

## Original Research Article

**Effectiveness of Hexanal as a novel post-harvest treatment for banana fruits (*Musa acuminata*) in Kenya (need to mention the banana variety used in title ('sweet banana'!).**

### **ABSTRACT**

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

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

### **1. INTRODUCTION**

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

In Kenya, banana is the most popular fruit crop often consumed as a dessert while the cooking varieties serve as a staple food in different regions of the country [11]. However, most of it is consumed locally with only a small percentage of approximately 7.2% being exported [11]. Production of banana is mostly dominated by small scale farmers though few medium and large scale growers are found in the major banana growing areas [8]. Banana is a security crop at the household level and the surplus is sold to 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  
46 [Maduwanthi and Marapana](#) [19], sugar levels increases from of an initial of 2% in green banana to  
47 approximately 15% -20% in the ripe fruit making it sweeter. However, once the fruit is fully ripe, it becomes  
48 very delicate and if not properly handled high postharvest losses can be incurred. In order to increase  
49 storage life of the fruits, appropriate post-harvest technologies aimed at reducing the deterioration rate  
50 have been developed over the years. These technologies are used to slow down fruits metabolic processes  
51 to deliver enhanced shelf-life and optimal quality without compromising on the consumer safety. Recently,  
52 efforts have been made to develop new and biological post-harvest technologies for extension of banana  
53 shelf-life while retaining quality [need few references](#) [35]. Use of hexanal and its formulations is one of the  
54 new innovations which have been proved effective in enhancing the post-harvest shelf life of banana fruits  
55 [33, 34]. Hexanal, is an aldehyde compound produced naturally by plants as a defence response to  
56 different biotic stresses and has an odour similar to that of freshly cut grass or cucumber [18]. The United  
57 States Food and Drug Administration Agency has approved the use of hexanal as a GRAS compound [22].  
58 Hexanal use offers a human-safe post-harvest preservation product that is environmentally friend and  
59 economically viable. Hexanal is oxidized to  
60 hexanoic acid in the body after consumption and further oxidized to carbon dioxide and water during respir  
61 ation through the tricarboxylic acid cycle [18]. It has also been noted that hexanal, has antimicrobial  
62 properties against several post-harvest pathogens such as *Alternaria alternate* and *Botrytis Cinerea* [29]. A  
63 biochemical formulation of an artificially synthesized version of hexanal (Enhanced Freshness Formulation)  
64 has been developed which delays fruit ripening [26]. This formulation can be applied in different ways such  
65 post-harvest dip, pre-harvest spray or as a vapor. Being a relative new technology, there is need to test its  
66 suitability to enhance banana shelf-life while preserving post-harvest quality in Kenya. A previous study in  
67 'Grand nain' variety [34], showed promising results of hexanal extending fruits shelf life by nine days  
68 without compromising on quality. However, since hexanal's effect is physiological, it is possible that its  
69 efficacy might vary between varieties. The objective of this study was therefore, to determine the effect of  
70 hexanal treatment on the post-harvest shelf-life and quality of 'sweet banana' fruits, a very popular variety  
71 in Kenya.

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## 73 2. MATERIALS AND METHODS

### 74 2.1. Study area

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

## 79 **2.2. Experimental setup**

80 For the pre-harvest spray mode of application, 15 banana trees at flowering stage in each study site were  
81 randomly selected and tagged in the farmer's field. Two concentrations of hexanal (2% and 3%) and a  
82 control (clean, plain water) were sprayed twice at 30 and 15 days before harvest. The dosing range used  
83 was informed by a previous study done on 'Grand nain' variety [34]. Since hexanal is immiscible with water,  
84 Tween 20 and ethanol were added to increase its solubility (mention ratio of addition of ethanol and tween  
85 20 and hexanal) [22]. The stock solutions were mixed with water and diluted accordingly to provide the  
86 required hexanal concentrations. Using a knapsack sprayer, the fruits were sprayed to the point of dripping  
87 with the solution. Spray contamination was avoided by using alternate rows of trees for the experiment and  
88 a 4 tree gap between treatments in the same row of trees. The fruits were left on the tree until  
89 approximately 20% per bunch had ripened. The fruits were then harvested and only the middle hands were  
90 used in the post-harvest analysis.

91 For the post-harvest dip mode of application, fruits were harvested at the mature green stage based on  
92 degree of fullness of the fingers, as indicated by the disappearance of angularity and the number of days  
93 after anthesis which was approximately 104 days. Only the middle hands of each banana bunch (a cluster  
94 of fruits attached together at the stalk) were used in the analysis. The harvested fruits were packed in  
95 cushioned crates, covered with wet magazine papers to reduce water loss, and immediately transported to  
96 the post-harvest laboratory at Jomo Kenyatta University of Agriculture and Technology (JKUAT).

## 97 **2.3. Sample preparation**

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

### 108 **2.3.1. Shelf life**

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

### 111 **2.3.2. Analysis of physiological parameters**

112 Gas chromatographs models GC-8A and GC-9A, Shimadzu Corp., Kyoto, Japan were used to determine  
113 the rate of respiration and ethylene production respectively. The gas chromatograph to determine rate of  
114 respiration was fitted with a thermal conductivity detector and a Poropak N column while that for ethylene  
115 determination was fitted with an activated alumina column and a flame ionization detector. The rate of  
116 carbon dioxide production (used to estimate respiration rate) was expressed as ml/Kg/h while ethylene

117 production was expressed as  $\mu\text{l/Kg/h}$ . Five fingers of bananas were randomly sampled from each  
118 treatment, numbered and their weights taken using a digital balance, Model Libror AEG-220, Shimadzu  
119 Corp. Kyoto, Japan. Each of the five fingers were incubated for two hours in air tight containers fitted with  
120 self-sealing rubber septa. Gas samples were taken from the headspace using an airtight 1 ml hypodermic  
121 syringe and injected into the respective gas chromatographs

### 122 **2.3.3. Pulp firmness**

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

### 128 **2.3.4. Analysis of fruit quality parameters**

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

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## 149 **2.4 Statistical analyses**

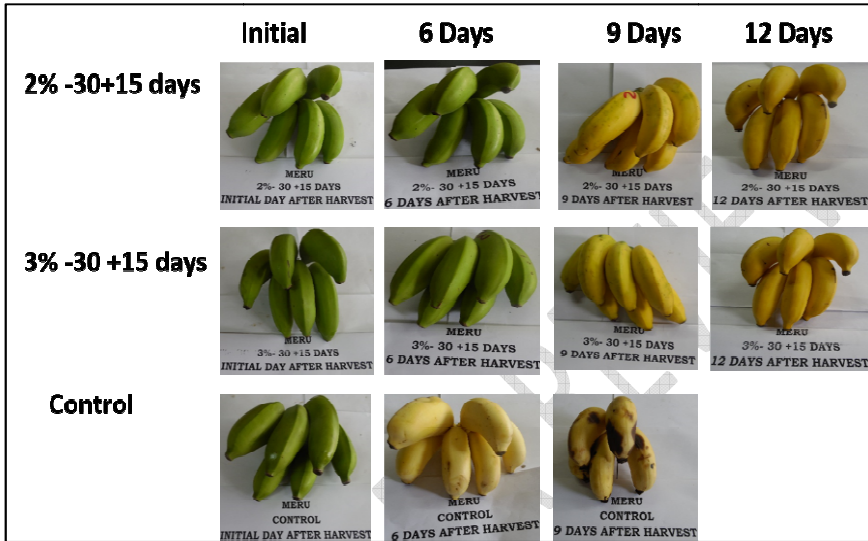
150 Data collected was subjected to analysis of variance (ANOVA) using Genstat statistical package (version  
151 15). The means were separated by Least Significance Difference (LSD) at  $p \leq .05$  using Fisher's protected  
152 test. The sensory quality evaluation data was analyzed using Statistical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

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154 **3.0 Results**

155 **3.1. Shelf life**

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



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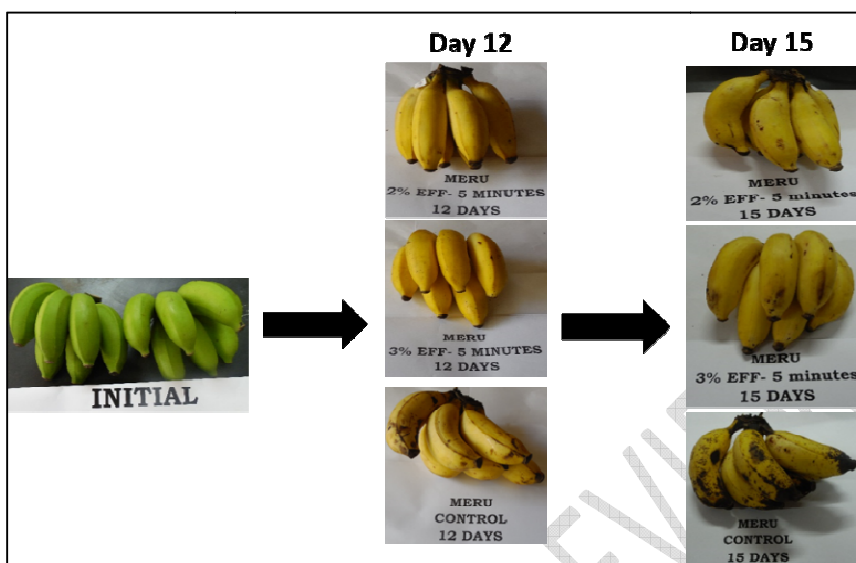


Plate 2: Ripening changes of 'sweet banana dipped in 2% and 3% Hexanal for 5 minutes and controls fruits during post-harvest storage (from initial day to day 15)

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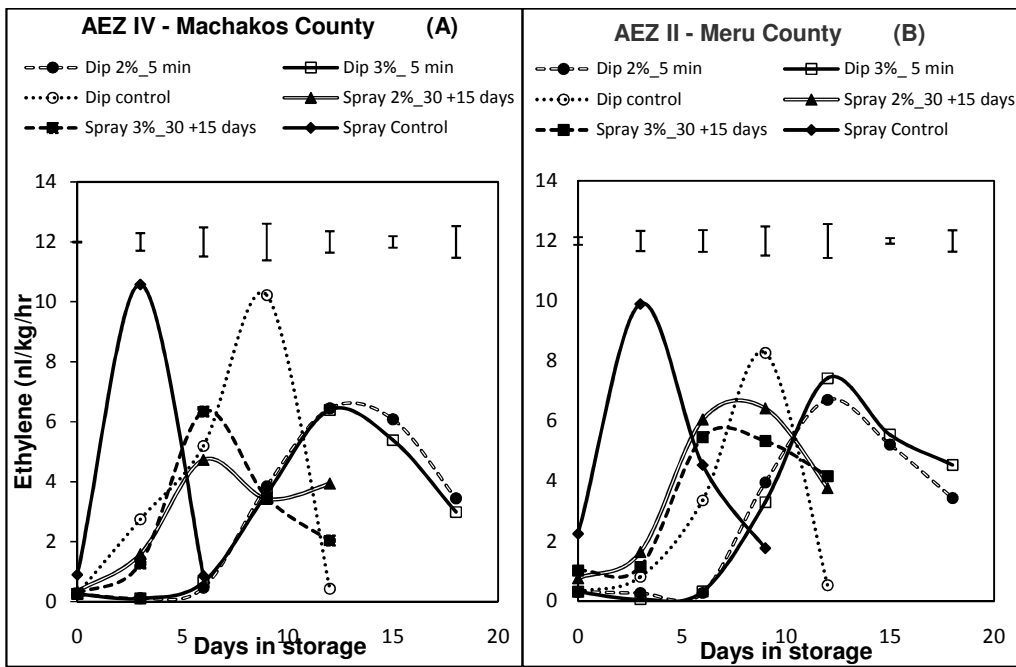
### 173 3.2 Rate of ethylene production

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

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

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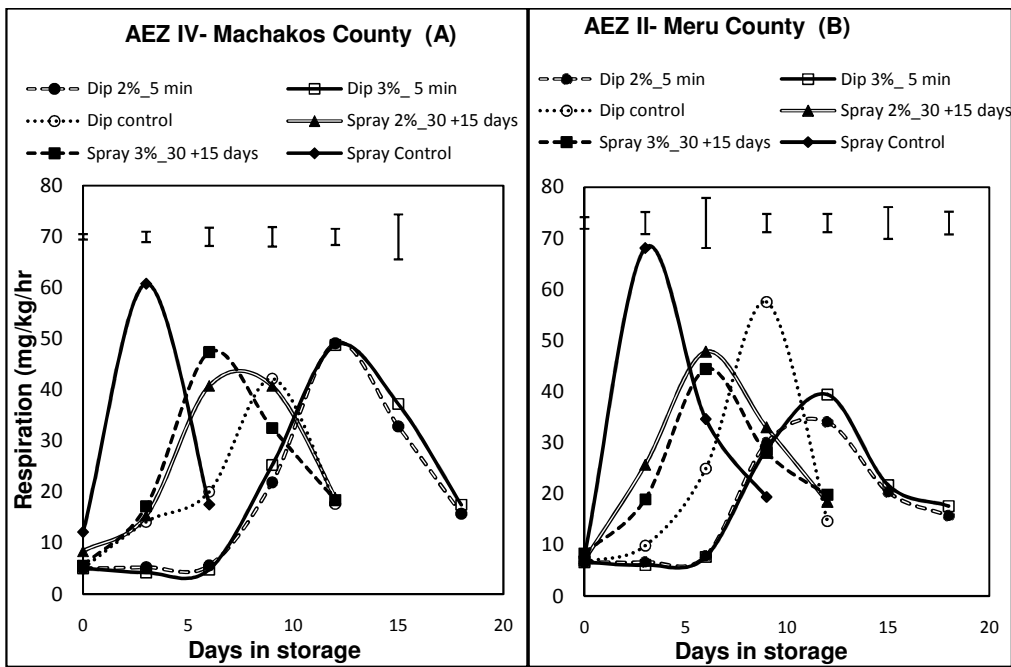
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 188 **Fig. 1. Effect of pre and post-harvest application of Hexanal on rate of ethylene production in 'sweet**  
 189 **banana' fruits from drier AEZ IV (A) and wetter AEZ II (B). Bars indicate least significant difference**  
 190 **(LSD) between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

191 **3.3 Respiration rate**

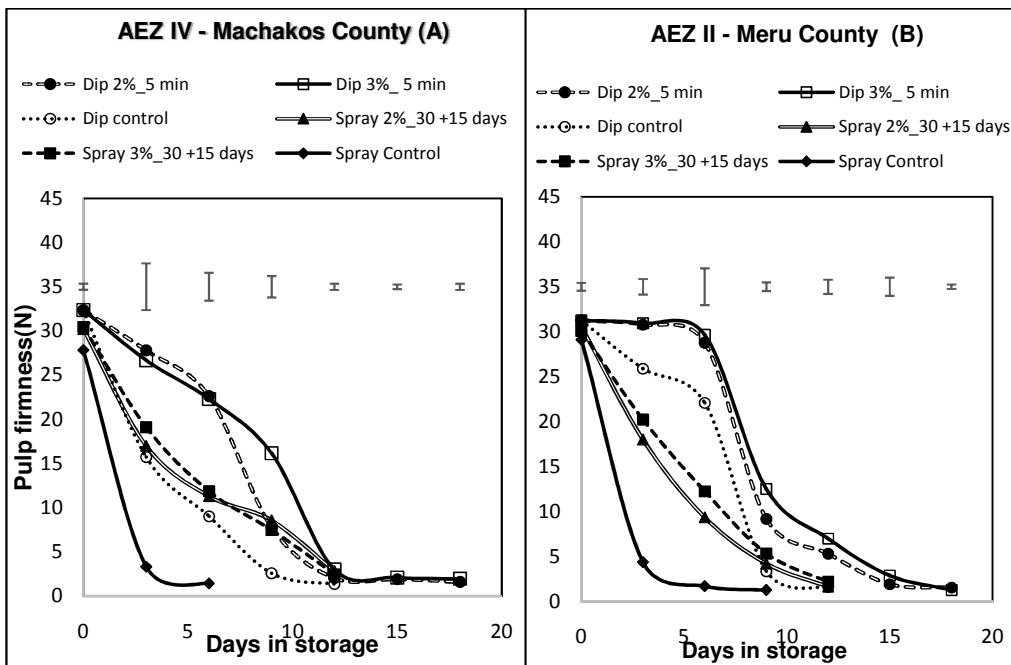
192 Respiration rate followed a similar pattern to the ethylene production. In both zones of production, hexanal  
 193 treatment significantly ( $P = .05$ ) reduced the rate of respiration, with a post-harvest dip mode of application  
 194 exhibiting lower rates compared to pre-harvest spray (Fig.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



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

206 **3.4 Pulp firmness**

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

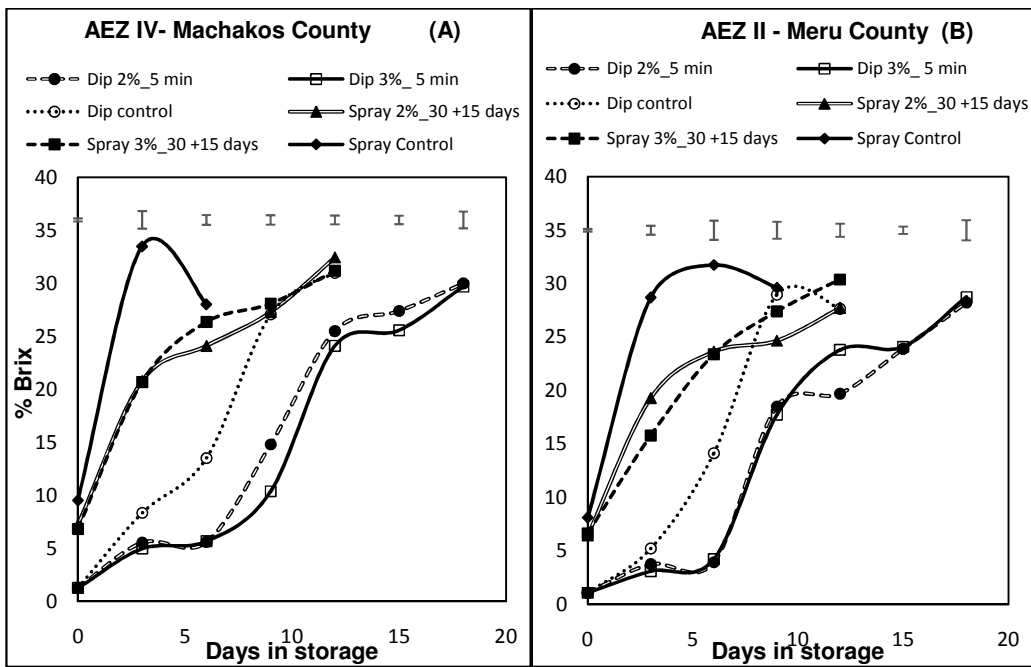


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 219 **Fig. 3. Effect of pre and post-harvest application Hexanal on pulp firmness in 'sweet banana' fruits**  
 220 **from drier AEZ IV (A) and wetter AEZ II (B). Bars indicate least significant difference (LSD) between**  
 221 **means at  $p < 0.05$ .**  
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223 **3.5 Total soluble solids (TSS, °Brix)**

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

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

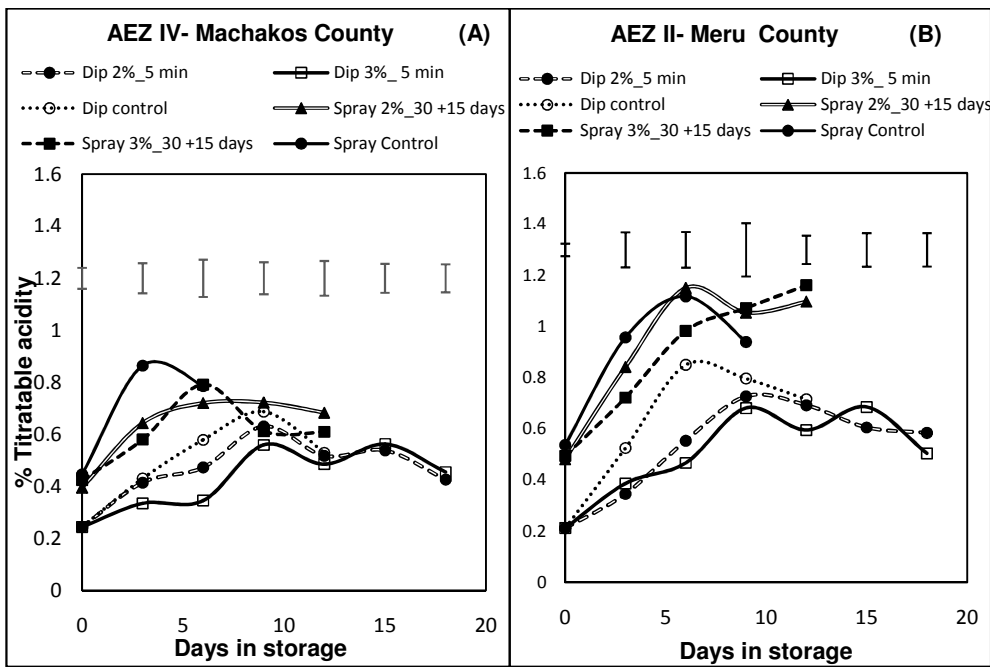


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236 **Fig. 4. Effect of pre and post-harvest application of Hexanal on Total Soluble Solids (TSS) in 'sweet**  
 237 **banana' fruits from drier AEZ IV (A) and wetter AEZ II (B). Bars indicate least significant difference**  
 238 **(LSD) between means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

239 **3.6 Total Titratable Acidity (TTA)**

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

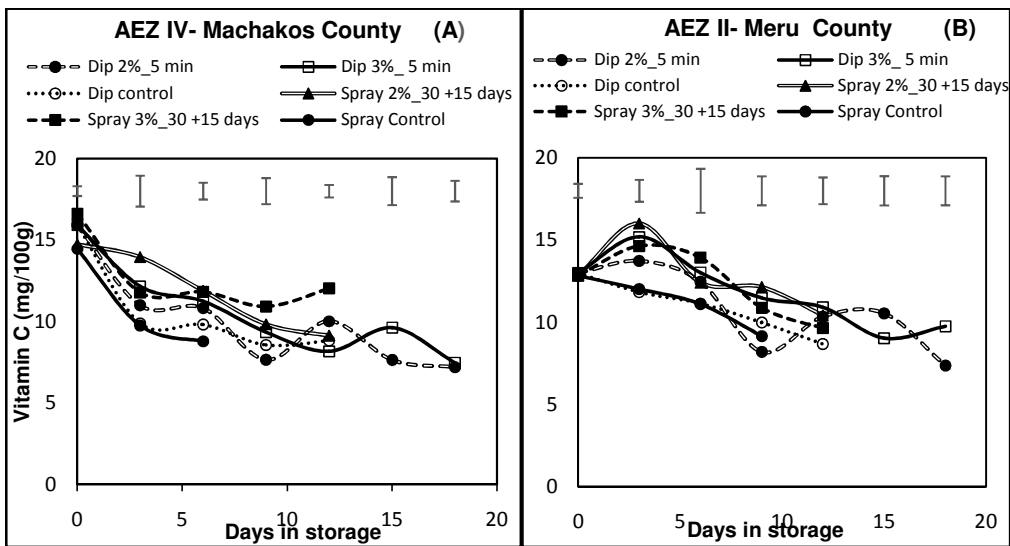


246  
247 **Fig. 5. Effect of pre and post-harvest application of Hexanal on Total Titratable Acidity (TTA) in**  
248 **'sweet banana' fruits from drier AEZ IV (A) and wetter AEZ II (B). Bars indicate least significant**  
249 **difference (LSD) between means at  $p < 0.05$ .**

### 250 3.7 Ascorbic Acid content

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

258 Ascorbic acid levels decreased rapidly in the control fruits from an initial of 14.5 mg/100g and 11.7 mg/100g  
259 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  
260 end of storage (day 9) in the pre-harvest spray mode of application (Fig. 6A & B). Contrasting results were  
261 observed in the hexanal treated fruits where 2% concentration was more effective in the drier AEZ IV fruits  
262 where else in wetter AEZ II, 3% concentration was more effective. In the post-harvest dip experiment, the  
263 ascorbic acid levels decreased from initial values of 15.9 mg/100g and 13 mg/100g to 7.4 mg/100g and 7.3  
264 - 9.6 mg/100g in the treated fruits at the end of storage (day 18), 6 days later compared to the controls in  
265 AEZ IV and AEZ II, respectively.



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**Fig. 6. Effect of pre and post-harvest application of Hexanal on ascorbic acid content 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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### 272 3.8 Simple sugars (Sucrose, glucose and Fructose)

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

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292 **Table 1. Effect of pre and post-harvest application of Enhanced fresh formulation (EFF) on**  
 293 **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	82.0	80.0	75.9	21.6	22.2	23.1	25.5	19.1	17.7
<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	63.0	50.9	51.1	38.1	24.8	20.7	35.8	22.8	23.1
LSD*	10.2			5.5			7.4		

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

296

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

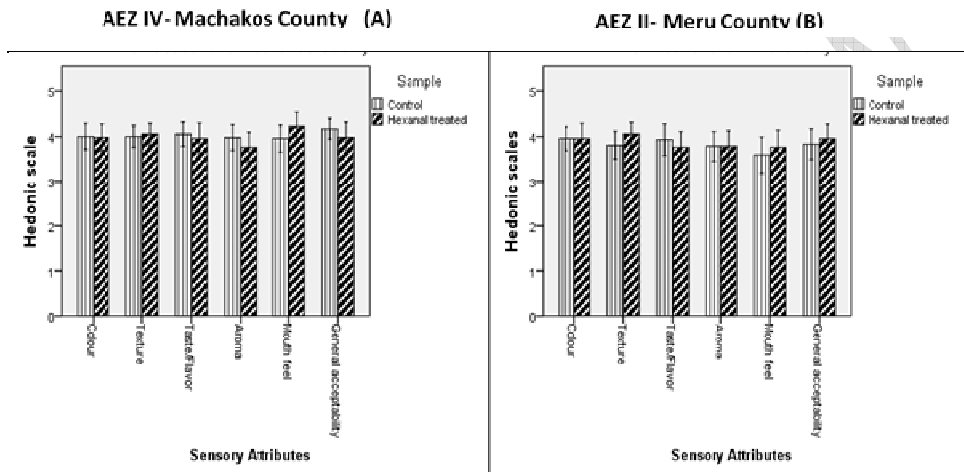
DAYS Dip	SUCROSE			GLUCOSE			FRUCTOSE		
	Control	2%	3%	Control	2%	3%	Control	2%	3%
0	3.8c	3.8e	3.8dc	4.1f	4.1f	4.1d	4.4e	4.4d	4.4e
3	27.5c	3.4e	7.5dc	7.5ef	5.0f	5.6d	4.5e	3.0d	3.6e
6	41.1c	12.0d	5.4dc	29.1d	5.9f	3.7d	15.7d	6.6d	3.7e
9	95.9b	31.5d	56.3c	28.5d	23.3d	32.4b	41.4a	18.9c	28.0c
12	155.0a	79.3c	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	65.6	61.9	67.2	22.8	22.6	25.8	22.4	19.1	21.7
<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	77.2	74.8	72.4	34.1	24	19.5	26.6	19.6	20.6
LSD*	35.6			4.8			4.9		

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

301

302 **3.9 Sensory Quality Evaluation**

303 Generally, there was no significant ( $P = .05$ ) differences observed in all the quality attributes scores in both  
304 zones between the hexanal treated and control fruits (Fig. 7A & B). The treated and control fruits from both  
305 AEZ scored almost the same scores for peel color, texture in AEZ IV fruits (Fig. 7A) and aroma in AEZ II  
306 (Fig. 7B). On the other hand, hexanal treated fruits scored slightly high for taste/flavour in both AEZs (Fig.  
307 7A & B) while general acceptability and aroma scored highest in AEZ IV (Fig. 7A) fruits though this was not  
308 significantly different.



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

315 **4.0. DISCUSSION**

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

327 Overall, zone of production had a significant effect on fruits shelf-life and quality. Fruits from the drier AEZ  
328 IV, ripened faster and had high content of <sup>0</sup>brix and simple sugars as compared to those from the wetter

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

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

369 treatment. This could be attributed to differences in temperatures and rainfall in the different zones; both  
370 having been reported to affect fruit softening [13].

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

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

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

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

409

410

411

## 412 5.0. CONCLUSION

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

421

## 422 COMPETING INTERESTS

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

424

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