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Research Article

Efficacy of Hexanal Field Spray on the Postharvest Life and Quality of Papaya Fruit (*Carica papaya* L.) in Kenya

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Papaya is a thin-skinned fruit that ripens and softens over a very short time, usually in 3 days, predisposing the fruit to physical damage and phyto-pathogen invasion even with careful handling further shortening postharvest shelf life. The objective of this study was to determine the efficacy of Hexanal, naturally occurring compound, on-farm spray, in managing the postharvest shelf life of papaya in two agro-ecological zones in Kenya. A formulation of Hexanal containing Tween 20 and ethanol was made by volume basis (v/v) and spray treatment at 1 and 2% in "Solo sunrise" and "Mountain" papaya cultivars. The experiment was a randomized block design with ninety-six plants per farm randomly selected. Spraying was applied at 30 days, 30 + 15 days, and 15 days to harvest time on mature green papaya. Control papaya fruits were sprayed with clean tap water as control. Data were collected on color changes and fruit retention on tree. The fruits were harvested when two to three yellow stripes were visible from the lower end of the fruits for postharvest analysis. Hexanal sprayed papaya fruits were retained for at least 13 days longer compared to the control fruits on tree. Hexanal treatment at 2% revealed an improved effect on managing papaya postharvest shelf life. All fruits treated with Hexanal significantly showed reduced rate of color break, softening, and enhanced extension of fruit shelf life by at least 6 days. Hexanal treatment also delayed ethylene and respiratory peaks by three days and showed no significant ($P \leq 0.05$) difference in the levels of total titratable acidity and total soluble solids. The results of this study indicate that Hexanal applied as a preharvest spray on mature green "Solo sunrise" and "Mountain" papaya cultivars grown in Kenya, is effective in prolonging shelf life and postharvest quality.

1. Introduction

Papaya is a leading priority fruit crop grown in many parts of Kenya for home and commercial use. The plant takes approximately 9 months from seed to initial flowering in most tropical climates. Fruits take three to four months from flower to full maturity on trees. Harvesting is done when one or two color stripes appear from the distal end of the fruit [1]. Under proper crop husbandry with good agricultural practices, a papaya farmer can enjoy the benefits of their labor after 12 or 13 months from initial planting. Profitable revenues can continuously be enjoyed for up to 5 years. However, papaya fruit is prone to damage and has a short postharvest life of less than a week under tropical weather. Papaya is thin skinned and usually soften at a faster rate of less than three days during ripening [2]. Papaya fruit ripening and softening involves breakdown of starch into sugars which gives the fruits tastes, loss of cell integrity making the fruit soft and watery, and major biochemical changes [3].

The desired changes in papaya fruit therefore should be realized and managed using safe and sustainable postharvest technologies. Some of these technologies have been studied and utilized overtime [4–10]. Nonetheless, these attempts still leave a substantial gap by their limitations including the development of off-flavors, abnormal coloring of fruits, and hindrance of essential volatiles from fruits [11, 12].

This study involved the investigation of the effects of a formulation of Hexanal as an alternative organic compound for potential use as a spray to manage the preharvest and postharvest life of papaya fruits in Kenya. Hexanal is a natural compound extracted from plants and is also generally regarded as a safe compound for use in food additives and has been approved by FDA [13]. A corresponding study on Hexanal dip has successfully been conducted and published [14]. Hexanal exists naturally in trace in most plants including grass, where it has been associated with the characteristics green flavor perceived when a plant tissue is wounded [15]. It is a safe and approved food additive [13]. It leaves no trace in plant tissues in 48 hours [16], completely broken down to CO_2 and water in animals through the TCA cycle [17]. Previous studies have been conducted in apples [11], pears [18], strawberry, peach, nectarines and cherries [19, 20], banana [21], and in papaya dip experiments [14], where it has been reported to enhance the shelf life of these fruits. Hexanal is proposed to work by inhibition of phospholipase *D* enzyme (PLD) which initiates membrane degradation [22]. The activity of PLD is reported toward fruits maturity. However, no study on Hexanal spray has been conducted in papaya fruits in Kenya or in any other part of Africa.

2. Materials and Methods

2.1. Study Site. Two papaya farms were identified in Meru and Machakos counties representing agroecological zones (AEZs) II and IV in Kenya, respectively. In Meru, a papaya farm growing both "Solo sunrise" and "Mountain" cultivars was picked in Ithitwe location 0.202493°S, 37.825214° E. The selected farm is in AEZ II which receives an average rainfall of 1300 mm per annum, well distributed throughout the year with an average temperature of 21°C. The second farm was selected in Machakos county, Matuu location, which lies 1.147699° S, 37.594130° E. This second farm lies in AEZ IV which receives an average rainfall of 850 mm per annum with an average temperature of 28°C and two dry seasons.

2.2. Selection Criterion. The two counties were selected because they are among the leading in papaya production in Kenya. The farms in AEZ II and IV were selected on the basis of availability of "Solo sunrise" and "Mountain" cultivars of papaya in substantial quantities, ease of accessibility, farmer's willingness to participate in the study, the farmers' ability to carry out good agricultural practices (GAP), and the farmers' information on the different varieties he/she grows. The two cultivars are the most preferred varieties for local consumption and export market in Kenya. "Mountain" types of papayas are least affected by papaya disease, although the "Solo sunrise" types are highly marketable and the most preferred for the export market.

2.3. Experimental Design and Treatment. A formulation containing Hexanal as the active ingredient was made at two concentrations of 1 and 2% and applied on-farm papaya as a preharvest spray. In each farm in Machakos (AEZ IV) and Meru (AEZ II), papaya plants with substantial fruits were tagged using stings with unique color codes for easy identification. "Mountain" papayas were tagged with a blue string and "Solo sunrise" varieties tagged with a green string in a randomized complete block design (RCBD). The fruits were monitored twice every week on Mondays and Thursdays for changes in color and fruit retention on trees. Target fruits were mature green papaya on the tree at three timings of 30 days, 30 + 15 days, and 15 days to harvest time. The papaya samples were then harvested, sorted, and packed in cartoon boxes and brought to the laboratory at Jomo Kenyatta University of Agriculture and Technology (JKUAT) in Juja, Kenya. A sum of 14 treatment combinations for sprayed samples included control (tap water spray), 1% Hexanal spray at 30 days, 1% at 30 + 15 days, 1% at 15 days, 2% at 30 days, 2% at 30 + 15 days, and 2% at 15 days of harvest per variety. A total of 192 papaya plants were used for the whole study.

2.4. Experimental Set-Up and Data Analysis. About 160 kg (480 fruits) of fruits were harvested from 48 papaya plants per AEZ (24 plants from each variety) and only 120 kg (360 fruits) were utilized. More fruits were harvested to compensate for any injury and allow for proper sorting of fruits used for the analysis in the laboratory. The fruits were then grouped by variety, absence of blemishes/injury, and by weight basis to ensure uniformity of fruit samples. The sprayed samples were harvested when most of the fruits revealed two to three yellow stripes from the distal end of papaya. The harvested fruits were left to undergo normal ripening under ambient room conditions (25 ± 1 C and RH 60 ± 5%).

Data were taken at intervals of 3 days for respiration rate, ethylene production rate, firmness, peel and pulp color, physiological weight loss, total soluble solids (TSS), total titratable acidity (TTA), beta-carotene content, and vitamin C content. The data were analyzed as a general analysis of Variance (ANOVA) with Genstat software version 15 and the means separated by LSDs.

2.5. Measurement of Physical Parameter

2.5.1. Fruit Firmness. A destructive sampling method was used where three fruits were randomly picked from each treatment lot of Hexanal sprayed fruits per cultivar and examined for firmness using a penetrometer (Model CR-100D, Sun Scientific Co. Ltd, Japan) fitted with an 8 mm probe. The probe was allowed to penetrate the fruit to a depth of 10 mm and fruit firmness expressed in Newton (N) [23].

2.5.2. Peel and Flesh Color. Color determination was done for each fruit examined for firmness (as above) using

Minolta color difference meter (Model CR-200, Osaka, Japan) calibrated with a clean white-and-black standard tile. The L^*, a^* and b^* coordinates were recorded, and a^* and b^* values converted to hue angle (H°) using the following formula:

Hue angle $(H^\circ) = \arctan(b/a)$, 180° was added for negative 'a' and 'b' values

2.6. Measurement of Physiological Parameters

2.6.1. Percentage Cumulative Weight Loss (% CWL). Five fruits were marked and monitored throughout the storage period for changes in weight using a digital weighing balance (Model Libror AEG-220, Shimadzu Corp., Kyoto, Japan). The initial weight (W_0) of each fruit was recorded and then the subsequent weight (W_1) measured at three day interval. Percent weight loss was then calculated using the following formula:

$$\%\,\text{CWL} = \left(\frac{W_\circ - W_i}{W_\circ}\right) * 100. \quad (1)$$

2.6.2. Ethylene Production and Respiration Rate. Papaya fruits from each lot (treated and control) were incubated in airtight transparent lockable containers of capacity 4500 ml with 1/3 head space and tightly sealed under room conditions (25°C, 55% R.H). The fruits were incubated for 1 hour and headspace gas collected using a 1 ml hypodermic syringe and then injected into a Gas chromatograph (Models GC-8A and GC-9A, Shimadzu Corp., Kyoto, Japan) for quantification of respiration and ethylene production, respectively. The gas chromatograph for carbon dioxide determination was fitted with a thermal conductivity detector (TDC) and a Poropak N column, while that for ethylene determination was fitted with an activated alumina column and a flame ionization detector (FID). The rate of carbon dioxide production (used to estimate respiration rate) was expressed as milliliters per kilogram per hour (ml/kg/hr.) at standard atmospheric pressure. Ethylene levels were expressed as microliters per kilogram per hour (μl/kg/hr.)

2.7. Measurement of Biochemical Parameters

2.7.1. Total Soluble Solids/°Brix/%Brix. Papaya pulp from each fruit used to evaluate fruits firmness was sliced out, and then placed in zip lock bags of size 6 by 4 and stored in a freezer at −20°C. At the end of all sampling period, 5 g of juice was squeezed from the papaya pulp using a clean muslin cloth for ripe fruits, whereas unripe papaya pulp was crushed using a pestle and mortar. A Hanna digital handheld refractometer (Model HI 96801, USA) was used to determine the TSS and expressed as % brix.

2.7.2. Total Titratable Acidity. The TTA was determined through titration where 5 g of fruit pulp was macerated and diluted with 20 ml of distilled water. Ten milliliters of the diluted solution was obtained, mixed with three drops of phenolphthalein indicator (colorless in acid medium) for titration using 0.1 N sodium hydroxide with constant shaking. The reaction end point was the appearance of a faint pink color that persisted for about 30 s. The titer volume was then recorded, and the results were expressed as percent citric acid content (titratable acidity) of fruit juice [24].

2.7.3. Ascorbic Acid/Vitamin C Content. Two to three grams of papaya pulp from the stored samples (as described for TSS) were weighed and extracted with 0.8% meta-phosphoric acid (MPA) under subdued light conditions. The extract was made to 25 ml of juice and centrifuged (Kokusan H-200, Tokyo Japan) at 100 revolutions per minute at 4°C for 10 min. The supernatant layer was extracted using a 15 ml syringe and filtered into plastic vials through 0.45μ microfilters. The samples were then set as a postrun in HPLC machine (Model LC-10AS, Shimadzu Corp., Kyoto, Japan), where 20 μL of the filtered sample was automatically injected into the HPLC machine on the same day of extraction. HPLC analysis was done using a C18-4D column and Shimadzu UV-VIS detector. Various concentrations of ascorbic acid standards were prepared at 10, 20, 40, 60, 80, and 100 ppm and a blank containing only degassed MPA and used to obtain a standard calibration curve. The mobile phase was 0.8% MPA, at 1.2 mL/min flow rate and a wavelength of 266.0 nm [25]. The amount of ascorbic acid was calculated using the standard vitamin C concentration regression curve obtained with the standards as shown in the following equation:

$$\text{ascorbic acid}, \left(\frac{\text{mg}}{100\,\text{ml}}\right) = \left(\left(\frac{\text{peak area from graphs}}{y}\right) * \left(\frac{\text{dilution volume}}{\text{sample weight (g)}}\right) * \left(\frac{100}{1000}\right)\right), \quad (2)$$

where y = calibration coefficient obtained from the standard regression curve when y-intercept is zero.

2.7.4. Beta-Carotene Content. Beta-carotene was analyzed using ultraviolet (UV) spectrophotometry as described by Rodriguez-Amaya and Kimura [26]. About 2 g of the stored papaya pulp was quantitatively transferred to a pestle and mortar and ground with acetone, and the extract is transferred to a 100 ml volumetric flasks. This was repeated until the sample gave no color in acetone. Partitioning was done using 25 ml of petroleum ether in a separating funnel. 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 channeled out to leave the upper layer mixture of carotenoids and petroleum ether. This was then transferred to a 25 ml volumetric flask through a funnel and filter paper with anhydrous sodium sulfate to remove water from the petroleum carotene mixture. All extractions were done under subdued light conditions. Standards at 0, 2, 4, 8, 10, 20, 40, 60, 80, and 100 ppm were also made from a freshly prepared beta-carotene standard 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). Beta-carotene content was determined using the following equation:

$$\text{carotenoid contents}\left(\frac{\mu g}{g}\right) = \frac{A \times V\,(ml) \times 10^4}{A_{1cm}^{1\%} \times P\,(g)}, \quad (3)$$

where A = absorbance, V = total extract volume, P = sample weight in grams, and $A_{1cm}^{1\%} = 2592$ (β-carotene extinction coefficient in petroleum ether).

3. Results

3.1. Firmness. The firmness of the papaya continued to drop consistently with significant ($P < 0.05$) differences between the initial day to the third day in storage. Hexanal spray treatment at 2% for 30 + 15 days showed a reduced rate of softening (Figure 1). "Solo sunrise" variety responded better to Hexanal treatment compared to "Mountain" cultivars for all levels of treatment with a firmness advantage of 44.5 N (80% firmness) compared to 39.8 N (63.4% firmness), respectively, by the third day of storage. This translated to 16.6% advantage in varietal papaya firmness in AEZ II. Hexanal application at 2% for 30 + 15 days improved firmness of the papaya by 88.9% (58.5–52N) in "Solo sunrise" cultivar compared to control fruits 15.2% (58.5–8.9 N) in AEZ IV. Overall, Hexanal spraying of on-farm papaya contributed to a 38% gain in fruit firmness.

3.2. Peel Color. Hexanal spray revealed a significant ($P < 0.05$) delay in the rate of color break for sprayed papaya fruits. Peel hue gradually and uniformly dropped under ambient (25°C, 55% R.H) room conditions as papaya skin color changed from green (120°) to lime (90°) to yellow (60°) and then amber (50°) across the 18 storage days (Figure 2). Fruits sprayed at 2% Hexanal for 30 + 15 days changed color from green hue of 127.5° to a yellow at 64.5°. All sprayed papaya fruits were preserved at lime color hue above 90° between days 3 and 12 in storage. On the contrary, 90% of the control batch, comprising 18 fruits had completely turned yellow with a hue angle below 90° for all varieties after the sixth day of storage (Figure 2). The end stage for all fruits was marked by a hue angle approximately above 55° and firmness above 1N. Hexanal effect in "Mountain" cultivars contributed to a less gradual peel color break compared to "Solo sunrise" cultivars regardless of the AEZ. However, there was no significant difference among the treated fruits in the rate of color break between the two varieties and the two agroecological zones studied.

3.3. Pulp Color. The intensity of red pulp color continued to increase in papaya as the fruits ripened with a steady drop in hue angle over a narrow range from 86° (unripe) to 48°(fully ripe) across the 18 storage days (Figure 3). Hexanal treatment significantly ($P < 0.05$) delayed colored changes within the first 6 days under ambient room conditions (Figure 3). However, no clear trend was observed for the effect of various concentrations of Hexanal in the two papaya varieties or between the two AEZ. The rate of pulp color change was more stable compared to the peel color break. It was also observed that the control fruits and papaya treated with Hexanal dosage of 1 or 2% at 15 days developed a watery pulp by day 9 of storage, phenomenon that lowered their hue angle reading to below 60°. In AEZ IV, "Solo sunrise" papaya recorded the lowest pulp hue angle reading to 47.7° compared to less watery pulp in fruits with Hexanal applied at 30 days (53.6°) and 30 + 15 days (58.9°) to harvesting. Beyond day 12, the pulp firmness was below 1N for all fruits. However, the sprayed fruits had a more solid pulp and a higher hue angle above 53° for all treatment combinations of Hexanal spray and 30 days and 30 + 15 days.

3.4. Percent Cumulative Weight Loss (% CWL). The total % CWL consistently increased in all fruits as they ripened (Figure 4). Papaya fruits from the cooler AEZ II lost more weight compared to fruits from the hotter AEZ IV. A significant ($P \leq 0.05$) difference was revealed in papaya treated with different concentrations of Hexanal. Sprayed samples depicted a reduced rate of total weight loss compared to their controls. A mean difference of 10% was noticed in all Hexanal sprayed papaya compared to the tap water sprayed control samples. The sprayed fruits had 10% less cumulative weight loss than the untreated fruits (Figure 4). Hexanal spray was more effective in reducing % CWL in "Mountain" papaya compared to "Solo sunrise."

3.5. Respiration Rate/CO_2 Evolution Rate. Hexanal spray had a significant ($P \leq 0.05$) effect on the rate of respiration, revealing a decreased level of CO_2 evolution (Figure 5). Varietal and AEZ differences were observed. Papaya from AEZ II produced more CO_2 compared to those from AEZ IV (Figure 5). Overall, "Solo sunrise" cultivars produced more CO_2 at a peak of 23.33 ml/kg/h (AEZ II) and 18.67 ml/kg/h (AEZ IV) compared to "Mountain" varieties that peaked at 23.78 ml/kg/h (AEZ II) and 14.65 ml/kg/h (AEZ IV). Hexanal treatment delayed the respiratory peak by 3 days. Control fruits produced more CO_2 on the third day, whereas the treated papaya had peak CO_2 on the sixth day. However, no significant difference was noticed between the controls and fruits sprayed using 1% Hexanal at 30 days (Figure 5). The respiratory peaks occurred at full yellow peel color (H°<90°) in both varieties (Figures 2 and 5).

3.6. Ethylene Evolution Rate. Different concentrations of Hexanal spray showed a significant ($P \leq 0.05$) effect on the rate of ethylene evolution as papaya ripened following a climacteric pattern (Figure 6). Ethylene peaks followed a similar behavior as respiratory peaks with Hexanal treatment at 2%_30 days and 2%_30 + 15 days yielding lower volumes of ethylene. A preharvest spray at 30 days to harvest both at 1 and 2% significantly produced lower amounts of

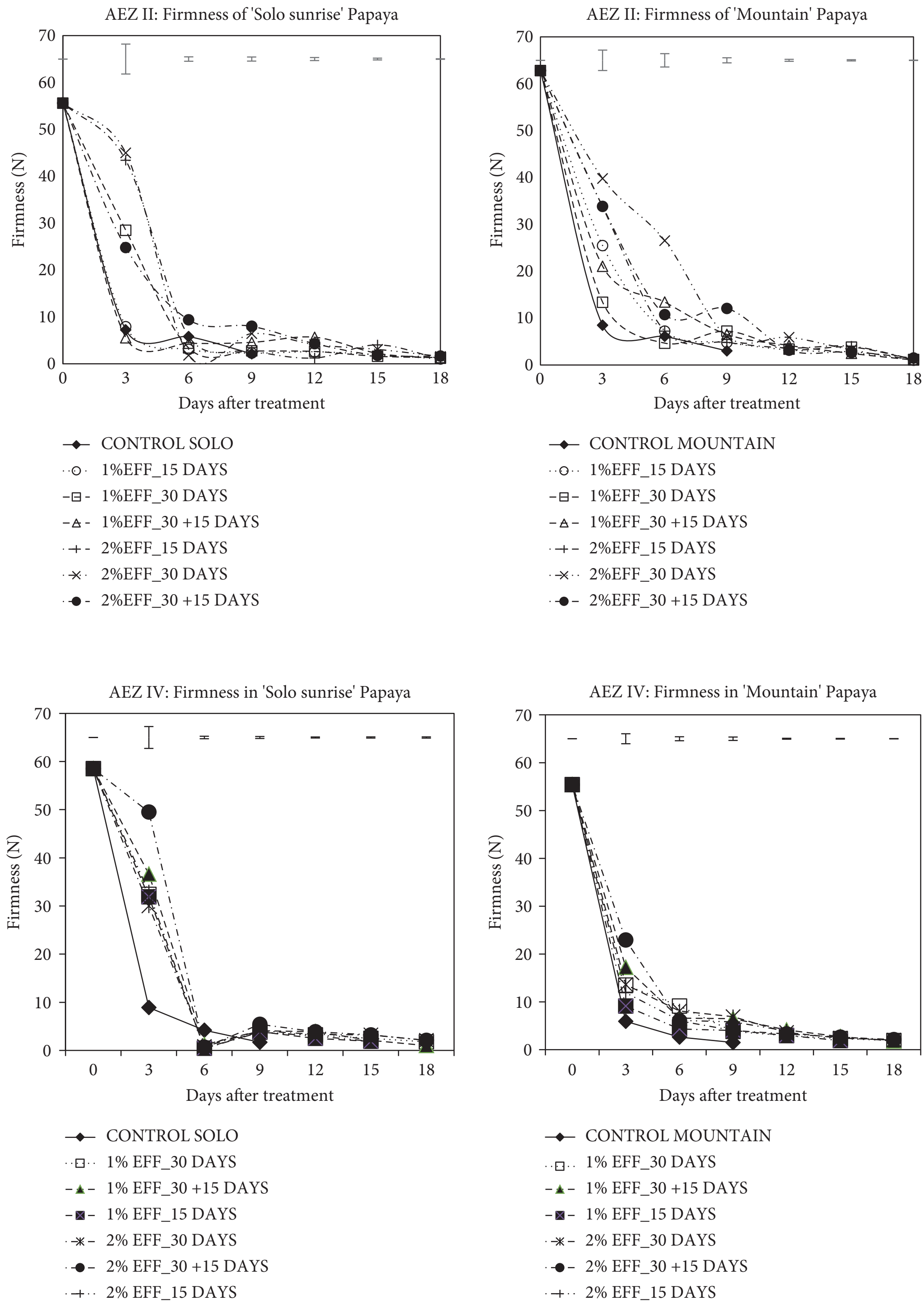

Figure 1: Papaya firmness N for Hexanal sprayed fruits from Machakos and Meru counties. Top bars represent LSD at 0.05.

ethylene irrespective of the variety and AEZ compared to the control fruits. Highest ethylene peak was noticed in control fruits at 2.52 μl/kg/hour in “Solo sunrise” cultivars from AEZ II. Fruits from AEZ II consistently produced more ethylene compared to those from the hotter AEZ IV.

3.7. Total Soluble Solids. The TSS content in papaya fruits increased with ripening across the storage period of 18 days for papaya fruits. Despite the lower levels of TSS in papaya sprayed with Hexanal, overall analysis of variance did not reveal any significant ($P < 0.05$) difference between

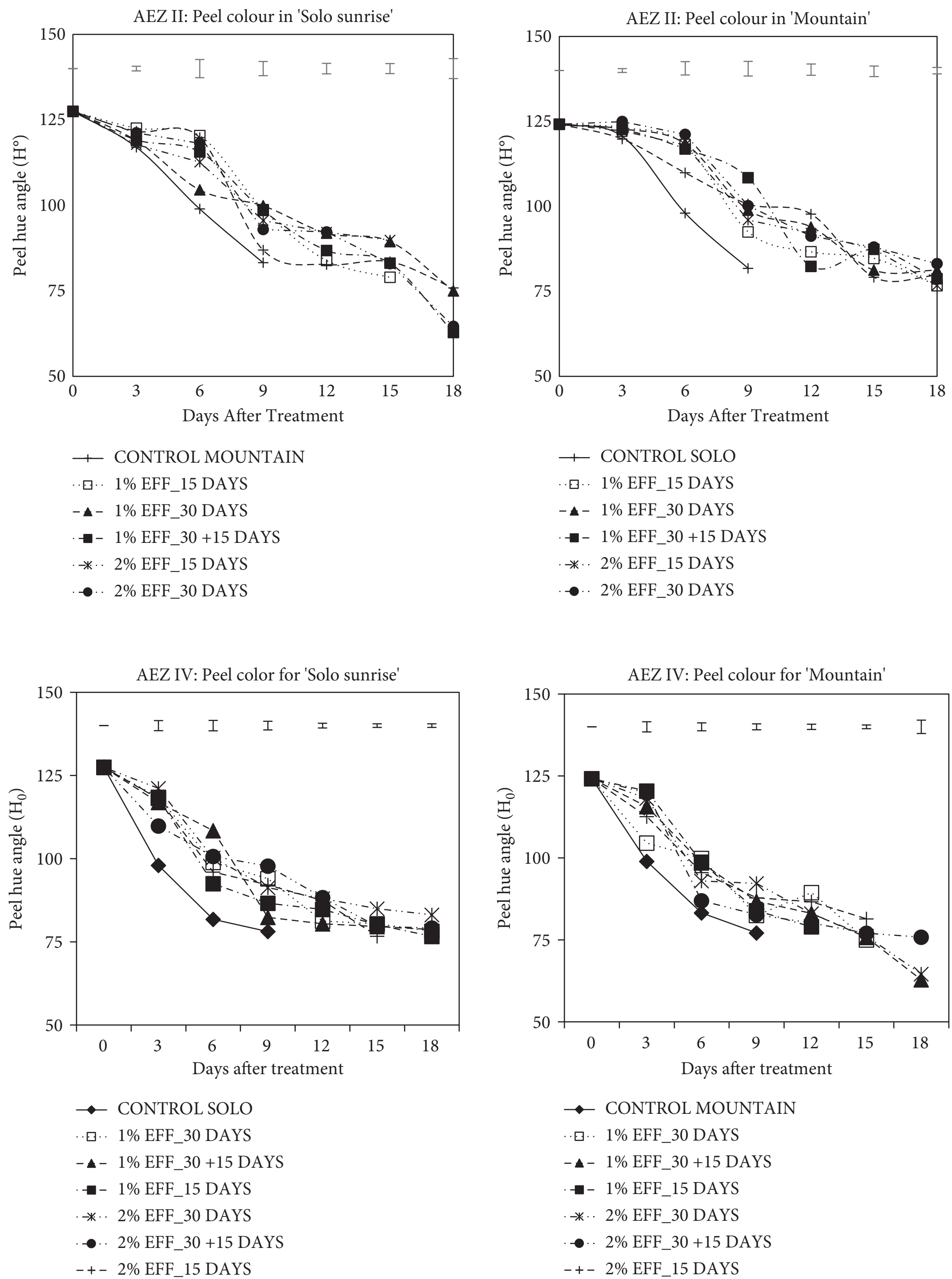

Figure 2: Papaya peel color (H°) of Hexanal sprayed fruits from Machakos and Meru counties. Top bars represent LSD at 0.05.

the field sprayed and control papaya fruits. A varietal difference was observed where "Mountain" variety had higher TSS level compared to "Solo sunrise" (Figure 7). However, the peak level in the two cultivars was the same in AEZ II, whereas the highest, 12.4% TSS levels were observed in "Mountain" papaya from AEZ IV in control fruits.

3.8. Total Titratable Acidity. A preharvest Hexanal spray on papaya fruits did not have any significant ($P < 0.05$) effect on the % TTA levels (Figure 8). Percent TTA increased up to a peak of 0.13% in AEZ II and 0.15% in AEZ IV, and then declined gradually to 0.08 and 0.07%, respectively (Figure 8). The overall trend revealed a general decline in the TTA levels over the storage period. "Solo sunrise" variety had higher

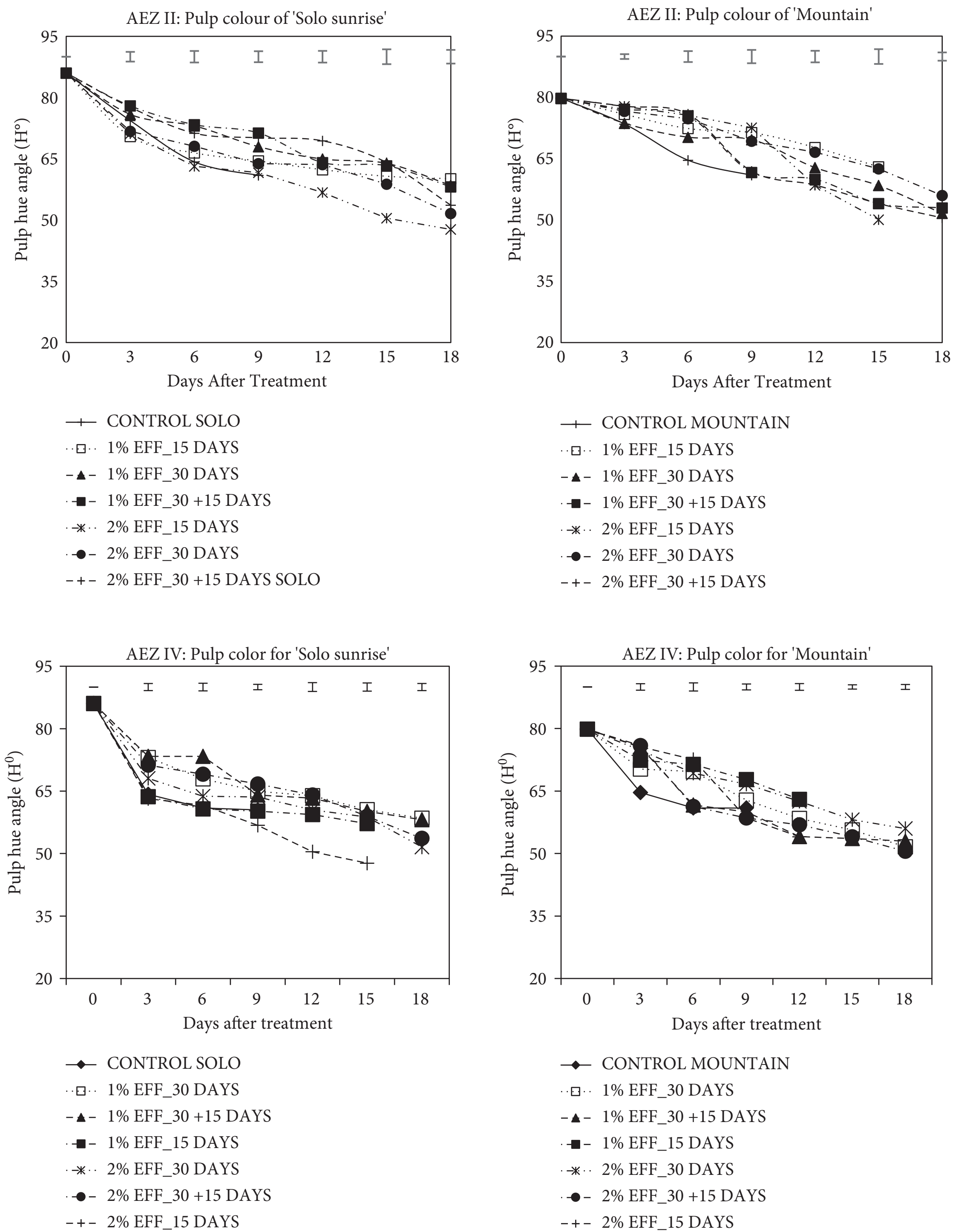

Figure 3: Papaya pulp color (H°) for Hexanal sprayed fruits from Machakos and Meru counties. Top bars represent LSD at 0.05.

levels of % TTA compared to “Mountain” papaya across the 18 days storage period, with the highest values observed in AEZ IV. Percent TTA trend also seemed to mimic the climacteric and respiratory peaks.

3.9. Beta-Carotene. The amount of beta-carotene in papaya pulp increased with ripening gradually and consistently throughout the 18 days storage period. Hexanal treatment did not show any significant ($P < 0.05$) impact on the concentration of beta-carotene in AEZ II (Figure 9). However, zone of production had a significant effect on the concentration of carotenoids, with fruits from AEZ IV having lower levels (Figure 9).

3.10. Ascorbic Acid (Vitamin C). Vitamin C levels declined gradually over the storage period in untreated and Hexanal

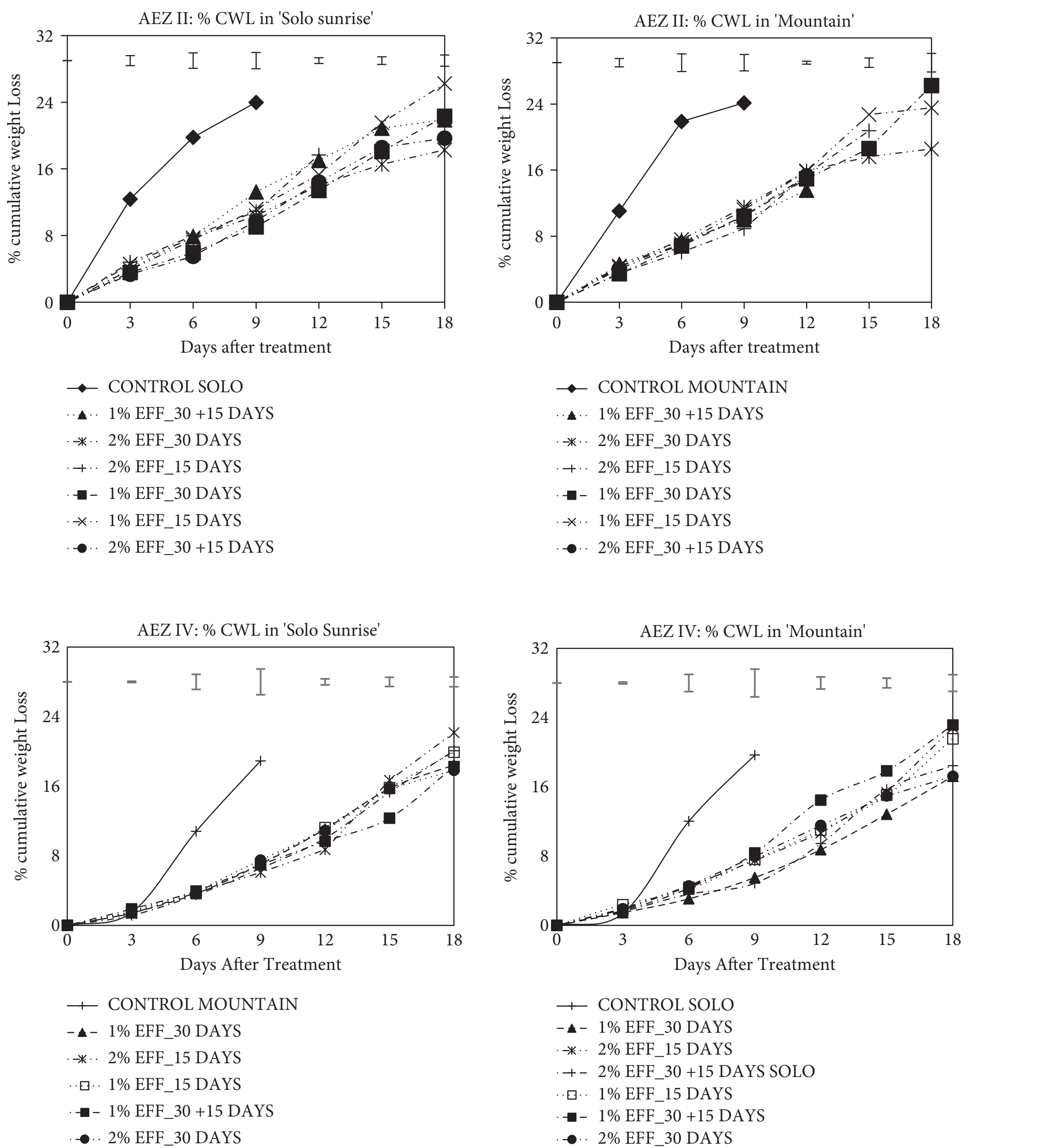

Figure 4: Papaya % cumulative weight lost for Hexanal sprayed fruits from Machakos and Meru counties. Top bars represent LSD at 0.05.

treated papaya fruits (Figure 10). Hexanal treatment significantly ($P < 0.05$) reduced the rate of vitamin C decline in fruits sprayed at 2% Hexanal for 30 + 15 and analyzed for 18 days during the ripening period. Vitamin C ranged from 78.7 to 32.1 mg/100 g in "Mountain" papaya and from 73.1 to 28.0 mg/100 g in "Solo sunrise" with higher means in fruits from the hotter and drier AEZ IV (Figure 10).

4. Discussion

Papaya is a delicious tropical and priority fruit in Kenya that continues to earn the country good revenues through export. It is one of the most delicate and thin-skinned [2] fruit whose postharvest management still poses a challenge leading to considerable losses. Papaya fruit consumption and preference to other tropical fruits is generally affected by the availability of quality fruits constrained by proper and timely harvesting. Fruits utilized in this study were harvested at peak maturity on the tree when two to three stripes of yellow color were seen from the distal end of the fruit [1]. This was also done to allow the papaya fruit to ripen normally in ambient room conditions (25° and 55% R.H) and to also ensure taste and sweetness were not affected [1].

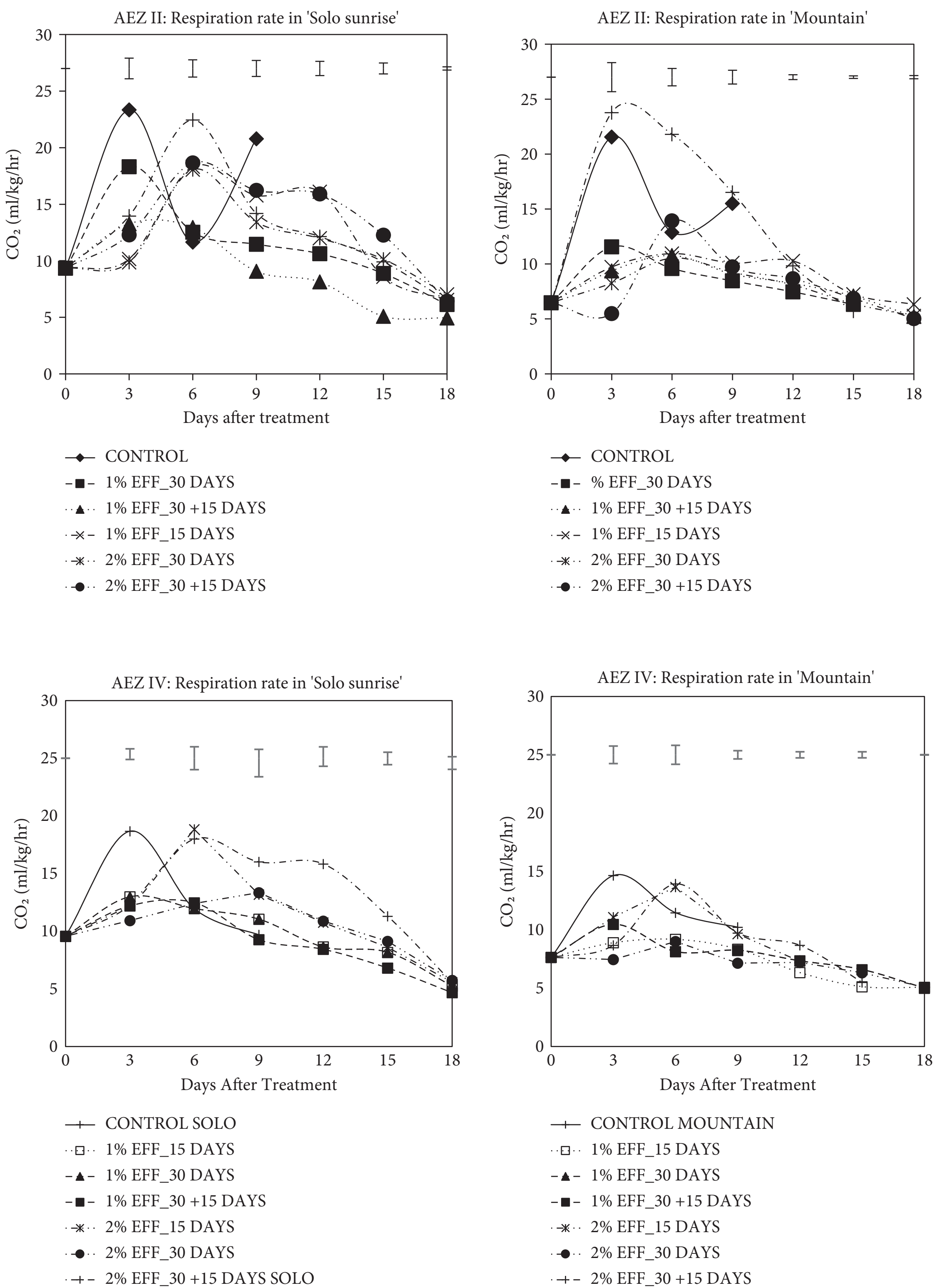

Figure 5: The rate of respiration/Co_2 evolved from ripening papaya fruits treated with Hexanal spray from Machakos and Meru counties. Top bars represent LSD at 0.05.

The utilization of papaya fruit is most often judged subjectively by the perceived fruit firmness. Consumers tend to avoid overripe fruits on the basis of color and degree of tissue softness. Papaya fruits sprayed with Hexanal revealed a less watery pulp with comparatively greater firmness strength in Newtons per mm of fruit tissue. For instance, papaya fruit ("Solo sunrise" and "Mountain" cultivars) firmness treated with Hexanal formulation using 2% spray at

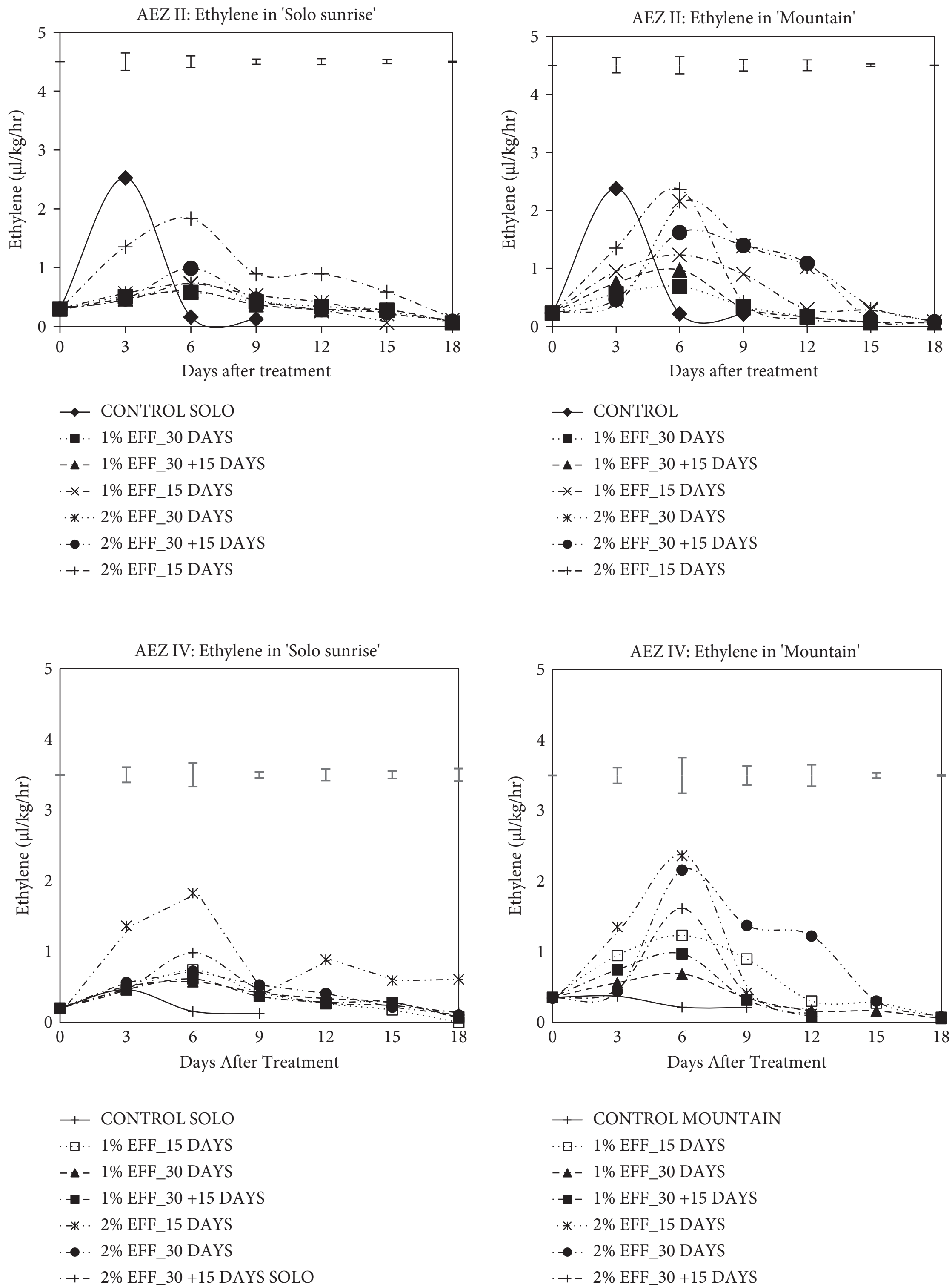

Figure 6: The rate of ethylene evolution from ripening papaya fruits treated with Hexanal spray from Machakos and Meru counties. Top bars represent LSD at 0.05.

30 + 15 days were enhanced by up to 38%. Hexanal seemed to have reduced the rate of cell wall disassembly and altered the internal pressure, thereby preserving cell integrity [27]. The observed slow softening could be associated with Hexanal inhibition of phospholipase *D* (PLD) enzyme that is responsible for the degradation of the cell wall [20]. The contribution of Hexanal in other activities associated with fruit softening, including the depolymerizing of the pectin chains that hold the cell membranes and the cell wall intact [28], could further be explored. In the current study, it was

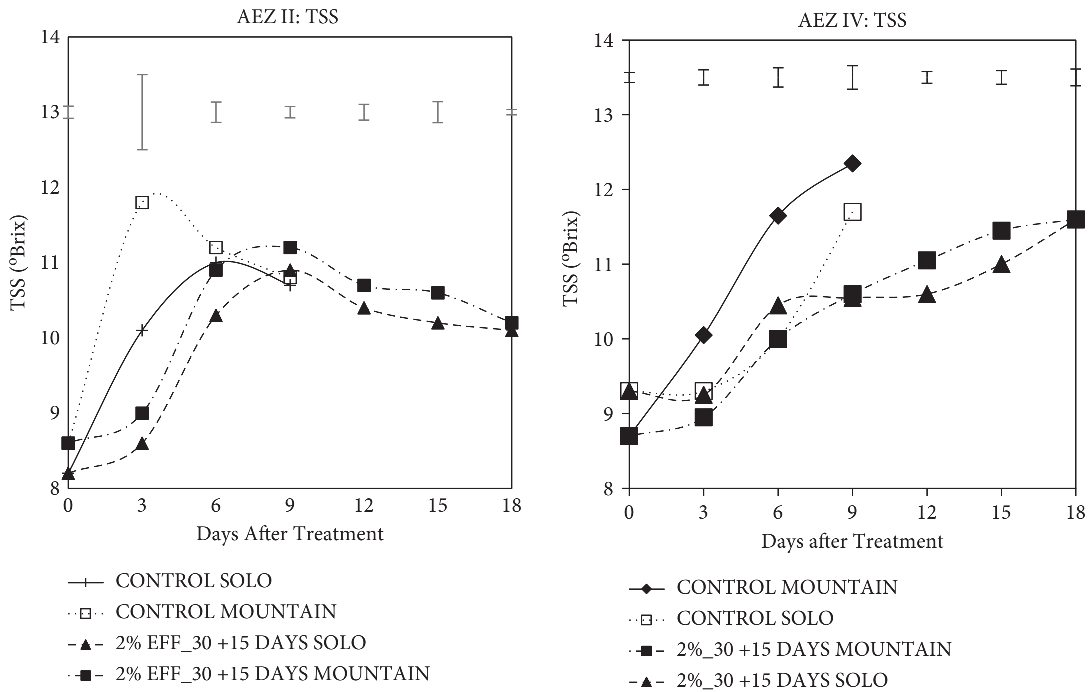

Figure 7: Percent TSS present in papaya fruits treated with Hexanal spray from Machakos and Meru counties. Top bars represent LSD at 0.05.

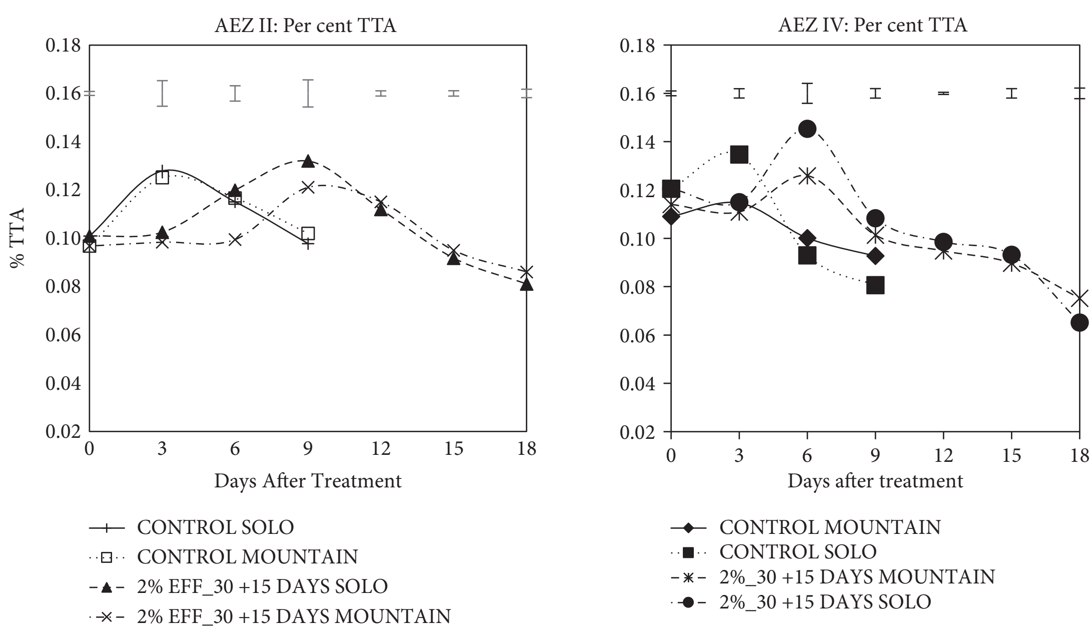

Figure 8: Percent TTA present in papaya fruits treated with Hexanal spray from Machakos and Meru counties. Top bars represent LSD at 0.05.

observed that by day 6 of storage, papaya fruit firmness had dropped below 5N in control fruits and above 8N in Hexanal treated using 2% Hexanal sprayed at 30 days and 30 + 15 days. Such loss in fruit firmness during ripening has been reported for peach fruits [29, 30]. The effects of Hexanal seemed to be limited to a certain extent of ripening. The firmness of the papaya fruits (treated and untreated), utilized in this study had dropped to below 2N. This occurred when all fruits were 100% yellow, with a hue angle less than 65°, beyond day 9 of storage.

The postharvest shelf life of the on-farm Hexanal sprayed papaya fruits was extended by 9 days. This nine-day shelf life annex could be attributed to the suppressed rates of respiration and ethylene evolution observed in fruits sprayed

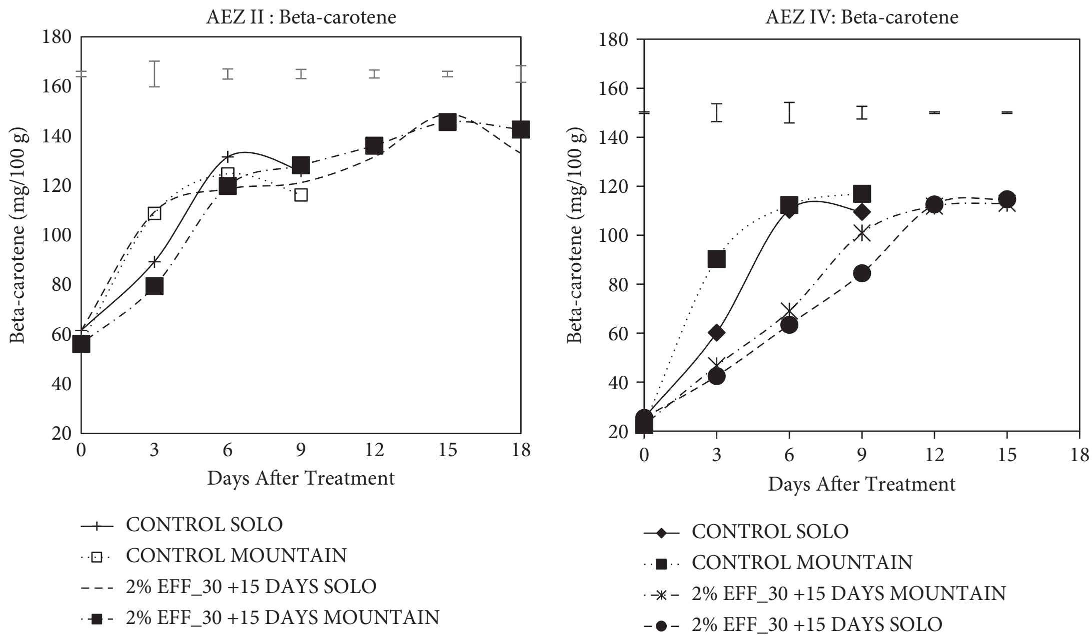

Figure 9: Beta-carotene content of papaya fruits treated with Hexanal spray from Machakos and Meru counties. Top bars represent LSD at 0.05.

with Hexanal. Shelf life is inversely related to the rate of respiration, and the lower the rate of respiration, the longer shelf life [31]. Softening rate contributed by ethylene [32] is directly related to the reduced shelf life. The low ethylene levels thus explain the prolonged shelf life. Additionally, the extended postharvest life could be attributed to the mild antifungal property of Hexanal reported by Fan [11] and Spotts [18]. This also accounts for the enhanced general appearance of treated papaya as a result of the reduced effect of the degrading actions of latent fungal infections on papaya peel. Ethylene has been reported to have a strong role in the modulation of enzymes associated with ripening [33]. The delayed peak of ethylene in "Solo sunrise" and "Mountain" papaya studied suggests an antagonistic response of ethylene and Hexanal as reported by Schobert and Elstner [34], in *Phaeodactylum triconutum* or a mild effect of Hexanal in the alteration of the ethylene biosynthesis pathway possibly downregulating ACC-synthase which limits the amount of ethylene produced from the fruits as reported by Tiwari and Paliyath [20]. Borrowing from the proposition Schobert and Elstner [34], the external application of Hexanal may have triggered the suppression of ethylene in the treated papaya fruits. If that's not the case, then further investigation are required to ascertain the levels of ethylene beyond which Hexanal may present no antagonist influence.

Peel color is a vital visual index that consumers and processors use to subjectively judge taste/preference [35]. Application of Hexanal as a natural technology in managing papaya shelf life was realized to contribute no hampering influence on color development. In the current study, the rate of peel color break from green to yellow and the intensity of red color development in the fruits pulp were negatively affected by Hexanal. The enzymatic degradation of chlorophyll and the concentration of carotenoids in the peel and pulp [36] were slowed down without affecting the final peak values. The changes in peel hue angle, green 127° to 107°; to lime 101° to 90°; toward yellow 85° to 60°, and amber 58° to 50° of the sprayed papaya are within the range of color degree hue guidelines given for color measurements using Minolta instruments described by Hunter [37].

Papaya is a fleshy fruit whose tissues are made up of up to 89.7% water [38] that could be lost as moisture from fruit. The % CWL was observed to increase with each day of storage, accounting for the moisture lost from papaya tissues to the environment. A maximum of 26.2% cumulative weight was lost from the papaya samples by the 18th day after storage of fruits from AEZ II. This large value may have resulted from the wounding of tissues from the long distance transportation to the laboratory, the difference in temperature from lower temperature ranges in AEZ II to higher average temperature in the laboratory site, fruit size, and surface area/volume ratio correlations of the papaya samples. Despite the level exceeding that reported by Paull and Chen [39], both the control and the Hexanal treated papaya fruits were still good looking and saleable. The considerable difference may be attributed to the improved genetic characteristics of "Solo sunrise" and "Mountain" papaya over papaya cultivars studied by the two scientists, environmental differences, and the size of the papaya fruits investigated in the studies. The variations in % CWL between the two AEZs could be attributed to the environmental impacts such as prevailing environmental weather conditions/climate in the production sites and different cultural practices in the sample farms within each zone.

Percent TSS level was consistently higher in papaya fruits from the hotter AEZ IV compared to fruits from the cooler

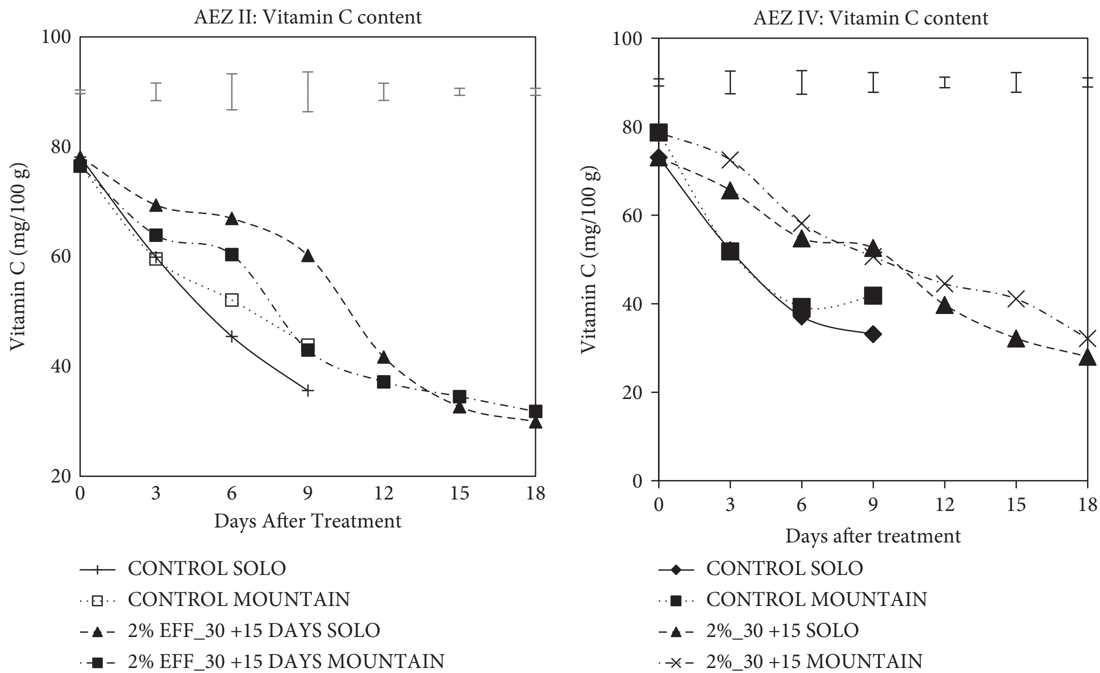

Figure 10: Vitamin C content of papaya fruits treated with Hexanal spray from Machakos and Meru counties. Top bars represent LSD at 0.05.

AEZ II. Papaya fruits from AEZ IV grew under longer sunlight exposure. The plants thus had greater photosynthetic activity [40] leading to a greater accumulation of soluble sugars in fruit tissues. The more the sun light, the higher the accumulation of TSS [41]. An inconsistent variation in TTA in papaya fruits both treated and untreated may occur due to variations of genotype-environment interaction of "Solo sunrise" and "Mountain" papaya in AEZ II and IV and the difference in cultural practices like the use of animal manure in AEZ IV as opposed to use of fertilizer in AEZ II, on-farm plant spacing, maturity stage [42]. Overall trend that mimicked the respiratory and ethylene peaks agrees with the findings from Shattir and Abu-Goukh [43], who reported that the TTA increases with fruit ripening to about 75% and decreases thereafter.

Beta-carotene content in AEZ II was higher compared to the levels in AEZ IV. The concentration of carotenoids improves as the temperature decreases and declines as light intensity increases. On the contrary, Vitamin C was higher in the hotter AEZ IV, which is drier and has limited moisture supply. Factors that influence the accumulations of water and fruit dry matter have been reported to impact on the biochemical attributes, especially ascorbic acid accumulation in fruits [44].

Overall, Hexanal spaying significantly improved overall fruit firmness by 38%, reduced the rate of peel color break, enhanced the rate of red color intensification in fruit pulp, reduced the general rate of physiological weight loss by 10%, suppressed and delayed ethylene evolution, and reduced the metabolic activity and respiration in papaya fruits. Hexanal allowed for extra time up to 21 days of antioxidants accumulation in fruit on the tree and reduced the degradation rate of provitamin A (beta-carotene) and vitamin C in papaya. The best effects were realized at 2% Hexanal double spray at $30 + 15$ days for most of the parameters studied in the two cultivars from the two agroecological zones.

5. Conclusion

Papaya fruit is one of the chief sources of vitamins in the tropical and subtropical regions where this fruit is grown. However, due to the considerable postharvest losses that have been reported to be >50, we are continuously deprived of these benefits. In Kenya, for instance, papaya fruit is the fifth priority fruit that is also available throughout the season. It is therefore, the main available fruit that supplies its readily available nutrients and vitamins in an affordable way and safe manner. By addressing the major challenge of the short shelf life and the drastic softening of papaya, the increasing population can therefore obtain the full benefits from the produced fruit for a longer time. From this study, Hexanal has shown a potential as a viable and a novel option to reduce the rate of papaya softening, extend papaya's availability, and maintain the main nutrients attainable from a papaya fruit.

Data Availability

The data used to develop this manuscript can be obtained on request by contacting Margaret Hutchinson through m.hutchinson@uonbi.ac.ke.

Conflicts of Interest

The authors declare that no competing interests exist.

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