

3 **Effectiveness of Hexanal as a novel post-harvest treatment for banana fruits (*Musa***  
4 ***acuminata*) in Kenya**

5 **ABSTRACT**

6 The short shelf-life of fruits in the tropics continues to be a pressing problem for farmers and other value  
7 chain actors. Hexanal is a naturally occurring compound that has received attention as a novel postharvest  
8 compound preservative. This study was conducted to determine the effect of hexanal on enhancing the  
9 postharvest shelf-life and quality of 'sweet banana' fruits. Two hexanal concentrations (2% and 3%) were  
10 applied as either a pre-harvest spray or a post-harvest dip. Fruits were obtained from two different agro  
11 ecological zones of Kenya (AEZs II and IV). The treated fruits were kept under ambient room conditions of  
12  $25 \pm 1^{\circ}\text{C}$  and  $\text{RH } 60 \pm 5\%$  to ripen. Hexanal treatment maintained the fruits quality and prolonged the shelf-  
13 life by 6 days in the dipped fruits, 6 and 3 days in the sprayed fruits from the drier AEZ IV and colder AEZ II  
14 respectively compared to the untreated controls. Hexanal treatments significantly ( $P = .05$ ) delayed or  
15 reduced the rate of most of the physicochemical parameters analysed irrespective of the concentration and  
16 mode of application used. Fruit firmness was significantly ( $P = .05$ ) maintained up to day 6 and 9 of storage  
17 in the treated fruits compared to the controls which softened drastically as from day 3 and 6 in the sprayed  
18 and dipped fruits respectively. Hexanal treatment delayed ethylene and respiratory peaks by 3 days in both  
19 modes of application and significantly delayed progression of other ripening related changes such as  $^{\circ}\text{Brix}$ ,  
20 titratable acidity, simple sugars and vitamin C. Sensory evaluation showed no significant differences in the  
21 various quality attributes analysed between the hexanal treated and control fruits. The results of this study  
22 indicate that, use of hexanal is a potential technology that could be adopted by banana farmers to enhance  
23 post-harvest shelf-life without compromising on quality.

24 *Keywords: Hexanal, fruit quality, shelf life, postharvest loss, 'sweet banana'*

25 **1. INTRODUCTION**

26 Kenya is endowed with good climatic conditions which favours production of different types of horticultural  
27 crops among them fruits, vegetables and cut flowers. Fruits are a key component of horticultural subsector  
28 in Kenya and come third in terms of income contribution after flowers and vegetables [11]. However, the full  
29 commercial potential of fruits such as banana has not been realized due to various challenges along the  
30 value chain among them high postharvest losses estimated at 40% [8]. The huge postharvest losses are  
31 mostly attributed to the highly perishable nature of the produce and further aggravated by failure to use  
32 appropriate post-harvest technologies.

33 In Kenya, banana is the most popular fruit crop often consumed as a dessert while the cooking varieties  
34 serve as a staple food in different regions of the country [11]. However, most of it is consumed locally with  
35 only a small percentage of approximately 7.2% being exported [11]. Production of banana is mostly  
36 dominated by small scale farmers though few medium and large scale growers are found in the major  
37 banana growing areas [8]. Banana is a security crop at the household level and the surplus is sold to  
38 provide the much-needed income for farmers. Nutritionally, banana contains high levels of calorie, a wide

39 range of vitamins, minerals, anti-oxidants and it is naturally low in fats [21]. However, once ripe the fruits  
40 have a short shelf life of approximately 3-4 days and this limits their utilization, postharvest handling and  
41 marketing [1].

42 Banana is a climacteric fruit which is often harvested at the physiological maturity stage and then ripened  
43 before marketing. During ripening, the fruit undergoes different biochemical and physiological changes that  
44 transforms the fruit to edible state. Some of these changes include fruit softening, changes in peel color,  
45 degradation of starch to sugars, changes in concentration of aroma volatiles and acids. According to [19],  
46 sugar levels increases from of an initial of 2% in green banana to approximately 15% -20% in the ripe fruit  
47 making it sweeter. However, once the fruit is fully ripe, it becomes very delicate and if not properly handled  
48 high postharvest losses can be incurred. In order to increase storage life of the fruits, appropriate post-  
49 harvest technologies aimed at reducing the deterioration rate have been developed over the years. These  
50 technologies are used to slow down fruits metabolic processes to deliver enhanced shelf-life and optimal  
51 quality without compromising on the consumer safety. Recently, efforts have been made to develop new  
52 and biological post-harvest technologies for extension of banana shelf-life while retaining quality. Use of  
53 hexanal and its formulations is one of the new innovations which have been proved effective in enhancing  
54 the post-harvest shelf life of banana fruits [33, 34]. Hexanal, is an aldehyde compound produced naturally  
55 by plants as a defence response to different biotic stresses and has an odour similar to that of freshly cut  
56 grass or cucumber [18]. The United States Food and Drug Administration Agency has approved the use of  
57 hexanal as a GRAS compound [22]. Hexanal use offers a human-safe post-harvest preservation product  
58 that is environmentally friend and economically viable. Hexanal is oxidized to  
59 hexanoic acid in the body after consumption and further oxidized to carbon dioxide and water during respir  
60 ation through the tricarboxylic acid cycle [18]. It has also been noted that hexanal, has antimicrobial  
61 properties against several post-harvest pathogens such as *Alternaria alternata* and *Botrytis Cinerea* [29]. A  
62 biochemical formulation of an artificially synthesized version of hexanal (Enhanced Freshness Formulation)  
63 has been developed which delays fruit ripening [26]. This formulation can be applied in different ways such  
64 post-harvest dip, pre-harvest spray or as a vapor. Being a relative new technology, there is need to test its  
65 suitability to enhance banana shelf-life while preserving post-harvest quality in Kenya. A previous study in  
66 'Grand nain' variety [34], showed promising results of hexanal extending fruits shelf life by nine days  
67 without compromising on quality. However, since hexanal's effect is physiological, it is possible that its  
68 efficacy might vary between varieties. The objective of this study was therefore, to determine the effect of  
69 hexanal treatment on the post-harvest shelf-life and quality of 'sweet banana' fruits, a very popular variety  
70 in Kenya.

71

## 72 **2. MATERIALS AND METHODS**

### 73 **2.1. Study area**

74 The experiment was conducted on 'sweet banana' fruits from two contrasting agro ecological zones (AEZs)  
75 in Kenya. Meru County is a high potential AEZ II that lies at an elevation of 1980–2700 m above sea level  
76 and receives an annual average rainfall of 1500 mm. Machakos County is a semi-arid AEZ IV that lies at an  
77 elevation of 1000-1600 m above sea level with an annual average rainfall of 600 mm.

### 78 **2.2. Experimental setup**

79 For the pre-harvest spray mode of application, 15 banana trees at flowering stage in each study site were  
80 randomly selected and tagged in the farmer's field. Two concentrations of hexanal (2% and 3%) and a  
81 control (clean, plain water) were sprayed twice at 30 and 15 days before harvest. The dosing range used  
82 was informed by a previous study done on 'Grand nain' variety [34]. Since hexanal is immiscible with water,  
83 Tween 20 and ethanol were added to increase its solubility [22]. The stock solutions were mixed with water  
84 and diluted accordingly to provide the required hexanal concentrations. Using a knapsack sprayer, the  
85 fruits were sprayed to the point of dripping with the solution. Spray contamination was avoided by using  
86 alternate rows of trees for the experiment and a 4 tree gap between treatments in the same row of trees.  
87 The fruits were left on the tree until approximately 20% per bunch had ripened. The fruits were then  
88 harvested and only the middle hands were used in the post-harvest analysis.  
89 For the post-harvest dip mode of application, fruits were harvested at the mature green stage based on  
90 degree of fullness of the fingers, as indicated by the disappearance of angularity and the number of days  
91 after anthesis which was approximately 104 days. Only the middle hands of each banana bunch (a cluster  
92 of fruits attached together at the stalk) were used in the analysis. The harvested fruits were packed in  
93 cushioned crates, covered with wet magazine papers to reduce water loss, and immediately transported to  
94 the post-harvest laboratory at Jomo Kenyatta University of Agriculture and Technology (JKUAT).

### 95 **2.3. Sample preparation**

96 In the post-harvest laboratory, the fruits were cleaned, dried, and selected for uniformity and freedom from  
97 mechanical injuries. Pre-harvest spray-treated fruits were left to undergo normal ripening under ambient  
98 room conditions of  $25 \pm 1^\circ\text{C}$  and  $\text{RH } 60 \pm 5\%$ . Fruits for post-harvest treatment were dipped in one of the  
99 two hexanal concentrations (2%, 3%) or plain water (control) for 5 minutes. The hexanal solution was  
100 mixed with Tween 20 and ethanol to increase its solubility. The hexanal concentrations and application time  
101 used was informed by a previous study done on 'Grand nain' variety [34]. All the fruits were left to undergo  
102 normal ripening under ambient room conditions. Five banana hands from each treatment combination were  
103 randomly sampled at 3-day intervals to evaluate respiration and ethylene evolution rates. Three fruits were  
104 also randomly sampled to evaluate other ripening related parameters including pulp firmness, °Brix,  
105 titratable acidity, ascorbic acid, simple sugars and sensory analysis evaluation.

#### 106 **2.3.1. Shelf life**

107 The time taken by the fruits from harvesting to reach the optimal, edible ripe stage was counted and  
108 reported in days. This was defined as stage 7 according to the standard banana ripening chart by [27].

#### 109 **2.3.2. Analysis of physiological parameters**

110 Gas chromatographs models GC-8A and GC-9A, Shimadzu Corp., Kyoto, Japan were used to determine  
111 the rate of respiration and ethylene production respectively. The gas chromatograph to determine rate of  
112 respiration was fitted with a thermal conductivity detector and a Poropak N column while that for ethylene  
113 determination was fitted with an activated alumina column and a flame ionization detector. The rate of  
114 carbon dioxide production (used to estimate respiration rate) was expressed as ml/Kg/h while ethylene  
115 production was expressed as  $\mu\text{l/Kg/h}$ . Five fingers of bananas were randomly sampled from each  
116 treatment, numbered and their weights taken using a digital balance, Model Libror AEG-220, Shimadzu

117 Corp. Kyoto, Japan. Each of the five fingers were incubated for two hours in air tight containers fitted with  
118 self-sealing rubber septa. Gas samples were taken from the headspace using an airtight 1 ml hypodermic  
119 syringe and injected into the respective gas chromatographs

### 120 **2.3.3. Pulp firmness**

121 Firmness was measured along the equatorial region of the fruit using a penetrometer (CR-100D, Sun  
122 Scientific Co. Ltd, Japan) fitted with an 8 mm probe. Four locations along the equatorial zone of the fruit  
123 were used and average value of firmness calculated. The banana was peeled first, before allowing the  
124 probe to penetrate the flesh to a depth of 8mm and the corresponding force required to penetrate this depth  
125 determined. Firmness was expressed as Newton.

### 126 **2.3.4. Analysis of fruit quality parameters**

127 Quality parameters such as Total soluble solids, Total titratable acidity, ascorbic acid and simple sugars  
128 were determined using standard operational protocols in the same set of fruit that were used for the fruit  
129 firmness analysis. Total soluble solids (TSS) content was determined using a digital refractometer (Model  
130 PAL-1, Atago, Tokyo, Japan) and expressed as °Brix. Total titratable acidity (TTA) was determined by  
131 titration with 0.1N NaOH in the presence of phenolphthalein indicator and expressed as percentage malic  
132 acid, the predominant organic acid in banana fruit. Ascorbic acid content (Vitamin C) was determined by  
133 use of high performance liquid chromatography (HPLC) method. Simple sugars were analysed using a high  
134 performance liquid chromatography (HPLC) (Model LC-20AS, Shimadzu Corp., Kyoto, Japan) fitted with a  
135 refractive index detector (RID). Sensory quality evaluation was done on the hexanal treated and untreated  
136 fruits once they were fully ripe; stage 6, standard banana ripening chart by [27]. The fruits were washed  
137 with clean water, dried and diced into approximately equal-sized slices, avoiding the extreme ends. Three  
138 slices were placed on white plates which were anonymously coded based on treatment to ensure  
139 objectivity. A panel of 36 untrained judges drawn from student population of faculty of Agriculture,  
140 University of Nairobi was guided on the scoring procedure of the various sensory attributes which included;  
141 fruit colour, aroma, texture, flavour, mouth feel and the general acceptability. The panellists scored for  
142 these attributes on five point hedonic scale where 1 = dislike (worst), 2 = (dislike moderately), 3 = (neither  
143 like nor dislike), 4 = (like moderately) and 5= Like extremely (Best). This was adapted from [9], but with few  
144 modifications.

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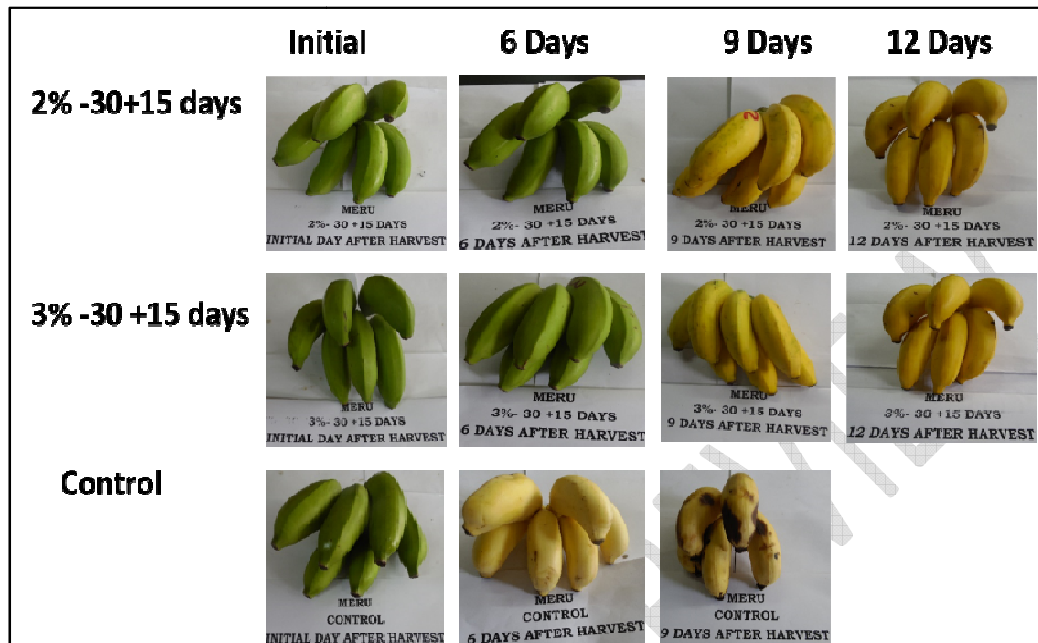
## 147 **2.4 Statistical analyses**

148 Data collected was subjected to analysis of variance (ANOVA) using Genstat statistical package (version  
149 15). The means were separated by Least Significance Difference (LSD) at  $p \leq .05$  using Fisher's protected  
150 test. The sensory quality evaluation data was analyzed using Statistical Package for the Social Sciences  
151 (SPSS) version 20.

## 152 **3.0 Results**

### 153 **3.1. Shelf life**

154 Hexanal treatment enhanced shelf life by 6 days (Plate 2) in the post-harvest dipped fruits, 6 and 3 days in  
155 the sprayed fruits (Plate 1) from the drier AEZ IV and the wetter AEZ II respectively as compared to the  
156 controls, irrespective of the production zone and hexanal concentration used.



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158 Plate 1: Ripening changes of 'sweet banana' fruits sprayed with 2% and 3% Hexanal and controls  
159 fruits during post-harvest storage (from initial day to day 12)  
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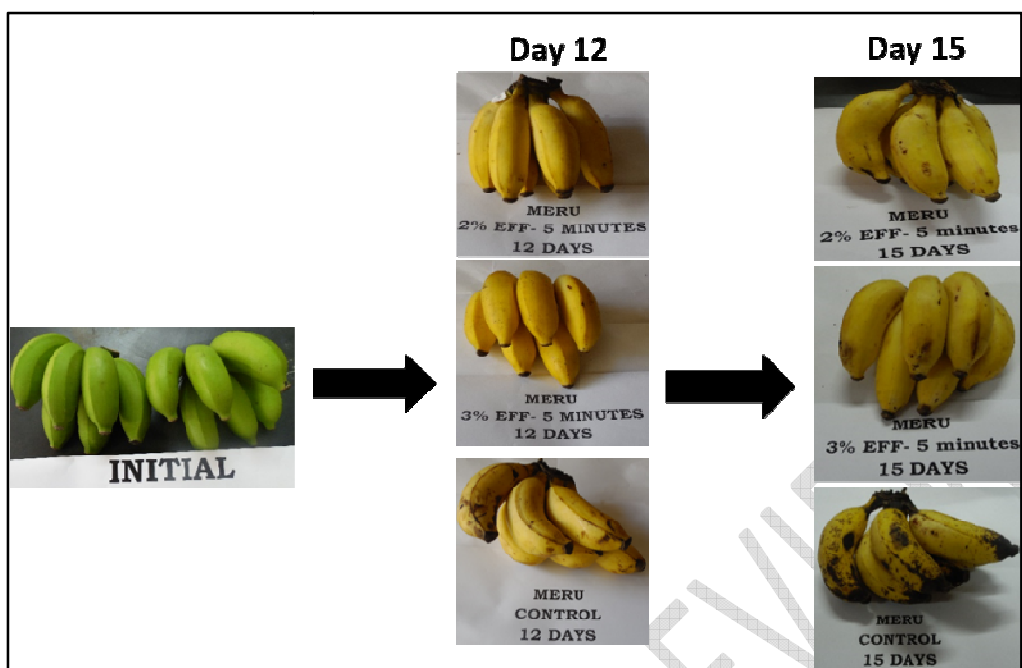


Plate 2: Ripening changes of 'sweet banana dipped in 2% and 3% Hexanal for 5 minutes and controls fruits during post-harvest storage (from initial day to day 15)

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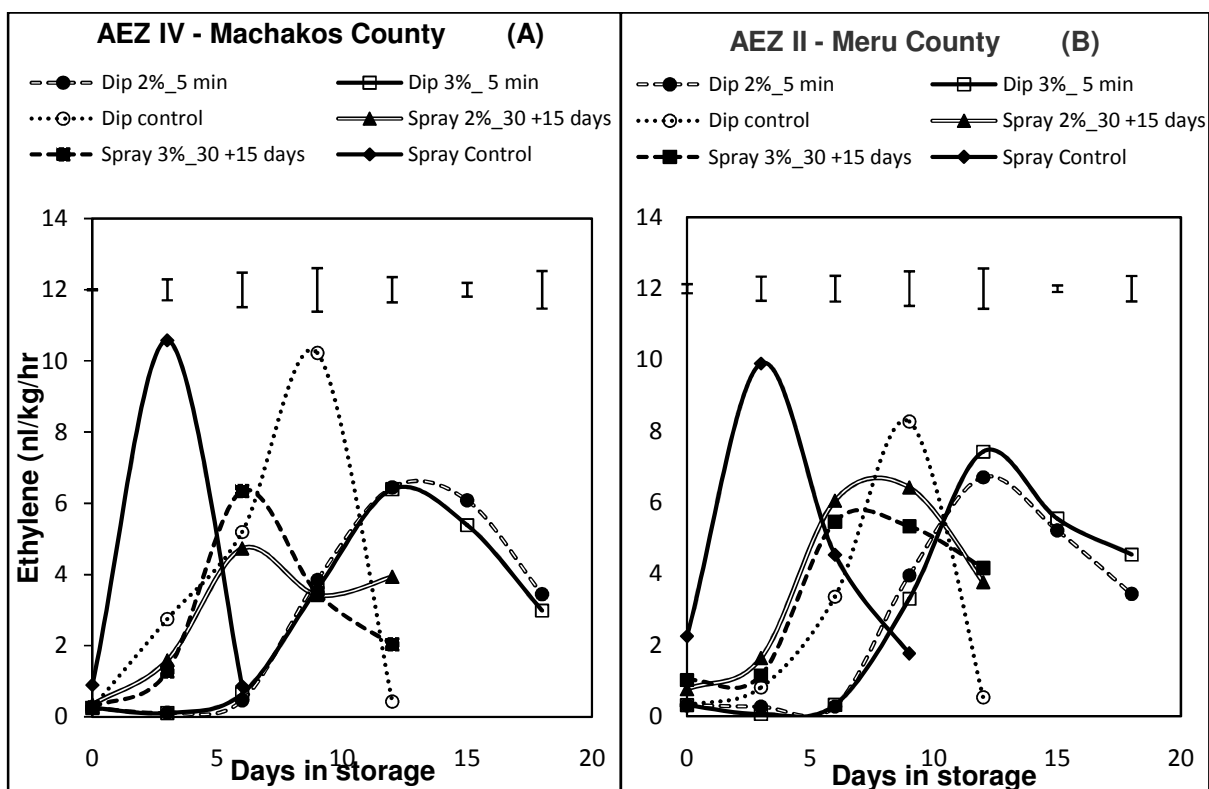
### 171 3.2 Rate of ethylene production

172 In the pre-harvest spray mode of application, the control fruits had significantly ( $P = .05$ ) high levels of  
 173 ethylene production with the climacteric peaks of approximately 10 nL/kg/hr occurring 3 days earlier  
 174 compared to the hexanal treated fruits (Fig. 1A & B). Hexanal treatment significantly ( $P = .05$ ) reduced the  
 175 rate of ethylene production in both AEZ and delayed the climacteric peaks by 3 days compared to the  
 176 untreated fruits. The reduced climacteric peaks of 4.8- 6.3 nL/kg/hr and 5.6 – 6.3 nL/kg/hr in the hexanal  
 177 treated fruits from the drier AEZ IV (Fig. 1A) and wetter AEZ II fruits (Fig. 1B) occurred at day 6 of storage,  
 178 then ethylene levels drastically declining till the end of storage exhibiting a true climacteric pattern.

179 A significant difference ( $P = .05$ ) was observed between the two modes of hexanal application where post-  
 180 harvest mode of application delayed the climacteric peaks by 6 days compared to the pre-harvest spray  
 181 (Fig. 1A & B). However, zone of production did not have any significant effect on the rate of ethylene  
 182 production.

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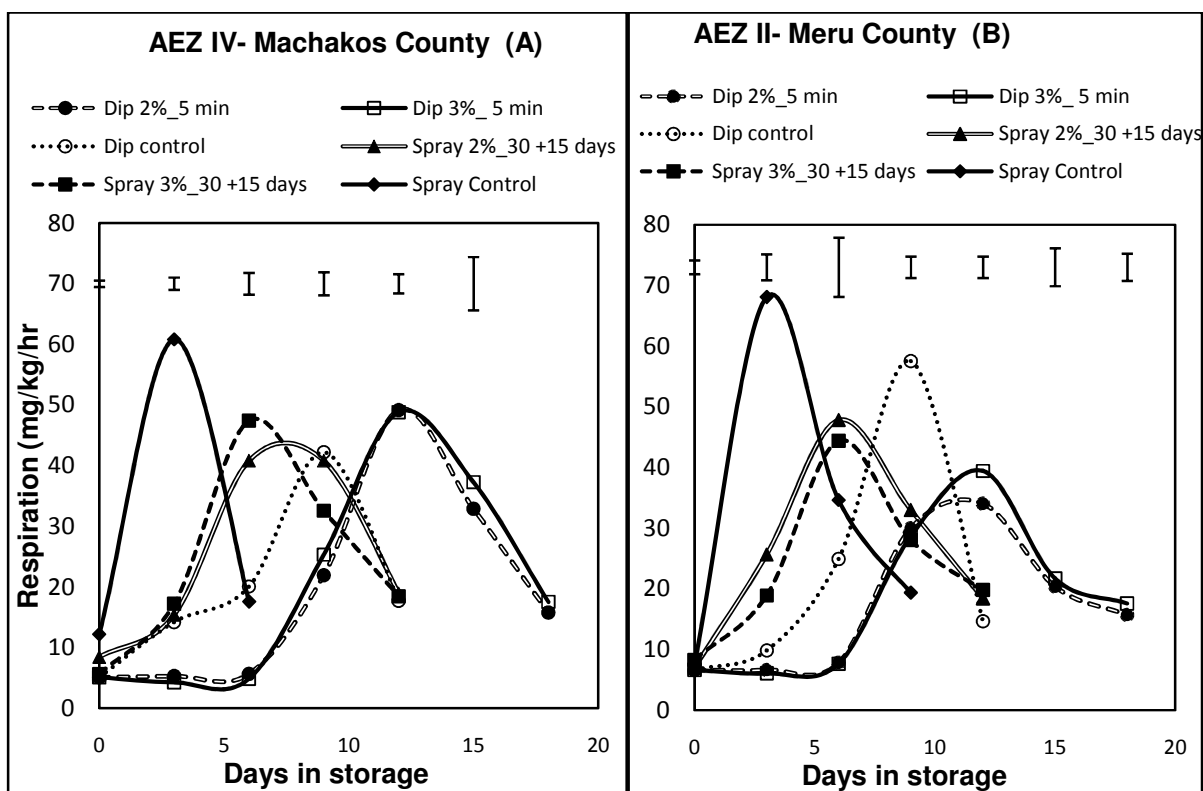


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186 **Fig. 1. Effect of pre and post-harvest application of Hexanal on rate of ethylene production in 'sweet**  
 187 **banana' fruits from drier AEZ IV (A) and wetter AEZ II (B). Bars indicate least significant difference**  
 188 **(LSD) between means at  $p < 0.05$ .**

### 189 3.3 Respiration rate

190 Respiration rate followed a similar pattern to the ethylene production. In both zones of production, hexanal  
 191 treatment significantly ( $P = .05$ ) reduced the rate of respiration, with a post-harvest dip mode of application  
 192 exhibiting lower rates compared to pre-harvest spray (Fig. 2A & B). Just like in ethylene production, fruits  
 193 from the pre-harvest spray mode of application had higher respiratory rate compared to the post-harvest  
 194 dipped ones. The high respiratory peaks of 61 ml/kg/hr and 69 ml/kg/hr in the controls occurred at day 3 of  
 195 storage, compared to 41 -47 mg/kg/h and 44 -48 mg/kg/h in the hexanal treated fruits, 3 days later in drier  
 196 AEZ IV and wetter AEZ II respectively (Fig. 2A & B). A similar trend was observed in the post-harvest dip  
 197 mode of application experiment, where the treated fruits had lower levels of respiration compared to the  
 198 pre-harvest spray experiment with respiratory peaks of 49 mg/kg/h and 34 -39 mg/kg/h, in drier AEZ IV and  
 199 colder AEZ II, respectively, occurring 6 days later.



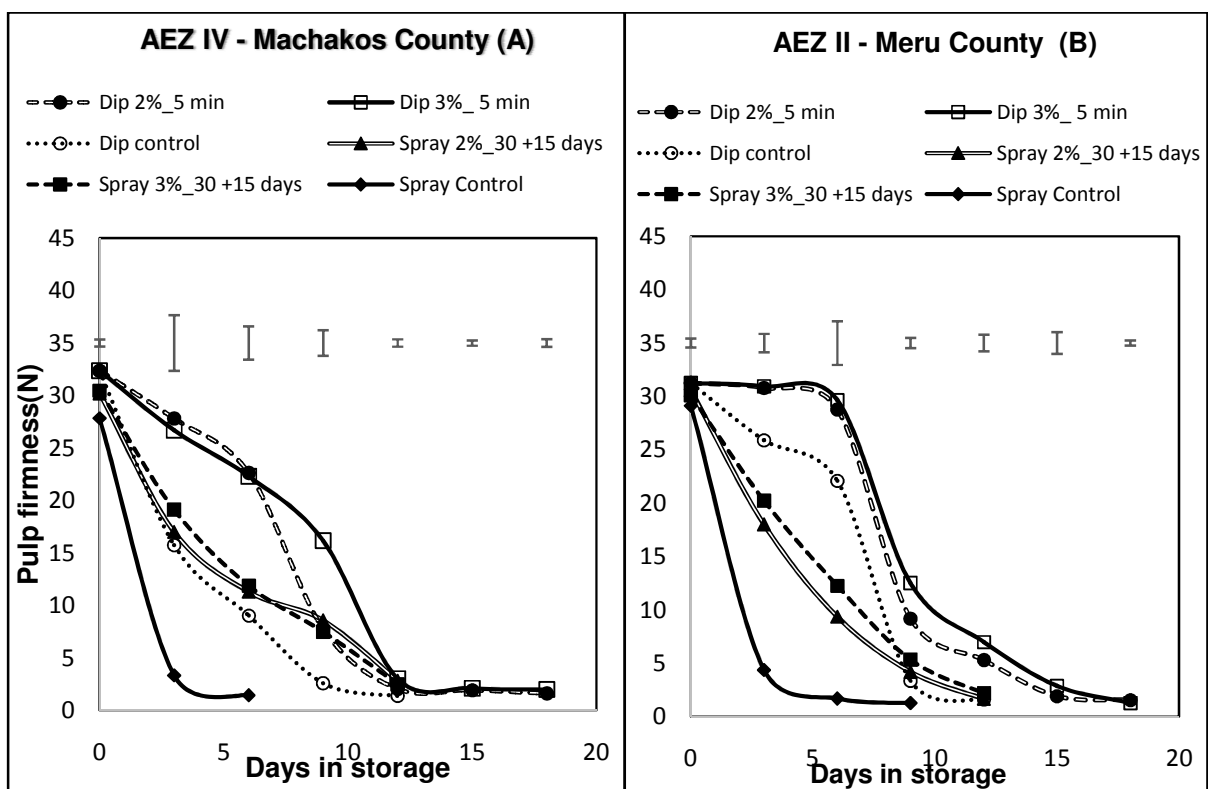
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201 **Fig. 2. Effect of pre and post-harvest application of Hexanal on the rate of respiration in 'sweet banana' fruits from drier AEZ IV (A) and wetter AEZ II (B). Bars indicate least significant difference (LSD) between means at  $p < 0.05$ .**

### 204 3.4 Pulp firmness

205 A general reduction in pulp firmness was observed in both the hexanal treated and control fruits as ripening progressed (Fig. 3A and B). Hexanal treatment applied either as a pre-harvest spray or post-harvest dip significantly ( $P = .05$ ) delayed pulp softening in both AEZ. Interaction between mode of application and zone of production had a significant ( $P = .05$ ) effect on the rate of softening with fruits from the drier AEZ IV (Fig 3A) softening faster compared to those from the colder AEZ II (Fig 3B). The control fruits drastically lost their pulp firmness by 96% in fruits produced in both AEZ, after 6 and 9 days of storage in the drier AEZ IV and wetter AEZ II, respectively in the pre-harvest spray mode of application. Similarly, in the post-harvest dip mode of application, the untreated control fruits had lost approximately 95% of their pulp firmness after 12 days of storage in both zones. By the 9<sup>th</sup> day of storage, pre-harvest sprayed fruits had lost approximately 72% -75% and 82%- 85% of their firmness compared to 50% - 76% and 60% - 71% in the post-harvest dip treated fruits in the drier AEZ IV and wetter AEZ II, respectively (Fig. 3A and B).

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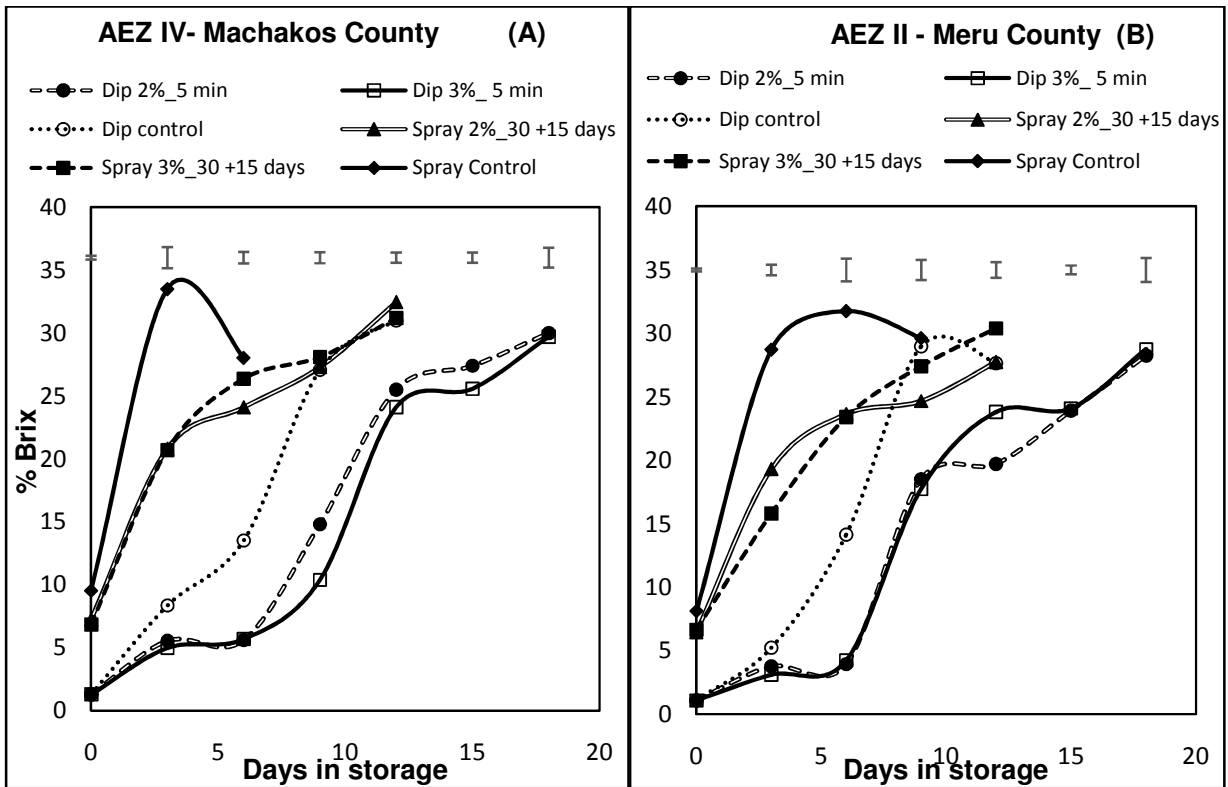
217 **Fig. 3. Effect of pre and post-harvest application Hexanal on pulp firmness in 'sweet banana' fruits**  
 218 **from drier AEZ IV (A) and wetter AEZ II (B). Bars indicate least significant difference (LSD) between**  
 219 **means at  $p < 0.05$ .**

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### 221 3.5 Total soluble solids (TSS, °Brix)

222 Total soluble solid (TSS) levels were significantly ( $P = .05$ ) affected by the interaction between zone of  
 223 production and hexanal treatment. Generally, fruits from the drier AEZ IV (Fig. 4A) had significantly high  
 224 TSS levels throughout storage compared to those from the colder AEZ II (Fig. 4B). The °brix levels of the  
 225 untreated fruits from the drier AEZ IV, increased rapidly from an initial value of 1.3 and 9.5° brix to a peak  
 226 value of 33.81° and 31° brix on day 12 and 3 of storage in the post-harvest dip and pre-harvest spray mode  
 227 of treatments respectively (Fig. 4A). On the other hand, TSS levels increased gradually from initial of 1.1°  
 228 brix to peak of 29° brix at day 9 of storage in the post-harvest dip mode of application in the wetter AEZ II  
 229 (Fig. 4B).

230 Hexanal treatment significantly ( $P = .05$ ) reduced the rate of TSS increase in both zones and mode of  
 231 application. However, at the end of storage, the hexanal treated fruits attained almost the same TSS level  
 232 of approximately 28°- 32° brix compared to the untreated controls.



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**Fig. 4. Effect of pre and post-harvest application of Hexanal on Total Soluble Solids (TSS) in 'sweet banana' fruits from drier AEZ IV (A) and wetter AEZ II (B). Bars indicate least significant difference (LSD) between means at  $p < 0.05$ .**

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### 3.6 Total Titratable Acidity (TTA)

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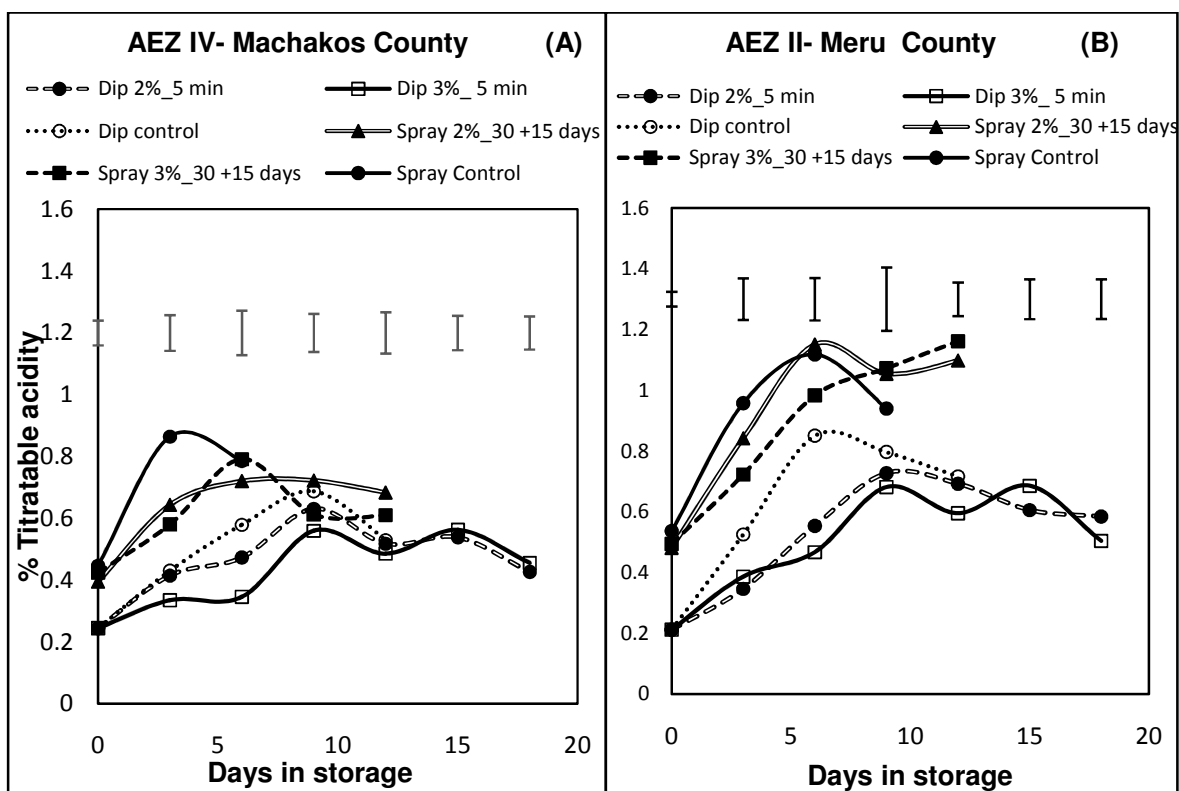
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As ripening progressed, total titratable acidity (TTA) increased up to a peak level then gradually decreased till the end of storage (Fig. 5A & B). A significant ( $P = .05$ ) interaction was observed between zone of production and hexanal treatment with fruits from the colder AEZ II (Fig. 5B) having high TTA levels throughout the storage period compared to those from the drier AEZ IV (Fig. 5A). Hexanal treatment significantly ( $P = .05$ ) slowed the rate of TTA increase in both zones of production, irrespective of the mode of application used (Fig. 5A & B).



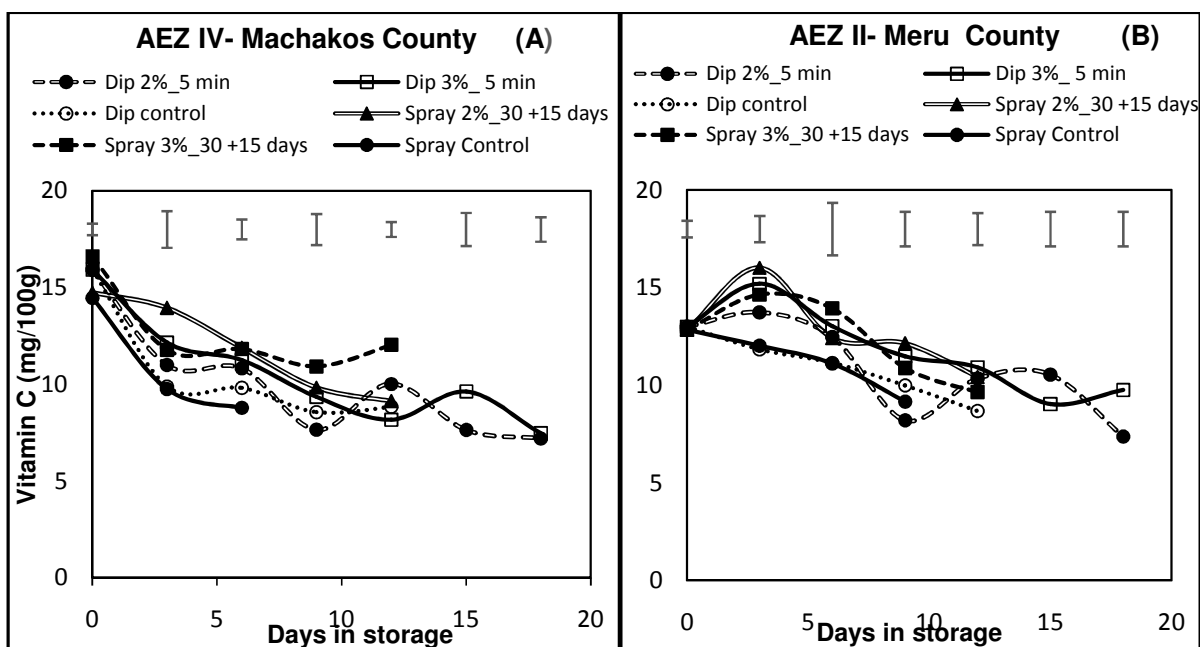
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245 **Fig. 5. Effect of pre and post-harvest application of Hexanal on Total Titratable Acidity (TTA) in**  
 246 **'sweet banana' fruits from drier AEZ IV (A) and wetter AEZ II (B). Bars indicate least significant**  
 247 **difference (LSD) between means at  $p < 0.05$ .**

### 248 3.7 Ascorbic Acid content

249 The ascorbic acid content decreased gradually during storage in all the fruits except in the hexanal treated  
 250 fruits (pre-harvest spray) from the wetter AEZ II, where an increase was observed up to day 3 of storage  
 251 (Fig. 6B). The ascorbic acid levels were significantly ( $P = .05$ ) affected by the interaction between zone of  
 252 production and hexanal treatment. Generally, fruits from the wetter AEZ II had significantly ( $P = .05$ ) high  
 253 ascorbic acid levels (Fig. 6B) compared to those from the drier AEZ IV (Fig. 6A). Hexanal treatment  
 254 significantly ( $P = .05$ ) slowed the rate of ascorbic acid reduction with the treated fruits maintaining relatively  
 255 higher levels throughout the storage period compared to the controls in both AEZ (Fig. 6A & B).

256 Ascorbic acid levels decreased rapidly in the control fruits from an initial of 14.5 mg/100g and 11.7 mg/100g  
 257 to an average of 8.8 mg/100g and 9.2 mg/100g in the drier AEZ IV and wetter AEZ II respectively, by the  
 258 end of storage (day 9) in the pre-harvest spray mode of application (Fig. 6A & B). Contrasting results were  
 259 observed in the hexanal treated fruits where 2% concentration was more effective in the drier AEZ IV fruits  
 260 where else in wetter AEZ II, 3% concentration was more effective. In the post-harvest dip experiment, the  
 261 ascorbic acid levels decreased from initial values of 15.9 mg/100g and 13 mg/100g to 7.4 mg/100g and 7.3  
 262 - 9.6 mg/100g in the treated fruits at the end of storage (day 18), 6 days later compared to the controls in  
 263 AEZ IV and AEZ II, respectively.



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266 **Fig. 6. Effect of pre and post-harvest application of Hexanal on ascorbic acid content in 'sweet**  
267 **banana' fruits from drier AEZ IV (A) and wetter AEZ II (B). Bars indicate least significant difference**  
268 **(LSD) between means at  $p < 0.05$ .**

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270 **3.8 Simple sugars (Sucrose, glucose and Fructose)**

271 Sucrose, glucose and fructose increased gradually with ripening in all the fruits irrespective of production  
272 zone and hexanal treatment (Table 1 and 2). Sucrose was the most abundant sugar in banana fruits  
273 compared to glucose and fructose irrespective of zone of production and hexanal treatment. A significant  
274 interaction ( $P = .05$ ) was observed between hexanal treatment and zone of production in both glucose and  
275 fructose (Table 1 and 2). Glucose and fructose levels were significantly high ( $P = .05$ ) in the drier AEZ IV  
276 fruits (Table 1) compared to those from the wetter AEZ II (Table 2) in both modes of application. However,  
277 zone of production did not have any significant effect on the sucrose levels (Table 1 and 2). The increase in  
278 sucrose, glucose and fructose content was significantly ( $P = .05$ ) affected by hexanal treatment, were the  
279 increase was lower in the treated fruits compared to the controls throughout the storage period. However,  
280 no significant differences were observed between 2% and 3% hexanal concentrations evaluated for  
281 sucrose and fructose while 3% significantly delayed the increase in glucose compared to 2% in the spray  
282 mode of application.

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**Table 1. Effect of pre and post-harvest application of Enhanced fresh formulation (EFF) on Glucose, fructose and sucrose content (g/100g) of 'apple' bananas from AEZ IV (Machakos County).**

DAYS Dip	SUCROSE			GLUCOSE			FRUCTOSE		
	Control	2%	3%	Control	2%	3%	Control	2%	3%
0	6.4e	6.4h	6.4i	5.4e	5.4e	5.4e	4.8d	4.8de	4.8c
3	48.6d	7.8gh	9.7i	6.9e	3.6e	3.1e	5.5d	2.2e	2.9c
6	68.5d	29.1f	46.4f	15.2d	7.1e	6.7d	18.4c	5.1de	4.5c
9	113.7b	67.1e	64.1e	29.5c	18.6c	19.6c	41.6b	7.6de	6.9c
12	173.0a	97.4d	92.5d	51.1a	33.2b	39.2a	57.3a	31.9b	24.9b
15		191.7a	161.8a		42.4a	44.5a		37.3b	37.8a
18		160.5b	150.6b		45.4a	43.5a		45.1a	41.9a
Mean	<b>82.0</b>	<b>80.0</b>	<b>75.9</b>	<b>21.6</b>	<b>22.2</b>	<b>23.1</b>	<b>25.5</b>	<b>19.1</b>	<b>17.7</b>
<b>Spray</b>									
0	4e	1.9h	2.6i	14.7d	4.7e	4.3e	4e	1.9h	2.6i
3	97.4c	17.8g	19.7h	55.7a	15.6d	11.3d	97.4c	17.8g	19.7h
6	87.5c	36.1f	32.5g	44b	22.8c	17c.1	87.5c	36.1f	32.5g
9		87.1d	85.8d		38.4b	34.3b		87.1d	85.8d
12		111.5c	114.9c		42.5a	36.4b		111.5c	114.9c
15									
18									
Mean	<b>63.0</b>	<b>50.9</b>	<b>51.1</b>	<b>38.1</b>	<b>24.8</b>	<b>20.7</b>	<b>35.8</b>	<b>22.8</b>	<b>23.1</b>
LSD*	<b>10.2</b>			<b>5.5</b>			<b>7.4</b>		

292 *Values followed by the same letter within the same column are not significantly different between the treatments using*  
293 *Fishers Least significant difference (( $p < 0.05$ )).*

294

295 **Table 2. Effect of pre and post-harvest application of hexanal on Glucose, fructose and sucrose**  
296 **content (g/100g) of 'sweet banana' fruits from the wetter AEZ II (Meru County).**

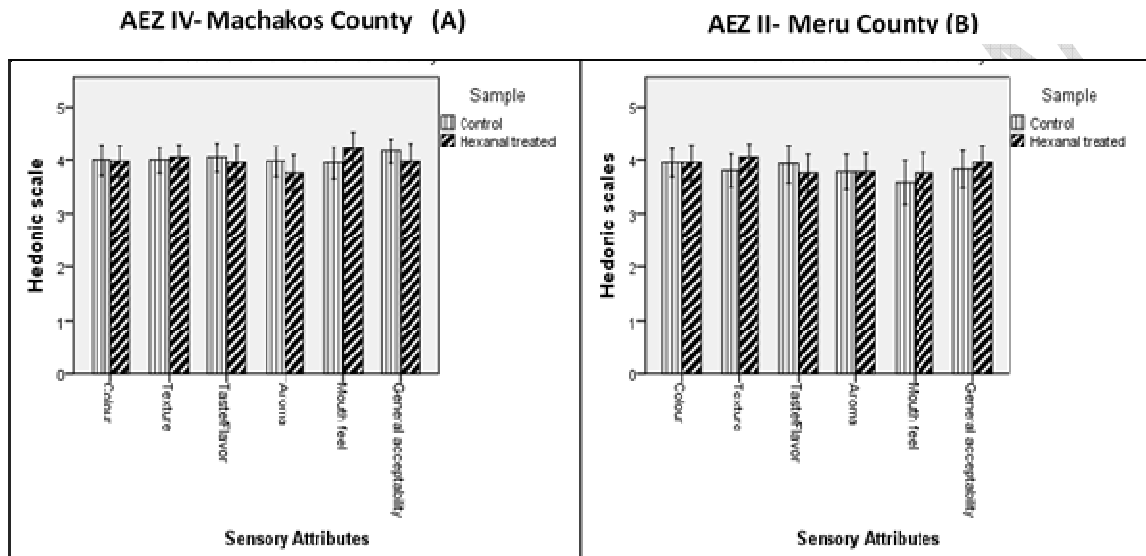
DAYS Dip	SUCROSE			GLUCOSE			FRUCTOSE		
	Control	2%	3%	Control	2%	3%	Control	2%	3%
0	3.8c	3.8e	3.8dc	4.1f	4.1f	4.1d	4.4e	4.4d	4.4e
3	27.5c	3.4e	7.5dc	7.5ef	5.0f	5.6d	4.5e	3.0d	3.6e
6	41.1c	12.0d	5.4dc	29.1d	5.9f	3.7d	15.7d	6.6d	3.7e
9	95.9b	31.5d	56.3c	28.5d	23.3d	32.4b	41.4a	18.9c	28.0c
12	155.0a	79.3c	109.3b	44.8a	34.0c	49.3a	46.2a	32.3a	36.1b
15		155.5a	152.2a		34.1c	53.3a		31.8a	42.4a
18		147.7a	135.9a		51.7a	32.2b		36.6a	33.7b
Mean	<b>65.6</b>	<b>61.9</b>	<b>67.2</b>	<b>22.8</b>	<b>22.6</b>	<b>25.8</b>	<b>22.4</b>	<b>19.1</b>	<b>21.7</b>
<b>Spray</b>									
0	6.1c	3.5e	5.1dc	10.2e	3.3f	3.1d	4.3e	2.8d	1.4e
3	93.1b	39.2d	28.8c	34.3b	14.6e	7.8d	25.3c	20.6c	14.8d
6	101.5b	119b	92.3b	41.2a	27.6d	23.2c	46.1a	16.2c	18.3d
9	107.9b	93b	126.4a	33b	31.2cd	29.2b	30.7b	27.5b	33.3b
12		119.5b	109.2		43.3b	35.1b		30.7b	35.3b
15									
18									
Mean	<b>77.2</b>	<b>74.8</b>	<b>72.4</b>	<b>34.1</b>	<b>24</b>	<b>19.5</b>	<b>26.6</b>	<b>19.6</b>	<b>20.6</b>
LSD*	<b>35.6</b>			<b>4.8</b>			<b>4.9</b>		

297 *Values followed by the same letter within the same column are not significantly different between the treatments using*  
298 *Fishers Least significant difference (( $p < 0.05$ )).*

299

### 3.9 Sensory Quality Evaluation

Generally, there was no significant ( $P = .05$ ) differences observed in all the quality attributes scores in both zones between the hexanal treated and control fruits (Fig. 7A & B). The treated and control fruits from both AEZ scored almost the same scores for peel color, texture in AEZ IV fruits (Fig. 7A) and aroma in AEZ II (Fig. 7B). On the other hand, hexanal treated fruits scored slightly high for taste/flavour in both AEZs (Fig. 7A & B) while general acceptability and aroma scored highest in AEZ IV (Fig. 7A) fruits though this was not significantly different.



307

308 **Fig. 7. Hedonic scores for sensory quality attributes of 'sweet banana' variety harvested from**  
309 **Machakos and Meru Counties and treated with Hexanal or left untreated to act as the control. The**  
310 **values on Y-axis represent scores on a 5-point hedonic scale (1 = dislike (worst), 2 = (dislike**  
311 **moderately), 3 = (neither like nor dislike) 4 = (like moderately) and 5= (Like extremely/best)). The**  
312 **vertical bars represent means  $\pm$  SE.**

### 313 4.0. DISCUSSION

314 Application of appropriate post-harvest technologies in banana fruits is of paramount importance in order to  
315 minimize losses after harvest and maintain the best possible quality. Over the past decades, different post-  
316 harvest technologies have been developed and tested in various fruits. However, the adoption rate of most  
317 of these technologies depends on its appropriateness, cost, versatility and value of the commodity.  
318 Moreover, most of the consumers and other actors in the value chain in the recent past have high affinity  
319 for naturally-occurring post-harvest preservative compounds which are environmentally friendly, pose no  
320 health hazard and are easy to use. Therefore, there is need to test the suitability of biological compounds  
321 such as hexanal to enhance banana shelf life while preserving its quality. The objective of this study was to  
322 evaluate the efficacy of hexanal, a naturally-occurring compound in enhancing shelf-life and quality of  
323 'sweet banana' fruits in Kenya when applied as a pre-harvest spray or post-harvest dip.

324 Overall, zone of production had a significant effect on fruits shelf-life and quality. Fruits from the drier AEZ  
325 IV, ripened faster and had high content of  $^{\circ}$ brix and simple sugars as compared to those from the wetter  
326 AEZ II. This could be as a result of differences on the prevailing environmental conditions such as

327 temperatures and light as well as cultural practices which have all been reported to impact on the  
328 physiology and post-harvest quality of fruits [13]. Hexanal treatment significantly extended shelf-life by 6  
329 days in the post-harvest dip mode of application in both zones compared to the controls. On the other  
330 hand, fruits sprayed with hexanal had a shelf life of 6 and 3 days in the drier AEZ IV and wetter AEZ II fruits  
331 respectively compared to the controls irrespective of the concentration used. This observed increase in  
332 shelf life is very significant especially to small scale farmers who will benefit by gaining an extra time to  
333 source for better market and minimize exploitation by middlemen along the value chain. Banana fruit  
334 especially the 'sweet banana' variety when ripe goes from marketable to unmarketable state rapidly,  
335 leading to huge post-harvest losses. The observed extended shelf-life of up to 6 days in this study could be  
336 as a result of the observed lower rates of ethylene production and respiration in the hexanal treated fruits.  
337 Physiologically, an increase in respiration rate leads to a quick utilization of substrates, such as free sugars  
338 that contributes to post-harvest losses as previously reported by [25]. Similar findings of extended shelf-life  
339 have been reported in other banana varieties such as 'Grand nain' [33], [34] and in other fruits including  
340 mangoes [2], papaya [12], Lime [6] and tomatoes [5]. The observed reduced rate of ethylene evolution in  
341 the treated fruits may be as a result of hexanal being a weak inhibitor of ethylene as previously reported by  
342 [31]. A study at molecular level in tomato fruit by [31], showed that hexanal treatment in tomato fruit caused  
343 moderate down regulation of 1-aminocyclopropane-1-carboxylate synthase 6 (ACS6) and 1-  
344 aminocyclopropane-1-carboxylate synthase (ACS) genes. The expression of ACS6 and ACS genes are  
345 responsible for the biosynthesis of 1-Aminocyclopropane-1-carboxylic acid (ACC) synthase enzyme, which  
346 converts the S-Adenosyl-L-methionine (SAM) to ACC in the ethylene biosynthesis pathway. Hexanal  
347 inhibition of ACS genes will lead to a reduction in the evolution of ethylene, and this may explain the low  
348 levels of ethylene production observed in this study.

349 Excessive softening is one of the main factors limiting fruit shelf life, transportability and storage in banana  
350 fruit resulting to high levels of post-harvest losses. In the present study, the rate of fruit softening was  
351 greatly delayed in the hexanal treated fruits compared to the controls throughout the storage period.  
352 Softening in banana fruits is majorly as a result of textural changes due to disassembly of the primary cell  
353 wall by various hydrolases such as pectin methylesterase, polygalacturonase and pectate lyase among  
354 others [32]. However, other mechanism may also be active in determining the overall textural  
355 characteristics of banana fruit such as loss of turgor and breakdown of starch to sugar [14]. The observed  
356 delayed softening in the treated fruits might be as a result of hexanal reducing the activity of the various  
357 enzymes involved in cell wall degradation and modification. A study in tomato [31], showed that hexanal  
358 treatment down regulates the expression of genes involved in pectin and hemicellulose degradation which  
359 are the major components of the plant cell wall. Additionally, the delay in fruit softening may also be as  
360 result of the observed low rate of ethylene production and respiration in the hexanal treated fruits.  
361 Ethylene, being a ripening hormone has a strong participation in modulating enzymes involved in fruit  
362 softening. Degradation of starch during respiration in fruits such as banana results into pronounced  
363 textural changes. Similar results have been reported in banana fruits by [33] in India. Zone of production  
364 had a significant effect on fruit firmness with fruits from the drier AEZ IV (Machakos County), softening  
365 faster compared to those from the wet AEZ II (Meru County), irrespective of the treatment. This could be

366 attributed to differences in temperatures and rainfall in the different zones; both having been reported to  
367 affect fruit softening [13].

368 Total soluble solids (TSS) increased gradually with ripening in all the fruits irrespective of zone of  
369 production and hexanal treatment. The observed increase in TSS during ripening may be associated with  
370 the breakdown of stored carbohydrates into simple sugars [14]. Fruits from the drier zone IV had higher  
371 TSS levels compared to those from the wetter zone II. This could be attributed to high temperatures and  
372 longer periods of exposure to sunlight characteristic of AEZ IV which led to increased accumulation of dry  
373 matter content. Similar results have been reported in papaya [12] and mangoes [20]. In general, the rate of  
374 TSS increase was significantly low in the Hexanal treated fruits throughout the storage duration and could  
375 be attributed to the observed low rate of respiration and ripening process. Low rate of respiration leads to a  
376 decrease in metabolic activity and slow conversion of starch to sugars, a possible explanation of delayed  
377 increase in TSS content in the hexanal treated fruits. Our results concur with those of [2], who reported  
378 similar results in mango fruits. Changes in simple sugars such as sucrose, glucose and fructose followed a  
379 similar trend to the one observed in TSS. In the present study, levels of this individual sugars increased  
380 drastically during the ripening process in all the fruits. However, hexanal treatment significantly slowed  
381 down the increase rate of glucose and fructose. This might be as a result of the observed delayed ripening  
382 and reduced rate of respiration in the hexanal treated fruits. During ripening process, starch, which is the  
383 major form of carbohydrates in banana fruit, is usually catabolized into simple sugars, which enters the  
384 metabolic pool where they are used as respiratory substrates or further converted to other metabolites.  
385 Similar findings have been reported in hexanal treated banana fruits by [33].

386 Banana is one of the few fruits whose TTA levels increases with ripening up to a maximum value then  
387 decreases in the fully ripe stage as reported by [13], [28]. This is as result of increase in malic acid from 1.8  
388 meq/100g to 6.2 meq/100g during ripening [14]. In the present study, hexanal treatment delayed the rate of  
389 TTA increase as compared to the drastic increase in the control fruits which peaked at day 3 of storage.  
390 This could be attributed to the observed reduced rate of ripening in the hexanal treated fruits. Additionally,  
391 reduced activities of enzymes such as malate dehydrogenase, which influence the level of malic acid in  
392 banana could further explain the delayed rate of TTA increase by hexanal treatment.

393 Ascorbic acid is an important quality trait in fruits. In the present study, ascorbic acid levels decreased  
394 gradually in all the fruits as ripening advanced during storage. The decrease in vitamin C during ripening is  
395 partly due to degradation of ascorbic acid through oxidation [3]. The decrease in ascorbic acid was less  
396 rapid in the hexanal treated fruits compared to the untreated controls. Higher retention of ascorbic acid  
397 observed in the hexanal treated fruits may be as a result of reduced enzymatic oxidation by hexanal.

398 Various quality attributes such as peel color, firmness, aroma, taste, mouth-feel and general acceptability  
399 were evaluated during the sensory evaluation analysis. The sensory evaluation results showed that,  
400 hexanal treatment did not have any significant effect on the various quality parameters scored. Further,  
401 there was no significant difference on the general acceptability of the treated and the control fruits. This  
402 indicates that hexanal's effect on shelf life of banana fruit did not have detrimental effects on the various  
403 quality parameters. These results are in agreement with a study by [28], who reported that hexanal  
404 treatment does not affect the expression of genes involved in quality development pathway of tomato fruit.

405

406

407

## 408 **5.0. CONCLUSION**

409 Overall, results of this study indicate that, the use of Hexanal has the potential to increase 'sweet banana'  
410 shelf-life by at least 6 days in case of post-harvest dip, 6 and 3 days in pre-harvest sprayed fruits from drier  
411 AEZ IV and the wetter AEZ II respectively, without affecting the quality attributes. This results have also  
412 showed that hexanal efficacy might be influenced by zone of production and further studies need to be  
413 conducted to validate this. However, there was no significant difference between the 2% and 3% hexanal  
414 concentrations tested and both concentrations were equally effective. Therefore, this technology shows  
415 great promise in enhancing the shelf life while preserving quality attributes of banana fruits. This in turn can  
416 reduce the huge post-harvest losses currently being incurred in developing countries such as Kenya.

417

## 418 **COMPETING INTERESTS**

419 Authors have declared that no competing interests exist regarding the publication of this paper.

420

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