteric peaks occurred at 75% colour break (H$^0$ = 102$^0$) contrary to the 20% to 50% colour breaks reported by these two scientists. This difference may be a result of variations in the research environment with respect to climactic conditions, cultural practices, and varieties used.

The TTA results from the current study compare with the findings of Lazan et al. (1989) who indicated that TTA increased with fruit ripening until approximately 75% yellow skin appeared and decreasing thereafter, unlike untreated papaya ripened in normal conditions reported by Wills and Widjanarko (1995) who indicated that high TTA levels occur at full yellow colour in papaya. In this study, percent TTA ranged from 0.07% to 0.12% in control fruits and from 0.09% to 0.14% in papaya fruits dipped in hexanal for 5 minutes. Our values are slightly higher than the findings by Bron et al. (2006) who recorded a range of 0.09% to 0.12%
Effects of hexanal dip on the post-harvest shelf life and quality of papaya (Carica papaya L.) fruit; M. J. Hutchinson et al.

on fresh Golden papaya fruits. The difference may be, at least partly, a result of varietal differences and production conditions.

The TSS values for fruits from AEZ IV were significantly higher than values from AEZ II. A study in mangos by Mendoza et al. (1972) reported a positive relationship between light exposure and TSS values. High temperatures and longer exposure to sunlight in AEZ IV could be possible causes of the relatively higher TSS levels in papaya from Machakos County. The overall increase in TSS in the present study could be attributed to the breakdown of starch to soluble sugars as described in Kulkani and Aradhya (2005).

High beta-carotene content was recorded during the hotter weather seasons. Pre-harvest factors including high solar intensity cause variations in fruits’ water accumulation and dry matter content and which impacts the biochemical attributes of fruits (Léchaudel and Joas 2006). Beta-carotene content increased as the fruit ripened due to chlorophyll degradation and synthesis of carotenoids in the fruit tissues (Ueda et al. 2000; Blackenship 2003). Vitamin A and vitamin C contents vary due to genotype differences, pre-harvest climatic conditions, cultural practices (Weston and Barth 1997), maturity, harvesting methods, and post-harvest handling (de Souza et al. 2014). Lee and Kader (2000) reported a positive correlation between light intensity and vitamin C content. The slow rate of vitamin C decline during storage was enhanced in extended storage as L-ascorbic acid was continually oxidized by a copper-containing enzyme, known as ascorbate oxidase, in the presence of molecular oxygen (Saari et al. 1995). This enzyme has been shown to bind to cell walls and to be associated with soluble proteins in the cytosol (Loewus and Loewus 1987). Since hexanal has been reported to inhibit phospholipase D (PLD) in the cell wall, it is likely that the reduced rate of vitamin C decline in hexanal-treated fruits are as a result of binding of ascorbate oxidase to the preserved cell wall. This, however, requires further investigation.

Our results indicate that the use of hexanal extended papaya shelf life by 6 days, and enhanced fruit firmness at 2% concentration with a 5-minute dip without affecting the biochemical attributes of papaya fruit. Hexanal is a safe compound that can be applied easily as a dip to improve the post-harvest shelf life of papaya in tropical regions like Kenya. This is a novel approach for potentially reducing the huge post-harvest losses that occur at present.

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Effects of smoke, hexanal, and calcium chloride on post-harvest quality of oranges [Citrus x sinensis (L.) Osbeck] cvs Msasa and Jaffa under different storage durations and conditions in Tanzania

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Experiments were conducted to assess the effects of hexanal, calcium chloride, and smoke on the post-harvest quality of oranges under ambient (room) temperature (28±2°C) and reduced temperature storage (18±2°C) conditions on two varieties of sweet orange (Citrus x sinensis (L.) Osbeck) cvs ‘Msasa’ and ‘Jaffa’. Fruit were dipped in enhanced freshness formulation (EFF) containing hexanal as the key ingredient at 0.01%, 0.02%, and 0.04% (volume/volume), or calcium chloride solution at 1%, 2%, and 4% (weight/volume) for five minutes each, or subjected to a smoking regime, simulating a popular traditional practice, by burning 0.5 kg, 1.0 kg, and 1.5 kg of dried banana leaves, or left untreated (control). Various parameters including physiological weight loss, fruit firmness, total soluble solids (TSS), titratable acidity (TA), and the TSS/TA ratio were assessed to determine effects on post-harvest quality of fruit. Results indicate that hexanal and calcium chloride treatments significantly (p < 0.001) reduced physiological weight loss, maintained fruit firmness and significantly higher TSS in both varieties compared to smoke treatment and untreated controls. Reduced temperature storage also significantly (p < 0.001) lowered physiological weight loss of hexanal- and calcium chloride-treated oranges. Based on the results of this study, post-harvest dip treatments with hexanal solution at 0.02% or calcium chloride solution at 2% coupled with reduced temperature storage at 18°C are recommended to maintain the quality of fresh oranges in Tanzania. On the contrary, the application of smoke is highly discouraged as it reduces the quality of oranges.

Keywords: Post-harvest treatments, post-harvest loss, shelf life, physiological weight loss, fruit firmness, total soluble solids (TSS), titratable acidity (TA), TSS/TA ratio

Post-harvest loss is a general term used to describe the fraction of produce that is rendered unfit for a particular use, whereas the term quality implies the degree of excellence or suitability of a product for a particular use (Abbott 1999). Post-harvest loss is a major constraint in the tropical fresh fruit industry (Kusumaningrum et al. 2015). About 40% to 50% of fresh horticultural produce in developing countries is lost after harvest (Ahmed and Siddiqui 2016; Ugoh et al. 2015). Post-harvest losses are commonly characterized by fruit shrivelling, weight loss, softening, decay, and changes in sugar content and acidity levels (Martin-Diana et al. 2007; Ahmed and Siddiqui 2016), which are major determinants of consumers’ choices of fresh fruits. Post-harvest losses are thus barriers to both local and international trade of tropical fresh fruits (Kusumaningrum et al. 2015). The major causes of post-harvest losses in developing countries include improper post-harvest practices, poor post-harvest management systems and lack of supporting infrastructure for quality maintenance (Ahmed and Siddiqui 2016). Moreover, harvesting fruit at stages other than horticultural maturity, storage under inappropriate conditions, especially temperature (Ahmed and Siddiqui 2016), and use of improper post-harvest treatments results in
Effects of smoke, hexanal, and calcium chloride on post-harvest quality of oranges (*Citrus x sinensis*) cvs Msasa and Jaffa under different storage durations and conditions in Tanzania; Anna Baltazari et al.

significant post-harvest losses (Heather and Hallman 2008).

Several practices are used by farmers to reduce post-harvest losses and to maintain the quality of fresh fruits. Smoke treatment is a common post-harvest practice used by farmers in Tanzania to hasten fruit ripening for bulk purchase and prior to transportation (Saltveit 1999). However, this technique results in increased fruit softening and reduced fruit shelf life (Watada 1986). Storage temperature is an important factor that affects respiration, transpiration, senescence, and other physiological processes in the fruit (Wani et al. 2014). Storage at low temperatures and high relative humidity is beneficial for maintenance of the natural resistance of the peel to infection (Wardowski et al. 2006). Storage of horticultural products in reduced temperatures has been reported to be effective in delaying the physico-chemical changes related to quality loss in fruits (Wani et al. 2014).

Chlorine, sourced from chloride salts, is commonly used in small-scale, post-harvest treatments of fruits (Bertzer et al. 2002) to extend their shelf life and to reduce incidences of decay (Singh et al. 1993). Calcium chloride has been widely used as a preservative and firming agent in the fruit and vegetable industry for whole and fresh-cut commodities (Martin-Diana et al. 2007). For instance, calcium chloride maintained the quality of apples (*Malus domestica*, L.) (Chardonnet et al. 2003), increased the total soluble solids of fig (*Ficus carica*, L.) fruits (Irfan et al. 2013), reduced weight loss of loquat (*Eriobotrya japonica*, L.) (Akhtar et al. 2010), and also delayed ripening and senescence of strawberries (*Fragaria ananassa*, L.), blueberries (*Vaccinium corymbosum*, L.), apples (Martin-Diana et al. 2007; Mishra 2002), and fig fruits (Irfan et al. 2013). Fruit treatment with a high concentration of calcium chloride, however, has been shown to lower fruit quality and increase susceptibility to fungal diseases (Chardonnet et al. 2003). Hexanal treatment is an emerging technique for reducing post-harvest losses of fresh horticultural produce (Paliyath et al. 2008; Paliyath 2011) as it inhibits the activities of phospholipase D enzymes, which are responsible for membrane degradation (Paliyath 2011). Hexanal has been used to reduce post-harvest losses in sweet cherry (*Prunus avium* L.) (Sharma et al. 2010) and tomato (*Solanum lycopersicum* L.) (Tiwari and Paliyath 2011). Hexanal was reported to reduce weight losses in mango (*Mangifera indica* L.), extend the shelf life of sweet cherries (Sharma et al. 2010), delay ripening of mango, and increase firmness and maintain total soluble solids in blueberry (Song et al. 2010). However, information is lacking on the effects of hexanal on post-harvest losses and quality maintenance of fresh citrus fruits. The objective of this study was to assess the effect of different post-harvest techniques on the reduction of post-harvest losses and quality maintenance of fresh oranges.

**Materials and methods**

Fruits of the two most popular sweet orange varieties, ‘Msasa’ and ‘Jaffa’, were harvested from Bwembera and Semngano villages in the Muheza district, Tanga Region in Tanzania. Both varieties were harvested at standard commercial horticultural maturity. Three post-harvest techniques were applied: (i) dipping of fruits in enhanced freshness formulation (EFF), (ii) dipping of fruits in calcium chloride solution, and (iii) smoke treatment. Control groups consisted of untreated oranges of both varieties.

Fruits were completely immersed in EFF solution at 0.01%, 0.02%, and 0.04% (volume/volume) for five minutes or in calcium chloride solutions of 1%, 2%, and 4% (weight /volume) for five minutes each, or subjected to smoke treatment generated by burning dried banana leaves, or were left untreated (control). For the smoke treatment, fruits in three chambers (each with a volume...
of 12 m$^3$) were treated with different smoke concentrations obtained from burning 0.5 kg, 1.0 kg, and 1.5 kg of dried banana leaves. The smoke treatment was done three times at intervals of 12 hours. The chambers were ventilated for 30 minutes by opening between smoke treatments. The chambers were located six metres from the source of smoke to reduce heat transfer to the oranges.

There were two storage conditions: ambient storage (28°C ± 2°C) and reduced temperature storage (18°C ± 2°C). Data were collected on the 4th, 8th, and 12th day from the date of fruit harvest (DAH). Thirty fruits of each variety were used for each treatment, each of which was replicated six times making a total of 360 fruits per treatment.

Data collection was stopped on the 12th day from the date of harvest due to the onset of post-harvest deterioration in some treatments.

Data were collected on fruit weight, firmness, total soluble solids (TSS), and titratable acidity (TA). Physiological weight loss and the total soluble solids/titratable acidity (TSS/TA) ratio were calculated. The physiological weight loss was determined by randomly selecting five fruits from each treatment. The selected fruits were numbered and used for measurement of initial and final weights using an electronic balance (BX 4200H, Shimadzu, Japan) and percentage fruit weight loss was calculated. A small peel disc (approx. 2 mm$^2$) on the opposite side of the fruit cheek was removed, and then fruit firmness was measured using a penetrometer (Wagner fruit test, FT 20 Model, Wagner Instruments, Italy). Total soluble solids content (°Brix) was measured using a hand-held digital refractometer (ATAGO, Japan) according to Nielsen (2010). Titratable acidity of the juice was determined by titration with 0.1 N sodium hydroxide (NaOH) using phenolphthalein as an indicator. The titratable acidity (%) was estimated as per Ranganna (1999) and expressed as per cent anhydrous citric acid. The TSS/TA ratio was computed by dividing the TSS by the TA (%). The data were analysed using R software and, where significant differences existed, using the F-statistic, and means were separated using Tukey’s Honestly Significant Differences (HSD) ($p ≤ 0.05$).

**Results**

Effects of post-harvest treatments, storage duration and storage conditions on physiological weight loss

Physiological weight loss of fruits in both varieties tested was significantly lower in hexanal treatment in ambient conditions on all three days of observation. However, no significant difference was observed when the fruits were kept in reduced temperature conditions (Fig 1). Overall, the physiological weight loss of oranges was lower in hexanal and calcium chloride-treated fruits compared to both smoked and untreated fruits of both varieties.

Effects of post-harvest treatments, storage duration and storage conditions on firmness

Our results showed that fruits remained firm after hexanal and calcium chloride treatments compared to smoke-treated and control fruits of both cultivars. The firmness decreased, as expected, throughout the study period (Fig 2). The highest firmness was 17.40 N/mm$^2$ for ‘Jaffa’ and 13.39 N/mm$^2$ for ‘Msasa’ when treated with 0.02% hexanal under ambient storage conditions at 4DAH.
Effects of smoke, hexanal, and calcium chloride on post-harvest quality of oranges (*Citrus x sinensis*) cvs Msasa and Jaffa under different storage durations and conditions in Tanzania; Anna Baltazar et al.

Figure 1: Physiological weight loss in sweet orange in ambient (Left; 28±2°C) and cold (Right; 18±2°C) conditions. Top panel depicts cv ‘Jaffa’ and the bottom panel depicts cv ‘Msasa’. Values are mean ± Standard deviation.

Effects of post-harvest treatments, storage duration and storage conditions on total soluble solids

Total soluble solids increased with duration of treatment in all treatments, conditions and days after harvest, which was not surprising. There were no significant differences in any of the factors tested in both varieties (Fig 3). Since hexanal only delays membrane deterioration, this result is not surprising and follows the anticipated trend. Fruits treated with hexanal at 0.02% had the lowest value for total soluble solids in both varieties.

Effects of post-harvest treatments, storage duration and storage conditions on titratable acidity

Titratable acidity decreased steadily over time in both varieties tested. The decrease was more pronounced in ‘Msasa’ than ‘Jaffa’ fruits stored at room temperature. For fruit stored under reduced temperature conditions the decrease was not as pronounced as in ambient conditions, although there were some anomalies in ‘Msasa’ fruit, at 12DAH, from hexanal and calcium chloride dip treatments (Fig 4).
Effects of smoke, hexanal, and calcium chloride on post-harvest quality of oranges (*Citrus x sinensis*) cvs *Msasa* and *Jaffa* under different storage durations and conditions in Tanzania; Anna Baltazari et al.

Figure 2: Fruit firmness in sweet orange in ambient (Left; 28±2°C) and cold (Right; 18±2°C) conditions. Top panel depicts cv ‘Jaffa’ and the bottom panel depicts cv ‘Msasa’. Values are mean ± Standard deviation.

Figure 3: Total soluble solids (°Bx) in sweet orange in ambient (Left; 28±2°C) and cold (Right; 18±2°C) conditions. Top panel depicts cv ‘Jaffa’ and the bottom panel depicts cv ‘Msasa’. Values are mean ± Standard deviation.
Effects of smoke, hexanal, and calcium chloride on post-harvest quality of oranges (*Citrus x sinensis*) cvs *Msasa* and *Jaffa* under different storage durations and conditions in Tanzania; Anna Baltazari et al.

Figure 4: Titratable acidity in sweet orange in ambient (Left; 28±2°C) and cold (Right; 18±2°C) conditions. Top panel depicts cv ‘Jaffa’ and the bottom panel depicts cv ‘Msasa’. Values are mean ± Standard deviation.

Figure 5: TSS-TA ratio in sweet orange in ambient (Left; 28±2°C) and reduced temperature (Right; 18±2°C) conditions. Top panel depicts cv ‘Jaffa’ and the bottom panel depicts cv ‘Msasa’. Values are mean ± Standard deviation.
Effects of post-harvest treatments, storage duration and storage conditions on the total soluble solids/titratable acidity ratio

Results showed that TSS/TA increased significantly with storage duration in fruit of both varieties. However, post-harvest factor and storage condition did not alter the TSS/TA ratio significantly in either cultivar (Fig 5). This is not surprising since we noticed opposite trends with TSS and TA as explained earlier.

Overall, our results consistently showed that, treating the fruits with hexanal did slow down the post-harvest damages in physiological factors, thus helping oranges to keep longer in very ordinary conditions that are prevalent in Tanzania. Smoke treatment of oranges, a common practice in Africa, is not beneficial as this research has confirmed. This is the first report of the effects of hexanal in the citrus family, one of the top five fruit crops of the world.

Discussion

Fruit physiological weight loss

Results showed that post-harvest treatments affected physiological weight loss of oranges. Further, the study found that smoke-treated oranges had the highest physiological weight loss. Fruits treated with smoke, shrivelled and lost freshness earlier compared to fruits from the other treatments and the control. Higher smoke concentration aggravated the loss of fruit freshness compared to the other treatments and the control. Smoke treatment results in higher ethylene concentration in the storage room, which accelerates physiological weight loss, ripening and fruit aging (Karthika et al. 2015). Weight loss is an important factor in citrus deterioration during storage, and it is essentially due to water loss by transpiration (Wardowski et al. 2006). A previous study associated the loss of fruit freshness with the rise in transpiration rate and an increase in wilting and shrivelling of stored fruits (Paul and Pandey 2016). Wardowski et al. (2006) have shown that respiration and transpiration rates are high immediately after fruit picking and decline during storage due to shrivelling and drying of peel.

Hexanal-treated oranges had low physiological weight loss regardless of the concentration. El Kayal et al. (2017) reported low weight loss in hexanal-treated raspberry compared to untreated controls. They found that there was delayed wilting in the fruit treated with calcium chloride and the fruit remained fresh for a longer time compared to untreated control fruit. Calcium chloride has been reported to stabilize cellular membranes and consequently delay senescence in horticultural produce Bertzer et al. (2002) and Akhtar et al. (2010) reported delayed senescence and reduced rates of respiration and transpiration in loquat (Eriobotrya japonica) treated with calcium chloride. The low weight loss in fresh, hexanal-and calcium chloride-treated oranges translates into maintained quality, improved shelf life and, therefore, potentially expanded market window.

Physiological weight loss increased during the storage period regardless of storage conditions and post-harvest treatment. Those under ambient (room) storage conditions experienced higher physiological weight loss than those under reduced temperature storage conditions. Singh and Reddy (2006) found that the percent cumulative weight loss in oranges during storage under ambient and refrigerated conditions for 17 days duration, increased with increasing storage period under both storage conditions. High temperatures are well known to result in increased rates of respiration, deterioration, and water loss in fresh produce, leading to reduced market, food, and nutritional values (Hailu and Derbew 2015).
Fruit pulp firmness

Results showed that regardless of the concentration of post-harvest treatment used, and the storage time at assessment, the firmest fruits were those treated with hexanal followed by those treated with calcium chloride. Similar results were reported by Sharma et al. (2010) in sweet cherries. Paliyath (2008) also reported high firmness in fruits treated with hexanal formulations after harvest. Hexanal acts as a strong inhibitor of phospholipase D action, and thus slows down ethylene stimulation of fruit ripening and softening processes (Karthika et al. 2015). Calcium chloride-treated fruits had higher firmness than untreated controls. Calcium chloride has been used as a firming agent for many fruits and vegetables (Mishra 2002). Calcium chloride accumulates in the cell walls leading to facilitation of the cross linking of the pectic polymers, which increases cell wall strength and cell cohesion (Akhtar et al. 2010). The greater firmness in hexanal- and calcium chloride-treated fruits may also be associated with fruit cells’ turgidity, which maintains fruit freshness and increases fruit shelf life. Results demonstrated that smoke treatment leads to increased fruit softness and senescence. Burning one kilogram of wood produces 2.245 g of ethylene (Todd 2003), which means that the effects of smoke are expected to be similar to those of ethylene (Porat et al. 1999). Fruit firmness is one of the most important fruit quality parameters and thus the degree of fruit firmness has been used as an indicator of fruit quality. Further, firmness is one of the final indices that buyers use to make decisions as to whether to buy fruits or not (Batu 2003). It is therefore important to extend fruit firmness so that shelf life and produce acceptance by buyers are improved, which will also result in reduced produce loss.

The reduced temperature storage conditions led to firmer fruits than the ambient storage conditions. This could be due to reduced metabolic reactions in fruits stored at the reduced temperature. Wardowski et al. (2006) reported that citrus firmness undergoes changes during storage depending on storage conditions, especially humidity. The firmness of most fruits and vegetables showed decreased firmness with increasing temperatures (Bourne 1982). The fruits stored under reduced temperature conditions were firmer than the fruits stored in ambient (room) storage, regardless of the variety.

Fruit juice total soluble solids

Hexanal- and calcium chloride-treated fruits had lower values of total soluble solids than smoke-treated oranges at eight days after harvest. This might be due to delayed fruit ripening in the hexanal- and calcium chloride-treated fruits. It has been reported that hexanal slows down ethylene-induced fruit ripening and softening processes (Karthika et al. 2015). The higher total soluble solids content in smoke-treated fruits might be due to the accelerated breakdown of starch, and ripening of the fruits caused by smoke. Goldschmidt (1997) reported that citrus fruits reveal ripening-related symptoms in response to exogenous ethylene treatment. On the contrary, Mayuoni et al. (2011) reported that ethylene had no effects on total soluble solids and acidic contents of citrus fruit juice. Like this study, Akhtar et al. (2010) also reported higher values of total soluble solids content in calcium chloride-treated fruits and the lowest values in the control group.

Fruit juice titratable acidity

The quality of orange juice is influenced by physico-chemical parameters such as pH, total soluble solid content, and total titratable acidity. Citric acid is the dominant organic acid in citrus fruits (Etienne et al. 2013) and it
determines the fruits’ organoleptic quality. In our study, the oranges’ titratable acidity decreased significantly with storage duration, but it was not affected by post-harvest treatments used. The titratable acidity was high at harvest and decreased with storage time, with higher values seen in ambient storage conditions than in reduced temperature storage conditions. This might be due to the ripening of the fruits, when starch is converted into sugar, which contributes to the sweetness of the fruits. The ripening of fruits is associated with softening, sweetening (or decreased bitterness) and colour change. The reduction in acidity may also be due to the conversion of the acids into sugars and their further utilization in the metabolic processes of the fruits. Faasema et al. (2011) reported a similar result of decreased acidity in citrus fruits during storage.

Fruit juice total soluble solids/titratable acidity ratio

The sugar to acid ratio (TSS/TA ratio) was influenced by storage conditions, and there was a higher TSS/TA ratio in ambient storage conditions than in reduced temperature storage conditions at the fourth day after fruit harvest. This could be due to decreased fruit acidity during ripening, and the reduced fruit metabolic activities in reduced temperature storage. The TSS/TA ratio is a key characteristic determining the taste and texture of fruit, and it contributes to characteristic fruit flavours (Wardowski et al. 2006). The TSS/TA ratio is a more reliable index of maturity than rind colour in sweet oranges especially in the humid, tropical regions (Ladaniya 2008). Although the respiratory rates of mature citrus fruits are relatively low, extended post-harvest storage can result in internal quality changes (Echeverria and Ismail 1987). It can be inferred that longer storage duration positively influenced the TSS/TA ratio of fruits in the current study.

Conclusion and recommendations

The current study shows that 0.02% hexanal treatment reduces physiological weight loss, and improves total soluble solids content and firmness in both Msasa and Jaffa oranges up to eight days of storage. Similarly, 2% calcium chloride treatment reduces physiological weight loss, increases total soluble solids content, and increases firmness of oranges. Conversely, smoke treatment increases physiological weight loss and reduces fruit firmness under both ambient (room) and reduced temperature storage conditions with the latter giving better results. Based on the results of this study, treatments with either 0.02% hexanal formulation or 2% calcium chloride coupled with reduced temperature storage at 18°C (± 2°C) are recommended for the maintenance of quality of fresh oranges in Tanzania. On the contrary, smoke treatment is highly discouraged as it reduces the quality of oranges. Further studies are required on the cost-benefit analysis of hexanal and calcium chloride treatment of oranges. Research is also needed to evaluate the effect of hexanal and calcium chloride treatments on the quality maintenance of other tropical fruits in Tanzania.

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Effects of smoke, hexanal, and calcium chloride on post-harvest quality of oranges (Citrus x sinensis) cvs Msasa and Jaffa under different storage durations and conditions in Tanzania; Anna Baltazari et al.

References


The effects of pre-harvest application of hexanal formulations on time to ripening and senescence and fruit retention time in limequat (*Citrofortunella floridana* J.W. Ingram & H.E. Moore)

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Limequat (*Citrofortunella floridana* J.W.Ingram & H.E.Moore), unlike many tropical fruits, is produced year-round in Trinidad and Tobago and there are periods where other seasonally available varieties of limes, for example, the West Indian variety, are in greater demand than the limequat, resulting in glut supplies and high losses in the field. Limequat has been known to produce in excess of 250,000 fruits per hectare and during periods of low demand, much of these fruits go to waste. Retention time of the fruit on the tree is usually around 35 days, after full colour change from green to yellow. Due to its soft texture, the fruit bruises very easily leading to high post-harvest losses and loss of earnings to farmers. This study was conducted to determine the effects of pre-harvest treatments with enhanced freshness formulation (EFF), applied at different concentrations and different application intervals, on retention time of the fruit on the tree and time to colour change of the fruit as an indicator of onset of senescence. Trials conducted showed that pre-harvest biweekly applications of EFF at four percent was more effective in delaying the onset of colour change of the limequat fruits than EFF application at two per cent. It was observed that application of two per cent EFF bi-weekly for four weeks gave a greater reduction in the average number of fruits showing full colour change after treatment when compared to weekly application. Results of the study indicated that application of four percent EFF at bi-weekly spray intervals for one month significantly reduced the rate of colour change of limequats on the trees. Weekly applications of two percent EFF gave the best retention times on the tree, in excess of 99 days, after treatment. Thus, treatment with EFF reduced pre-harvest losses and increased the time for which marketable quality of fruits was maintained.

Keywords: Enhanced freshness formulation, hexanal, limequat, pre-harvest, applications, fruit retention

There are several cultivars of limes grown in the twin island nation of Trinidad and Tobago but the West Indian variety remains predominant while the limequat variety (*Citrofortunella floridana*) is least propagated since not many farmers have access to the planting material. Nevertheless the limequat, once properly managed, is available year-round, while other preferred varieties are seasonally available. The limequat has the capacity to produce a minimum of 250,000 units of limes per hectare per six month bearing cycle. These values were captured based on a three year study (NAMDEVCO records) on a farm located in Central Trinidad. Traditional uses include domestic utilization for the preparation of beverages, fish and meat meals and condiments.

The limequat is a smooth-skinned, soft-textured fruit with an average diameter of 48mm, average juice content of 19 ml, which is comparable to the juice content of a medium-sized lime of the West Indian variety, and an average weight of 35g. The fruit is soft, thus excessive force is not required to express its juice. However, the softness of the skin increases the susceptibility of the fruit to high post-harvest losses if poor handling practices are employed. Brown discolouration is the major indicator of end of shelf life and normally develops only after full colour change from green to yellow takes place, signalling loss of marketability of the fruit.

The limequat is harvested at the full, green, mature stage for optimum juice content and less post-harvest losses rather than at its full...
yellow colour stage, while limes of the West Indian variety are best utilized when at the full yellow colour stage, since the juice content is high and less force is required to express it. Limequat fruits harvested at physiological maturity have better post-harvest shelf life properties (Baldwin 1993). Along with its other quality parameters that provide good marketability, the retention of the green colour increases its demand; as such, retention of green colour of the fruit in the field is significant importance to the farmer. Chlorophyll degradation is the main reason for yellowing of lime fruit (Drazkiewice 1994; Sriloang et al. 2011). During ripening and senescence, membrane degradation occurs as a result of the presence of phospholipase D (PLD). Degradation is also enhanced as a result of stress and the presence of reactive oxygen species (ROS) (Paliyath and Droillard 1992). Research has shown that hexanal, a naturally occurring volatile aldehyde, is a significant inhibitor of PLD activity and can enhance the shelf life and marketability of flowers, fruits and vegetables significantly (Paliyath et al. 1999, 2003; Paliyath and Murr 2007).

Year-round availability, high yields and numerous marketing avenues make the limequat non-competitive when compared to limes of the West Indian variety, which can create gluts on the market whenever the latter is in production. Further, fruit of the West Indian variety normally have a lower selling price than limequat because of the lower cost of production, contributing to the lower demands for limequat when both are in season and glut conditions exist. With very few agro-processing options, the advantage obtained from year-round production in the limequat, is eroded by high post-harvest losses resulting from glut supplies and reduced demand. The problem can be solved if the retention time of limequats on the tree can be increased in order to extend fruit availability beyond the glut period. Previous studies conducted on mango fruits using hexanal formulations showed that pre-harvest applications of hexanal formulations increased the retention time of fruits on the trees (Anusuya et al. 2016).

In this study, pre-harvest application of hexanal was used to observe the effects on the rate of senescence as indicated by fruit yellowing, and retention time of fruit on the trees. Treatments were applied at different concentrations and at different time intervals in an attempt to determine the efficacy of combination of treatment time and concentration to increase fruit retention and reduce the rate of senescence.

**Materials and methods**

**Experiment procedure**

Research investigations were conducted on a limequat orchard located in Central Trinidad. The trees were approximately 15 years old and are pruned periodically to encourage increased flower production and to support ease of harvesting. Treatment plots were selected to prevent drift affecting selected plots. Four pre-harvest spray treatments of EFF (Paliyath and Murr 2007) were applied as follows:

1. Hexanal at 2% v/v - enhanced freshness formulation (EFF1) applied weekly for 3 weeks (total of 4 applications).
2. Hexanal at 2% v/v - enhanced freshness formulation (EFF1) applied bi-weekly for 4 weeks (total of 3 applications).
3. Hexanal at 4% v/v - enhanced freshness formulation (EFF2) applied weekly for 3 weeks (total of 4 applications).
4. Hexanal at 4% v/v - enhanced freshness formulation (EFF2) applied bi-weekly for 4 weeks (total of 3 applications).

Corresponding control plots were treated with control solutions, EFF0, comprising EFF1 or EFF2 minus hexanal. Treatment solutions were applied to trees using a pressurized nozzle sprayer to give good coverage. A 2 x 3 factorial in a completely
randomized experimental design was used to collect data.

Data Analysis

Limequats are estimated to reach harvest maturity within 10 weeks of flower drop. Maturity indices used for limequats were loss in glossy appearance of the fruit and full green skin colour with no signs of yellowing. All fruit that were at harvest maturity as well as all fruit showing signs of yellowing were removed from the trees prior to application of spray solutions. The variables measured (response variables) were:

1. Number of fruits showing 50% colour change by 49 days after spraying,
2. Number of fruits showing full colour change (green to yellow) by specified number of days after spraying and
3. Number of fallen fruit observed after treatment.

Fruits were counted to have 50% colour change when visual observation noted 50% skin colour had changed from green to yellow. Fruits were counted to have full colour change when visual observation noted that 100% skin colour had changed to full yellow. Fruit fall was recorded as the total number of fruits that fell from the trees during the recording period. Fallen fruits were removed from the plot each week. Observations were done on a total of 8600 mature fruit from the six groups of ten trees (replicates) selected from each treatment x spraying frequency combination (Table 1).

<table>
<thead>
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<th>Treatment</th>
<th>Biweekly Interval</th>
<th>Weekly Interval</th>
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<tr>
<td>EFF0</td>
<td>1500</td>
<td>1500</td>
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<tr>
<td>EFF1</td>
<td>1800</td>
<td>1800</td>
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<tr>
<td>EFF2</td>
<td>1650</td>
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The data collected were analysed using two-way ANOVA modelling. The estimated marginal mean effects were then derived for number of fruits observed with 50% and 100% colour change and for the number of fruits fallen observed across the trees that were sprayed with EFF0, EFF1 and EFF2 weekly and bi-weekly. Two-way ANOVA modelling was adopted for this study because of the significant interaction effect between treatment type and spray frequency for which comparisons could have been made. All models were assessed using at least a 5% significance level. If the interaction effect analysed in the ANOVA model was not significant, then the individual variables (treatment, and spray frequency) were then analysed separately for statistical differences.

Results and discussion

Colour change in limequats fruits

There was a general reduction in the rate of colour change from full green to full yellow for fruit from treated trees when compared to fruit from control trees at both the biweekly and weekly treatment intervals for both EFF1 and EFF2 pre-harvest treatments. Fruits sprayed at one week intervals per month with EFF2 showed the least mean percentage change in colour when compared to fruit that had been sprayed twice per month with the same EFF concentration.

Colour change from green to 50 percent yellow was observed within the first seven days from spraying in fruits from trees treated with EFF 1 as well as in those from control trees. However, the mean number of fruits showing colour change was less than 2% in the latter when compared to greater than 40% for those from control trees. Generally, fruits treated with EFF2 had the least mean number of fruits showing initial change in colour compared to the other treatments.

The association between treatment concentration and spray interval on the rate of colour change for limequat fruits is represented...
in Figure 4. It should be noted that the mean percentage of fruits showing 50 per cent colour change remained the same for biweekly applications of both EFF1 and EFF2 treatments when compared to the control.

Therefore, treatments with EFF1 and EFF2 gave significant reductions in the mean percentage of fruits showing 50 per cent colour change by day 49 when compared to fruit on control trees. Differences were found in mean number of fruits with 50% and full colour change at 49 days after spray application between the EFF1 and the EFF2 at the same spraying frequencies (biweekly or weekly) (Table 2). Treatment with EFF1 at biweekly intervals showed a higher mean number of fruits with 50% colour change when compared to treatment with EFF1 at weekly intervals. Treatment with EFF2 at weekly intervals however; showed a higher mean number of fruits with 50% colour change and full colour change when compared to EFF2 at biweekly treatment intervals. Generally, application of EFF2 biweekly showed a lower mean number of fruits with 50% colour change and full colour change when compared to EFF1 at weekly intervals. Biweekly applications of EFF1 showed a lower mean percentage of fruits with full colour change by day 49 when compared to applications of EFF2 at the same rate of application.

Fifty percent colour change

The Analysis of Variance (ANOVA) table for number of fruit per 100 with 50% colour change (Table 3) indicates significant treatment x spraying frequency interaction; for which the interaction plot is shown in Figure 1. The plot shows that spraying EFF2 solution at biweekly intervals results in the smallest mean number of fruit with 50% colour change. There was no significant difference in the efficacy of spraying EFF1 and EFF2 at weekly intervals, with respect to number of fruit with 50% colour change, compared to spraying EFF2 at biweekly intervals (Figure 1).

Full colour change

Trees treated with EFF1 at the biweekly spray interval showed the least average percentage of fruits with full colour development after 49 days when compared trees treated with EFF1 at weekly spray intervals.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Spraying frequency/month</th>
<th>Biweekly intervals</th>
<th>Weekly Intervals</th>
</tr>
</thead>
<tbody>
<tr>
<td>EFF0 (Control)</td>
<td>Number of fruit with 50% colour change per 100 fruit</td>
<td>82.7 (8.07)</td>
<td>68.3 (13.79)</td>
</tr>
<tr>
<td>EFF1</td>
<td>82.9 (14.16)</td>
<td>18.1 (8.46)</td>
<td></td>
</tr>
<tr>
<td>EFF2</td>
<td>9.3 (5.58)</td>
<td>16.5 (6.73)</td>
<td></td>
</tr>
<tr>
<td>Number of fruit with full colour change per 100 fruit</td>
<td>EFF0 (Control)</td>
<td>19.4 (5.03)</td>
<td>9.0 (10.62)</td>
</tr>
<tr>
<td>EFF1</td>
<td>9.8 (4.14)</td>
<td>23.2 (27.24)</td>
<td></td>
</tr>
<tr>
<td>EFF2</td>
<td>13.9 (14.59)</td>
<td>15.0 (7.57)</td>
<td></td>
</tr>
</tbody>
</table>

Table 2: Mean number of fruit (and standard deviations) showing colour change at 49 days after spray application
Effects of pre-harvest application of hexanal formulations on ripening and senescence and fruit retention time in limequat (*C. floridana* J.W. Ingram & H.E. Moore); N. Debysingh *et al.*

Table 3: Analysis of Variance: Number of fruit per 100 with 50% colour change

<table>
<thead>
<tr>
<th>Source</th>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treatment</td>
<td>39724.542</td>
<td>2</td>
<td>19862.271</td>
<td>197.369</td>
<td>≤ 0.001</td>
</tr>
<tr>
<td>Spraying</td>
<td>8611.383</td>
<td>1</td>
<td>8611.383</td>
<td>85.570</td>
<td>≤ 0.001</td>
</tr>
<tr>
<td>Treatment * Spraying</td>
<td>13666.041</td>
<td>2</td>
<td>6833.020</td>
<td>67.899</td>
<td>≤ 0.001</td>
</tr>
<tr>
<td>Error</td>
<td>5434.299</td>
<td>54</td>
<td>100.635</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>67436.265</td>
<td>59</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*** indicates a p-value of less than 1% significant

Figure 1: Estimated marginal means of number of fruit with 50% colour change per 100 fruit. Treatment x spraying frequency interaction plot.

There was no significant difference in the mean percentage of fruits showing full colour change at different spray intervals for treatments with EFF2 when compared to EFF1. The results indicate that biweekly applications of EFF2 had the same effect as weekly applications of EFF2 on full colour change in limequats fruits.

It can be deduced from the results of the trials that pre-harvest spray applications of EFF1 applied biweekly for approximately thirty days before harvest, significantly reduces the rate of full colour change from green to yellow in limequats fruits.

The general delay in the development of full colour was noticeable for up to 99 days after application of EFF1 and EFF2 as pre-harvest treatments when compared to control. Fruit on control trees showed full colour change by day 42.
The interaction plot shows that biweekly applications of EFF1 solution is the preferred treatment for retarding full colour change. Table 4 shows the Analysis of Variance ANOVA table for number of fruit per 100 with full colour change. The table shows significant treatment x spraying frequency interaction ($p = 0.034$); for which the interaction plot is shown in Figure 2.

![Figure 2: Estimated marginal means of number of fruit fall with full colour change per 100 fruit. Treatment x spraying frequency interaction plot.](image-url)
Effects of pre-harvest application of hexanal formulations on ripening and senescence and fruit retention time in limequat (*Citrofortunella floridana* J.W. Ingram & H.E. Moore); N. Debysingh et al.

Fruit fall

A total of 176 out of 8600, that is, 2.05% fruit fell before the last spray application and as such were not considered in this study. The mean and standard deviation of fruit fall per 100 fruit are given in Table 5: treatment and spraying frequency. The corresponding ANOVA table is Table 6 and the interaction plot is shown in Figure 3.

The ANOVA model (Table 6) developed for fruit fall as explained by the interaction between treatment type and spray frequency showed that a significant difference ($p \leq 0.001$) exists in the average number of fruits observed falling among the various treatment and spray frequency combinations.

Measuring the estimated marginal means effect (Figure 3) showed that bi-weekly spraying resulted in a comparatively smaller average fruit fall for EFF1 and EFF2 when compared to the control. Further, weekly spraying with EFF resulted in a decrease in the observed number of fruit fall. Thus, the results suggest that the number of fruit fall can be decreased by weekly application of EFF1.

Table 4: ANOVA table for number of fruit per 100 with full colour change

<table>
<thead>
<tr>
<th>Source</th>
<th>Sum of Squares</th>
<th>Df</th>
<th>Mean Square</th>
<th>F</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treatment</td>
<td>64.641</td>
<td>2</td>
<td>32.321</td>
<td>.166</td>
<td>.847</td>
</tr>
<tr>
<td>Spraying</td>
<td>27.563</td>
<td>1</td>
<td>27.563</td>
<td>.142</td>
<td>.708</td>
</tr>
<tr>
<td>Treatment *S</td>
<td>1408.271</td>
<td>2</td>
<td>704.136</td>
<td>3.618</td>
<td>.034</td>
</tr>
<tr>
<td>Error</td>
<td>10509.337</td>
<td>54</td>
<td>194.617</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>12009.812</td>
<td>59</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 5: Summary Statistics for fruit fall for spray treatments

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Spraying frequency/month</th>
<th>Two times Number of fruit per 100</th>
<th>Four times Number of fruit per 100</th>
</tr>
</thead>
<tbody>
<tr>
<td>EFF0 (Control)</td>
<td></td>
<td>6.2 (3.89)</td>
<td>0.1 (0.35)</td>
</tr>
<tr>
<td>EFF1</td>
<td></td>
<td>1.59 (1.14)</td>
<td>0.0 (-)</td>
</tr>
<tr>
<td>EFF2</td>
<td></td>
<td>1.9 (2.62)</td>
<td>1.4 (1.59)</td>
</tr>
</tbody>
</table>

Table 6: ANOVA: Number of fruit fall per 100 fruit

<table>
<thead>
<tr>
<th>Source</th>
<th>Sum of Squares</th>
<th>Df</th>
<th>Mean Square</th>
<th>F</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treatment</td>
<td>59.908</td>
<td>2</td>
<td>29.954</td>
<td>6.933</td>
<td>.002</td>
</tr>
<tr>
<td>Spraying</td>
<td>109.350</td>
<td>1</td>
<td>109.350</td>
<td>25.309</td>
<td>(\leq 0.001)</td>
</tr>
<tr>
<td>treatment * Spraying</td>
<td>88.261</td>
<td>2</td>
<td>44.131</td>
<td>10.214</td>
<td>(\leq 0.001)</td>
</tr>
<tr>
<td>Error</td>
<td>233.310</td>
<td>54</td>
<td>4.321</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>490.829</td>
<td>59</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Figure 3: Estimated marginal means of number of fruit fall per 100 fruit for treatment concentrations EFF1 and EFF2 applied at biweekly and weekly spray intervals on fruit fall in Limequat fruits.
Effects of pre-harvest application of hexanal formulations on ripening and senescence and fruit retention time in limequat (*Citrofortunella floridana* J.W. Ingram & H.E. Moore); N. Debysingh et al.

Retirement time

Fruit fall from both control and treated trees occurred only after fruits showed full yellow colour change. Full yellowing and subsequent fruit drop commenced in control trees after 35 days. Development of full yellow colour and accompanying fruit fall was not observed in treated trees until day 99. The trials demonstrated that mean percentage fruit drop was predicted by treatment applications of EFF and treatment intervals. Fruit drop was lowest for treatments with EFF1 applied at weekly intervals when compared to EFF2 treatments (Table 5). Additionally, the application of EFF2 at weekly intervals and biweekly intervals showed no significant difference on the rate of fruit fall when compared to fruit fall from trees treated with EFF1.

Fruits treated with EFF1 and EFF2 showed fruit drop after a minimum of 99 days (when weekly and biweekly spray treatments were applied) and a maximum of 120 days fruit retention after an initial colour change (for fruits treated with EFF2). However, results indicated that fruits treated with EFF1 at weekly treatment intervals had the lowest mean percentage of fruit fall when compared to biweekly applications using the same concentration (Table 6).

Fruit drop was observed in control trees from 35 days after full colour change. Fruits from trees treated with EFF1 and EFF2 showed fruit fall after ninety-nine (99) days. The mean percentage of fruit fall per tree for treated trees was <1% per week compared to >6% per week for control trees.

<table>
<thead>
<tr>
<th>Days</th>
<th>Control</th>
<th>2% Treatment - 2 week spray interval</th>
<th>4% Treatment - 2 week spray interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td></td>
<td>[Image]</td>
<td>[Image]</td>
</tr>
<tr>
<td>35</td>
<td>[Image]</td>
<td>[Image]</td>
<td>[Image]</td>
</tr>
<tr>
<td>49</td>
<td>N/A</td>
<td>[Image]</td>
<td>[Image]</td>
</tr>
</tbody>
</table>

Figure 4: The effect of EFF1 and EFF2 treatments at biweekly applications on colour change and fruit fall on limequat fruits.

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Conclusion

Pre-harvest applications of EFF1 and EFF2 (either at biweekly or weekly spray intervals) were effective in extending time of fruit retention on treated trees than non-treated trees. Applications of EFF1 at biweekly spray intervals were most effective than weekly and biweekly spray applications of EFF2 for the same period, resulting in a reduction in the rate of full colour change for fruits on the tree. Applications of EFF2 (4%) bi-weekly gave greater delay in 50% colour change than weekly application of EFF2. Additionally, the rate of senescence, as indicated by the rate of colour change from full green to full yellow, was also decreased in fruits on treated trees, so that overall time to full colour change in the treated fruit was longer than for fruits on the control trees up to in excess of ninety-nine (99) days.

However, given the interaction between spray concentration and spray intervals, it appears that spraying weekly at the higher concentration, i.e., four percent, accelerated colour change enough to make application of EFF1 (two percent) at biweekly intervals more effective at delaying full colour change. This was probably as a result of a slight toxicity effect of the higher application concentration. Therefore, treatment with EFF1 at biweekly intervals is recommended for use by farmers to increase income generation, given the advantage on the reduced rate of colour change from full green to full yellow. Weekly applications of EFF1 however, gave the highest retention time for lime fruit on the trees.

References


The effects of pre-harvest treatments with hexanal formulation on selected post-harvest quality parameters of limequat (Citrofortunella floridana J.W.Ingram & H.E.Moore) fruits

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Generally, limequat (Citrofortunella floridana J.W.Ingram & H.E.Moore) fruits have a relatively short shelf life at supermarket display temperatures (17-22°C). In some cases, shelf life can be as short as four days, after which surface discolouration becomes evident, along with shrivelling, and in many instances, the development of post-harvest diseases. Therefore, for maintenance of marketable quality, these three factors must be controlled. Pre-harvest treatments are known to positively affect the post-harvest quality of many commodities. Among these, treatment with hexanal has resulted in improved post-harvest quality maintenance because of its retarding effect on enzyme-driven cellular degradation. This study was conducted to observe the effect of pre-harvest treatments with hexanal on the length of the shelf life and the post-harvest quality of limequat fruits. Pre-harvest spray applications of 2% and 4% EFF (Enhanced Freshness Formulation), containing hexanal as the active ingredient, were made at weekly and biweekly intervals 30-35 days before the expected date of harvest. Pre-harvest spray treatments of EFF at 2% and 4% to trees of limequat resulted in the delay in the rate of colour change from green to yellow by an average of 7 days and 14 days, respectively, in harvested mature fruit. Senescent changes and other signs of deterioration including surface discoloration as brown patches, appeared on the fruit only after full colour change from green to yellow had occurred. Pre-harvest treatment also resulted in a reduction in the incidence of post-harvest diseases by up to 21 days during storage at 17-19°C / 90-95% RH. Thus, pre-harvest spray application had a marked effect on appearance by delaying both yellowing and shrivelling of the fruit, and consequently on marketability since appearance is one of the main factors determining acceptability in the marketplace.

Keywords: Enhanced freshness formulation, EFF, hexanal, limequat, pre-harvest

The establishment of sustainable market opportunities for fresh fruits is heavily dependent on the length of fruit shelf life. Limequat (Citrofortunella floridana J.W.Ingram and H.E.Moore) has the potential to provide sustainable livelihoods for farmers in Trinidad and Tobago because of its economic importance in both local and export markets. However, this lucrative opportunity can be realized if the fruits have a suitably long shelf life to allow for successful marketing. Generally, limequat fruits have a shelf life of no more than four days at supermarket display temperatures (17-22°C). After four days, surface discolouration becomes evident, along with shrivelling, and in many instances, the development of post-harvest diseases. Therefore, for maintenance of marketable quality, these three factors: surface discolouration, shrivelling and development of post-harvest diseases, must be controlled. Normally, the major factor affecting the length of the shelf life is postharvest handling. Given the tender nature of the fruit surface, regimes that minimize postharvest handling are desirable to extend marketing time. Previous studies showed that pre-harvest treatments such as gibberellic acid can reduce pre- and post-harvest losses of limequats (Shah et al. 2017).

Pre-harvest treatments are known to positively affect the postharvest quality of
The effects of pre-harvest treatments with hexanal formulation on selected postharvest quality parameters of limequat (Citrofortunella floridana J.W. Ingram & H.E. Moore) fruits; Nirmalla Debysingh et al.

many commodities. Among these, treatment with hexanal has resulted in improved post-harvest quality maintenance because of its retarding effect on enzyme-driven cellular degradation. Studies conducted on cherries and other stone fruits showed that pre-harvest treatments using Enhanced Freshness Formulation (EFF) with hexanal as the active ingredient, enhanced shelf life properties of the respective fruits for up to thirty days after harvest (Sharma et al. 2010). Other studies showed that the application of hexanal as a combination pre-harvest and post-harvest dip enhanced firmness, ascorbic acid content, and brightness in greenhouse tomatoes (Cheema et al. 2014). The objective of this study was to observe the effect of EFF spray containing hexanal at 2% and 4% concentration, on the shelf life of limequats when applied as a pre-harvest treatment only.

Materials and methods

Limequat trees were selected from a field in Central Trinidad, Trinidad and Tobago, West Indies. Six treatments were applied to selected trees: EFF spray containing hexanal at 2% and 4% concentration and applied as pre-harvest sprays, twice within thirty (30) days from the planned date of commencement of harvest and four times within thirty days from planned date of commencement of harvest. Control trees were sprayed with solutions made up as EFF without the hexanal. Mature green fruits and fruits showing any signs of yellowing were removed from the trees before spray application. Fruits that fell from the trees were disregarded in this study. Fruits were harvested from treated and control trees at full, green, mature stage and placed into storage at 17-19°C and 90-95% RH, for observation on time to change in fruit colour from full green to full yellow, development of surface discolouration, incidence of postharvest diseases, changes in firmness and development of shrivelling. Relative humidity was maintained by inclusion of water-filled trays in the storage area.

Change in fruit colour

Colour change was measured using an indicator of <50% colour change (green to yellow) on the fruit surface or >50% colour change.

Development of surface discolouration and postharvest diseases

Limequat fruits stored at 17-19°C and 90-95% RH, were observed for the development of surface discolouration and visual evidence of microbial rots on the surface of the fruit. The presence of microbial rots was checked for individual fruits to be recorded on a percentage basis. The presence of discolouration was similarly recorded.

Firmness and shrivelling

Observations were made on the nature of the skin surface and time to first signs of development of shrivelling was recorded. Firmness was measured at seven day intervals for up to 21 days. Measurements were read using a manual penetrometer (Koehler Model K19500) using a 10mm tip and the results were recorded in kg-force (Bundit and Udomsak, 2007).

Results and discussion

Effect of EFF treatment on change in fruit colour

Change in colour of limequat fruits from full green to yellow is an indicator of ripening and senescence. For fruits treated pre-harvest with 4% EFF, colour change from full green to full yellow occurred after 21 days of storage at 17-19°C when compared to control fruits which changed to full yellow by seven days storage at...
the same temperature regime. Thus, the results of the trial showed that pre-harvest treatments of 4% EFF applied at weekly intervals or biweekly intervals 30 days prior to the expected date of harvest delayed colour change from full green to full yellow by 14 days. For fruits treated pre-harvest with 2% EFF, colour change from full green to full yellow occurred after fourteen (14) days of storage at 17-19°C with an average delay of one week compared to control fruit.

The results (Table 1) showed that 54% of the fruits observed in the control group had more than 50% colour change within the observation period. For fruits treated with 2% EFF, 93% of the fruit observed had less than 50% colour change within the observation period. The chi square analysis (Chi Sq. Value = 44.676; P = 0.000) showed that there is a mutual dependence between treatment and colour change. The results indicated that the application of 2% EFF sprayed twice within a 21 day observation period will delay postharvest yellowing that indicates senescence.

Effect of EFF treatment on development of surface discolouration and postharvest diseases

Surface discolouration, as brown patches, developed on all fruits during storage but appeared only after full colour change from green to yellow. Thus, while surface discolouration began to develop in control fruit after seven days, in treated fruit, discolouration began to develop after 14 and 21 days storage for treatments at 2% and 4%, respectively. A chi square analysis was used to determine if there is a mutual dependence existing between the treatment and post-harvest disease and between treatment and colour changes. Fifty per cent of fruits from control trees, observed within the 21 day observation period, showed the presence of post-harvest diseases whereas 12.5% of fruit from treated trees had evidence of post-harvest disease incidence in the same observation time period. This showed a significant reduction in the incidence of postharvest diseases as a result of treatment with 2% EFF (Table 2).

### Table 1: Test of mutual dependence between treatment and colour change

<table>
<thead>
<tr>
<th>Treatment</th>
<th>&lt;50%</th>
<th>&gt;50%</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>37</td>
<td>43</td>
<td>80</td>
</tr>
<tr>
<td>2% EFF</td>
<td>82</td>
<td>6</td>
<td>88</td>
</tr>
</tbody>
</table>

Chi Sq. Value = 44.676; P = 0.000
*** p-value indicating less than 1% significance

### Table 2: Test of mutual dependence between treatment and the presence of postharvest disease

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Observed</th>
<th>None Observed</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>40</td>
<td>40</td>
<td>80</td>
</tr>
<tr>
<td>2% EFF</td>
<td>11</td>
<td>77</td>
<td>88</td>
</tr>
</tbody>
</table>

Chi Sq. Value = 27.873; P = 0.000***
*** p-value indicating less than 1% significance

For fruit treated with 4% EFF, fungal rotting was observed in about 5% of fruit. Based on the results observed, the 2% EFF treatment effectively reduced the incidence of postharvest diseases in limequat fruit. The chi square analysis (Chi Sq. Value = 27.873; P = 0.000) showed that a mutual dependence exists between the treatment used and the presence of a postharvest disease. After storage for 21-days at 17-19°C / 90-95% RH postharvest microbial rotting was evident in 12.5% of the pre-harvest treated fruits and 50% of the control fruits (Table 2).
Shrivelling of the skin in limequats reduces marketability of the fruit. It was observed that the incidence of shrivelling was concomitant with the development of full yellow colour change in EFF pre-treated fruits as well as in control fruits. Fruits pre-treated with 4% EFF at both weekly and bi-weekly intervals 30 days prior to harvest showed no visible shrivelling for up to 21 days storage at 17-19°C. Similarly, fruits pre-treated with 2% EFF at the same times, showed no signs of shrivelling for up to 14 days storage at 17-19°C. Shrivelling started in control fruit after seven days.

Fruits treated with 4% and 2% EFF remained firm during storage for up to 21 days and 14 days respectively, after harvest. Control fruits maintained firmness up to seven days after harvest when stored at 17-19°C. One-way analysis of variance was used to test if a statistical difference exists between the average fruit firmness for the treated fruits and control fruits. The average firmness for the fruit treated with 2% EFF sprayed twice for a two week period was 1.5194 kg-force whereas control fruits had an average firmness of 1.2855 kg-force (Table 3).

### Table 3: Firmness of fruits treated with 2% EFF and control fruits

<table>
<thead>
<tr>
<th>Independent Variable</th>
<th>Sub Categories</th>
<th>N</th>
<th>Mean Score</th>
<th>Std. Dev.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treatment</td>
<td>Control</td>
<td>38</td>
<td>1.2855</td>
<td>0.267</td>
</tr>
<tr>
<td></td>
<td>2% EFF</td>
<td>36</td>
<td>1.5194</td>
<td>0.296</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>F = 12.764; P = 0.001***</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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

The one way ANOVA model showed that a statistical difference was observed at a 1% significance level ($F = 12.764; P = 0.001$). Essentially, the results showed that pre-harvest spray application of 2% EFF will yield firmer fruit than untreated control fruits.

### Conclusion

Application of pre-harvest spray treatment of EFF at 2% and 4% to trees of limequat resulted in the delay in the rate of colour change from green to yellow by an average of seven days and 14 days, respectively in harvested fruit. Surface discolouration, as brown patches, appeared on the fruit surface only after full colour change from green to yellow had occurred. Shrivelling also became evident after yellowing of the fruit surface. Senescent changes and other signs of deterioration appeared on the fruit only after full colour change from green to yellow. Thus, pre-harvest spray application had a marked effect on appearance by delaying both shrivelling and yellowing in the fruit, and consequently on marketability since appearance is the main factor determining acceptability in the marketplace. Pre-harvest applications of 2% and 4% EFF resulted in a reduction in the incidence of postharvest diseases by up to 21 days during storage at 17°C / 90-95% RH. The effects observed suggest that fruit yellowing occurred as a result of senescent changes in the fruits. This would most likely be associated with tissue breakdown and possible water loss.

Hence, visible shrivelling was evident as fruits turned full yellow. Measurable loss of firmness, also associated with tissue breakdown, was also apparent after development of full yellow colour. The skin of fruits stored at high relative humidity, remained soft and pliable indicating advance of senescence as demonstrated by browning discolouration of the skin; further softening and incidence of postharvest rotting were also likely associated with tissue breakdown. Under conditions of the experiment, where fruit were handled carefully and mechanical injury was not allowed to occur, fruits developed postharvest diseases only after senescence was ongoing. In normal commercial practice, rotting was more common because the thin-skinned fruit is susceptible to easy bruising.
The effects of pre-harvest treatments with hexanal formulation on selected postharvest quality parameters of limequat (Citrofortunella floridana J.W. Ingram & H.E. Moore) fruits; Nirmalla Deby singh et al.

Therefore, pre-harvest spray treatment with EFF offers a viable option for farmers to increase their earning and must be coupled with careful post-harvest handling to avoid bruising, water loss and postharvest disease incidence in order to maximise the positive effects of the treatment.

Acknowledgement

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References


Extending storage life of mango (*Mangifera indica* L.) using a new edible wax formulation incorporated with hexanal and cinnamon bark oil

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Two formulations of bees wax-based edible coatings with added anti-ripening and antifungal compounds, C5 (hexanal and cinnamon bark oil) and C6 (cinnamon bark oil only), were developed and tested on mangoes stored at low temperature (13.5 °C ± 2 °C) for quality attributes including internal CO2 accumulation and marketability. The particle size distribution of the waxes and the surface morphology of the coating were also assessed. Our results demonstrate a low rate of disease incidence with higher marketability in wax-treated fruits after two weeks of storage at the low temperature compared to untreated controls (*p* < .05). Internal CO2 accumulation in the wax-coated mangoes was high compared to un-waxed controls indicating the formation of a semi-permeable coating around the fruit. No significant differences (*p* < .05) in other quality parameters such as fruit colour, fruit firmness, and pH were observed in wax-treated fruits compared to controls. However, significantly higher (*p* < .05) fruit acidity with lower total soluble solid content was observed in wax-coated fruits after one week of storage indicating a delay in the ripening process. No off-flavours were reported for the wax-coated fruits by the sensory panellists.

Keywords: Hexanal, cinnamon bark oil, edible wax, mango, storage life, post-harvest loss

Mango (*Mangifera indica* L.) is a nutritious tropical fruit with distinct flavour characteristics. Mango variety, Karthakolumban, is widely grown in Sri Lanka. The fruits are of commercial importance in the domestic market and have the potential for export to countries where mango is an exotic fruit. However, post-harvest losses due to diseases, such as anthracnose and stem end rot, and physical damage during transportation and storage contribute to severe quality loss rendering fruits unmarketable and undesirable for consumption. Preventing these substantial economic losses may be achieved by maintaining the quality of mangoes in terms of firmness, colour, texture, flavour, and shelf life.

A number of technologies have been developed and are currently in use to prolong shelf life and enhance the quality of fruit and vegetables. Wax coatings are applied to many commodities to delay fruit ripening, control moisture loss, and modify gas exchange and thereby reduce the rate of respiration and extend shelf life (Dhall 2013). These coatings often create a modified atmospheric condition in fruits by modifying their internal gas composition. Wax formulations derived from biological compounds or GRAS (Generally Regarded as Safe) compounds could be considered as bio-waxes and edible coatings. It has been reported that edible coatings are able to carry active ingredients such as anti-browning agents, colorants, flavours, nutrients, spices, and antimicrobial compounds that could extend product shelf life and reduce the risk of pathogen growth on food surfaces (Pranoto et al. 2005; Pena and Torres 1991).

Cinnamon bark oil has been reported to be a strong antibacterial and antifungal compound (Fei Lu et al. 2011; Usha et al. 2012) that can be incorporated into wax formulations in order to, hopefully, enhance antifungal properties.

Since ethylene plays a key role in fruit ripening (Carrari and Fernie 2006), functional modifications of the ethylene biosynthetic pathway through inhibition of key enzymes or receptors have been tested for commercial application, such as using aminoethoxyvinylglycine, and exposure to 1-
Extending storage life of mango (Mangifera indica L.) using a new edible wax formulation incorporated with hexanal and cinnamon bark oil; M. M. N. P. Gunesekara et al.

methylcyclopropene (1-MCP). Phospholipase D (PLD) is the key enzyme that initiates a series of catabolic cascades that lead to the eventual deterioration of the cell membrane. The initial changes of the membrane associated with ripening and senescence affect cellular compartmentalization and accelerate the senescence process (Paliyath and Subramanian 2008; Paliyath et al. 2008). Inhibition of PLD activity could therefore enhance membrane stability and hence increase the firmness of fruits (Cheema et al. 2014). Previous studies have shown that PLD activity may be selectively inhibited by primary alcohols, hexanol, and aldehydes such as hexanal (Paliyath et al. 1999; Tiwari and Paliyath 2011). Hexanal formulations increased fruit firmness, soluble solids, and antioxidant enzyme activity when applied as a pre-harvest spray treatment for tomatoes, fresh cut vegetables, and sweet cherries (Paliyath et al. 2003; Sharma et al. 2010).

In this study, two bio-wax formulations—one with hexanal and cinnamon bark oil and the other with only cinnamon bark oil—were tested as post-harvest dips to enhance shelf life and improve the quality of cold-stored mango.

Materials and methods

Development of edible waxes

A series of water-based wax emulsions using beeswax (purchased locally), Tween 20 (Sigma Aldrich, USA), and stearic acid (BDH, England) were formulated and screened with initial fruit trials. The two best formulations were selected (Sri Lanka patent application no 18030) for further improvements and named as C5 and C6. Hexanal (FCC, Sigma Aldrich, USA) and cinnamon bark oil were incorporated as anti-senescent and antimicrobial agents in wax formulations C5 (0.02% hexanal and 0.02% cinnamon bark oil) and C6 (0.02% cinnamon bark oil only). Physical properties of the wax emulsions and coating formations were evaluated with a particle size analyser (Fritsch Analysette 22, MicroTec Plus, Germany) and a scanning electron microscope (SEM: LEO 1420VP, LEO Electron Microscopy Inc, USA), respectively. Specimens were coated with a thin gold layer using a sputter coater to avoid electrical charge accumulation during SEM examination.

Post-harvest dip treatment of hexanal and cinnamon bark oil-containing waxes

Mango, cv Karthakolumban, harvested from Ellawala Horticulture (Pvt) Ltd, Galkiriyagama, Sri Lanka, were used to test the efficacy of wax treatments. Mature green, blemish-free mangoes of uniform size were harvested at 13 weeks after full bloom, de-sapped, and randomly assigned to coating treatment (C5, C6, and controls). Sets of 30 mangoes were dipped in each wax formulation (C5 and C6), air-dried at room temperature, and transferred to ventilated cardboard boxes lined with shredded paper (six fruits per box with five replicate boxes per treatment). A set of 30 untreated fruits (six fruits per box with five replicate boxes) were used as controls and they were also assigned to ventilated cardboard boxes lined with shredded paper. All cartons containing treated and untreated mango were transported to the laboratory and stored at the optimum temperature of 13.5°C ± 2°C and 90% relative humidity (RH) for 21 days. Quality evaluations of fruits were done at seven day intervals. Samples were brought to room temperature over 18 hours prior to evaluating physico-chemical parameters. The experiment was repeated in three consecutive mango seasons.

Quality evaluation of mango

Physico-chemical analyses

Physico-chemical tests were carried out including fruit firmness (using a Guss FTA-
Extending storage life of mango (*Mangifera indica* L.) using a new edible wax formulation incorporated with hexanal and cinnamon bark oil; M. M. N. P. Gunesekara et al.

Fruit Texture Analyzer, Guss Manufacturing (Pty) Ltd., South Africa), peel colour (using a Minolta Colour meter, Model CR-400, Minolta, Japan), total soluble solids (as °Brix using a hand-held prism refractometer, Kruss 0-30, Kruss Optronic GmbH, Germany), titratable acidity (by titration with 0.1 N NaOH with phenolphthalein as an indicator), and pH (HACH, Loveland, USA) and were conducted in accordance with methods described by Ranganna (1977). Weight loss, firmness, and peel colour were determined using 15 fruits from both the treatments and control. Five composite mango samples, each having flesh materials from three mango fruits, were obtained for the determination of total soluble solids, titratable acidity, and pH.

Sugar and organic acid analyses

Sample preparation

For the chromatographic analysis, 5.0 g of flesh material was homogenized in 25.0 mL of distilled water prior to filtration with a 0.45 µm regenerated cellulose filter membrane (Agilent, USA).

HPLC instrumentation and chromatographic conditions – The chromatographic separation of sugars and organic acids was carried out using an Agilent 1260 infinity HPLC system equipped with a quaternary gradient pump, a refractive index detector for sugars, a DAD (λ<sub>max</sub> = 210 nm for organic acids), and an auto injector. Agilent’s OpenLAB Chromatographic Data System software was used to obtain chromatographic data.

Sugar analysis – The separation was achieved on a Zorbax Carbohydrate (NH2) column (250 mm x 4.60 mm x 5 µm, Agilent, USA). The mobile phase consisted of isocratic acetonitrile: water (79: 21, v/v). Each run was completed within 20 minutes with a flow rate of 1.2 mL min<sup>-1</sup> and an injection volume of 10 µL. The column temperature and detector temperature were maintained at 30°C. The results were expressed as g/100 g of fresh weight.

Organic acids analysis – The separation was achieved on a SUPELCOSIL LC-18 column (300 mm x 4.00 mm x 5 µm, Supelco, USA). The mobile phase consisted of 97% A (A = dipotassium hydrogen phosphate buffered at pH 2.6 with orthophosphoric acid) and 3% B (B = 100% methanol). Each run was completed within 30 minutes with a flow rate of 0.5 mL min<sup>-1</sup> and an injection volume of 10 µL. The column temperature and detector temperature were maintained at 30°C. The detection was carried out at UV 210 nm. The results were expressed as mg/100 g of fresh weight.

Internal gas analysis

A sample of gas was obtained from inside each of the six fruits of the two treatments and the control via a hole bored into the surface of the fruit using a cork-borer (diameter: 5 mm). A glass tube, open at one end and sealed with a Teflon septum on the other end, was inserted into the prepared hole and kept for three hours before taking the sample. A headspace sample of 0.5 mL was drawn from the tube and injected into the gas chromatograph. The CO<sub>2</sub> gas content of the internal gas composition of mangoes was analysed by gas chromatograph (Model 9A Shimadzu Porapack Q column). The column oven temperature, injector port temperature, and thermal conductivity detector (TCD) temperature were maintained at 90°C, 110°C, and 200°C, respectively.

Headspace analysis of volatile compounds

Solid Phase Micro Extraction (SPME) was used to evaluate the volatile aroma compound profile of treated and untreated mango. Six equally-sized mango fruits from each treatment (C5 and C6) and the control were sealed in three separate airtight glass containers, each having two fruits. Sampling
was conducted with Supelco 65 μm polydimethylsiloxane/divinylbenzen, fused silica, 24 Ga SPME fibre assembly, and manual SPME holder (Supelco Park, Bellefonte, PA, USA) for 30 minutes at a room temperature of 30°C. A Shimadzu 2010 gas chromatographic system equipped with a flame ionization detector and a Supelcowax-10 (30 m x 0.25 mm x 0.2 μm, Sepelco, USA) capillary GC column was used to obtain the volatile profiles. Of the identified volatile compounds, such as pinenes, terpenes, alcohols, and esters described by Macleod and Pieris (1984), variation in ethyl hexanoate, β-ocimene and ethyl octanoate levels were evaluated with respect to treatment and storage period. A GC-MS (a Thermo scientific Trace 1300 GC coupled with an ISQ QD single quadruple mass spectrometer) was used for compound identification (Mass Spectral Database: NIST11).

Disease incidence and marketability

The incidence of disease was rated on a scale of 1 to 10, with 1 meaning no signs of disease and 10 meaning that fruits had entirely succumbed to disease. Fruits that had a rating of 1 or 2 were considered as marketable (Figure 1).

Sensory analysis

A trained sensory panel (as per ISO 8586-1: 1993 guidelines) of nine people analysed the fruits for appearance, colour, odour, texture, taste, and overall acceptability based on a hedonic scale from 1 to 9, where 1 indicated “dislike extremely” and 9 indicated “like extremely”, after low temperature storage. Both wax treated and untreated control fruits were removed from storage at the same time intervals for sensory analyses.

Data analysis

Experimental means were subjected to an Analysis of Variance and means were compared with Tukey’s tests using the general linear model (GLM) procedure of SPSS software (SPSS, version 16). To compare means of values from treated mangoes with those from control sets, a type I error rate of \( p < .05 \) was used for all trials.

Figure 1: Disease severity index for mango.
1 meaning no signs of disease and 10 meaning that fruits had entirely succumbed to disease. Fruits rated as 1 or 2 were considered marketable.
Results

Particle size distribution and scanning electron microscopy

The cumulative particle size distribution of the wax formulations resembled each other, with C5 and C6 wax emulsions having 90% of the particle sizes falling below 16.7 µm and 16.4 µm, respectively (Figure 2). The SEM images of the surface morphology confirmed that both C5 and C6 waxes formed an even coating and covered the stomata on the fruit surface while stomata of control fruits were observed as remaining uncovered (Figure 3).

![Particle size distribution](image_url)

Figure 2: Particle size distributions. A, for C5: Q3(x) [90%] = 16.7 µm. B, for C6: Q3(x) [90%] = 16.4 µm. Q3(x) is the cumulative distribution of particle size and Q3(x) [90%] means 90% of the particles falls below the given value.
Extending storage life of mango (*Mangifera indica* L.) using a new edible wax formulation incorporated with hexanal and cinnamon bark oil; *M. M. N. P. Gunesekara et al.*

Figure 3: Surface morphology of mango fruit peel, SEM x 1k. A, uncoated. B, C5 wax coated. C, C6 wax coated.
Quality evaluation of mango

Physico-chemical analyses

No significant difference in skin colour (Hue angle), fruit firmness, weight loss, and pH of mangoes was observed, irrespective of the treatment applied and storage duration (Tables 1, 2, 3, and 4). However, significantly lower total soluble solid (TSS) content with higher titratable acidity (TA) was observed in mangoes dipped in wax C5 and C6 formulations compared to the untreated controls indicating a delay in ripening in the first week of storage. However, no significant difference in TSS contents was observed between the treatments and control after 14 and 21 days storage (Tables 5 and 6). The results of the sugar profile and acid profile analysis confirmed the above findings. A significantly higher content of fructose and glucose were observed in control fruits compared to wax treatments. The sucrose content did not show any significant change with the treatment applied (Table 7). In the acid profile, the citric acid content in wax treated fruits was significantly higher compared to control fruits with respect to the storage duration over 7 to 21 days (Table 8).

Table 1: Variation in flesh colour of mangoes subjected to post-harvest wax treatments (C5 and C6) and controls after low temperature storage at 13.5 °C ± 2 °C for 1 week, 2 weeks, and 3 weeks

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Colour as Hue angle</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1 week</td>
</tr>
<tr>
<td>Control (untreated)</td>
<td>77.10 ± 1.61a</td>
</tr>
<tr>
<td>Wax C5</td>
<td>81.96 ± 3.88a</td>
</tr>
<tr>
<td>Wax C6</td>
<td>75.60 ± 1.35a</td>
</tr>
</tbody>
</table>

Note: The data shown are mean ± standard error of 15 fruits each. Statistically significant values (p < .05) within columns are designated by different letters

Table 2: Variation in fruit firmness of mangoes subjected to post-harvest wax treatments (C5 and C6) and controls after low temperature storage at 13.5 °C ± 2 °C for 1 week, 2 weeks, and 3 weeks

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Firmness of mango (Kpa)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1 week</td>
</tr>
<tr>
<td>Control (untreated)</td>
<td>3.10 ± 0.96a</td>
</tr>
<tr>
<td>Wax C5</td>
<td>3.70 ± 1.68a</td>
</tr>
<tr>
<td>Wax C6</td>
<td>3.96 ± 0.74a</td>
</tr>
</tbody>
</table>

Note: The data shown are mean ± standard error of 15 fruits each. Statistically significant values (p < .05) within columns are designated by different letters

Table 3: Variation in weight loss (g) of mangoes subjected to post-harvest wax treatments (C5 and C6) and controls after low temperature storage at 13.5 °C ± 2 °C for 1 week, 2 weeks, and 3 weeks

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Weight Loss (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1 week</td>
</tr>
<tr>
<td>Control (untreated)</td>
<td>11.80 ± 0.91a</td>
</tr>
<tr>
<td>Wax C5</td>
<td>10.72 ± 0.88a</td>
</tr>
<tr>
<td>Wax C6</td>
<td>9.76 ± 0.82a</td>
</tr>
</tbody>
</table>

Note: The data shown are mean ± standard deviation of 15 fruits each. Statistically significant values (p < .05) within columns are designated by different letters
Extending storage life of mango (Mangifera indica L.) using a new edible wax formulation incorporated with hexanal and cinnamon bark oil; M. M. N. P. Gunesekara et al.

Table 4: Variation in fruit pH of mangoes subjected to post-harvest wax treatments (C5 and C6) and controls after low temperature storage at 13.5 °C ± 2 °C for 1 week, 2 weeks, and 3 weeks

<table>
<thead>
<tr>
<th>Treatment</th>
<th>pH</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1 week</td>
</tr>
<tr>
<td>Control (untreated)</td>
<td>3.67 ± 0.03a</td>
</tr>
<tr>
<td>Wax C5</td>
<td>3.22 ± 0.29a</td>
</tr>
<tr>
<td>Wax C6</td>
<td>3.47 ± 0.14a</td>
</tr>
</tbody>
</table>

Note: The data shown are mean ± standard error of 5 composite samples each. Statistically significant values (p < .05) within columns are designated by different letters

Table 5: Variation in total soluble solids (°Brix) of mangoes subjected to post-harvest wax treatments (C5 and C6) and the controls after low temperature storage at 13.5 °C ± 2 °C for 1 week, 2 weeks, and 3 weeks

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Total soluble solids (°Brix)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1 week</td>
</tr>
<tr>
<td>Control (untreated)</td>
<td>15.33 ± 0.88a</td>
</tr>
<tr>
<td>Wax C5</td>
<td>11.00 ± 0.58b</td>
</tr>
<tr>
<td>Wax C6</td>
<td>12.66 ± 0.88ab</td>
</tr>
</tbody>
</table>

Note: The data shown are mean ± standard deviation of 5 composite samples each. Statistically significant values (p < .05) within columns are designated by different letters

Table 6: Variation in titratable acidity (as % citric acid) in mangoes subjected to post-harvest wax treatments (C5 and C6) and controls after low temperature storage at 13.5 °C ± 2 °C for 1 week, 2 weeks, and 3 weeks

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Titrable Acidity (as % citric acid)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1 week</td>
</tr>
<tr>
<td>Control (untreated)</td>
<td>0.17 ± 0.01a</td>
</tr>
<tr>
<td>Wax C5</td>
<td>0.61 ± 0.01b</td>
</tr>
<tr>
<td>Wax C6</td>
<td>0.31 ± 0.00a</td>
</tr>
</tbody>
</table>

Note: The data shown are mean ± standard deviation of 5 composite samples each. Statistically significant values (p < .05) within columns are designated by different letters

Table 7: Variation in sugar content (sucrose, fructose, and glucose; g/100 g fresh weight) of mangoes subjected to post-harvest wax treatments (C5 and C6) and controls after low temperature storage at 13.5 °C ± 2 °C for 1 week, 2 weeks, and 3 weeks

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Sugar content (g/100g fresh weight)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1 week</td>
</tr>
<tr>
<td>Sucrose Control (untreated)</td>
<td>6.62 ± 0.89a</td>
</tr>
<tr>
<td>C5 wax</td>
<td>5.83 ± 0.15a</td>
</tr>
<tr>
<td>C6 wax</td>
<td>5.45 ± 0.19a</td>
</tr>
<tr>
<td>Fructose Control (untreated)</td>
<td>1.28 ± 0.03a</td>
</tr>
<tr>
<td>C5 wax</td>
<td>1.60 ± 0.01b</td>
</tr>
<tr>
<td>C6 wax</td>
<td>1.40 ± 0.07b</td>
</tr>
<tr>
<td>Glucose Control (untreated)</td>
<td>1.23 ± 0.04b</td>
</tr>
<tr>
<td>C5 wax</td>
<td>1.01 ± 0.05a</td>
</tr>
<tr>
<td>C6 wax</td>
<td>1.06 ± 0.08a</td>
</tr>
</tbody>
</table>

Note: The data shown are mean ± standard deviation of 5 composite samples each. Statistically significant values (p < .05) within columns are designated by different letters
Internal gas analyses

The internal CO₂ levels of the C5 and C6 wax-treated fruits were observed to be higher compared to control fruits (Figure 4). This may be attributed to the semi-permeable coating formed around the fruits.

Table 8: Variation in citric and malic acid content (mg/100 g fresh weight) of mangoes subjected to post harvest wax treatments (C5 and C6) and controls after low temperature storage at 13.5 °C ± 2 °C for 1 week, 2 weeks, and 3 weeks

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Organic acid content (mg/100g fresh weight)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1 week</td>
</tr>
<tr>
<td>Citric acid (untreated)</td>
<td>480.79 ± 14.82&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>C5 wax</td>
<td>643.36 ± 20.28&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>C6 wax</td>
<td>557.30 ± 7.36&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Malic acid (untreated)</td>
<td>54.14 ± 1.53&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>C5 wax</td>
<td>43.14 ± 0.01&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>C6 wax</td>
<td>50.93 ± 1.48&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

Note: The data shown are mean ± standard deviation of 5 composite samples each. Statistically significant values (<p> < .05) within columns are designated by different letters.

Figure 4: The internal gas composition (as percentage CO₂) of mangoes subjected to the post-harvest wax treatments (C5 and C6) and the controls after low temperature storage at 13.5 °C ± 2 °C for 21 days.
Extending storage life of mango (*Mangifera indica* L.) using a new edible wax formulation incorporated with hexanal and cinnamon bark oil; M. M. N. P. Gunasekara et al.

**Headspace analysis of volatile compounds**

The levels of ethyl hexanoate, β-ocimene did not change with respect to treatment or storage time, the level of ethyl octanoate was observed to be markedly higher in the control fruits after two and three weeks, respectively (Figure 5).

**Disease incidence and marketability**

The percentages marketability of fruits treated with wax C6 and C5 and the control after 14 days storage at low temperature were 96% and 90%, and 93% respectively, indicating a higher disease resistance capacity in wax C6. After 21 days of low temperature storage, the percentages of marketability for C5 and C6 were lower (63% and 66%, respectively). This was, however, still higher than the 40% marketable fruits observed in the untreated controls after low temperature storage at 13.5 °C ± 2 °C (Figure 6).

![Figure 5: The SPME-headspace analysis of selected volatile compounds of mango subjected to the post-harvest wax treatments (C5 and C6) and controls after low temperature storage at 13.5 °C ± 2 °C for 3 weeks. [A, ethyleoctanoate. B, β-ocimeme. C, ethyl hexanoate].](image-url)
Extending storage life of mango (*Mangifera indica* L.) using a new edible wax formulation incorporated with hexanal and cinnamon bark oil; M. M. N. P. Gunesekara et al.

![Figure 6: Percentage marketability of mangoes subjected to post-harvest wax treatments (C5 and C6) and the controls after low temperature storage at 13.5 °C ± 2 °C after 1 week, 2 weeks, and 3 weeks.](image)

**Sensory analysis**

Sensory analysis of mango fruits subjected to the two wax formulations or control treatment and stored at low temperature for 21 days revealed that control fruits had the highest ratings for appearance, aroma, taste, and overall acceptability. As both treatments were evaluated on the same day, this indicates that ripening was delayed in the wax treated fruits. However, no undesirable sensory attributes were perceived in wax treated fruits.

**Discussion**

Particle size distribution indicates similarity in stability, ease of application and appealing cosmetic appearances of the final wax coating. In order to get the maximum advantage of edible coatings, the coatings should adhere to the fruit surface. However, adhesions of most hydrophilic edible coatings on the hydrophobic whole fruit surfaces are inherently poor due to the differences in the chemical nature of the two surfaces (Lin and Zhao 2007). In addition, non-uniform or sticky surfaces may result, making the product unattractive to consumers (Zhao and McDaniel 2005). According to previous studies, surfactants added to the coating formulations have improved the wettability and surface adhesion of the coating (Choi et al. 2002; Lin and Krochta 2005).

This study attempted to evaluate the application of modified wax coatings with natural anti-senescent and antimicrobial compounds on the keeping quality of mangoes. Although the cosmetic appearance, physicochemical parameters, and sensory characters can be positively affected in wax-coated fruits, further improvements in effective delivery of these bioactive compounds onto the fruit could potentially enhance the functionality of wax treatments. Significant changes in treated fruits compared to controls was not evident due to the natural diversity of individual fruits and complexity of the fruit ripening process, which involves several biochemical processes.
Extending storage life of mango (Mangifera indica L.) using a new edible wax formulation incorporated with hexanal and cinnamon bark oil; M. M. N. P. Gunesekara et al.

including the breakdown of cell walls and pectin, degradation of membranes, the breakdown of stored carbohydrates into sugars, a reduction in acidity, and an increase of biosynthesis in colour and volatile aroma compounds (Cheema et al. 2014).

Sensory data confirmed that wax C5 and C6 retarded the rate of ripening compared to the control fruits during the study period. Sensory data also revealed no off-flavour development after storage when mangoes were coated with either of the two biowax formulations. Hence, these two edible coatings show potential for meeting the challenges associated with minimizing loss while maintaining stable quality and market safety during low temperature storage.

The coatings allow CO₂ exchange through the partially covered stomata, so that fruits maintained an acceptable flavour and did not succumb to anaerobic respiration as a consequence of high levels of CO₂ accumulation within the fruit. This microclimate or modified atmosphere condition created by the wax combined with the antimicrobial compounds helps increase the shelf life of fruit. The gas-barrier function could in turn retard the enzymatic oxidation and protect the fresh produce from browning (i.e. discolouration) and texture softening during storage (Lin and Zhao 2007). Development of undesirable sensory properties on coated fruits is one potential adverse effect of the use of edible coating. Off-flavours could occur due to the existing flavour of coating materials or as the result of anaerobic respiration from excess inhibition of O₂ and too low a rate of CO₂ exchange. Therefore, it is necessary to consider these important sensory attributes when developing an edible coating for fresh and minimally processed produce (Zhao and McDaniel 2005).

It is reported that the aroma profile could change dramatically during the post-harvest life of fresh produce, particularly in climacteric fruits in which the dominant volatile may vary significantly based on the maturity of the fruit (Lin and Zhao 2007). The increase in levels of ethyl octanoate and other esters towards the later stage of ripening in this study are consistent with the previous studies reported (Lalel et al. 2003). Elevated levels of ethyl octanoate in control fruits compared to treatments C5 and C6 during the storage period of three weeks could potentially be used as a marker compound to identify the level of ripening in future studies.

**Conclusion**

The present study is an attempt to determine the effectiveness of the post-harvest application of waxes containing hexanal and cinnamon bark oil as active ingredients against senescence and microbial infection, and for maintaining quality parameters of Karuthakolumbaan mangoes during low temperature storage. Both waxes showed improved physico-chemical, and marketability attributes in the mangoes with no development of off flavours, compared to the untreated control fruits. Effective concentration of hexanal and cinnamon bark oil in the wax emulsion could be a key consideration in the future development of edible waxes.

**Acknowledgement**

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Extending storage life of mango (*Mangifera indica* L.) using a new edible wax formulation incorporated with hexanal and cinnamon bark oil; M. M. N. P. Gunasekara et al.


The effects of hexanal incorporated composite material (HICM) made of banana fibre and polymers on extending the storage life of mango fruit (*Mangifera indica* L. var TEJC) in Sri Lanka

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Maintaining the quality of perishable commodities during storage and transportation remains a challenge to the fruit and vegetable industry in many countries. In order to minimize post-harvest loss, a hexanal incorporated composite material (HICM) was created using hexanal, banana fibre, polymeric materials, and biopolymers. Efficacy of the HICM was tested on mango variety TEJC. Trials were conducted over two consecutive fruit seasons in 2016 and 2017. Six fruits were packed in corrugated cardboard cartons and eight cartons per treatment (with and without HICM) were stored at 13.5°C ± 2 °C and 92% relative humidity. Quality observations for each treatment were recorded at 7-day intervals for 28 days. Higher retention of fruit firmness and marketability were observed in fruits packed with the HICM with 50% of the fruit marketable after 21 days storage at 13.5 °C ± 2 °C (p <.05). Control fruits were not marketable at 21 days. Qualitative headspace gas chromatography molecular spectroscopy (GCMS) analyses were executed to determine the stability of released hexanal and the fate of hexanal when absorbed into fruit. Hexyl esters and hexanoate esters were observed in the headspace of HICM-treated fruits. Results from this study indicate that HICM treatment could be used along with low temperature storage to promote the marketability of TEJC mangoes.

Keywords: Mango storage, hexanal, polymer composite, banana fibre, fruit firmness, post-harvest loss, Sri Lanka

Mango (*Mangifera indica* L.) is among the five most widely grown fruits in the world. It is a popular fruit in many tropical countries with increasing availability and growing markets in developed nations. However, meeting the quality requirements of these new, lucrative markets poses many challenges. Post-harvest losses of mangoes continue to be high in most producing countries, particularly during storage and transportation.

Ripening plays an important role in the development and expression of mango characteristics such as colour and flavour. In mangoes and other climacteric fruits, ripening is initiated by the release of required (i.e. threshold) levels of ethylene, the hormone that triggers the natural ripening process (Burg and Burg 1962). Ripening results in fruit softening caused by cell wall and plasma membrane deterioration. Soft, ripe fruits are more susceptible to diseases and physical injury when passing through the supply chain.

Mature mango fruits are harvested just before initiation of natural ripening and at the firm-to-touch stage in order to minimize loss during storage and transportation. Fruit firmness is maintained at this stage of maturity when fruits are held at suitably low temperatures. Ethylene-inhibiting compounds, such as 1-methylcyclopropene (1-MCP), aminoethoxyvinylglycine (AVG), and abscissic acid, are also known to inhibit
The effects of hexanal incorporated composite material (HICM) made of banana fibre and polymers on extending the storage life of mango fruit (Mangifera indica L. var TEJC) in Sri Lanka; D.S. Samarawickrama et al.

ethylene synthesis and can be used to delay ripening of fruits (Zarah et al. 2013; Yuan and Li 2008). The compound 1-MCP has been registered for commercial use in several countries for climacteric and some non-climacteric commodities. However, it is a competitive gaseous ethylene inhibitor that binds irreversibly to ethylene receptors present in plant tissue (Blankenship and Dole 2003). It has been used to regulate tissue response to ethylene by blocking ethylene receptors in different fruits by varying application parameters such as concentration, time, and temperature (De Ell et al. 2001; Gong et al. 2002).

Phospholipase D activity is an autocatalytic reaction that takes place during the process of fruit ripening and senescence, and results in the destabilization of plant tissue (Tiwari and Paliyath 2011). Membrane degradation can be prevented by inhibiting the action of phospholipase D (PLD), present in the membranes of plant tissue, and the key enzyme involved in the process (Cheema et al. 2014). Hexanal has been used as a PLD inhibitor and both pre- and post-harvest applications have been shown to inhibit ripening in some commodities (Cheema et al. 2014; Tiwari and Paliyath 2011; Sharma et al. 2010).

Hexanal has also been observed to show anti-fungal properties. For instance, exposure of apple slices to hexanal vapour (4.1 µL/L for 48 hours) was reported to inhibit growth of pathogenic fungi by 50% (Song et al. 1996).

Hexanal occurs naturally in plants and is categorized as a generally recognized safe (GRAS) compound (Gunasekaran et al. 2015). It is recommended for use as a food grade additive as it is naturally produced through fatty acid degradation (Tiwari and Paliyath 2011; Sharma et al. 2010). Linoleic acid and linolenic acid are the biological precursors of hexanal and several enzymatic reactions are responsible for the generation of hexanal in biological systems (Gunasekaran et al. 2015).

Our study was initiated for the purpose of developing technology to facilitate the export of premium quality, Sri Lankan TEJC mangoes to distant markets. The retention of fruit firmness over extended storage periods plays an important role in preventing post-harvest loss. The technology developed is thus focused on maintaining firmness and quality of this perishable commodity during storage and transportation via the slow release of hexanal into the individual cartons carrying fruits.

Banana pseudo-stem fibre extracted from common banana varieties was utilized as the matrix for the HICM. Milani et al. (2016) have described banana fibres in detail. In light of their research and together with the fibres' porous structure, high cellulose content, and the possibility of its use as a substrate for absorption and the slow release of absorbed materials, banana fibre was determined to be a suitable ingredient for the composite material developed in our study and its effectiveness was tested against a control.

Materials and methods

Materials

Pseudo-stems of common banana varieties cultivated in Sri Lanka were used for fibre extraction (Milani et al. 2016). The mango variety TEJC harvested from Ellawala Horticultural Farm at Galkiriyagama, Dambulla, Sri Lanka, was used to test the efficacy of HICM. Hexanal (> 97% purity, Food Grade) and kappa-carrageenan were purchased from Sigma-Aldrich Inc., USA. Polyvinylpyrrolidone (M.W. approximately 44,000; product code P4405) was purchased from Superchem Products Ltd, Needham Market, Suffolk, England. Tapioca starch and polythene sheets were purchased from local, food-grade ingredient suppliers.
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**Methods**

**HICM preparation**

Banana pseudo-stems were collected from local plantations. Dried sheaths and debris were cleaned manually. Pseudo-stem sheaths were separated and fibre was extracted using a mechanical fibre extractor. Separated fibre was sun dried for 24 to 48 days, depending upon weather conditions. The extracted fibre was then cut into pieces of less than 2 mm in length using a mechanical cutter.

The HICM was prepared as single units. Each unit of HICM consisted of banana fibre (11.0%), polymeric material such as polyvinylpyrrolidone (3.0%), a biopolymer mixture including tapioca starch (15.5%) and kappa-carrageenan (5.0%). The remaining percentage of material was comprised of low-density polyethylene film (50.5%). Each HICM unit was prepared by mixing hexanal (15.0% of final weight) with biopolymers and coating this mixture onto the banana fibre with polyvinylpyrrolidone, followed by storage in a closed glass bottle for 24 hours. The mixture was then transferred to a polyethylene sleeve and sealed. Thereafter, each sealed sleeve was wrapped in aluminum foil and subjected to a hot press for one minute at 130°C.

**Headspace analysis**

Headspace studies were carried out to investigate the hexanal release pattern of the HICM and to investigate the role played by hexanal in extending the storage life of mango. The slow release pattern of hexanal from the HICM was observed via two repeated trials using the headspace gas chromatographic technique. Observations were recorded over 31 days.

Freshly prepared composite material (2 g) was transferred into a 610 mL airtight bottle. Headspace gas samples (0.5 mL) for the analyses were drawn manually from the bottle via the septum on the lid, at daily intervals. The peak area was determined by gas chromatography (Agilent 6890 series system) using a Supelcowax 10 (fused silica) capillary column (30 m x 0.25 mm x 0.2 µm). The peak position for hexanal was observed at 5.68 min. The analyzing temperature was 60°C. The concentration was calculated using the constructed calibration curve. Cumulative release of hexanal was determined using the following equation:

\[ X_n = 0.5 \left( \frac{X}{610} \right) \]

Where, \( X \) is the derived concentration of headspace hexanal in bottle at the \( n \)th time and \( X_n \) is the extracted concentration of hexanal at the \( n \)th time interval. The cumulative extracted concentration was determined and plotted against the time of analysis. The analysis was done at both room temperature (28°C ± 2°C) and at 13.5°C ± 2°C - the optimum temperature for extending storage life of TEJC mangoes. Chilling injury in TEJC mango is observed below 11°C (authors unpublished data).

Headspace gas chromatography/mass spectrometry (GCMS) analysis was carried out for the qualitative detection of the headspace constituents of HICM, the respective converted products of the hexanal throughout the storage time, and the aromatic volatiles created by the HICM-treated fruits. The gas samples drawn from the headspace were injected into a Thermo Scientific Trace 1300 series gas chromatograph coupled with an ISQ QD single quadruple mass spectrometer. A Thermo Scientific fused silica capillary column (Supelcowax: 30 m x 0.25 mm x 0.2 µm) was used for the analysis. Mass spectrometry was carried out with an ion capture detector operating in electronic impact mode with impact energy of 70 eV, a scan interval of 0.50 fragments, and fragments detected in the range of 50 Da to 450 Da. The headspace aromatic compounds were identified through the mass spectrum with spectra from the equipment database (NIST11). Analyses were done at room temperature (28°C ± 2°C).
In-vivo fruit testing

The aluminum foil cover enclosing the HICM was opened immediately before use and pasted inside the lid of individual, corrugated cardboard cartons after fruits were packed, and just prior to taping the cartons for storage. Six randomly selected mango fruits harvested at the mature green stage were placed in each carton (approximately 3.5 kg of fruit per carton) prior to low temperature storage at 13.5°C ± 2°C and 90% relative humidity. The trial consisted of TEJC mango fruits packed in cartons with the HICM, and control fruits packed in cartons without HICM. There were eight replicate cartons per treatment. Trials were repeated over two consecutive seasons to test the reproducibility of results. Two randomly selected cartons containing 12 TEJC mangoes per treatment were analysed at 7-day intervals over a period of 28 days. Fruit firmness, flesh firmness, total soluble solid content (°Brix), acidity (expressed as % citric acid), pH, and overall cosmetic appearance for marketability were recorded.

Fruit and flesh firmness of mangoes were measured using a Guss Fruit Texture Analyser (GS-25) by compression to a depth of 5 mm and expressed in kilograms. Total soluble solid content was determined in juice obtained from mango fruits at room temperature using a hand-held prism refractometer (Kruss, 0-30, Germany). To determine the acidity, mango flesh (10 g) was blended with distilled water (40 mL) using a domestic blender (Summit, India), and the extract was filtered and titrated against 0.1 N NaOH using phenolphthalein as an indicator. Acidity was calculated as the equivalent fresh weight of mango fruit and expressed as per cent citric acid. The pH of extract was measured at room temperature by a pH metre (Hatch, Loveland, USA). Marketability of TEJC mango fruits was determined by visual examination of fruits in accordance with an index (developed by the Postharvest Technology Laboratory, ITI, Sri Lanka) from 1 to 10 where 1 is “marketable” and 10 is “not marketable.” Percentage marketability was expressed as the number of marketable fruits as a percentage of total fruits for each treatment.

Statistical analysis

The experiment was conducted as a Completely Randomized Design (CRD) with eight replicate boxes per treatment and the trial was repeated in two consecutive fruit seasons. The experimental means for physico-chemical parameters were analysed via Student’s t-test at a p<0.05 significance level using SPSS statistical software (version 13).

Results

The hexanal release pattern of HICM is presented in Figure 1. Hexanal release was observed to take place at a rapid rate during the first 200 hours and slow down thereafter as seen in Figure 1. The pattern of release of hexanal vapour was the same at both 13.5°C ± 2°C and at an ambient temperature of 28.0°C ± 2°C. Cumulative release of hexanal vapour did not reach a plateau for up to 744 hours).

Similar results were obtained in both seasons—January 2016 and July 2017—with respect to variation in fruit firmness, total soluble solid content, pH and acidity (% citric acid) in the HICM treated and the untreated controls during storage at 13.5°C ± 2°C, over 7, 14, and 21 days. The means of the above fruit quality parameters recorded during the second season (July 2016) are summarized and presented in Table 1.

The percentage marketable fruits in the untreated controls and those in the HICM treatment are presented in Figure 2. Both HICM treated and the untreated controls remained in good condition at 13.5°C ±2°C during the first two weeks. However at 21 day, due to the emergence of disease symptoms associated with the anthracnose and stem end rot pathogens, only 50% of HICM treated fruits were of marketable quality whereas all control fruits were not in marketable condition.
Figure 1: Cumulative release pattern over time of hexanal from hexanal incorporated composite (HICM) Material during storage at room temperature (28°C ± 2°C) and at cold temperature (13°C ± 2°C).

Table 1: Fruit quality parameters of TEJC mangoes in relation to hexanal incorporated composite (HICM) and control treatments after cold storage at 13.5°C ± 2°C

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Storage period (days)</th>
<th>Control</th>
<th>HICM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fruit firmness (kg)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>5.48 ± 0.61</td>
<td>6.62 ± 0.05</td>
</tr>
<tr>
<td></td>
<td>14</td>
<td>3.00 ± 0.16</td>
<td>3.80 ± 0.11</td>
</tr>
<tr>
<td></td>
<td>21</td>
<td>-</td>
<td>1.62 ± 0.32</td>
</tr>
<tr>
<td>Total soluble solids content (°Brix)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>15.75 ± 0.25</td>
<td>15.50 ± 0.29</td>
</tr>
<tr>
<td></td>
<td>14</td>
<td>16.75 ± 0.25</td>
<td>16.75 ± 1.31</td>
</tr>
<tr>
<td></td>
<td>21</td>
<td>-</td>
<td>15.50 ± 0.64</td>
</tr>
<tr>
<td>pH</td>
<td>7</td>
<td>4.07 ± 0.05</td>
<td>3.93 ± 0.02</td>
</tr>
<tr>
<td></td>
<td>14</td>
<td>4.88 ± 0.06</td>
<td>4.82 ± 0.06</td>
</tr>
<tr>
<td></td>
<td>21</td>
<td>-</td>
<td>5.27 ± 0.07</td>
</tr>
<tr>
<td>Acidity (% citric acid)</td>
<td>7</td>
<td>0.81 ± 0.02</td>
<td>0.83 ± 0.03</td>
</tr>
<tr>
<td></td>
<td>14</td>
<td>0.36 ± 0.02</td>
<td>0.37 ± 0.01</td>
</tr>
<tr>
<td></td>
<td>21</td>
<td>-</td>
<td>0.22 ± 0.02</td>
</tr>
</tbody>
</table>

Note: Control fruits were not in marketable condition at day 21 and thereafter. Data presented as mean ± standard deviation. Statistical significance (*) defined as p < .05 was determined by t-tests
The effects of hexanal incorporated composite material (HICM) made of banana fibre and polymers on extending the storage life of mango fruit (Mangifera indica L. var TEJC) in Sri Lanka; D.S. Samarawickrama et al.

Figure 2: Percentage difference in marketability of TEJC mangoes in relation to treatments (HICM and control) over 28 days of cold storage (13°C ± 2°C) with significant difference observed after 21 days (p=0.05).

Discussion

TEJC mango fruits were developed as an export-oriented mango variety in Sri Lanka. The variety is in high demand due to its inherent good taste, cosmetic appearance, and high flesh content. Shelf life extension of the said variety provides the opportunity to ship them by sea to lucrative overseas markets with economic benefit to Sri Lanka. Therefore, the HICM was developed to achieve the slow release of hexanal vapour into the fruit pack to extend the storage shelf life of TEJC mango fruits.

The HICM released hexanal at a rapid rate during the first 200 hours but was observed to slow down thereafter (Figure 1). The releasing pattern of hexanal vapour was the same at 13.5°C ± 2°C and 28.0°C ± 2°C. The in vivo HICM treatment trials with mango fruits were conducted over 28 days. The cumulative release of hexanal vapour in the closed environment in vitro studies did not reach a plateau up to 744 hours (day 31), indicating the possibility of using the active composite material (HICM) during storage for a period of 31 days. This would make it particularly useful for the export of mango.

Hexanal is a reactive aliphatic aldehyde and has high oxidizing potential on exposure to air. Our qualitative headspace GCMS study of HICM indicated that hexanal is oxidized into hexanoic acid and 2-butyl, 2-octenal—a crotonated product of hexanal—at day 7 at room temperature (28°C ± 2°C). According to our qualitative headspace GCMS study on aroma volatiles, β-ocimene, α-pinene, ethyl butanoate, and caryophyllene were observed as prominent aroma compounds for the TEJC variety. Hexyl esters and hexanoate esters, such as hexyl acetates, hexyl butanoate, and hexyl hexanoate, were also found in our qualitative GCMS headspace analysis of HICM-treated fruits. These hexyl esters and hexanoic esters were released into the headspace on absorption of hexanal by the
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Variation in fruit quality parameters in relation to treatments and the storage duration (7, 14, and 21 days) at 13.5°C ± 2°C is summarized in Table 1. Reduction of fruit firmness and fruit softening are natural phenomena associated with ripening and are the result of degradation of the cell wall architecture (Tiwari and Paliyath 2011). Determination of the extent of softening of stored fruits through firmness methodologies is practiced as a predictive measure of post-harvest condition. Firm fruits are less susceptible to bruising. Reduction of losses due to damage during post-harvest operations and retention of fruit firmness through Phospholipase D inhibition have been reported previously (Sharma et al. 2010; Valero et al. 2007). Decrease in firmness is a common phenomenon observed during storage of fruits and is due to weakness of cells below the outer skin of fruits (Sirisomboon and Lapchareonsuk 2012). The current study revealed that controlled release of hexanal vapour results in a significantly higher (p=0.05) fruit flesh firmness at day 7 (Table 1). Firmness has an impact on fruit quality as excessive degradation of polymeric components present in the cell wall results in loss of fruit quality (Sharma et al. 2010). Retention of fruit firmness helps to reduce post-harvest loss as well as reduce the incidence of disease due to fungal invasion through the weakened fruit skin. After absorption, hexanal is not accumulated in fruit tissue, but is further converted to hexanol which is metabolized during the respiratory cycle (Cheema et al. 2014). Unlike the ripening inhibitor, 1-methylcyclopropene (1-MCP), which down-regulates several genes involved in cell wall degradation and does not have significant effect on maintaining cell wall rigidity and firmness, hexanal treatment preserves the firmness of fruits without the heavy involvement of down-regulating genes related to cell wall degradation (Tiwari and Paliyath 2011).

Our study revealed that pH was low at day 7 of low temperature storage in fruits exposed to the HICM treatment compared to controls. Hexanal vapour released by the composite material had no effect on the total soluble solids content and per cent acidity of the fruits, and enabled the normal development of these characters during the ripening process. Our study indicates that HICM treatment has the potential to maintain the marketability of mangoes for more than 21 days, while 100% of the control fruits deteriorated at 13.5°C ± 2°C with symptoms of senescence and disease after 21 days of storage.

Conclusion

While all control TEJC mangos in this study were not of marketable quality after prolonged storage, 50% of the HICM treated fruits remained marketable even after 21 days when stored at 13.5 °C ± 2 °C. Incorporation of an effective slow release volatile antifungal agent into the current HICM formulation is necessary to reduce incidence of disease and extending the storage period of these fruits at commercially acceptable levels of loss for 21 to 28 days. Sri Lanka’s TEJC mangoes have a rich, exotic flavour and an attractive appearance and are well suited for both domestic and lucrative, distant export markets. The slow release of hexanal by the HICM at room and cold storage temperatures as observed in this study indicates the potential
The effects of hexanal incorporated composite material (HICM) made of banana fibre and polymers on extending the storage life of mango fruit (Mangifera indica L. var TEJC) in Sri Lanka; D.S. Samarawickrama et al.

for further adaptation of this product for commercial use in the shipment of mangoes to distant destinations. Further, the utilization of banana pseudo-stem fibre as an ingredient provides the opportunity for exploiting a hitherto underutilized agricultural waste product, which would otherwise act as a breeding ground for pathogens and pests in banana orchards, and contribute to the emission of greenhouse gases when it is burned.

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Women’s prospects to adopt enhanced freshness formulation (EFF) technologies for banana in Morogoro rural district, Tanzania

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This paper draws lessons from a study based on forecasts rather than actual results. The study was conducted to identify factors that could potentially affect women’s decisions to adopt enhanced freshness formulation (EFF) technologies among banana growers in Morogoro, Tanzania. The study tested whether men and women were equally likely to adopt EFF technologies. The authors also explored whether women who are willing and able to influence adoption decisions and women who are willing but unable to influence adoption decisions face similar adoption challenges. The results from logit model suggest that the adoption prospect is lower among female adopters than male adopters (p < .05). The study predicted a higher probability of female growers to be willing and able to influence adoption decisions among younger female growers compared to those over 35 years old (p < .1) although the overall impact on the adoption rate was low, owing to limited participation of young farmers (11 %) in banana production. The findings reveal less willingness and ability to adopt the technologies among female growers who perceived EFF applications as labour-insensitive technologies (p < .05). Likewise, the study identified higher willingness and ability to influence the adoption among growers whose bananas were not about to be harvested (p < .05). The authors recommend continued efforts to address a priori challenges that can potentially undermine adoption with easy-to-use preparation and application methods, and by targeting growers whose fruits are at early stages of maturation. Future studies could focus on the potential impacts of specific types of EFF technologies on the adoption prospect.

Keywords: Women, technology adoption, enhanced freshness formulation technologies, EFF technologies, shelf life, post-harvest loss, banana, fruit, Morogoro, Tanzania

Gender-based differences in the adoption of new technologies have long been recognized in farming communities. While there are varied and context-specific reasons for such differences, there is evidence that female farmers tend to adopt new agricultural technologies at a lower rate than male farmers (Doss 2001; Tiruneh et al. 2001; Bourdillon et al. 2002; Phiri et al. 2004; Kakooza et al. 2005; Jagger and Pender 2006; Thapa 2009; World Bank and IFPRI 2010; Peterman, Behrman, and Quisumbing 2010; FAO 2011). Consequently, there has been a growing interest to identify means to enhance the adoption of agricultural technology innovations amongst both male and female smallholder farmers. This interest has motivated the development of specific guidelines and user-tailored toolkits, such as a toolkit for gender-sensitive work in value chains (Farnworth 2011), that are used for streamlining gender-specific issues in agricultural development initiatives. These guidelines and toolkits are important references to guide current and future agricultural interventions but are based on specific case studies, experiences, and lessons that may not apply to all types of technologies and circumstances of potential adopters. To overcome gender-based barriers to technology adoption effectively, there is need for context-specific studies that examine how the adoption decisions are made and identify factors underlying the decision-making process.

Enhanced freshness formulation technologies are applications of nanotechnology that involve treating fruits with a natural compound – hexanal – that tends to slow down ripening and retain the freshness and nutrients of the fruits for a longer time. Such technologies are
considered vital for enhancing fruit quality and prolonging shelf life. These twin benefits can allow farmers to sell fruits in niche and high value markets and reduce post-harvest losses that are estimated to be as high as 30% (Paliyath et al. 2009; Hailu, Workneh, and Belew 2014). These changes in quality and shelf life may also allow farmers to make more money from prolonged sales of fruits. Trials in Sri Lanka and India have shown the potential of EFF technologies in reducing post-harvest losses by extending the shelf life up to 21 days for mangoes and banana (Paliyath et al. 2009). It may be very beneficial for fruit growers in Tanzania to adopt EFF technologies. Technologies that prolong shelf life (i.e., quality-related benefits) will not only enhance the marketability of fruits but also likely provide economic gains for growers and other actors in the industry.

There is global evidence of the efficacy of the use of EFF technologies in addressing post-harvest freshness problems for apples, bananas, mangoes, and strawberries (Paliyath et al. 2009; De Kock and Taylor 2012). However, the full potential of EFF technologies to help the poor and support sustainable growth cannot be realized in Tanzania if the rate of adoption is lower for some groups of fruit growers than others. An understanding of gender dynamics in the adoption of these technologies is crucial for the discovery of complementary measures that can be adopted to improve package designs and to improve implementation strategies to ensure the desired development outcomes and impacts.

Adoption of enhanced freshness formulation technologies in Tanzania

The EFF technologies are currently being introduced in Tanzania for direct evaluation at farm level. It is likely that some of these technologies will be recommended for extension to growers of fruits such as bananas, mangoes, and oranges. However, no study has so far assessed the adoption prospect of these technologies from a gender perspective although gender differences tend to have different effects on men’s and women’s adoption of agricultural technologies (Doss and Morris 2001; Ogunlela and Mukhtar 2009; FAO 2011; Ndiritu, Kassie, and Shiferaw 2014). This understanding is important for promoters of these technologies to foresee real adoption challenges and identify a priori effective means for overcoming the challenges.

The existing literature reveals that women might be disadvantaged when making rapid adoption decisions where the technologies require specific knowledge and skills, because African women have relatively lower levels of education than men and may require longer time to learn about the technologies before they decide to adopt (Doss and Morris 2001; FAO 2011; Ndiritu, Kassie, and Shiferaw 2014). Also, experience has shown that efforts to mechanize agricultural operations tend to overlook women’s needs and constraints (Carr and Hartl 2010; Ndiritu, Kassie, and Shiferaw 2014). These oversights normally lead to the generation of technologies that do not address women’s concerns, thereby precluding their participation in the adoption process and eventual adoption. In the past, promoters of new technologies often did not account for these potential (i.e., gender) differences during the design and promotion phase.

Overall, what matters for potential adopters of the EFF technologies in Tanzania, is whether they perceive the technologies to be relevant. In typical farming communities, farmers encountering unique problems may decide against adopting the technologies (Satyavathi, Bharadwaj, and Brahmanand 2010; Doss 2001). Understanding all, or at least many or most of these adoption challenges is crucial to informing a programme seeking to promote the adoption and commercialization of the technologies in Tanzania. This understanding is vital for ensuring that gender issues are considered in the design and promotion of agricultural interventions and research for development.
Decision to adopt agricultural technology

The actual adoption and use of any new agricultural technology is primarily determined by farmers’ decisions to adopt it. Historically, this decision appears to be biased along gender lines. The authors wish to establish whether men and women stand equal chances of adopting EFF technologies and under what circumstances.

The literature shows that there are differences in men’s and women’s decisions to adopt and use agricultural technologies. One of the fundamental differences is with respect to their risk attitude (FAO 2011) and access to knowledge, critical support services and agricultural assets; and men tend to have a competitive edge over women (Ndiritu, Kassie, and Shiferaw 2014). Moreover, women are more liable to perform both household chores and agricultural activities, which reduces their time available to learn about new technologies (Ogunlela and Mukhtar 2009; Meinzen-Dick et al. 2010; Satyavathi, Bharadwaj, and Brahmanand 2010). These factors can potentially limit women’s adoption of both labour- and capital-intensive agricultural technologies (Satyavathi, Bharadwaj, and Brahmanand 2010; Doss 2001). The differential impacts of these factors on men’s and women’s decisions to adopt and use agricultural technologies have been widely studied and are well documented. Much is based on the assumption that members of households pool resources and make joint decisions (Ndiritu, Kassie, and Shiferaw 2014). However, men and women are expected to make different decisions owing to power imbalances and inequalities that exist within households and between men and women (FAO 2011; World Bank and IFPRI 2010). The belief that households pool resources and make joint decisions could tempt researchers to target heads of households as interviewees during surveys (FAO 2011; World Bank and IFPRI 2010) leading to biased information, because women’s opinions may not be adequately captured. Thus, new ways are needed to account for both men’s and women’s decision-making at the household level. The potential bias could be reduced through solicitation of detailed information that describes power dynamics and pinpoints factors that can make some family members more likely to adopt new technologies than others.

In view of this focus, leadership and decision-making within a household should be treated as separate aspects of data collection and analysis because the head of a household may not necessarily be the main decision maker. This separation allows for examination of the decision-making processes in both female- and male-headed households and is the approach that the authors adopted to examine whether men and women are equally likely to adopt EFF technologies and to identify specific factors underlying the adoption prospect among female adopters. Studies that have solely assessed differences in the adoption of agricultural technologies among female adopters have been rare.

Technology adoption theory

The adoption of EFF technologies is likely to follow the theory of five stages of technology adoption (Yoh et al. 2003; Rogers et al. 2005). The theory suggests that awareness creation is the first stage of technology adoption. However, men and women in the same household are likely to be differentially aware as they are likely to be linked to different social networks (Gotschi, Njuki and Delve 2008; FAO 2011; Kassie et al. 2013; Di Falco and Bulte 2011; Pandolfelli, Meinzen-Dick and Dohrn 2008; Doss et al. 2003). Consequently, their perceptions of the cost and benefits associated with the adoption and use of new agricultural technologies are likely to be different.

Men’s and women’s desires to adopt agricultural technologies are likely to be
influenced by several factors including differences in access to and control over resources such as land, other assets, and financial resources (Bryant and Pini 2006; Doss and Morris 2001; Doss 2002); and socio-economic characteristics and other household-specific dynamics such as power relations and social and family obligations (Haque et al. 2010; FAO 2011). The roles and responsibilities they assume in farming and at the household level have important ramifications for their decisions to adopt agricultural technologies. In households where men are more powerful than women, the ability of female members to influence decisions is normally restricted. Moreover, if women are liable to perform both family and agricultural activities, they are less likely to have time to learn about new technologies. Consequently, they will be less informed about the technologies and disadvantaged in the adoption of the technologies (Doss 2001).

Preferences for crops have also been reported to affect the adoption of agricultural technologies. In many agrarian communities in Africa, women tend to disassociate themselves from decisions that lead to adoption of technologies that will affect the production of cash crops alone. In these communities, cash crops are perceived to be men’s crops. Women are instead interested in crops that ensure steady supplies of food for family members and in the shelf life of these crops (Badstue 2006; Bellon et al. 2003).

Overall, there are several factors that can potentially affect men’s and women’s decisions differently. The EFF technologies are relatively complex technologies and new to potential adopters in Tanzania. In view of the fundamental differences in men’s and women’s decision-making approaches, it is reasonable to expect that there will be some differences in their preferences to adopt the technologies. It is important to assess the factors hypothesized to influence the adoption of agricultural technologies in the study area.

Conceptual framework of the study

The authors perceive the decision to adopt agricultural technologies to be an inherently complex process that is primarily under the influence of social and cultural factors that define norms and affect men and women differently (van Eerdewijk and Danielsen 2015). When the norms subject women to more social obligations such as farm and family caretaking, their burdens will be great with little time for accessing critical information on agricultural production and business development. In Tanzania, for example, social and cultural factors normally force women to allocate more time for farm and family obligations than men do (Meeker and Meekers 1997). This difference in men’s and women’s roles may indirectly undermine women’s access to agricultural support services as there could also be preferential targeting in favour of household heads who, in many African societies, are men. Moreover, the norms could also be against women’s independence and voicing of concerns. The combined effect of these cultural hindrances undermines women’s demand for, and their adoption of, agricultural technologies. If the norms also allow men to have better access to and greater control over resources than women, women will have limited ownership of resources and less control over the resources and income. The ultimate effect is to reduce women’s prospects of adopting the technologies as depicted in Figure 1. The severity of effects of norms that are against women’s independence and voicing of concerns is also likely to vary among women as they have different levels of exposure to resources, as well as knowledge of and skills in agricultural technologies.

The research conducted and hence this paper, hinges on the conceptual framework discussed under this section to statistically assess differences in the adoption prospects of EFF technologies between men and women, and among women. The paper focuses on
identifying factors that can potentially affect women’s decisions to adopt EFF technologies in Tanzania and it contributes to the adoption literature in three ways: In terms of analytical methods, it proposes a better way to analyse sex disaggregated data for technology adoption and diffusion. In terms of empirical evidence, it establishes whether men and women are equally likely to adopt the EFF technologies and it explores further, whether women who are willing and able to influence adoption decisions, face similar adoption challenges to those who are willing but unable to influence the decisions.

Figure 1: Gender perspective on effects of norms and other cultural factors on the adoption of technology.

*Note:* The above figure shows causes and effects of norms that tend to be against women’s voicing of concerns and ownership of resources, and that disproportionately subject women to more obligations. It portrays the conceptual framework adopted to assess differences in the adoption prospects of EFF technologies in study areas. Dashed arrows represent inhibitory or negative effects while solid arrows represent potentiating or positive effects.

*Source:* Adapted from van Eerdedwijk and Danielsen (2015).
Materials and methods

Frequencies and mean values which were computed using STATA (version 12) are some of the statistics used to describe farmers’ opinions about adopting the EFF technologies. The authors measured both farmers’ willingness to adopt and their perceived ability to influence the ultimate adoption decision. These and other variables that are presented in subsequent sections were collected during a survey that was conducted in banana growing areas using a pretested questionnaire. Farmer’s willingness to adopt EFF technologies was assessed through a binary response variable (coded one if a farmer was willing to adopt the technologies and zero, otherwise). The assessment was done after awareness creation with respect to cost of adoption and potential benefits of EFF technologies. Also respondents were asked whether they were the main decision makers, i.e., were able to influence decisions to adopt the EFF technologies. These two variables were then used to construct a surrogate variable that measured whether a particular respondent was willing to adopt the technologies and able to influence the adoption decisions when the technologies become available in the market. In subsequent sections, the term perception is used to mean farmers’ own assessment of technology adoption prospect and their perceived ability to influence such decisions.

A z-test that is similar to the single-group t-test, popularly known as the z-test for the difference between two proportions, was adopted to test whether there was no difference between men’s and women’s prospects of adopting EFF technologies in two banana growing areas within Morogoro region. The proportions are aggregate measures (point estimates) of men’s and women’s willingness to adopt the technologies and their ability to influence the adoption decisions. Thus, the application of this test is not based on the normality assumption because respondents that were willing to adopt the technologies but unable to influence the adoption decisions were not considered in this analysis. The null hypothesis assumed equal proportions of male and female adopters. The test statistic was computed as:

\[
 z = \frac{p - \pi}{\sqrt{\pi(1 - \pi)/n}} \tag{1}
\]

In equation (1), \( p \) is the proportion of women that was willing to adopt the technologies and able to influence the adoption decisions, \( \pi \) is the null hypothesis value signifying the expected proportion if there is no difference between the proportions of men and women with such attributes, and \( n \) is the sample size.

The study also tested whether there were differences between men’s and women’s perception of labour intensity of the EFF technologies. This analysis was motivated by the fact that there could be differences between men’s and women’s prospects of adopting EFF technologies attributable to their perception of the labour intensity of the technologies as it has already been established that Tanzanian women dislike technologies that increase their labour burden (Meeker and Meekers 1997). The test was performed using the Mann-Whitney U which is a non-parametric test used to determine if the independent groups (men vis-à-vis women) differ significantly from each other with respect to perception of labour intensity of the EFF technologies.

The test allows two groups or conditions or treatments to be compared without making the assumption that values are normally distributed. The test requires the samples to be
independent and random and the variables being compared to be measured as continuous units and the scale used to be at least ordinal. The logic behind this test is that when the samples differ, the distributions of the two populations will differ only with respect to the central location. If the sum of rankings from one sample differs enough from the sum of rankings from the other sample, the conclusion is that there is a difference in the population medians (Kasuya 2001). The test statistic is computed as:

\[
U_1 = n_1 n_2 + \frac{n_1 (n_1 + 1)}{2} - \sum R_1
\]

\[
U_2 = n_1 n_2 + \frac{n_2 (n_2 + 1)}{2} - \sum R_2
\]

where:

- \( n_1 \) and \( n_2 \) are the sample sizes for male men and women, respectively; and
- \( \sum R_1 \) and \( \sum R_2 \) = Sum of ranks for samples 1 and 2, respectively.

Moreover, the study also tested whether there was no difference in willingness and ability to adopt the technologies between female adopters on the basis of observable characteristics of adopters. The difference was tested using the conventional random utility model for binary choices (Ali and Abdulai 2010; Becerril and Abdulai 2010). The chosen model was fitted as a logit to associate the categories of female adopters (\( y \)) with specific, independent variables (\( x \)). The null hypothesis assumed no difference in willingness and ability to influence adoption decisions between female adopters. The analytical model was specified as:

\[
\text{Prob}(y = 1|x) = \Lambda(x\beta) = \frac{\exp(x\beta)}{1+\exp(x\beta)}
\]

\[\text{…………………... (3)}\]

In equation (3), \( \Lambda \) stands for the cumulative distribution function of the logistic distribution while \( x \) and \( \beta \) are vectors of independent variables and parameters to be estimated, respectively.

In the logit model the dependent variable is an indicator of whether a woman in a particular household was willing to adopt and able to influence the decision to adopt EFF technologies (Table 1). Independent variables included in the model were those identified in contemporary literature to influence farmers’ decisions to adopt agricultural technologies (Gabre-Madhin and Haggblade 2001; Ouma et al. 2002; Reardon, Stamatelis and Pingali 2007). Independent variables included both socio-economic characteristics of farmers along with those measuring farmers’ perceptions of the EFF technologies (Table 1).

Farmers’ perceptions of the labour intensity of the EFF technologies were believed to be important, particularly for female farmers. According to previous research, women tend to disassociate from decisions leading to the adoption of labour-intensive technologies as their workload is normally already heavy (Berti, Krasevec and FitzGerald 2004). Farmers’ ages were included as a measure of potential differences in risk attitudes and experiences. The literature reveals that when risk aversion predominates, older farmers might be less willing to adopt new technologies than younger farmers (Alexander and Van Mellor 2005).
Table 1: Factors influencing farmers’ decision-making for adopting EFF technologies

<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
<th>Expected sign</th>
</tr>
</thead>
<tbody>
<tr>
<td>( Y_i ) = Adopter category</td>
<td>Coded as 1 if the main decision maker was a woman and willing to adopt EFF technologies; 0 if she was willing to adopt the technologies but unable to influence adoption decision.</td>
<td></td>
</tr>
<tr>
<td>( X_1 ) = Age category</td>
<td>Coded as 1 if the age of the main decision maker was above 35 years; 0 otherwise.</td>
<td>+/-</td>
</tr>
<tr>
<td>( X_2 ) = Income share</td>
<td>Coded as 1 if household share of income from agriculture was greater than 60%; 0 otherwise.</td>
<td>+</td>
</tr>
<tr>
<td>( X_3 ) = Fruit status</td>
<td>Coded as 1 if fruits were about to be harvested; 0 otherwise.</td>
<td>-</td>
</tr>
<tr>
<td>( X_4 ) = Savings</td>
<td>Coded as 1 if the decision maker saved money; 0 otherwise.</td>
<td>+</td>
</tr>
<tr>
<td>( X_5 ) = Labour intensity</td>
<td>Coded as 1 if the technology was perceived to be labour intensive, 0 otherwise.</td>
<td>-</td>
</tr>
<tr>
<td>( X_6 ) = Fruit production</td>
<td>Coded as 1 if the main decision maker was experienced in fruit production; 0 otherwise.</td>
<td>+</td>
</tr>
<tr>
<td>( X_7 ) = School-aged kids</td>
<td>Coded as 1 if the main decision maker had school-age kids; 0 otherwise.</td>
<td>+</td>
</tr>
<tr>
<td>( X_8 ) = Plot owned</td>
<td>Amount of plot owned in acreage.</td>
<td>+</td>
</tr>
</tbody>
</table>

The status of the farmed fruit was included as one of the variables. It was expected that fruit growers would be more willing to adopt the EFF technologies when time-to-maturity allowed them to both improve fruit quality (i.e., increase value) and prolong the harvesting period so as to hedge against price risk. Saving behaviour was included as a measure of a farmer’s ability to finance the adoption of the technologies and was expected to have a positive effect on the adoption decision. The share of income derived from agriculture was considered as an appropriate measure of the lucrativeness of the farming business and was expected to have a positive effect on the decision to adopt EFF technologies. Having school-age kids was included as a measure of the parents’ social obligation. It was expected that females with school-age kids would be particularly hesitant to adopt capital- and labour-intensive technologies as they attempt to save time and resources for their kids. Plot ownership was included as a measure of farmers’ resource bases for agricultural production and was believed to be positively associated with the decision to adopt agricultural technologies.

The model was estimated using data that were collected by the authors in 2015 from a random sample of 96 banana growers. The respondents were proportionately drawn from two banana-growing areas in Morogoro, a rural district of Tanzania, based on the actual number of growers in each area. The banana growing areas that were selected were those where the EFF project was implemented. During the interview, respondents were randomly selected from a list of banana growers obtained from extension officers working in the project areas. In addition to the variables described in preceding sections, the survey also solicited information on other aspects of banana farming including farmers’ socio-economic and demographic characteristics, their levels of involvement in planning and performing different activities, and access to and control over assets and other resources at the household level. During the analysis, the data were not disaggregated by study areas to retain the sample size and enhance robustness of parameters that were estimated using the maximum likelihood method.
Results

Results demonstrated that the proportion of men and women who appeared to be willing and able to adopt the EFF technologies was different ($z = -1.97, p < .01$). Overall there were more men than women who appeared willing and able to influence the adoption decision ($z = -1.86, p < .01$). Also, the proportion of female farmers (mean rank = 63.75) that perceived EFF technologies as labour intensive technology was significantly higher ($z = -3.352, p < .05$) than the proportion of men with that perception (mean rank = 43.80).

Results from the descriptive analysis revealed that most of the female banana growers who were willing and able to influence the decision to adopt EFF technologies along with those who were willing but unable to influence the decisions were over 35 years old, more able to save money, and did not perceive EFF as labour-intensive technologies (Table 2). Also, a relatively large number of these decision-makers were those whose bananas were about to be harvested, had a share of income from agriculture above 60%, but were less experienced in banana production.

Overall, the proportions presented in Table 2 suggest that women who were willing and able to influence decisions to adopt the EFF technologies might share similar characteristics. This assumption was tested using parameters generated from the logit model and the results are presented in Table 3.

Table 3 reveals age ($p < .1$), perception of labour intensity ($p < .05$) of the EFF technologies, and status of banana fruit ($p < .05$) as variables that affect the likelihood of female growers to be willing and able to make the adoption decision. The odds of influencing the adoption decision were estimated to be 0.77 lower among farmers who were above 35 years than those below this age. Similarly, the odds of influencing such a decision were estimated to decrease by 0.75 when a female decision-maker perceived EFF as labour-intensive technologies, and to decrease by 0.82 when the decision-maker had banana fruits that were being harvested.

Table 2: Number of women (proportion or mean) for nine survey variables collected in 2015 in two locations in Morogoro rural district, Tanzania

<table>
<thead>
<tr>
<th>Variables</th>
<th>Number of women (proportion or mean)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Willing and able to influence adoption decision</td>
</tr>
<tr>
<td>Adopter category</td>
<td>4 (58 %)</td>
</tr>
<tr>
<td>Age category</td>
<td></td>
</tr>
<tr>
<td>&lt; 35 years</td>
<td>50 (4.2 %)</td>
</tr>
<tr>
<td>≥ 35 years</td>
<td>11 (52.7 %)</td>
</tr>
<tr>
<td>Income share</td>
<td></td>
</tr>
<tr>
<td>&lt; 60 %</td>
<td>43 (11.6 %)</td>
</tr>
<tr>
<td>≥ 60 %</td>
<td>15 (45.3 %)</td>
</tr>
<tr>
<td>Fruit status</td>
<td></td>
</tr>
<tr>
<td>About to be harvested</td>
<td>39 (15.8 %)</td>
</tr>
<tr>
<td>Not about to be harvested</td>
<td>23 (41.0 %)</td>
</tr>
<tr>
<td>Savings</td>
<td></td>
</tr>
<tr>
<td>No</td>
<td>31 (24.2 %)</td>
</tr>
<tr>
<td>Yes</td>
<td>47 (32.6 %)</td>
</tr>
<tr>
<td>Labour intensity</td>
<td></td>
</tr>
<tr>
<td>No</td>
<td>(50.5 %)</td>
</tr>
<tr>
<td>Yes</td>
<td>6 (6.3 %)</td>
</tr>
<tr>
<td>Fruit production experience</td>
<td></td>
</tr>
<tr>
<td>No</td>
<td>32 (33.7 %)</td>
</tr>
<tr>
<td>Yes</td>
<td>22 (23.1 %)</td>
</tr>
<tr>
<td>School-age kids</td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>53 (2.3)</td>
</tr>
<tr>
<td>Plot owned acreage</td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>53 (1.03)</td>
</tr>
</tbody>
</table>


Women’s prospects to adopt enhanced freshness formulation (EFF) technologies for banana in Morogoro rural district, Tanzania; Moses P. Subert et al.

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Table 3: Regression coefficients, standard errors, Z-values, p-values and 95% confidence intervals of the logit model fitted to assess willingness to adopt the EFF technologies in two locations in Morogoro rural district, Tanzania

| Variable                        | Odds Ratio | Standard Error | Z    | P>|Z|  | 95% Confidence Interval |
|---------------------------------|------------|----------------|------|------|--------------------------|
| Constant                        | 2.65       | 2.61           | 0.99 | 0.32 | 0.38                     | 18.20                        |
| Age category                    | 0.23       | 0.19           | -1.80| 0.07 | 0.05                     | 1.13                         |
| Income share                    | 1.32       | 0.75           | 0.49 | 0.62 | 0.43                     | 4.04                         |
| Fruit status                    | 0.25       | 0.17           | -2.06| 0.04 | 0.07                     | 0.94                         |
| Savings                         | 1.82       | 0.93           | 1.18 | 0.24 | 0.67                     | 4.96                         |
| Labour intensity                | 0.18       | 1.31           | -2.37| 0.02 | 0.45                     | 0.75                         |
| Fruit production experience     | 2.17       | 1.17           | 1.43 | 0.15 | 0.75                     | 6.26                         |
| School aged kids                | 1.01       | 0.08           | 0.07 | 0.96 | 0.86                     | 1.16                         |
| Plot owned                      | 1.08       | 0.18           | 0.49 | 0.63 | 0.78                     | 1.49                         |

Note: Number of observations = 91; chi² = 13.68; prob. > chi² = 0.0492; log pseudo likelihood = 0.1106

Discussion

The implication of the results is that female growers in the study area who were young (i.e., < 35 years) and willing and able to influence the adoption decisions, were more likely to adopt the EFF technologies than older growers with similar characteristics. However, the proportion of young, female farmers in the study areas was small (10.5%) implying less impact on the overall adoption rate.

The findings also revealed a low probability to be willing and able to influence the adoption decision among females who perceived EFF as labour-intensive technologies. About 16% of the decision makers felt that the technologies were labour-intensive. Furthermore, the findings suggest that decision-makers whose fruits were just about to be harvested were less likely to adopt the EFF technologies than those whose fruits were at earlier stages of maturation. Time-to-fruit maturity served as a proxy for time available for decision-makers to adopt the practice and allow the realization of sufficient gains and benefits. The adoption of EFF technologies when fruits were maturing might not accord growers sufficient time to reap benefits through prolonged sales. According to the descriptive statistics presented in Table 2, a majority of the decision-makers (78.9%) who were willing to adopt the technologies were those whose fruits were not about to be harvested.

The findings of this study affirmed the general view that men are more likely to adopt new agricultural technologies than women and are consistent with findings from other studies conducted in Sub-Saharan Africa (Doss 2001; Ndiritu, Kassie and Shiferaw 2014). Using the Mann-whitney U test, the analysis identified that poor access to support services, especially financial services (z=-3.467, p < .05), and lack of relevant knowledge and experience (z=3.371, p < .05) were the main reasons to justify the observed difference in the study area. Also, the finding of higher adoption prospects among farmers whose banana trees are at early stages of maturation implies that selective treatment of the banana fruits with EFF formulations at this stage could delay fruit maturity, thereby prolonging the sale of fruits and hedging bets against the low prices that are normally offered when the supply is high.

This study found higher adoption prospects of EFF technologies among young farmers,
especially females but the proportion of these farmers in the study area was negligible (about 11%). Previous research by others found higher adoption prospects among this group of farmers and associated the higher adoption rate with their willingness to try new things and their greater ability to learn and acquire new skills (Alexander and Van Mellor 2005). Our study predicted a lower adoption rate among female farmers perceiving EFF technologies as labour intensive which implies that easing the formulation and application of the EFF technologies can potentially make the technologies more appealing to female growers and accelerate adoption.

With respect to labour intensity of the technologies, female growers in the study area were accustomed to agricultural technologies involving the use of labour-intensive equipment such as knapsack sprayers that are widely used to spray agro-chemicals. This experience might have caused them to perceive the EFF technologies to be similar to other labour-intensive technologies that exist in their communities. Previous studies have also established that women are less likely to adopt technologies that raise their total labour burden and intensity (Berti, Krasevec and FitzGerald 2004; Doss 2001).

The authors acknowledge that there could be potential confounding with location (i.e., data arose from two locations) as we did not control for location in our statistical analysis. The potential impact of this is unknown and is worth exploring in future studies.

Conclusion and recommendations

The study found that the adoption prospect for EFF technologies is lower among female farmers than male farmers. This calls for continued efforts to address a priori challenges that can potentially undermine adoption, especially unequal access to agricultural support services and knowledge.

The study also found a higher adoption prospect among growers whose bananas were not about to be harvested, so efforts to promote the adoption of these technologies among new users should primarily focus on growers when fruits are in early stages of maturation. Future studies could focus on impacts of specific formulations of EFF technologies on the adoption prospect.

References


Women’s prospects to adopt enhanced freshness formulation (EFF) technologies for banana in Morogoro rural district, Tanzania; Moses P. Subert et al.
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Factors influencing gendered intra-household allocation of land and capital assets in banana (Musa spp.) production: The case of Meru County, Kenya

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Unequal access to agricultural resources such as land, labour and capital has driven women to less rewarding roles along the banana value chain while allowing men to take up the (dominant) management roles. This study seeks to determine factors that influence gendered intra-household resource allocation in banana production in Meru County in Kenya. Currently, intra-household distribution of land and capital assets for banana production in the study area is skewed towards married men. A systematic random sampling technique was used to select 160 household respondents in March 2017. A fractional logit model was used to determine the effects of independent variables on the proportions of land and capital assets allocated jointly or to husbands or to wives. The value of livestock owned by the household emerged as one of the key factors that favoured ‘joint’ allocation of land (p < 10%) while the variable ‘age of the wife’ reduced the likelihood of a ‘husband’ (p < 5%) being allocated land in banana production. The results also show that the key driver for ‘wife’ allocation with both land and capital assets is education of wives (significant at p < 5% in both cases), a factor associated with the enhancement of the human capital of women, and thus their empowerment. For both land and capital assets, group membership reduced the likelihood of ‘joint’ allocation (significant at p < 5% in both cases). Thus, investments in social capital may not address the problem of unequal intra-household distribution of productive agricultural resources. To increase equity in intra-household distribution of land and capital assets in banana production in the study area, policy interventions needed include diversification of banana production into livestock keeping, and investment in the formal education of girls.

Keywords: Banana, capital assets, gender, land, intra-household allocation, Kenya, Meru County

The part played by traditions and social norms in defining the different roles of both men and women in Kenya’s key agricultural value chains is of paramount importance and should be understood for the efficient structuring of interventions to increase farm incomes. A gendered value chain analysis is one of the tools that can be used to determine the different roles of men and women in value chain development. For decades now, gender bias has pushed women to the periphery of the value chain and in turn reduced their overall effectiveness as chain actors and even more so in high-value, horticultural value chains (Mason and King 2001). Particularly in sub-Saharan Africa, women are excluded from high-income ventures because of their limited access to productive resources compared to their male counterparts.

Over the years, traditional cash crops in Kenya, such as tea and coffee have provided farmers with less and less income. This has led to a shift in focus from cash crops to other crops such as banana, passion fruit, and papaya fruit. The profitability of bananas has been growing because of increased urbanization and increasing consumer demand for the produce in urban markets.

Banana production is carried out both as sources of food and income for low-income and resource-poor households in Kenya. During the precolonial period, the crop was characterized as semi-subsistence and its production involved women only. However, due to urbanization and population growth, there has been an increase in the demand for bananas in urban areas and this has resulted in commercialization of the enterprise (Wambu and Kiome 2001). Commercialization has redefined the gender roles along the value chain and increased income-generation opportunities for both men and women while creating challenges at the same time. In particular, over the last decade there has been
Factors influencing gendered intra-household allocation of land and capital assets in banana (Musa spp.) production: the case of Meru County, Kenya; Violet Nyabar et al.

a drastic change of resource allocation in terms of labour and land in sub-Saharan Africa (Mason and King 2001). Gender differences in accessing and using agricultural resources needs to be recognized to facilitate successful agricultural development, particularly in sub-Saharan African countries.

The gender roles of men and women in traditional African society play a critical role in determining how intra-household resource allocation takes place. Despite women constituting 80% of smallholder farmers in Africa, their agricultural productivity is hampered by little access to and control over agricultural resources (Ferguson 2010). Thirty years ago, Virji and Meghji (1989) argued that low access to capital by women had hindered their ability to accumulate assets – assets that are mandatory as collateral for obtaining credit.

Evidence documenting gender disparities in development initiatives in developing countries is ample. According to the FAO (2010), women are less likely to own land and to have access to rented land, and if they have access to land, it is often of poorer quality and smaller in size than that of men. Also, disparities in accessing financial services and capital assets have far-reaching implications on investment in agriculture. Studies have shown that improving women’s direct access to financial resources leads to higher investments in human capital in the form of children’s health, nutrition, and education (Vargas-Lundius 2009). There are also clear differences in terms of accessing both formal and informal sources of credit between men and women. However, these differences in access to capital are not a result of non-availability, but because men have fewer time constraints, are more able to work outside the home, possess greater social networks, and have more control over household income than women.

Social and economic factors, including gendered norms and practices, often hinder women from participating on par with men in agricultural activities and initiatives. For instance, in most African societies, gender division of labour results in women undertaking a disproportionate share of non-productive work in conditions of drudgery, which in turn leads to time wastage, limited mobility, and relegation to the private sphere (Spilsbury et al. 2002). Unequal access to agricultural resources such as land, labour, and capital has driven women to less rewarding roles along agricultural value chains while allowing men to take up the (dominant) management roles.

Resource allocation and benefit sharing are contentious issues especially in high-income enterprises such as banana. According to Vargas-Lundius (2009), women are frequently excluded from high profit markets, and access to and control over productive resources. Quisumbing (2001) and IFAD (2002), among others, have widely documented the impact of women’s access to productive resources and their engagement in profitable markets on the outcome of improved household welfare. However, there is little literature about intra-household division of labour, access to and control over land, and access to capital assets in high-value, horticultural value chains such as banana. Moreover, factors that affect intra-household allocation of these resources in value chain activities have not been well documented either.

The objective of our study was to identify factors that influence gendered allocation of land and capital assets within banana-producing households in Meru County, Kenya. Specifically, the study identified the drivers of the allocation of land and capital assets to husbands, to wives, and jointly to husband and wife pairs. Results from this study will provide information on conditions that can favour impactful intra-household allocation of productive agricultural resources in the banana value chain. This information can form the basis of science-based decisions by policy makers and other stakeholders when promoting interventions geared towards.
Factors influencing gendered intra-household allocation of land and capital assets in banana (Musa spp.) production: the case of Meru County, Kenya; Violet Nyabarongo et al.

increasing productivity within the value chain and increasing women’s incomes. Such interventions include the enhanced freshness formulation (EFF) technologies that have already been piloted in the study area and found useful for enhancing fruit quality, and therefore, increasing farm incomes (Yumbya et al. 2017).

Theoretical background

A household is both a producer and a consumer, and thus decision making on production, labour allocation, and consumption are intertwined with and dependent on each other. The production behavior of smallholder farmers across sub-Saharan Africa and Asia and the impact of this behavior on their economies can be comprehensively explained using agricultural household models. For a household it is assumed that utility maximization from the available agricultural resources is the goal. The agricultural household model is consistent with utility maximization. The model also helps in describing the relation of explanatory variables to the outcome of a choice or intervention by households. The household model suggests that household members have different preferences and these affect how production and consumption decisions are made and the outcome of such decisions.

Researchers have widely documented two household models that can be used to conceptualize intra-household resource allocation: the unitary model and the collective model (Quisumbing and Maluccio 2003). The unitary model depicts the household as a single unit of decision-making for which there is always consensus on production and consumption issues. There are a number of arguments against the use of the unitary model for household modelling. Alderman et al. (1995) have pointed out a key failure of the unitary model – its inability to capture and take into account individual preferences, intra-household inequalities and conflicts, and different levels of bargaining power between members of different sex, age, and gender within the household. Since the household is assumed to maximize utility from the available resources as a unit (Doss 1996), the unitary model does not help in understanding the dynamics of intra-household decision-making.

Alternatively, the collective model views intra-household resource allocation as an outcome of bargaining processes among the household members. It therefore recognizes individual preferences and utility functions that exist within a household. With respect to agriculture, collective models of the household recognize that there are differences in ownership, use, and control of production resources between men and women in a household (Browning and Chiappori 1998). A collective model allows assessment of how resources held and controlled by either men or women are utilized to enhance agricultural productivity and welfare outcomes. This model is thusly applied in our study.

The collective model suggests that exogenous factors that affect maximization of utility have an impact on how individuals are involved in decision-making within the household and their level of bargaining power. These factors include an individual’s income, access to land, and other resources. For instance, Doss and Morris (2001) have argued that access to, and the ability of a person to effectively use the available technologies, dictate the amount of income obtained by the individual.

Ideally suited for the type of analysis we desired in our study is Osmani’s (1998) bargaining model because it helps to explain the outcome of gender conflicts and the negotiation process within the household. Bargaining power within the household plays an important role in access to and control over resources as women with higher education levels, more assets, and who are older are favoured (Agarwal 2011). This premise is tested in the current study.
Materials and methods

Study area

This research was conducted in Meru County in eastern Kenya. The study focused on rural households in South Imenti sub-county that produce bananas for both household consumption and sale. Meru County was selected because of its recent commercialization of banana production as a result of the introduction of tissue culture technology by non-governmental organizations (NGO) initiatives (e.g., TechnoServe) and government interventions. It is also the area where the EFF project has already been piloted (Yumbya et al. 2017). The area has an altitude ranging from 300 m to 5,199 m above sea level and therefore has a variety of agro-ecological zones. The average annual rainfall is 1,250 mm. Temperatures as low as 8°C during the rainy periods, and as high as 32°C during the dry season, are typical.

Data collection procedure

Data were collected in March 2017. Key informant interviews and focus groups were conducted to better understand the banana sub-sector within the region. These were followed by household surveys (sample size = 160); respondents were interviewed using semi-structured questionnaires. To generate a sampling frame of potential study households, a list of farmers from banana groups and cooperatives was generated. The farmers to be interviewed were randomly selected in a systematic manner using an interval of 10 on the list. The household interviews were only conducted with the household head or the spouse. For households where heads or spouses were absent, substitution was systematically done using the household list.

The semi-structured questionnaire was used to gather information on household demographic characteristics, as well as physical, institutional, and socio-economic attributes related to gendered banana production and resource allocation within households. Information on the type of resources available in a household were also collected taking into account issues such as who owns a certain resource, the quantity owned, and the current value in Kenyan shillings. Also, data on kinds of services (e.g., extension, credit) sought from the governments and other value chain supporters were collected. Data on gender issues, and on access to productive resources as well as credit were gathered and documented too. Names and measurements used to describe the dependent and explanatory (or independent) variables used in the land allocation and capital assets regression analyses are shown in Table 1.

Enumerators who could speak the local language administered the questionnaire. Data entry was done using SPSS (Version 22) while analyses were done with STATA (Version 14). While the former statistical package is easy to use for data entry and manipulation, the latter gives more robust econometric results.

Statistical analyses

Descriptive statistics were calculated for all independent variables. The two kinds of dependent variables—land allocation and capital assets allocation—in the regression analyses of independent variables possibly influencing intra-household allocation of productive resources in banana production were each denoted as ‘husband,’ ‘wife,’ and ‘joint’ allocations; this resulted in a total of six dependent variables (e.g., land allocation under ‘husband’). The dependent variables were calculated as the proportion of the resources allocated to the husband, wife, and jointly, out of the total resources available in the household. Given the nature of the data, a fractional response model (FRM) was used to estimate the six regressions. The FRM is the most suitable econometric model and it was selected since it is capable of modelling empirically-bounded dependent variables that exhibit piling-up at one of the two corners (Papke and Wooldridge 1996).
Table 1: Names and measurements used to describe the explanatory (or independent) and dependent variables used in the land allocation and capital assets regression analyses of banana production in March 2017 in Meru County, Kenya

<table>
<thead>
<tr>
<th>Explanatory variables</th>
<th>Measurement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sex of the household head</td>
<td>Dummy (1 = male, 0 = female)</td>
</tr>
<tr>
<td>Age of husband</td>
<td>Years</td>
</tr>
<tr>
<td>Age of wife</td>
<td>Years</td>
</tr>
<tr>
<td>Household size</td>
<td>Total number of people in the household in the last 12 months</td>
</tr>
<tr>
<td>Level of education of husband</td>
<td>Years of formal schooling</td>
</tr>
<tr>
<td>Level of education of wife</td>
<td>Years of formal schooling</td>
</tr>
<tr>
<td>Farming experience</td>
<td>Number of years the household has been practicing farming</td>
</tr>
<tr>
<td>Group membership</td>
<td>Dummy (1 = yes, 0 = no)</td>
</tr>
<tr>
<td>Total income</td>
<td>Amount of money in KES(^a) generated per year from all activities</td>
</tr>
<tr>
<td>Access to extension</td>
<td>Dummy (1 = yes, 0 = no)</td>
</tr>
<tr>
<td>Livestock value</td>
<td>Current value in KES of livestock owned</td>
</tr>
<tr>
<td>Off-farm income</td>
<td>Amount of money earned in KES from off-farm activities per year</td>
</tr>
<tr>
<td>Access to credit</td>
<td>Dummy (1 = yes, 0 = no)</td>
</tr>
<tr>
<td>Non-agricultural assets value</td>
<td>Current total value in KES of all non-agricultural household assets</td>
</tr>
<tr>
<td>Total land</td>
<td>Farm land owned in acres</td>
</tr>
<tr>
<td>Total cost of inputs</td>
<td>Total cost of inputs used in production of bananas in KES</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Dependent variables</th>
<th>Measurement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Land allocation under ‘husband’</td>
<td>Proportion of land used by husband for banana production</td>
</tr>
<tr>
<td>Land allocation under 'wife’</td>
<td>Proportion of land used by wife for banana production</td>
</tr>
<tr>
<td>Land under ‘joint’ allocation</td>
<td>Proportion of land jointly used by husband and wife for banana production</td>
</tr>
<tr>
<td>Capital assets allocation under ‘husband’</td>
<td>Proportion of value of capital assets used directly in banana production by the husband</td>
</tr>
<tr>
<td>Capital assets allocation under ‘wife’</td>
<td>Proportion of value of capital assets used directly in banana production by the wife</td>
</tr>
<tr>
<td>Capital assets under ‘joint’ allocation</td>
<td>Proportion of value of capital assets used directly in banana production jointly by husband and wife</td>
</tr>
</tbody>
</table>

\(^a\)KES = Kenyan shillings

With allocation ratios ranging from 0 to 1 for land and capital assets, six estimations of factors that influence ‘husband allocation’, ‘wife allocation,’ and ‘joint allocation’ were conducted. The data for land and capital assets allocations were collected directly from farmers practicing banana production. The explanatory variables of age, years of education, off-farm income, as well as the other socio-economic variables were regressed on the six dependent variables to capture their effect on intra-household resource allocation.
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by gender. Age and years of education are human capital variables and according to Quisumbing (2001), they are likely to have a positive influence on agricultural activities. The influence of off-farm income on land and capital asset was hypothesized to be neutral. This is because off-farm income the total household income needed for investment in agriculture. However, higher off-farm income could act as motivation for investment in non-agriculture ventures due to higher returns generated. The results were assessed for significance at three levels ($p < 0.10$, $p < 0.05$, and $p < 0.01$) and presented in tabular form.

The dependent variables land and capital asset allocation were generated as a proportion allocated to each gender (husband, wife or joint) from the total resources owned by the household. The general estimation of the regression is:

$$y_{xi} = \beta_0 + \beta_i x_i + \epsilon_i$$

where $y_{xi}$ is the proportion of resource $x$ (land or capital assets) allocated to individual $i$ (husband, wife, or joint) within the household, $\beta_0$ is the constant, $\beta_i x_i$ is the independent variable, and $\epsilon_i$ is the error term which is expected to be normally independent and distributed with a zero mean and constant variance. In our study the outcome variables were truncated and could only take on values between 0 and 1.

Maximum likelihood estimation was used to eliminate the errors of biased and inconsistent estimates that manifest in the use of ordinary least squares regression estimators. The explanatory variables that exhibited a dispersed distribution, such as current value of livestock, total household income, off-farm income, total production cost, value of non-agricultural assets, and value of inputs used in production were converted into natural logs (base 10).

Results and discussion

Socio-economic characteristics of the sampled farmers

Descriptive statistics for household characteristics are shown in Table 2. In our sample, 86% of the households were headed by men. This is an indication of the social setting of African households in which men are always considered to be the household heads even if they are working far away from home. The mean land holding size in the study area was 2.11 acres and this is consistent with small-scale farmers’ land size in Meru County (Miriti et al. 2014). The average household size was 4.0 members with the household head having an average age of 58.0 years. The household mean level of education (of adults) was 9.0 years of formal schooling. This means that, on average, most of the householders in the area have not acquired secondary school education.

Only 36% of the study households had access to extension services that provide information on the production and marketing of bananas. This finding concurs with Miriti et al. (2014) who found that 64% of the farmers in the region lacked regular access to extension services despite the region being a major banana producer. The current survey results also reveal that of the 36% of households that had access to extension services, only 27.1% were headed by women. The gender parity in agricultural extension that we saw could be attributed to the fact that male extension providers tend to pay more attention to male farmers, and the assumption is that the spillover effects of extension will eventually reach women farmers (Mason and King 2001). However, we did not study the gender aspects of extension service in the area and so the assumption of spillover effects may require further investigations.
Factors influencing gendered intra-household allocation of land and capital assets in banana (*Musa* spp.) production: the case of Meru County, Kenya. Violet Nyabaro et al.

Table 2: Mean or proportion (standard deviation) of the independent and dependent variables in of a sample of households (n = 160) involved in banana production in March 2017 in Meru County, Kenya

<table>
<thead>
<tr>
<th>Independent variables</th>
<th>Mean (standard deviation at 95% confidence level)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Household size</td>
<td>4.00 (1.45)</td>
</tr>
<tr>
<td>Sex of the household head (proportion)</td>
<td>0.86 (0.35)</td>
</tr>
<tr>
<td>Age of the husband in years</td>
<td>57.52 (14.51)</td>
</tr>
<tr>
<td>Age of the wife in years</td>
<td>49.84 (13.85)</td>
</tr>
<tr>
<td>Years of schooling of the husband</td>
<td>9.39 (4.44)</td>
</tr>
<tr>
<td>Years of schooling of the wife</td>
<td>8.89 (4.60)</td>
</tr>
<tr>
<td>Total land size in acres</td>
<td>2.11 (1.66)</td>
</tr>
<tr>
<td>Access to credit (proportion)</td>
<td>0.15 (0.39)</td>
</tr>
<tr>
<td>Group membership (proportion)</td>
<td>0.51 (0.50)</td>
</tr>
<tr>
<td>Access to extension (proportion)</td>
<td>0.36 (0.48)</td>
</tr>
<tr>
<td>Total cost (KES)a</td>
<td>36213.35 (51873.40)</td>
</tr>
<tr>
<td>Total income (KES)</td>
<td>250157.6 (332616.10)</td>
</tr>
<tr>
<td>Livestock value (KES)</td>
<td>165130.8 (143001.40)</td>
</tr>
<tr>
<td>Non-agricultural assets value (KES)</td>
<td>667080.50 (1012110.00)</td>
</tr>
<tr>
<td>Total costs of inputs (KES)</td>
<td>50779.16 (151182.50)</td>
</tr>
<tr>
<td>Off-farm income (KES)</td>
<td>83121.26 (247597.70)</td>
</tr>
</tbody>
</table>

**Dependent variables (all proportions)**

| Land allocation under wife                         | 0.22 (0.41)                                      |
| Land allocation under husband                      | 0.33 (0.46)                                     |
| Land under joint allocation                        | 0.45 (0.49)                                     |
| Capital assets under joint allocation              | 0.23 (0.40)                                     |
| Capital assets under wife allocation               | 0.13 (0.3177)                                   |
| Capital assets under husband allocation            | 0.63 (0.46)                                     |

*KES = Kenyan shillings*

Our study found that 37% of the respondents sourced their extension services from government officers while 25% of the extension services were received from farmer groups. The NGOs provided 15% of the extension services. Banana is a perishable crop and the quality attributes after harvesting dictate the price it fetches in the market. Most of the information sought from extension officers was on product handling (71.7%). Post-harvest handling, in light of banana’s perishability, is one of the major constraints facing the banana value chain actors. Other kinds of information and services sought from the extension officers were on chemical handling (11.3%), soil and water management (9.4%), and pest management (7.6%).

Credit access and financial capital plays an important role in agricultural production in the African agriculture setting. Credit access in our study was found to be at 15% which is consistent with Miriti et al. (2014) who found that of all the respondents interviewed in South Imenti, only 10% had access to credit. The low access to credit could be attributed to the requirement for collateral by financial institutions before securing credit. Focus group discussions and key informant interviews attributed this to lack of collateral and guarantors by banks and microfinance institutions.
Factors influencing intra-household land allocation in banana (Musa spp.) production: the case of Meru County, Kenya; Violet Nyabaro et al.

institutions. Farmer groups such as banana cooperatives were the leading lender to farmers (29.2%) in our study. These survey findings are consistent with our focus group discussions and key informant interviews wherein the participants stated their preferences for farmer group loans where no collateral security is required. The other relatively minor sources of credit were commercial banks (20.8%) and the Agricultural Finance Cooperation (12.5%). Gender disaggregation analysis showed that 13.3% of those who had access to credit were women. The existing literature on gender and credit access however show mixed results. For instance, Meinzen-Dick et al. (2010) argue that the difference between men and women when it comes to credit access is small and insignificant, and in some instances, men have low credit access compared to their counterparts who are favoured by the credit institutions.

Our results demonstrate that 51% of the households surveyed participated in groups, whether formally or informally. About 29% of the respondents cited ease of market access as one of the major reasons of joining groups. Respondents reported that the banana cooperatives in the region have been used as marketing channels because they are secure and efficient compared to roadside markets. Other reasons for participating in groups included access to production information as well as access to credit.

Factors influencing intra-household land allocation

A number of factors were found to influence gendered land allocation in banana production within the households. As shown in Table 3, factors that favoured ‘joint’ allocation of land for banana production include total costs of inputs of production (p<10%), value of livestock (p<10%), household size (p<5%), access to credit (p<1%), and sex of the household head (p<1%). Factors that hindered ‘joint’ allocation were years of education of the wife (p<5%), participation in groups (p<5%), and age of the wife (p<5%) (see also Table 5-7 for detailed results). Allocation to ‘husband’ was favoured by education of the wife (p<1%) and participation in groups (p<10%) while it was inhibited by size of the household (p<5%) and access to credit (p<5%). Allocation to ‘wife’ was driven up by education of the wife (p<5%) and possession of non-agricultural assets (p<1%) while it was driven down by sex of the household head (p<5%), access to credit (p<5%), total costs of inputs of production (p<10%), and value of livestock owned by the household (p<5%).

Turning to the effect of each factor across ‘joint,’ ‘husband,’ and ‘wife’ land allocation categories or dependent variables, it was found that current value of livestock in the household had a positive influence (at p<10%) on ‘joint’ land allocation while it had a negative effect (at p<5%) on ‘wife’ land allocation (Table 3, bottom). This can be explained by the fact that livestock ownership in African society is mainly accorded to the husband. Women are only allowed to own small stocks such as chicken and goats. In some cases, they are also allowed to have control over livestock products such as milk (Zimmerman 1982). Thus, as the number of livestock increases within the household, less land is likely to be allocated to wives as much of it is needed for grazing and fodder production.
Table 3: Marginal effects (standard error) and significance levels of variables influencing intra-household land allocation in banana-producing households (n = 160) in March 2017 in Meru County, Kenya

<table>
<thead>
<tr>
<th>Variable</th>
<th>Joint</th>
<th>Husband</th>
<th>Wife</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sex of household head</td>
<td>3.1462***</td>
<td>0.1550(0.2034)</td>
<td>-0.3848** (0.1448)</td>
</tr>
<tr>
<td>Household size</td>
<td>0.3167**</td>
<td>-0.2619**</td>
<td>0.0274 (0.0881)</td>
</tr>
<tr>
<td>Age of the wife</td>
<td>-0.2995**</td>
<td>0.0842 (1.431)</td>
<td>0.1015 (0.1333)</td>
</tr>
<tr>
<td>Access to extension</td>
<td>0.0518 (0.0325)</td>
<td>-0.0285 (0.0297)</td>
<td>-0.0113 (0.0198)</td>
</tr>
<tr>
<td>Log total cost of inputs</td>
<td>0.4578* (0.2404)</td>
<td>-0.2119 (0.1732)</td>
<td>-0.1977* (0.1185)</td>
</tr>
<tr>
<td>Education of wife</td>
<td>-0.3959**</td>
<td>0.2414***</td>
<td>0.1713** (0.0759)</td>
</tr>
<tr>
<td>Group membership</td>
<td>-0.0927**</td>
<td>0.0872* (0.0471)</td>
<td>0.0032 (0.0273)</td>
</tr>
<tr>
<td>Access to credit</td>
<td>0.0320***</td>
<td>-0.0194**</td>
<td>-0.0158** (0.0057)</td>
</tr>
<tr>
<td>Log non-agricultural assets</td>
<td>-0.1216 (0.2413)</td>
<td>-0.2934 (0.2236)</td>
<td>1.1577*** (0.3523)</td>
</tr>
<tr>
<td>Log value of livestock</td>
<td>0.8199* (0.4742)</td>
<td>0.1407 (0.2545)</td>
<td>-0.6880** (0.2663)</td>
</tr>
<tr>
<td>Log Off-farm income</td>
<td>0.0390 (0.0416)</td>
<td>-0.0362 (0.0366)</td>
<td>0.0024 (0.0403)</td>
</tr>
</tbody>
</table>

* p < 0.10; ** p < 0.05; *** p < 0.01

Table 4: Marginal effects (standard error) and significance levels of variables influencing intra-household allocation of capital assets in banana-producing households (n = 160) in March 2017 in Meru County, Kenya

<table>
<thead>
<tr>
<th>Variable</th>
<th>Joint</th>
<th>Husband</th>
<th>Wife</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sex of household head</td>
<td>0.1893(0.1606)</td>
<td>-0.0042 (0.0596)</td>
<td>-0.0072 (0.1522)</td>
</tr>
<tr>
<td>Household size</td>
<td>-0.1487** (0.0721)</td>
<td>0.0374 (0.0893)</td>
<td>0.1014** (0.0500)</td>
</tr>
<tr>
<td>Age of the wife</td>
<td>0.1503 (0.1272)</td>
<td>0.4026*** (0.1487)</td>
<td>0.2572* (0.1522)</td>
</tr>
<tr>
<td>Group membership</td>
<td>-0.0635** (0.0301)</td>
<td>0.0466* (0.0275)</td>
<td>-0.0244*** (0.0062)</td>
</tr>
<tr>
<td>Access to extension</td>
<td>-0.0982 (0.2239)</td>
<td>0.2677 (0.2426)</td>
<td>-0.1897* (0.1020)</td>
</tr>
<tr>
<td>Log nonagricultural assets</td>
<td>0.5777 (0.3702)</td>
<td>0.2677 (0.2426)</td>
<td>-0.2211* (0.1259)</td>
</tr>
<tr>
<td>Log livestock value</td>
<td>1.1245** (0.4604)</td>
<td>-0.7165** (0.3464)</td>
<td>-0.0414** (0.0184)</td>
</tr>
<tr>
<td>Log Off-farm income</td>
<td>0.0524 (0.0573)</td>
<td>-0.0090 (0.0560)</td>
<td>-0.0416** (0.0189)</td>
</tr>
</tbody>
</table>

* p < 0.10; ** p < 0.05; *** p < 0.01
Table 5: Marginal effects (standard error) and significance levels of variables influencing intra-household joint land allocation in banana-producing households (n = 160) in March 2017 in Meru County, Kenya

| Variable                        | dy/dx  | Std. Error | P>|z|  | 95% Confidence interval |
|---------------------------------|--------|------------|-----|-----------------|
| Sex of the household head       | 3.1462 | 0.2676     | 0.000| 2.6216-3.6707   |
| Household size                  | 0.3167 | 0.1191     | 0.008| 0.0206-0.1404   |
| Age of wife                     | -0.2995| 0.1458     | 0.038| -0.0114-0.0003  |
| Education of wife               | -0.3959| 0.0715     | 0.000| -0.0589-0.0291  |
| Group membership                | -0.0927| 0.0421     | 0.024| -0.3414-0.0235  |
| Access to credit                | 0.0320 | 0.0093     | 0.020| 0.0411-0.4899   |
| Extension contact               | 0.0518 | 0.0325     | 0.122| -0.0354-0.3009  |
| Log total cost of inputs        | 0.4578 | 0.2404     | 0.049| 0.0005-0.2184   |
| Log nonagricultural assets      | -0.1216| 0.2413     | 0.613| -0.1095-0.0645  |
| Log value of livestock          | 0.8199 | 0.4742     | 0.081| -0.0198-0.3460  |
| Log off-farm income             | 0.0390 | 0.0416     | 0.354| -0.0167-0.0469  |

* p < 0.10; ** p < 0.05; *** p < 0.01

Wald chi2(11)=356.9
Prob > chi2=0.0000
Pseudo R2=0.2496
Log pseudo likelihood = -63.458585

The value of non-agicultural assets owned by the household had a positive influence (at p<1%) on ‘wife’ land allocation and no significant effect on the other two types of allocation. This implies that as the non-agicultural assets increase in a household, individual bargaining power of wives increases and in the process they gain control of land. Thus, as the household gets wealthier, the probability of a wife being allocated land increases. These study results concur with past findings that indicate that ownership of assets increases the woman’s bargaining power within the household, which results in more resource allocation (Quisumbing and Pandolfelli 2009).

Credit access by the household increased the probability of ‘joint’ land allocation (at p<1%) but at the same time reduced chances of ‘husband’ (p<5%) and ‘wife’ allocation (p<5%). This may be because most of the credit accessed by households is secured by having land as collateral and both wife and husband have to participate in land cultivation to ensure regular repayment. As expected, access to credit does not favour ‘wife’ land allocation. In fact a number of studies have found that even in situations where households have access to credit services, women’s control over productive resources remains limited (White 1991).

‘Joint’ land allocation was negatively affected by participation in groups (p<5%). However, the same variable had a positive influence on ‘husband’ land allocation (p<10%). Group participation was mainly by men who seek the benefits of market access and higher profits associated with the selling of bananas in kilograms as opposed to bunches. It is likely that due to these incentives husbands hold onto the land and do not allow joint ownership or transfer of the property rights to their wives.

Education of wives had a negative effect on ‘joint’ land allocation (p<5%) while it
Factors influencing gendered intra-household allocation of land and capital assets in banana (*Musa* spp.) production: the case of Meru County, Kenya. Violet Nyabaro et al.

The education of the wife exhibited a positive influence on both ‘husband’ (p < 1%) and ‘wife’ allocations (p<5%). Thus, education as an investment in human capital plays a critical role in according married women a higher bargaining power in negotiations on ownership of resources like land. The results further indicate that as the education of the wife increases, households are not likely to have joint allocation of land but would rather favour husband allocation. Considering that the right to allocate land in the study area is mainly assigned to husbands, this result implies that married men retain control over land even if their wives are highly educated. This result concurs with the assertion of Kimani (2008) that no matter how hard women in Africa fight over access to and control over land, men will always have the decision-making power.

Total costs of inputs had a positive effect on ‘joint’ land allocation (p<10%) and a negative effect on ‘wife’ allocation (p<10%). This may be because using large amount of inputs in the production of bananas and other crops in the study area is associated with wealth which favours joint decision-making on the farms. Similarly, total costs of inputs reduced the likelihood of ‘wife’ land allocation since safeguarding wealth in the African set-up is associated with men (Soetan 2001).

The age of the wife negatively influenced ‘joint’ land allocation (p<5%). This implies that joint allocation was not common in households with older women and this is perhaps due to cultural barriers. The size of the household, however, positively influenced ‘joint’ land allocation (p<5%) but had a negative effect on ‘husband’ allocation (p<5%). With large families, it might be expected that husbands would be more motivated to transfer land rights to their wives and, to some extent, to mature children in order to encourage production of the much needed food and to achieve self-sufficiency. As expected, having male-headed households favoured ‘joint’ land allocation (p<1%) but negatively influenced ‘wife’ allocation (p<5%). This is likely because the right to land is mainly held by men who can allocate land to whomever they want. The result also implies that husbands in the study area do not have a problem with ‘joint’ land allocation.

Factors influencing intra-household capital assets allocation

Factors influencing intra-household capital assets allocation are somewhat different from the ones influencing land allocation except for value of livestock, group membership, and age of the wife (Table 4). For capital assets allocation, the value of livestock had a similar negative and significant influence on ‘wife’ allocation (p<10%), and group membership had a similar negative influence on ‘wife’ allocation (p<5%) (see also Tables 8-10 for detailed results). The results of the ‘education of wife,’ in the capital assets allocation model almost matched those of the land allocation. The variable showed a similar negative influence on ‘joint’ capital assets allocation (p<5%) and a positive influence on ‘wife’ capital assets allocation (p<5%).
Factors influencing gendered intra-household allocation of land and capital assets in banana (Musa spp.) production: the case of Meru County, Kenya; Violet Nyabar et al.

Table 6: Marginal effects (standard error) and significance levels of variables influencing intra-household husband land allocation in banana-producing households (n = 160) in March 2017 in Meru County, Kenya

| Variable                  | dy/dx   | Std. error | P>|z  | 95% confidence interval |
|----------------------------|---------|------------|-----|------------------------|
| Sex of household head     | 0.1550  | 0.2034     | 0.438| -0.2454-0.5669          |
| Household size            | -0.2619 | 0.1039     | 0.016| -0.1291--0.0132         |
| Age of the wife           | 0.0842  | 0.1431     | 0.552| -0.0038-0.0071          |
| Access to extension       | -0.0285 | 0.0297     | 0.371| -0.2369-0.0884          |
| Log total cost of inputs  | -0.2119 | 0.1732     | 0.223| -0.1348-0.0314          |
| Education of wife         | 0.2414  | 0.0923     | 0.005| 0.00079-0.0443          |
| Group membership          | 0.0872  | 0.0471     | 0.040| 0.0069-0.3103           |
| Access to credit          | -0.0194 | 0.0095     | 0.014| -0.3625-0.0546          |
| Log non-agricultural assets| -0.2934| 0.2236     | 0.188| -0.1341-0.0263          |
| Log value of livestock    | 0.1407  | 0.2545     | 0.578| -0.0705-0.1265          |
| Log Off-farm income       | -0.0362 | 0.0366     | 0.346| -0.0466-0.016           |

* p < 0.10; ** p < 0.05; *** p < 0.01
Wald chi2(11)=26.38
Prob > chi2=0.0057
Pseudo R2=0.3523
Log pseudo likelihood = -39.396314

Table 7: Marginal effects (standard error) and significance levels of variables influencing intra-household wife land allocation in banana-producing households (n = 160) in March 2017 in Meru County, Kenya

| Variable                  | dy/dx   | Std. error | P>|z  | 95% confidence interval |
|----------------------------|---------|------------|-----|------------------------|
| Sex of household head     | -0.3848 | 0.01448    | 0.004| -0.6822- -0.1317       |
| Household size            | 0.0274  | 0.0881     | 0.753| -0.0352- 0.0487        |
| Age of the wife           | 0.1015  | 0.1333     | 0.435| -0.0030-0.0070         |
| Access to extension       | -0.0113 | 0.0198     | 0.594| -0.1454-0.0832         |
| Log total cost of inputs  | -0.1977 | 0.1185     | 0.060| -0.1099-0.0108         |
| Education of wife         | 0.1713  | 0.0759     | 0.014| 0.0033-0.0298          |
| Group membership          | 0.0032  | 0.0273     | 0.904| -0.0967-0.1095         |
| Access to credit          | -0.0158 | 0.0057     | 0.004| -0.3967-0.0575         |
| Log non-agricultural assets| 1.1577 | 0.3523     | 0.001| 0.0833-0.3198          |
| Log value of livestock    | -0.6880 | 0.2663     | 0.010| -0.2454- -0.0326       |
| Log Off-farm income       | 0.0024  | 0.0403     | 0.952| -0.0248-0.0264         |

* p < 0.10; ** p < 0.05; *** p < 0.01
Wald chi2(11)=26.38
Prob > chi2=0.0057
Pseudo R2=0.3523
Log pseudo likelihood = -39.396314
Factors influencing gendered intra-household allocation of land and capital assets in banana (Musa spp.) production: the case of Meru County, Kenya. Violet Nyabaro et al.

Table 8: Marginal effects (standard error) and significance levels of variables influencing intra-household joint allocation of capital assets in banana-producing households (n = 160) in March 2017 in Meru County, Kenya

| Variable                  | dy/dx    | Std. error | P>|z|   | 95% confidence interval          |
|---------------------------|----------|------------|------|-------------------------------|
| Education of wife         | -0.1487  | 0.0721     | 0.037| -0.0347-0.0001               |
| Age of wife               | 0.1503   | 0.1272     | 0.222| -0.0018-0.0079               |
| Group membership          | -0.0635  | 0.0301     | 0.018| -0.2752-0.0079               |
| Log nonagricultural assets| -0.0982  | 0.2239     | 0.656| -0.1005-0.0632               |
| Log livestock value       | 0.5777   | 0.3702     | 0.118| -0.0285-0.2531               |
| Log total income          | 1.1245   | 0.4604     | 0.018| 0.0162-0.1692                |
| Log total land            | 0.0524   | 0.0573     | 0.380| -0.0249-0.0655               |

* p < 0.10; ** p < 0.05; *** p < 0.01

Wald chi2(7)=14.82
Prob > chi2=0.0383
Pseudo R2=0.1008
Log pseudo likelihood = -63.957321

Table 9: Marginal effects (standard error) and significance levels of variables influencing intra-household husband allocation of capital assets in banana-producing households (n = 160) in March 2017 in Meru County, Kenya

| Variable                  | dy/dx    | Std. error | P>|z|   | 95% confidence interval          |
|---------------------------|----------|------------|------|-------------------------------|
| Sex of the household head | 0.1893   | 0.1606     | 0.470| -0.2068-0.4480               |
| Education of wife         | 0.0374   | 0.0893     | 0.314| -0.0094-0.0295               |
| Age of wife               | 0.0374   | 0.1487     | 0.001| -0.0126--0.0016              |
| Extension contact         | 0.0466   | 0.0275     | 0.010| -0.0650-0.2799               |
| Log of nonagricultural assets| 0.2677  | 0.2426     | 0.305| -0.0443-0.1419               |
| Log total income          | -0.7165  | 0.3464     | 0.017| -0.1468-0.0266               |
| Log total land            | -0.0090  | 0.0560     | 0.480| -0.06597-0.0310              |

* p < 0.10; ** p < 0.05; *** p < 0.01

Wald chi2(7)=13.21
Prob > chi2=0.0671
Pseudo R2=0.0764
Log pseudo likelihood = -67.313945
Factors influencing gendered intra-household allocation of land and capital assets in banana (Musa spp.) production: the case of Meru County, Kenya; Violet Nyabaro et al.

Table 10: Marginal effects (standard error) and significance levels of variables influencing intra-household wife allocation of capital assets in banana-producing households (n = 160) in March 2017 in Meru County, Kenya

<table>
<thead>
<tr>
<th>Variable</th>
<th>dy/dx</th>
<th>Std. error</th>
<th>P&gt;z</th>
<th>95% confidence interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sex of household head</td>
<td>-0.0042</td>
<td>0.0596</td>
<td>0.309</td>
<td>-0.2306-0.0729</td>
</tr>
<tr>
<td>Household size</td>
<td>-0.0724</td>
<td>0.1522</td>
<td>0.108</td>
<td>-0.1407-0.0057</td>
</tr>
<tr>
<td>Education of wife</td>
<td>0.1014</td>
<td>0.0500</td>
<td>0.020</td>
<td>0.0041-0.0271</td>
</tr>
<tr>
<td>Age of the wife</td>
<td>0.2572</td>
<td>0.1522</td>
<td>0.084</td>
<td>-0.0034-0.0026</td>
</tr>
<tr>
<td>Group membership</td>
<td>0.0183</td>
<td>0.0294</td>
<td>0.737</td>
<td>-0.0916-0.0648</td>
</tr>
<tr>
<td>Access to extension</td>
<td>-0.0244</td>
<td>0.0062</td>
<td>0.001</td>
<td>-0.1801-0.0508</td>
</tr>
<tr>
<td>Log nonagricultural assets</td>
<td>-0.1897</td>
<td>0.1020</td>
<td>0.057</td>
<td>-0.1235-0.0087</td>
</tr>
<tr>
<td>Log livestock value</td>
<td>-0.2211</td>
<td>0.1259</td>
<td>0.065</td>
<td>-0.0129-0.1141</td>
</tr>
<tr>
<td>Log Off-farm income</td>
<td>-0.0414</td>
<td>0.0184</td>
<td>0.021</td>
<td>-0.0302-0.0009</td>
</tr>
<tr>
<td>Log of total land</td>
<td>-0.0416</td>
<td>0.0189</td>
<td>0.019</td>
<td>-0.0364-0.0047</td>
</tr>
</tbody>
</table>

* p < 0.10; ** p < 0.05; *** p < 0.01

Wald chi2(10)=65.8
Prob > chi2=0.000
Pseudo R2=0.3471
Log pseudo likelihood = -8.2262506

The only significant factor with a different direction of influence was the value of non-agricultural assets (p<10%). This factor negatively influenced capital assets allocation of the ‘wife.’ It is most likely that households that already have higher values of non-agricultural assets are already regarded as well endowed with capital assets and therefore this factor is not a key driver for ‘wife’ allocation of assets needed for banana production. There are two other variables worth mentioning here: access to extension and age of wife. Access to extension did not have any significant influence in the land allocation model, however, it had a significant, positive influence on ‘husband’ allocation of capital assets (p < 10%) and a negative influence on ‘wife’ allocation of capital assets (p < 1%). These results are likely associated with the fact that extension services in the study area target mainly male members of the households as we have already explained in the descriptive statistics. In the capital assets modelling, the age of the wife had a significant, negative influence on ‘husband’ capital assets allocation (p < 1%) and this differs from what was seen in the land allocation modelling. This may be because capital assets in banana production are normally allocated to older children in the household as women (and men) age. Total land owned by a household had a negative influence on ‘wife’ capital assets allocation (p < 5%) (Table 4, bottom). This may be mainly because in the traditional African society, land ownership is a man’s affair and a wife is not empowered to negotiate with her husband on land issues. In fact, findings from the focus group discussions and key informant interviews in the study area indicate that land is predominantly owned by the men and is rarely owned by women. This result is closely related to the results of the total household income variable. As expected, increased income positively drove ‘joint’ allocation (p < 5%) and reduced the likelihood of ‘husband’ allocation (p < 1%). However, increased off-
farm income had a different direction of influence, although it was tested only for ‘wife’ capital assets allocation due to model specification problems (i.e., multi-collinearity mainly). This factor was found to have a negative influence on ‘wife’ capital assets allocation ($p < 5\%$). This is mainly because husbands often spend off-farm income the way they want, including directly apportioning it to the farm activities. In most cases, there are no household discussions on the use of off-farm income earned by men. It is important to note that given the socio-cultural setting of traditional African society, it is easier for men to work outside the homestead compared to women who are burdened with household chores. Therefore, there is a high likelihood that a ‘wife’ does not access capital assets associated with banana production as off-farm income increases, since this kind of income solely belongs to men. For the same reasons, the values of livestock ($p < 10\%$) and non-agricultural assets ($p < 10\%$) negatively affected the ‘wife’ allocations to capital assets.

Access to agricultural extension had a positive effect on ‘husband’ capital assets allocation ($p < 10\%$) while it exhibited a negative effect on ‘wife’ capital assets allocation ($p < 1\%$). This may be because extension agents, as discussed above, mainly target husbands, who are also mainly the household heads, to deliver their messages to households. For example, a study undertaken by Miriti et al. (2014) in Kenya found that women have low access to extension services and even if they have high access, the benefits thereof are marginal and limited compared to those of their male counterparts.

Just like in land allocation analyses, group membership had a significant, negative influence on ‘joint’ allocation of capital ($p < 5\%$) for banana production. This implies that much of the capital assets remain with men who are also the main participants in group activities related to banana production.

The age of wife had a positive influence on ‘wife’ capital assets allocation ($p < 10\%$) and a negative influence on that of the ‘husband’ ($p < 1\%$). Similarly, years of formal education of the wife had a positive influence on ‘wife’ capital assets allocation in banana production ($p < 5\%$). These two factors are associated with human capital, and thus empowerment of the woman. Older wives and educated ones have a higher bargaining power and therefore have a higher likelihood of accessing household capital assets than younger wives and uneducated ones. This may also help explain why education of wife does not favour ‘joint’ allocation of capital assets.

**Conclusion and policy recommendations**

This paper investigated factors that influence intra-household resource (land and capital assets) allocations in Meru County, Kenya, a region that has experienced exclusion of women in the distribution of agricultural productive resources for many decades. From the study findings, we conclude that wealthier households, particularly through livestock ownership and high household income, have a higher probability of adopting ‘joint’ allocation compared to poorer households. Thus, diversification of banana production into livestock keeping and sustainable ways of increasing household incomes could increase intra-household equity in the sharing of land and the capital assets used for banana production in the study area.

The study showed that the age of the wife reduces the likelihood of ‘husband’ land and capital assets allocations. Thus, policy interventions geared towards ensuring equity in intra-household resource sharing should mainly target younger families and smaller households. Such targeting would be favoured by the fact that younger families are also small.

Since increasing years of education of the wife positively affects ‘wife’ land and capital assets allocations and since this is linked to human capital, it is important for female empowerment. Thus, if policy interventions
Factors influencing gendered intra-household allocation of land and capital assets in banana (Musa spp.) production: the case of Meru County, Kenya; Violet Nyabaro et al.

Included investments in the education of girls in the study area, there might be more women eventually benefiting from the intra-household allocation of land and capital assets in banana production.

One of the factors hindering ‘joint’ intra-household allocation of land and capital assets was membership in groups. Group membership, a proxy for social capital, favours allocation of land to ‘husband’. This implies that households with higher social capital do not value allocation of land and capital assets to married women. Although social capital has been identified in the literature as one of the drivers of rural economies, it may not be one of the solutions for achieving equitable intra-household distribution of land and capital assets in banana production in the study area.

References

Factors influencing gendered intra-household allocation of land and capital assets in banana (Musa spp.) production: the case of Meru County, Kenya. Violet Nyabaro et al.


A study on gender participation in post-production operations of selected fruits in Trinidad and Tobago

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This study was undertaken in Trinidad and Tobago as part of the project, ‘Enhanced Preservation of Fruits using Nanotechnology’, which focussed on pre- and post-harvest treatments for delayed ripening and post-harvest extension of shelf life of fruits. The purpose was to gauge the type of impact the project outcomes was likely to have on post-production operations for mango and papaya through increased availability of fruit for processing and the potential effect on gender participation in Trinidad and Tobago. Convenience sampling was used to collect data from six countries in Trinidad and Tobago. Retail outlets located along major roadways in Central and South Trinidad were surveyed. Additionally, phone surveys of processors (well-established processing plants and cottage industries) located in Tobago and in East, Central and South Trinidad were conducted. A structured questionnaire was administered to respondents at mini-marts, supermarkets and roadside parlours. Frequency counts and percentages were used to analyse the data collected. Four main activities were identified – i) the production of preserves in well-established processing plants and cottage industries, ii) the production of preserves in small-scale home units, iii) the distribution and sale of products from the processing plants and cottage industries, and iv) sale of products from home processing. Findings revealed that, in all cases, the production of preserves and other processed products from mango and/or papaya occurred alongside the production of preserves and snacks from other commodities, and that production was always linked to availability of the raw material for processing. In all cases encountered in the survey, preserved products from mango and papaya were made from unripe fruit. The major source of preserved fruit sold in retail outlets was well-established processing plants and cottage industries located across the island with smaller quantities coming from home processing. Retail outlet operators indicated that preserves were delivered to them via middlemen so that negotiations for sale occurred between the operator of the retail outlet and middlemen, with no input from processors. Most of the surveyed processing plants and cottage industries (71%) were owned and/or managed by men. Men were also predominant as middlemen in the collection and transport of preserves to retail outlets. Women were more likely to be the sole operators in retail outlets, particularly in roadside parlours (83%) and mini-marts (64%). The study also found that of the respondents interviewed, those engaged in home processing of mango and other fruits were all female, selling the preserved snacks in their own or family-owned roadside parlours. Given the survey results, it was concluded that the potential for increased utilization of mango and papaya fruit in preserved forms would be greatly enhanced by the project outcomes that resulted in increased availability of fruit in the unripe state. Further, this was likely to affect females more than males, since mostly females were sole operators in retail outlets, and were engaged in relevant post-production processing activities at the household level as well as in the sale of preserved products for increased household income.

Keywords: Gender participation, post-production operations, mango, papaya, preserved fruit products

In Trinidad and Tobago, as in the rest of the Caribbean Region, fruit production and utilization are important activities in the food and agriculture sector. Mango (Mangifera indica L.) and papaya (Carica papaya L.) are among the more popular tropical fruits and have become commercialized for national, and to a lesser extent, international trade, supplying domestic municipal markets, supermarkets and roadside parlours, with large volumes being traded and consumed in the ripened state. These fruits are produced in backyard gardens, mixed fruit orchards and on small-scale agricultural holdings. Mango is a seasonal fruit while papaya is readily available, albeit sometimes in smaller quantities, throughout the year.

Popular mango cultivars produced include Julie, Starch, Vert/Long, Doux doux, Rose, Graham and Calabash (UWI 2010, 3). Papaya varieties produced include Red Lady, Tainung No. 1 and Tainung No. 2 (Trinidad and Tobago. MALMR 2008). In 2010, the Ministry of Food Production, Land and Marine Affairs (now Ministry of Agriculture, Land and Fisheries) estimated annual consumption of
mango and papaya to be 50 and 1,716 tonnes respectively (Trinidad and Tobago. MFPLMA 2011). National production supports domestic consumption as well as international, regional and a very significant domestic trade in processed products from these fruits.

The importance of the contribution of processed fruit to the domestic market cannot be over-emphasized. In 2011, the Food and Agriculture Organization of the United Nations (FAO) estimated that 90 per cent of tropical fruits produced worldwide is consumed domestically, 5 percent is traded as fresh fruits and 5 per cent is traded as processed products (FAO 2011). However, in some countries, a significant quantity of the domestic fruit production consumed is as processed products, with the processed fruit utilization arising out of necessity to deal with glut supplies of seasonally available fruit or to circumvent potentially high levels of post-harvest losses from extremely perishable fruit types. This is true of Trinidad and Tobago, where mango and papaya are largely consumed as fresh fruits but also form the basis of a very lucrative preserved fruit market, targeting children and young adults and serving as snacks popular at social gatherings, festivals and sporting events and available at mini-marts, roadside parlours and supermarkets. Additionally, many of these items become part of an informal “suitcase trade” supplying the demand of ethnic populations primarily in North America and Europe.

In Trinidad and Tobago, it is surmised that women play an integral role in the processing and retailing of snacks, whereas men are generally more involved in the transportation and distribution from processors to retail outlets. Given that women are more likely to participate in the production and sale of these items, the extent of their involvement needs to be determined in order to assess its relevance and potential contribution to income generation and poverty alleviation in rural and single-parent households led by women.

**Theoretical perspectives**

Buckland (1993) describes gender participation as the roles and activities of men and women according to traditions and beliefs of a particular culture. The lack of awareness of specific gender roles in and contributions to farming and food security is known as “gender blindness” (FAO 1998). Where men may be dominant in agricultural production activities, women tend to be more active than men in some of the post-production operations along the agricultural value chain (Sarku 2016; Adefalu, Adekunle and Komolafe 2016). The theoretical perspective of the gender division of labour for agriculture is that the women in rural agrarian societies would specialize in activities centred on the household whereas the men are the ones more engaged in business activities outside of home (Alesina, Giuliano and Nunn 2011). The literature documents that the roles of men and women are constantly in flux depending on the socioeconomic condition of the rural communities. With the continuous marginalization of rural, agricultural communities especially in developing and less developed countries (Admassia and Abebaw 2013; Cecchini and Scott 2003; Ghimire 2002; Ghattas et al. 2013), rural women are now seeking more viable options to source income.

The literature shows that women in agrarian societies are mostly responsible for ensuring household food security and food sovereignty whereas, men in agrarian societies more focus on diversifying their business operation, investing in new business opportunities and expanding their scope of operations (FAO 1998). Due to the productive and household roles of women in agrarian societies, home based processing and cottage industries are now popular income earning activities for many rural women. A study conducted by Rugumamu (2009) showed women were more involved in processing and packaging maize for home storage in Eastern Tanzania. Harris-White (2005) highlighted
that women primarily manage household retailing as a post-harvest operation for rice in South Asia but still depend on men for wholesale and middlemen services. Adeyemi (2010) stated that women were primarily involved in processing and storage of primary agricultural produce, but it is often viewed as household responsibility rather than a productive role, especially in the patriarchal household.

Scholarly work on women in agriculture in the past twenty years has focused on documenting the activities of women in relation to men extending beyond the traditional views of the gender divisions of labour (Kanji, Tan and Toulmin 2007). As societies globally are more gender sensitive, the changing agricultural policies, globalization forces and technological advancements are all re-shaping the social and economic landscape for rural men and women.

This study was undertaken in Trinidad and Tobago as part of the project, ‘Enhanced Preservation of Fruits using Nanotechnology’, which focussed on pre- and post-harvest treatments for delayed ripening and post-harvest extension of shelf life of fruits. The study was conducted to ascertain gender participation in the operations associated with production, procurement and sale of preserved products from mango and papaya. The main purpose was to gauge the types of impact the anticipated project outcomes: i) increased time of fruit retention on the trees, ii) reduced post-harvest losses through increased shelf life, iii) longer period of fruit availability in the unripe state through increased time to ripening, were likely to have on post-production activities and specifically, to identify from a qualitative perspective, which gender was more likely to be affected in the post-production phase of mango and papaya.

Materials and methods

This study was carried out in the rural communities of eastern, central and south Trinidad, as well as in south-west Tobago during November 2016. Rural areas were targeted rather than urban areas since it was anticipated that the type of operations described in the study were more likely to be found in rural areas. The sampling framework adopted was convenience sampling. Convenience sampling is a non-random sampling method that relies on data collection from individuals who are easily accessible and available to participate in a study. There is no inclusion criteria identified prior to the selection of participants, who are typically interviewed wherever they are located (Research Methodology 2017). Convenience sampling allows ease of research and data are collected fairly quickly. However, this type of sampling may not represent the population as a whole and may be vulnerable to selection bias (Research Methodology 2017).

Six counties in Trinidad – St. George East, Caroni, Nariva, Mayaro, Victoria and St. Patrick, and one county in Tobago – St. Andrew, were surveyed. Field surveys of retail outlets started in Chaguanas and proceeded south to rural communities in the Trinidad counties identified above. Phone surveys of well-established processing plants and cottage industries in St. George East, Caroni and St. Andrew were also conducted. Processors were selected based on the fact that their products were sold at the surveyed retail outlets. All clearly visible retail outlets on or near to the major roadways were targeted. Total numbers were small as expected for small island states with small populations such as Trinidad and Tobago. A total of 14 processing plants and 117 retail outlets were surveyed. Retail outlets consisted of 52 mini-marts, 41 supermarkets and 24 roadside parlours.
In this study, a mini-mart (also known as a convenience store) was defined as a small retail business that stocked a variety of products including snacks, baked goods, beverages, toiletries, newspapers and over-the-counter drugs. Some mini-marts formed part of a petrol station establishment. A supermarket was defined as a retail store that primarily stocked fresh and processed foods, along with some household items and small-scale appliances. A roadside parlour (also called a “tuck shop”) was defined as a downsized mini-mart which was strategically positioned along roadways to provide easy accessibility for commuters (or making it easily accessible to commuters). Some roadside parlours were located near to schools and stocked items such as bakery products, snacks, confections, juices and drinks.

Data were collected through a structured questionnaire designed with both open and closed-ended questions. Questionnaires were administered to prospective respondents who were willing to participate at the mini-marts, supermarkets and roadside parlours. Respondents were interviewed in order to identify i) the most common type of establishment where preserves made from mango and/or papaya were sold, and ii) the gender of key players in the relevant post-production activities related to mango and papaya – operation of retail outlets, sale of preserved fruits and procurement of preserved fruits. The term ‘operator’ was applied to the person in charge of day-to-day activities in the retail outlets, including vending and procurement. Processing plants and cottage industries were surveyed to identify gender differences in the ownership and/or management of these establishments. The expression ‘home processing’ as opposed to ‘cottage industry’ was applied to situations in which products were made by individuals as a household operation and offered for sale with no name applied to the establishment, no use of labels or approved packaging and no apparent conformity to processing regulations. The collected data were coded and electronically entered using the Statistical Package for the Social Science (SPSS) Version 20 software. With the non-random sampling framework, questionnaire design and variety in target populations sampled, the data collected were assigned as qualitative and interpreted as such. Trends, descriptive and frequency counts were used to assess the qualitative data in order to accomplish the primary objective of this study. Figured illustrations describing gender participation were used to highlight the findings and outline the participation of men and women in post-production activities for mango and papaya. The data were not conducive for any inferential statistical techniques and the study objective did not need this rigour of statistical analysis.

Results and discussion

Gender differences in ownership/management of processing plants and cottage industries

Preserves and other processed products from mango and/or papaya as well as from other commodities were made at well-established processing plants and cottage industries in Trinidad and Tobago. All the products identified were made from unripe fruit. It was found that production was always linked to availability of the raw material for processing. At the time of the survey, mango was abundant, so a greater quantity of mango preserves (than other fruit preserves) was processed and distributed to the retail outlets. Most of the surveyed processing plants and cottage industries (71%) were owned and/or managed by males (Figure 1), indicating that more men than women were likely to own and/or manage the well-established processing plants and cottage industries.
Gender participation in operation of retail outlets

Roadside parlours had the highest percentage of female participation as operators (83%), followed by mini-marts (64%) and supermarkets (51%). By contrast, male participation as operators was highest in supermarkets (49%) and lowest in roadside parlours (17%). It was also found that roadside parlours were mainly operated by one person (Figure 2).

These findings imply that a higher concentration of women than men in the research area saw the need to extend their income availability in order to support their families, so they had to take available jobs that were close to home. It was also interesting to note that women who were otherwise unemployed and unskilled, tended to open a roadside parlour and sell, among other items, fruit preserves that they made themselves to increase their income. The majority of mini-marts and roadside parlours were located near the operators’ homes because it was convenient to the women who were mothers to keep their babies and younger children close to them during the day.

The survey found that relatively equal numbers of males and females occupied supervisory positions in supermarkets in the sample. This reflected a positive change from known traditional roles and is possibly reflective of the rising prevalence of women employed in the food retail sector.

![Figure 1](image1.png)

Figure 11: Gender of owner/manager of surveyed processing plants and cottage industries.

![Figure 2](image2.png)

Figure 2: Gender participation in operation of retail outlets.
Gender participation in the sale of preserved fruits

Preserves made from mango and/or papaya were sold in mini-marts, supermarkets and roadside parlours. More females than males were involved in the sale of mango and papaya preserves in all retail outlets (Figure 3). Anecdotal evidence suggests that papaya and other fruits are usually processed to make preserves and snacks when mango is not readily available. All respondents in the study were involved in the sale of mango preserves at their respective outlets, reflecting the significance of availability in their determination of which fruit was processed. However, not every respondent sold preserves made from papaya (16% males and 20% females) and other commodities (58% males and 68% females). Other fruit preserves and snacks sold at retail outlets included those made from other locally produced fruits. Generally, women’s participation was higher than men’s in the sale of mango, papaya and other fruit preserves (Figure 3).

With respect to the packaging of fruit preserves, the majority of respondents (97%) sold mango preserves in transparent, sealed plastic bags. Labels were not always used and were usually absent from packages of products that were prepared at the household level. A small percentage of products (3%) was sold wrapped in brown or waxed paper, again reflective of the level of the operation. Of the respondents who sold papaya preserves, 91% used transparent, sealed plastic bags. Others used paper strips which were similar to those used for mango preserves.

Gender participation in procurement of preserved fruits

The respondents who sold preserves at retail outlets indicated that they either made the preserves at home, or procured them from middlemen. Middlemen were defined as independent distributors who typically acted as the intermediary between the fruit processors and retail outlets.

The respondents who processed fruits into preserves (all females) indicated that they did the processing activities at their homes and then sold the home-made preserves at their respective retail outlets. This information suggests that women, particularly housewives, are the ones who engage in fruit processing at home, and sell the products to school children and adults who conveniently stop at the roadside parlours and mini-marts, located along the main roads.

Figure 3: Gender participation in the sale of preserved fruits at retail outlets.
Note: * = Multiple responses
The operators of retail outlets indicated that all middlemen who supplied them were males. This supported the notion that females were less involved in this activity because they preferred to stay close to home to conduct home-related activities including the supervision of minor children. Therefore, the role of middlemen is supportive of women who serve as operators of retail outlets since their procurement of items for sale is largely through that avenue.

**Conclusion**

The study indicated that mango and papaya fruits were used to make preserves which were supplied to various retail outlets (mini-marts, supermarkets and roadside parlours) in Trinidad and Tobago. At the time of the study, mango preserves were the most popular fruit preserves sold in retail outlets particularly because mangoes were in season and abundantly available to processors. Production of preserves was done in well-established processing plants, cottage industries and household units. Most of the surveyed processing plants and cottage industries were owned and/or managed by males indicating that males are more influential in the financial decision-making when it comes to post harvest production. This finding is similar to the disposition of Damisa and Yohanna (2007) and Ogunlela and Mukhtar (2009) who postulated that men still maintain a significant control of financial resources and financial decisions.

The study also indicated that a greater number of women than men was involved in the sale of mango, papaya and other fruit preserves at all surveyed retail outlets. Female participation as operators was higher than men in the roadside parlours and mini-marts while in supermarkets, there was gender parity. This finding was similar to findings of Harris-White (2005) which identified a higher involvement of women in small retailing outlets for rice in South Asia. The majority of mango and papaya preserves was packaged in transparent and sealed plastic bags and distributed via middlemen to operators at the different retail outlets. Men were the main players in this activity (transportation and distribution) while mainly women were involved in home processing of fruits and the selling of fruit preserves in their respective places of business. The study findings correspond to the theoretical perspectives within the gender division of labour for agriculture outlined by Alesina, Giuliano and Nunn (2011), as the women observed in this study are seemingly more involved in post-production retailing around the household based on the convenience of maintaining household responsibilities whereas men are more engaged in post production activities away from the household.

The results obtained from this study suggest that the project will be useful to all operators who are involved in the post-production processing activities of fruits. Since fruit preserves, widely consumed by children and young adults in Trinidad and Tobago, are prepared from unripe fruit, the technologies used in the project will be expected to impact positively on the availability of raw material for production of these items. This, in turn, may provide the opportunity for income generation for operators in the post-production sector, especially women, since it has been shown that mostly females are engaged in relevant post-production processing activities at the household level and in the sale of preserved products for increased household income.

**References**

A study on gender participation in post-production operations of selected fruits in Trinidad and Tobago; Katrina Ammon-Aguillera et al.


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