

**EFFECTIVENESS OF HEXANAL AND ITS MODE OF ACTION ON THE  
POST-HARVEST QUALITY OF BANANA FRUITS (*MUSA SPP*)**

**SUBMITTED BY**

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**A80/50768/2016**

**A THESIS SUBMITTED IN FULFILMENT OF THE REQUIREMENTS  
FOR THE AWARD OF THE DEGREE OF DOCTOR OF PHILOSOPHY IN  
HORTICULTURE**

**DEPARTMENT OF PLANT SCIENCE AND CROP PROTECTION  
FACULTY OF AGRICULTURE  
UNIVERSITY OF NAIROBI**

**2020**



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## DEDICATION

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## ACKNOWLEDGEMENTS

I would like to thank my supervisor, Prof. Dr. [Name], for his guidance and support throughout the project. I also thank my colleagues and friends for their help and encouragement. Finally, I thank my family for their love and support.

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compared to control on pulp firmness in ‘Grand nain’ bananas.. 2

compared to control on peel color in ‘Grand nain’ bananas. Top bars indicate least significant differences ( $p < 0.05$ ) (Figure 22). 2



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log<sub>2</sub>fold ratio ≥ 1 at day one of storage in the hexanal treated fruits

log<sub>2</sub>fold ratio ≥ 1 at day 5 of storage in the hexanal treated fruits

log<sub>2</sub>fold ratio ≥ 1 at day 4 of storage in the hexanal treated fruits

log<sub>2</sub>fold ratio ≥ 1 at day 4 of storage in the ethylene treated fruits

log<sub>2</sub>fold ratio ≥ 1 at day 18 of storage in the hexanal treated fruits

log<sub>2</sub>fold ratio ≥ 1 at day of 18 storage in the ethylene treated fruits

log<sub>2</sub>fold ratio ≥ 1 at day 2 of storage in the ethylene treated fruits













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## CHAPTER ONE

### 1.0 INTRODUCTION

#### 1.1 Background Information

Horticulture plays a significant role in the Kenyan economy and it's the fastest growing subsector (Mwangi, 2002). Horticulture is a branch of agriculture that deals with the growing of fruits, vegetables, ornamental plants, and nursery stock. It is a diverse sector that includes a wide range of crops and products. Horticulture is an important part of the Kenyan economy, contributing significantly to the country's GDP and providing employment for a large number of people. It is also a key sector for export earnings and foreign exchange. Horticulture is a dynamic and growing sector, driven by increasing demand for fresh produce and ornamental plants both locally and internationally. The sector has the potential to become a major contributor to Kenya's economic growth and development.

Kenya's horticulture sector has experienced rapid growth over the past few years. The sector's contribution to the country's GDP has increased significantly, and it is expected to continue to grow at a fast pace in the coming years. Horticulture is a key sector for export earnings and foreign exchange. The sector has the potential to become a major contributor to Kenya's economic growth and development. Horticulture is a dynamic and growing sector, driven by increasing demand for fresh produce and ornamental plants both locally and internationally. The sector has the potential to become a major contributor to Kenya's economic growth and development.

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## CHAPTER TWO

### 2.0 Literature Review

#### 2.1. Background information

Musa is a member of the Musaceae family. It is a perennial herbaceous plant that grows in tropical and subtropical regions. The banana is a fruit that is eaten worldwide. It is a staple food for many people in developing countries. The banana is a fruit that is eaten worldwide. It is a staple food for many people in developing countries. The banana is a fruit that is eaten worldwide. It is a staple food for many people in developing countries.

#### 2.2. Banana production in Kenya

Small scale farmers dominate Kenya's banana farming with an average holdings of about 0.5 hectares. The banana is a fruit that is eaten worldwide. It is a staple food for many people in developing countries. The banana is a fruit that is eaten worldwide. It is a staple food for many people in developing countries. The banana is a fruit that is eaten worldwide. It is a staple food for many people in developing countries.

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(20%), Murang'a (11.7%), Kirinyaga (8.1%), Taita Taveta (6.6%) and Th...56  
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26...r...d...r...r...r...r...r...  
...r...r...r...d...r...d...r...r...d...  
...r...r...d...d...r...d...et al...6...r...  
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...r...M...d muraru...et al...22...  
...d Kiganda, Uganda green, ng'ombe, nusu ng'ombe, mutahato...d Gradi Shisikame  
...et al...22...d...M...et al...2...r...r...r...  
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**Table 1: Banana production statistics in selected Counties, 2015-2018**

| COUNTY       | 2015          |                  | 2016          |                  | 2017          |                  | 2018          |                  |
|--------------|---------------|------------------|---------------|------------------|---------------|------------------|---------------|------------------|
|              | Area (Ha)     | Volume (Tons)    | Area (Ha)     | Volume (Tons)    | Area (Ha)     | Volume (Tons)    | Area (Ha)     | Volume (Tons)    |
| Morogoro     | 7,038         | 251,132          | 7,503         | 276,919          | 11,305        | 288,266          | 10,542        | 308,095          |
| Morogoro     | 5,757         | 159,790          | 5,987         | 154,172          | 7,160         | 166,641          | 7,214         | 173,439          |
| Morogoro     | 6,318         | 142,036          | 6,670         | 145,036          | 6,208         | 122,850          | 5,485         | 152,409          |
| Morogoro     | 2,891         | 67,865           | 4,288         | 63,300           | 2,528         | 58,420           | 2,972         | 74,231           |
| Morogoro     | 4,204         | 75,544           | 3,734         | 76,633           | 3,622         | 74,940           | 4,112         | 87,540           |
| Morogoro     | 4,856         | 132,253          | 4,288         | 63,300           | 6,233         | 117,951          | 4,262         | 70,194           |
| Morogoro     | 3,088         | 60,975           | 3,919         | 77,415           | 4,193         | 67,986           | 3,791         | 64,158           |
| Morogoro     | 1,985         | 22,692           | 1,852         | 23,091           | 1,861         | 24,246           | 1,400         | 23,550           |
| Morogoro     | 2,206         | 20,544           | 2,572         | 23,334           | 2,742         | 20,716           | 4,419         | 42,299           |
| Morogoro     | 3,402         | 38,929           | 3,824         | 34,717           | 2,210         | 31,723           | 2,518         | 38,380           |
| Morogoro     | 2,005         | 30,708           | 2,259         | 42,475           | 1,943         | 44,000           | 1,898         | 37,840           |
| Morogoro     | 2,057         | 30,856           | 1,987         | 40,098           | 2,765         | 30,667           | 2,829         | 42,014           |
| Morogoro     | 850           | 28,050           | 862           | 27,584           | 1,706         | 45,828           | 1,801         | 49,628           |
| Morogoro     | 1,730         | 39,584           | 1,876         | 37,230           | 1,264         | 26,597           | 1,531         | 35,194           |
| Morogoro     | 12,332        | 189,192          | 13,013        | 188,254          | 10,547        | 175,149          | 10,744        | 162,875          |
| <b>TOTAL</b> | <b>60,718</b> | <b>1,290,150</b> | <b>63,299</b> | <b>1,288,588</b> | <b>69,376</b> | <b>1,357,162</b> | <b>68,248</b> | <b>1,419,176</b> |

Source: (HCD reports 2016 & 2018)

### 2.3 Nutritional value of Banana fruit

The nutritional value of banana fruit is high in carbohydrates, fiber, potassium, and vitamin B6. It is also a good source of antioxidants and phytochemicals. The fruit is rich in potassium, which helps to regulate blood pressure and maintain heart health. It is also a good source of fiber, which aids in digestion and prevents constipation. The fruit is also a good source of vitamin B6, which is essential for the production of red blood cells and the maintenance of the nervous system. The fruit is also a good source of antioxidants, which help to protect the body against oxidative stress and chronic diseases. The fruit is also a good source of phytochemicals, which have anti-inflammatory and anticancer properties.







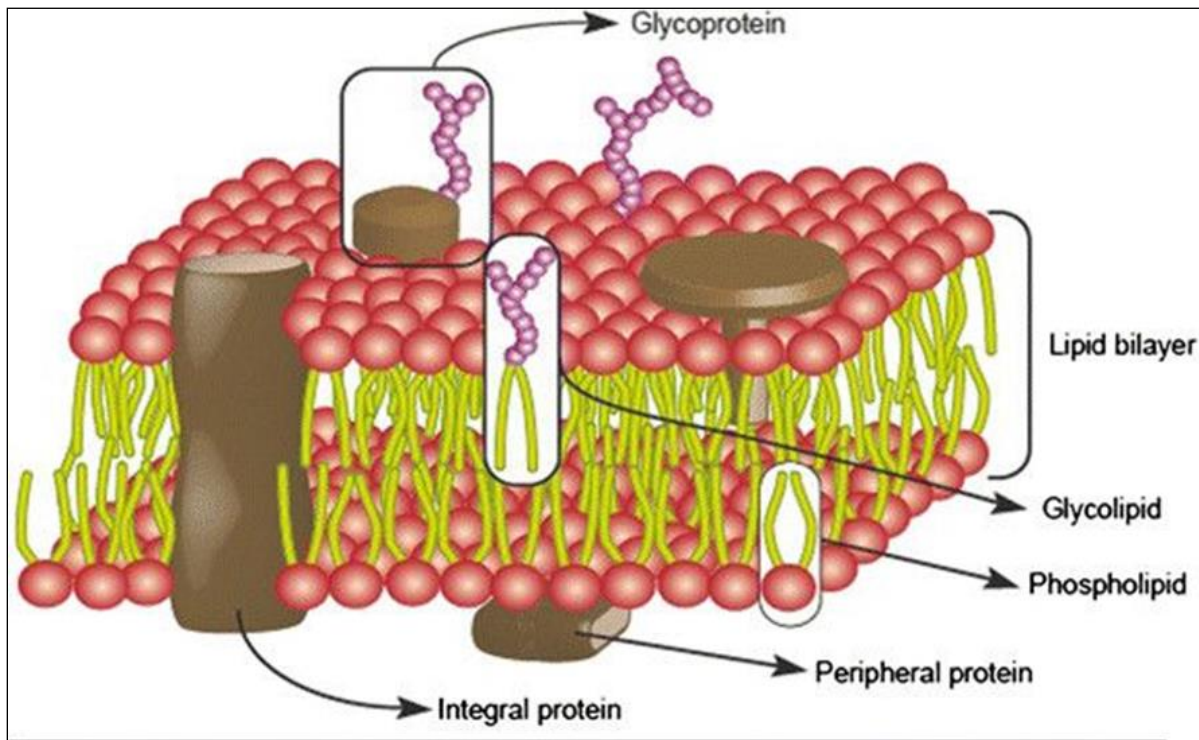






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**Figure 2:** et al 2 d

**2.4.1.2.1. Role of enzyme phospholipase D in membrane deterioration**

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annual average rainfall of 600mm (FAO, 1996). The soils in Machakos County are generally sandy and low in organic matter. A detailed soil analysis of the two study sites is presented below (Table 3). Meru County is currently the leading producer of banana fruits in Kenya (HCD, 2018) while Machakos county is located in a dry region where banana production is practiced on a limited scale. 'Grand nain' is a popular banana variety in Meru County and is known for its high yield and resistance to pests and diseases. The experiment were conducted in two successive seasons, July to November 2016 and January to April 2017.

**Table 3: Soil analysis results for the two study sites (AEZ II and AEZ IV)**

| Soil parameters         | AEZ II     | AEZ IV     |
|-------------------------|------------|------------|
| Soil texture            | Sandy loam | Sandy loam |
| pH                      | 6.5        | 6.6        |
| Soil moisture (%)       | 15         | 15         |
| Soil temperature (°C)   | 22         | 22         |
| Soil organic carbon (%) | 2.6        | 2.6        |
| Soil nitrogen (%)       | 0.2        | 0.2        |
| Microbial biomass C (%) | 2          | 2          |

□

### 3.3.2. Experimental designs and treatments

The experiment was conducted in a randomized complete block design with two replicates. The treatments were: 1) Control (no banana plants), 2) Grand nain banana plants, 3) Grand nain banana plants + organic fertilizer, 4) Grand nain banana plants + inorganic fertilizer, 5) Grand nain banana plants + organic and inorganic fertilizer. The experiment was conducted in two successive seasons, July to November 2016 and January to April 2017.









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#### 3.3.4.4. Percentage weight loss (PWL)

Percentage weight loss (PWL) was determined by weighing fresh samples (200 g) and after 22 days of storage at 2 °C. The samples were then oven-dried at 70 °C for 24 hours. The difference in weight between the fresh and dried samples was divided by the fresh weight and multiplied by 100 to obtain the percentage weight loss. The formula used was:  $PWL = \frac{(W_{fresh} - W_{dried})}{W_{fresh}} \times 100$

#### 3.3.4.5. Peel and pulp firmness

Peel and pulp firmness were determined using a penetrometer (PFT-2000, Food Tester Systems, Inc., Columbus, OH, USA). The measurements were taken on the peel and pulp of the samples. The firmness was expressed in grams force (gF). The formula used was:  $Firmness = \frac{Force}{Area}$

#### 3.3.4.6. Peel Color

Peel color was determined using a colorimeter (Chromameter 2, Hunter Associates, USA). The measurements were taken on the peel of the samples. The color was expressed in L\*, a\*, and b\* values. The formula used was:  $Color = L^*, a^*, b^*$

#### 3.3.5 Statistical analyses

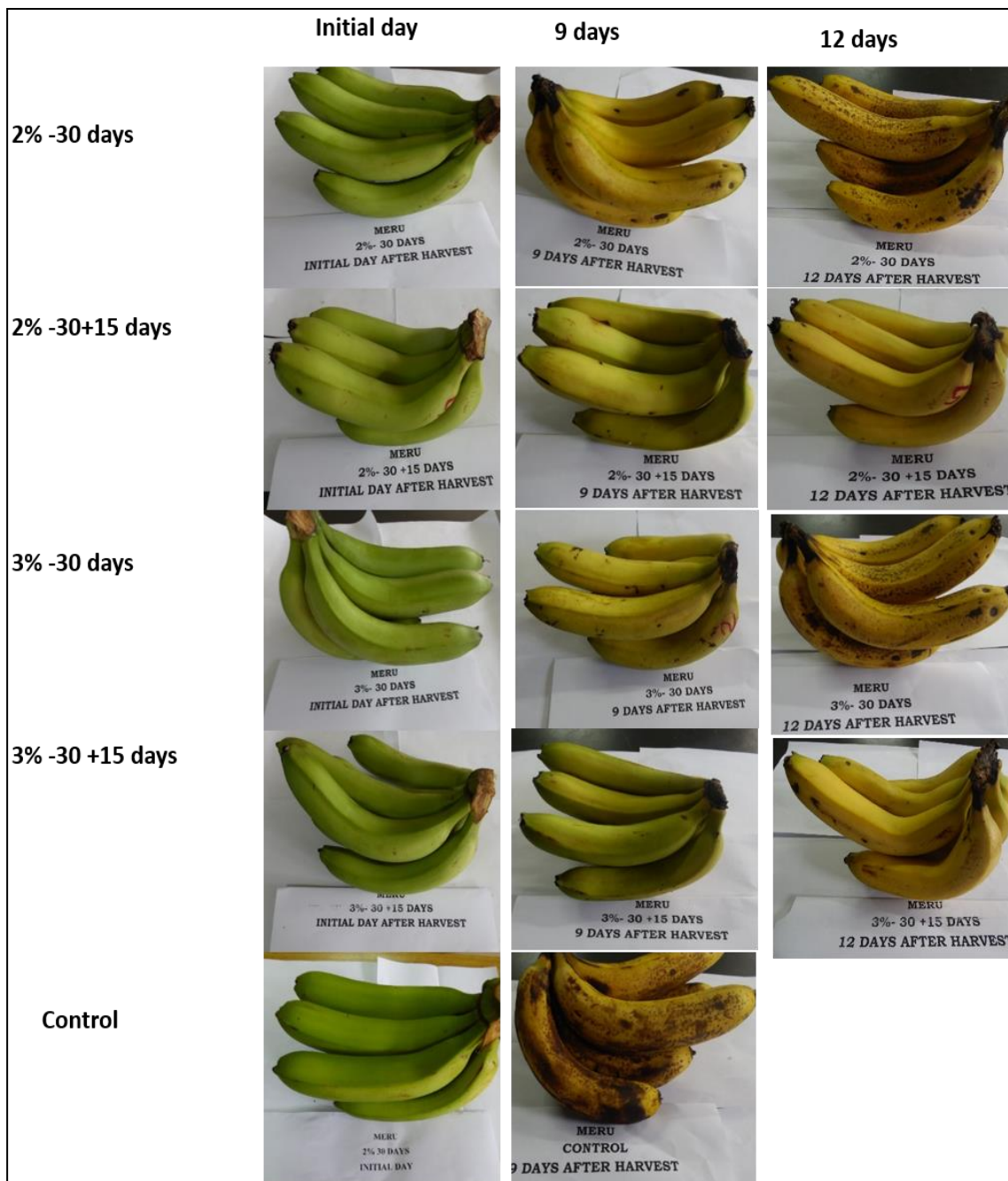
Data were analyzed using SPSS (IBM SPSS, Armonk, NY, USA). The results were expressed as mean and standard deviation. The differences between treatments were tested using Fisher's protected test.  $p \leq .05$  using Fisher's protected test. □







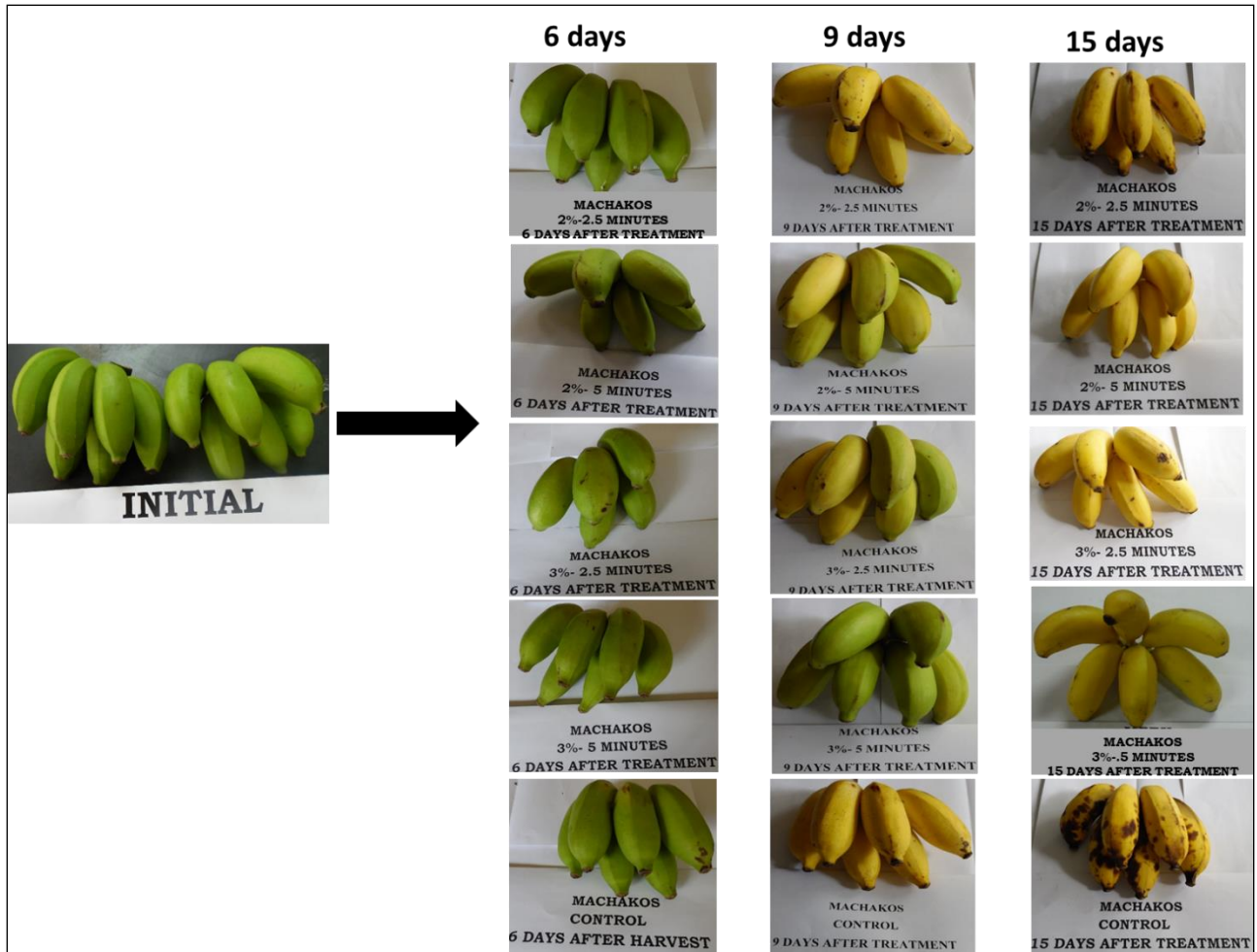
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**Figure 6:** Progression of ripening in ‘Grand nain’ banana fruits sprayed with  $2\% \text{CaCl}_2$  and  $3\% \text{CaCl}_2$  at 30 days and 30+15 days after harvest. The control group was not sprayed. The images show the progression of ripening from green to yellow over 12 days for each treatment.

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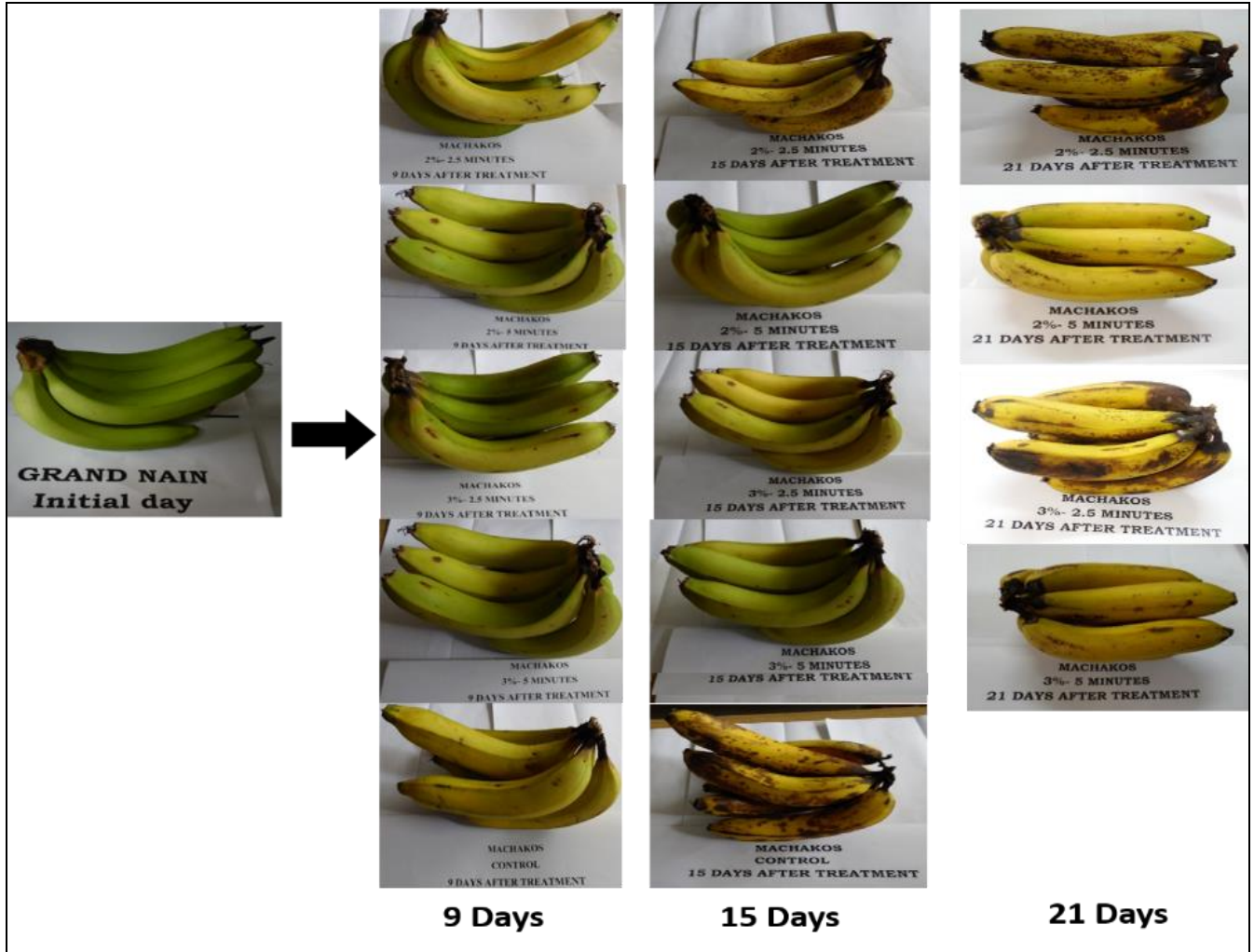


**Figure 7:** Progression of ripening in 'sweet banana' fruits post treatment with 2% and 3% concentrations for 2.5 and 5 minutes, and control group, at 6, 9, and 15 days after treatment.

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**Figure 8:** Progression of ripening in ‘Grand nain’ banana fruits post treatment with 2% ethylene for 2.5 minutes, 5 minutes, 3% ethylene for 2.5 minutes, and control for 9, 15, and 21 days after treatment.

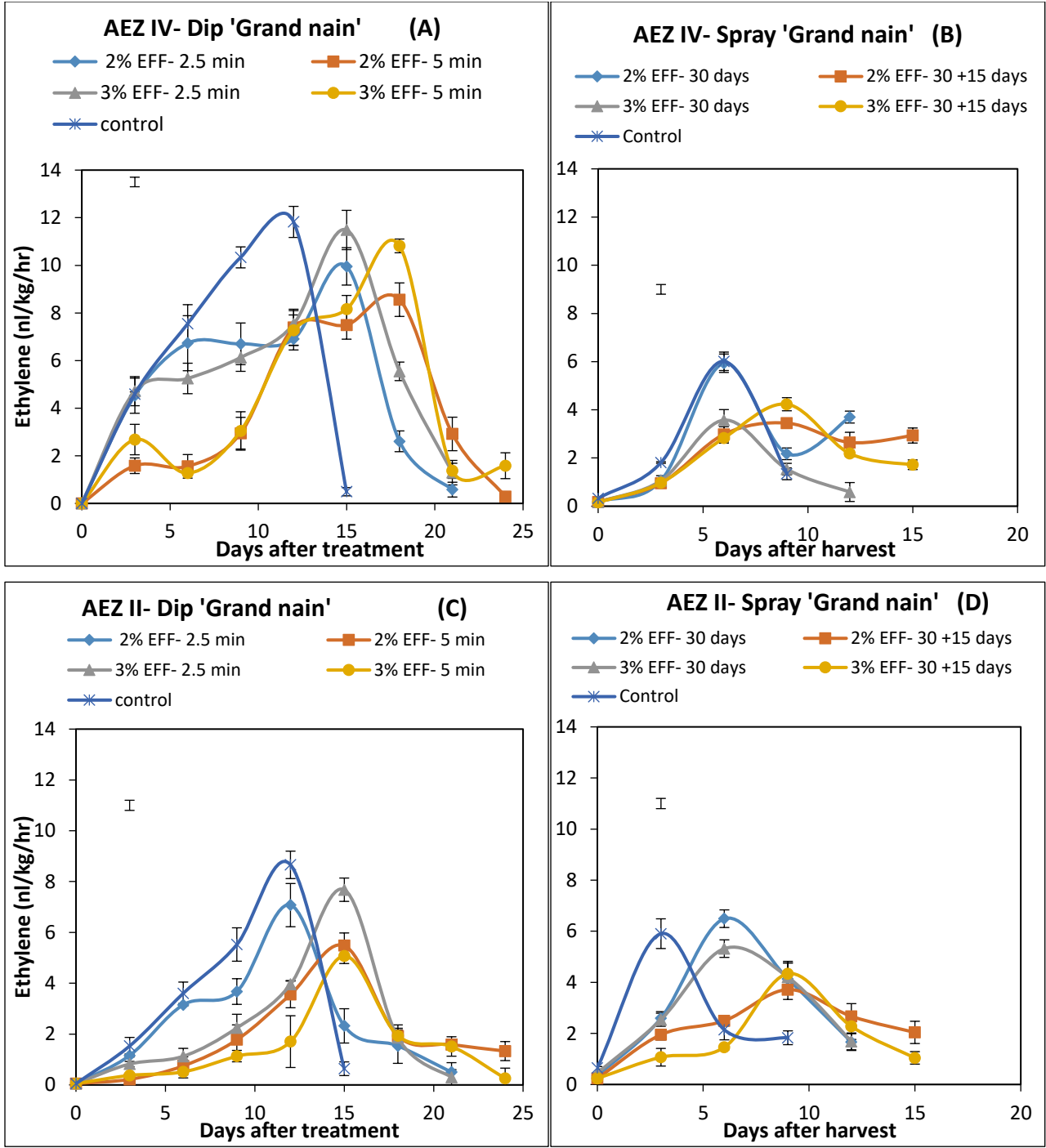
### 3.4.2. Ethylene production Levels

The text in this section is mostly illegible due to heavy noise and artifacts. It appears to discuss the relationship between ethylene production and ripening, mentioning that ethylene production increases as the fruit ripens. It also notes that the rate of ethylene production is higher in the 2% and 3% ethylene treated bunches compared to the control bunches.

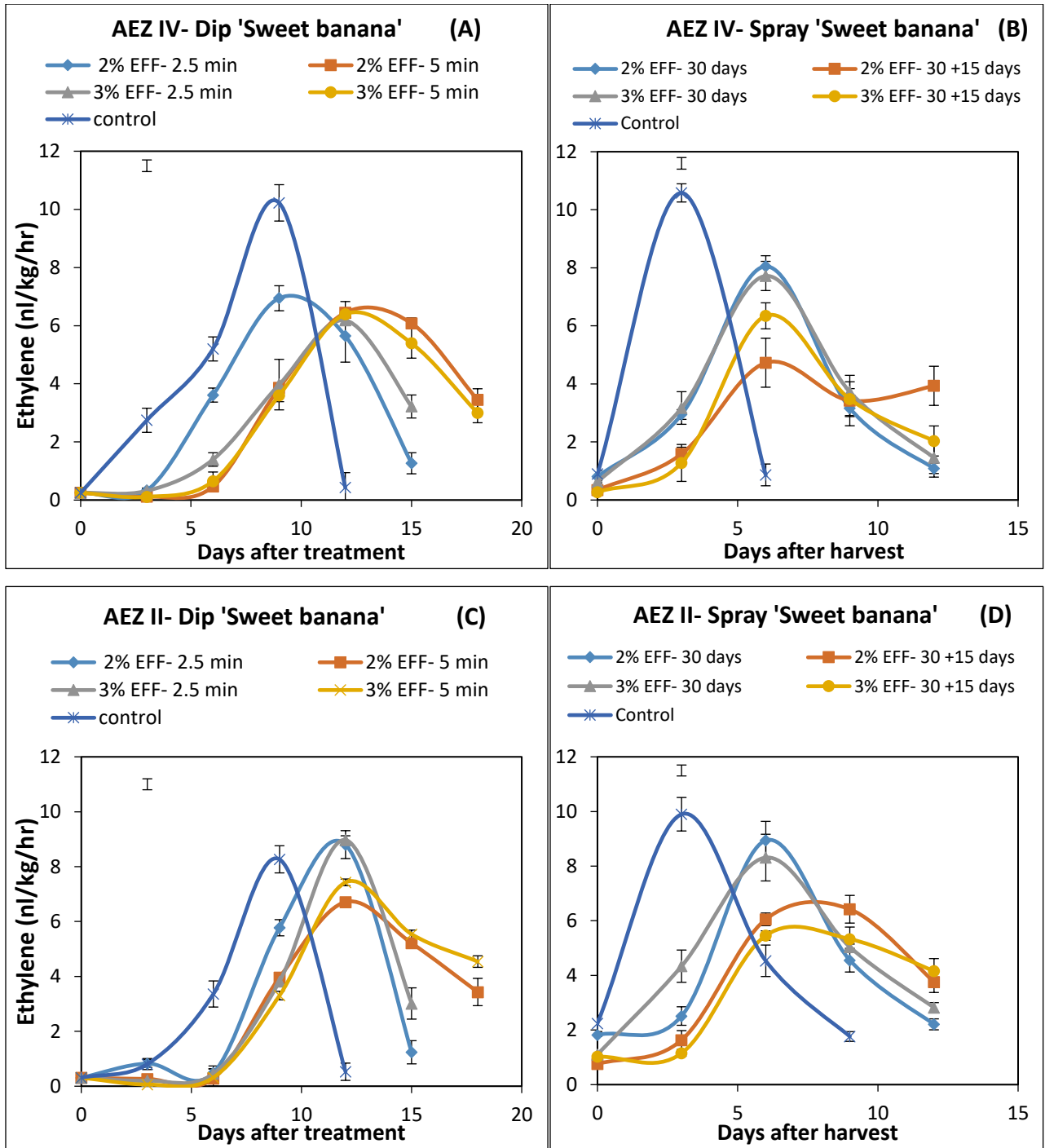




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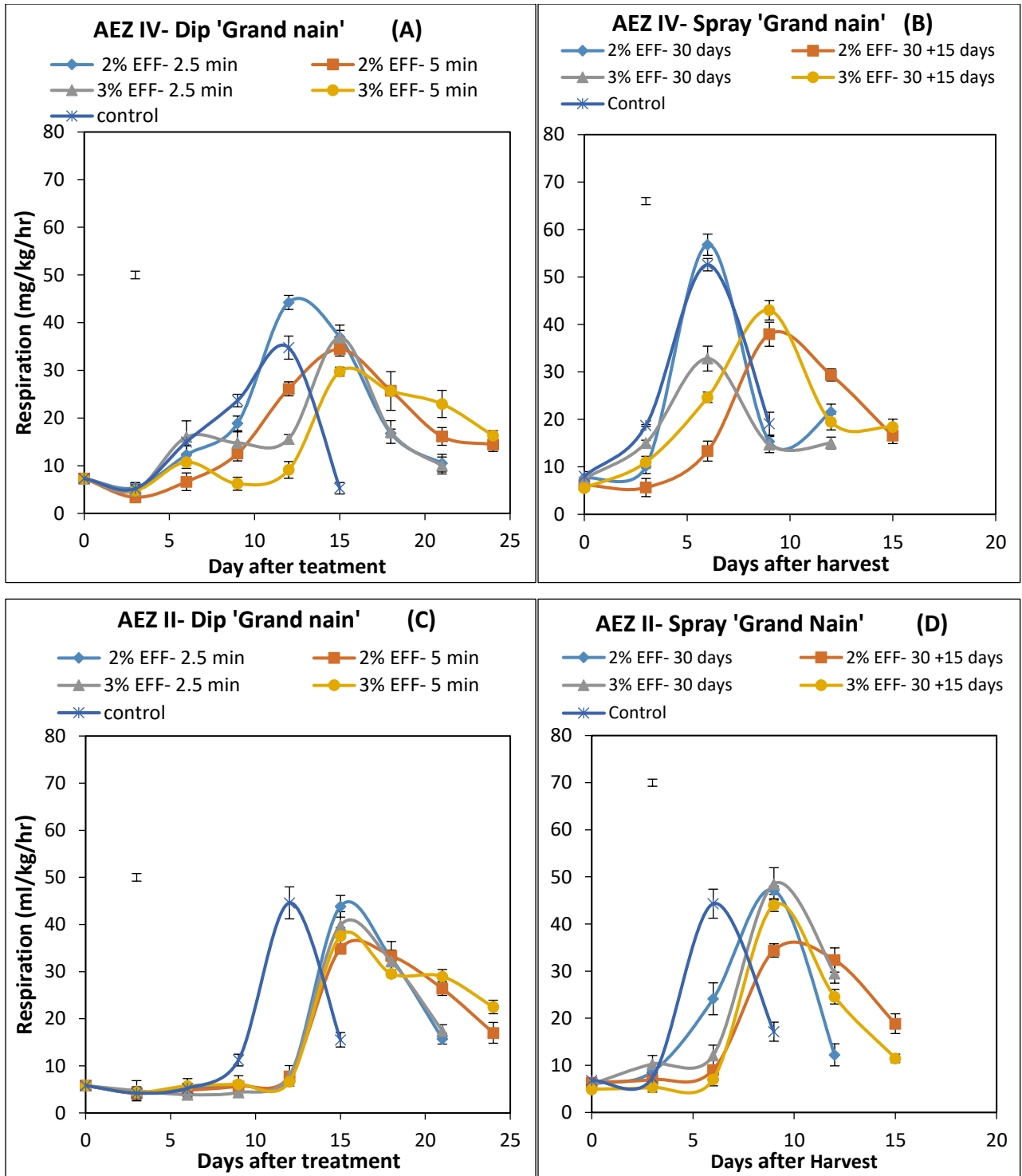


**Figure 9:** Ethylene production (nl/kg/hr) over time for 'Grand nain' under different treatments. The graphs show that ethylene production peaks around 10-15 days after treatment or harvest. The control groups generally show higher ethylene production compared to the EFF-treated groups. The treatments include 2% and 3% EFF concentrations at 2.5 min, 5 min, 30 days, and 30 +15 days.

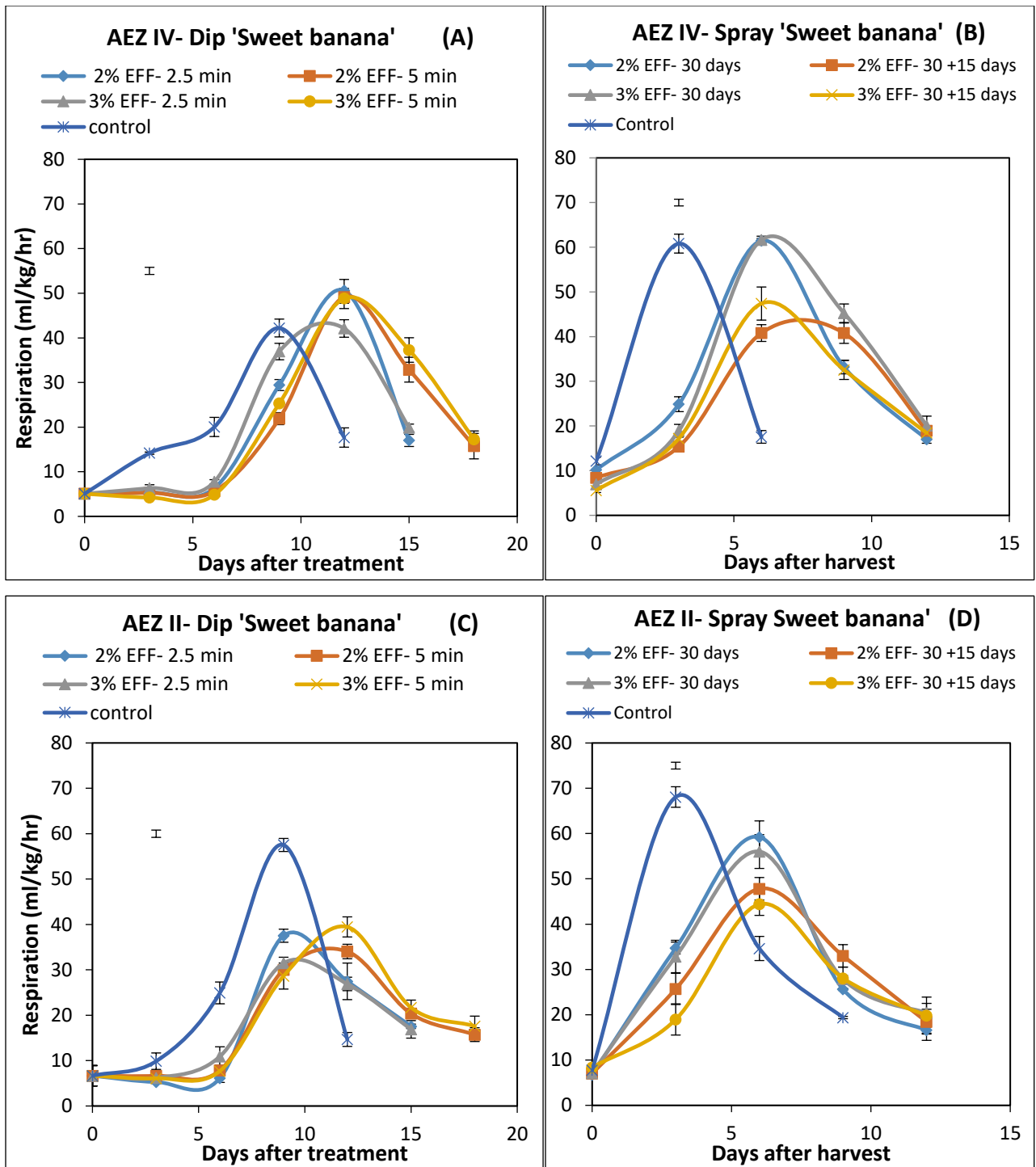


**Figure 10:** Ethylene production (nl/kg/hr) in 'Sweet banana' fruits under different treatments and harvest conditions. The graphs show that ethylene production peaks at different times depending on the treatment and harvest method. In general, the control group shows the highest and earliest peak, while the 2% EFF- 2.5 min treatment shows the lowest and latest peak. The 3% EFF- 5 min treatment shows a peak similar to the control. The 2% EFF- 5 min treatment shows a peak similar to the 3% EFF- 5 min treatment. The 2% EFF- 30 days treatment shows a peak similar to the 3% EFF- 30 days treatment. The 2% EFF- 30 +15 days treatment shows a peak similar to the 3% EFF- 30 +15 days treatment. The 3% EFF- 30 days treatment shows a peak similar to the 2% EFF- 30 days treatment. The 3% EFF- 30 +15 days treatment shows a peak similar to the 2% EFF- 30 +15 days treatment.





**Figure 11:** Effect of different treatments on the respiration rate of 'Grand nain' banana. The figure consists of four line graphs (A, B, C, D) showing respiration rates (mg/kg/hr or ml/kg/hr) over time (Days after treatment or Days after Harvest) for various treatments. The treatments include different concentrations of EFF (2% and 3%) and different durations (2.5 min, 5 min, 30 days, 30 +15 days) and a control. The graphs show that respiration rates generally increase over time, with the control and 2% EFF- 2.5 min treatments showing the highest peaks. The 3% EFF- 30 days treatment shows a significant peak at 9 days after harvest in graph D.



**Figure 12:** Respiration rate (ml/kg/hr) of 'Sweet banana' under different treatments and time points. The figure consists of four panels (A, B, C, D) showing respiration rates over time. Panel A shows the effect of dipping treatments (2% and 3% EFF for 2.5 min and 5 min) and a control. Panel B shows the effect of spraying treatments (2% and 3% EFF for 30 days and 30+15 days) and a control. Panel C shows the effect of dipping treatments (2% and 3% EFF for 2.5 min and 5 min) and a control. Panel D shows the effect of spraying treatments (2% and 3% EFF for 30 days and 30+15 days) and a control. Error bars represent standard deviation.



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**Table 5** Cumulative weight loss of ‘Grand nain’ fruits from AEZ IV (Machakos County) and AEZ II (Meru) over 24 days postharvest under different postharvest and preharvest spray treatments.

| DAYS           | Postharvest Dip |            |            |            |          | Preharvest spray |            |            |            |            |      |
|----------------|-----------------|------------|------------|------------|----------|------------------|------------|------------|------------|------------|------|
|                | Zone IV         | 2%-A       | 2%-B       | 3%-A       | 3%-B     | Ctrl             | 2%- S      | 2%-D       | 3%-S       | 3%-D       | Ctrl |
| <b>0</b>       | 0.00            | 0.00       | 0.00       | 0.00       | 0.00     | 0.00             | 0.00       | 0.00       | 0.00       | 0.00       | 0.00 |
| <b>3</b>       | 2.50            | 2.20       | 2.60       | 2.00       | 2.00     | 5.20             | 5.60       | 6.20       | 5.50       | 5.50       |      |
| <b>6</b>       | 5.50            | 5.00       | 5.00       | 5.00       | 5.00     | 6.00             | 6.00       | 6.00       | 6.00       | 6.00       |      |
| <b>9</b>       | 6.00            | 6.00       | 6.00       | 6.00       | 6.00     | 6.00             | 6.00       | 6.00       | 6.00       | 6.00       |      |
| <b>12</b>      | 6.00            | 6.00       | 6.00       | 6.00       | 6.00     | 6.00             | 6.00       | 6.00       | 6.00       | 6.00       |      |
| <b>15</b>      | 6.00            | 6.00       | 6.00       | 6.00       | 6.00     | 6.00             | 6.00       | 6.00       | 6.00       | 6.00       |      |
| <b>18</b>      | 6.00            | 6.00       | 6.00       | 6.00       | 6.00     | 6.00             | 6.00       | 6.00       | 6.00       | 6.00       |      |
| <b>21</b>      | 6.00            | 6.00       | 6.00       | 6.00       | 6.00     | 6.00             | 6.00       | 6.00       | 6.00       | 6.00       |      |
| <b>24</b>      | 6.00            | 6.00       | 6.00       | 6.00       | 6.00     | 6.00             | 6.00       | 6.00       | 6.00       | 6.00       |      |
| <b>Zone II</b> |                 |            |            |            |          |                  |            |            |            |            |      |
| <b>0</b>       | 0.00            | 0.00       | 0.00       | 0.00       | 0.00     | 0.00             | 0.00       | 0.00       | 0.00       | 0.00       |      |
| <b>3</b>       | 6.00            | 6.00       | 6.00       | 6.00       | 6.00     | 6.00             | 6.00       | 6.00       | 6.00       | 6.00       |      |
| <b>6</b>       | 6.00            | 6.00       | 6.00       | 6.00       | 6.00     | 6.00             | 6.00       | 6.00       | 6.00       | 6.00       |      |
| <b>9</b>       | 6.00            | 6.00       | 6.00       | 6.00       | 6.00     | 6.00             | 6.00       | 6.00       | 6.00       | 6.00       |      |
| <b>12</b>      | 6.00            | 6.00       | 6.00       | 6.00       | 6.00     | 6.00             | 6.00       | 6.00       | 6.00       | 6.00       |      |
| <b>15</b>      | 6.00            | 6.00       | 6.00       | 6.00       | 6.00     | 6.00             | 6.00       | 6.00       | 6.00       | 6.00       |      |
| <b>18</b>      | 6.00            | 6.00       | 6.00       | 6.00       | 6.00     | 6.00             | 6.00       | 6.00       | 6.00       | 6.00       |      |
| <b>21</b>      | 6.00            | 6.00       | 6.00       | 6.00       | 6.00     | 6.00             | 6.00       | 6.00       | 6.00       | 6.00       |      |
| <b>24</b>      | 6.00            | 6.00       | 6.00       | 6.00       | 6.00     | 6.00             | 6.00       | 6.00       | 6.00       | 6.00       |      |
| <b>Mean</b>    | <b>7.8</b>      | <b>9.3</b> | <b>7.7</b> | <b>9.2</b> | <b>6</b> | <b>8.1</b>       | <b>9.2</b> | <b>7.2</b> | <b>9.1</b> | <b>6.6</b> |      |

AEZ IV (Machakos County) and AEZ II (Meru) over 24 days postharvest under different postharvest and preharvest spray treatments. The data shows that the 2% and 3% treatments generally resulted in lower cumulative weight loss compared to the control and other treatments, especially in Zone II. The 2% and 3% treatments also showed lower weight loss at 24 days postharvest compared to the control and other treatments.

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**Table 6:** Cumulative weight loss of 'Sweet banana' fruits from AEZ IV (Machakos County) and AEZ II (Meru County)

| DAYS           | Postharvest Dip |            |            |            |            | Preharvest spray |            |            |            |            |      |
|----------------|-----------------|------------|------------|------------|------------|------------------|------------|------------|------------|------------|------|
|                | Zone IV         | 2%-A       | 2%-B       | 3%-A       | 3%-B       | Ctrl             | 2%-S       | 2%-D       | 3%-S       | 3%-D       | Ctrl |
| 0              | 0.00            | 0.00       | 0.00       | 0.00       | 0.00       | 0.00             | 0.00       | 0.00       | 0.00       | 0.00       | 0.00 |
| 3              | 0.00            | 0.00       | 2.00       | 0.00       | 0.00       | 5.00             | 5.00       | 5.00       | 6.00       | 5.00       | 5.00 |
| 6              | 5.00            | 5.60       | 5.50       | 5.20       | 6.60       | 6.60             | 6.60       | 6.60       | 5.60       | 5.00       | 5.00 |
| 9              | 6.00            | 6.00       | 6.00       | 6.00       | 6.00       | 6.00             | 6.00       | 6.00       | 5.60       | 5.00       | 5.00 |
| 12             | 6.00            | 6.00       | 6.00       | 6.00       | 6.00       | 6.00             | 6.00       | 6.00       | 6.00       | 6.00       | 6.00 |
| 15             | 6.00            | 6.20       | 6.00       | 6.00       | 6.00       | 6.00             | 6.00       | 6.00       | 6.00       | 6.00       | 6.00 |
| 18             | 6.00            | 6.00       | 6.00       | 6.00       | 6.00       | 6.00             | 6.00       | 6.00       | 6.00       | 6.00       | 6.00 |
| <b>Zone II</b> |                 |            |            |            |            |                  |            |            |            |            |      |
| 0              | 0.00            | 0.00       | 0.00       | 0.00       | 0.00       | 0.00             | 0.00       | 0.00       | 0.00       | 0.00       | 0.00 |
| 3              | 0.00            | 2.20       | 2.00       | 0.00       | 2.00       | 2.00             | 2.00       | 2.00       | 5.00       | 5.20       | 5.20 |
| 6              | 2.00            | 5.00       | 5.00       | 5.00       | 5.00       | 5.00             | 5.00       | 5.00       | 5.00       | 5.00       | 5.00 |
| 9              | 6.60            | 6.00       | 5.00       | 6.00       | 6.00       | 6.00             | 6.00       | 6.00       | 6.00       | 6.00       | 6.00 |
| 12             | 5.00            | 6.00       | 6.00       | 6.00       | 6.00       | 6.00             | 6.00       | 6.00       | 6.00       | 6.00       | 6.00 |
| 15             | 6.00            | 6.00       | 6.00       | 6.00       | 6.00       | 6.00             | 6.00       | 6.00       | 6.00       | 6.00       | 6.00 |
| 18             | 6.00            | 6.00       | 6.00       | 6.00       | 6.00       | 6.00             | 6.00       | 6.00       | 6.00       | 6.00       | 6.00 |
| <b>Mean</b>    | <b>6.8</b>      | <b>8.8</b> | <b>6.9</b> | <b>8.9</b> | <b>6.3</b> | <b>10.5</b>      | <b>9.6</b> | <b>9.4</b> | <b>9.5</b> | <b>6.7</b> |      |

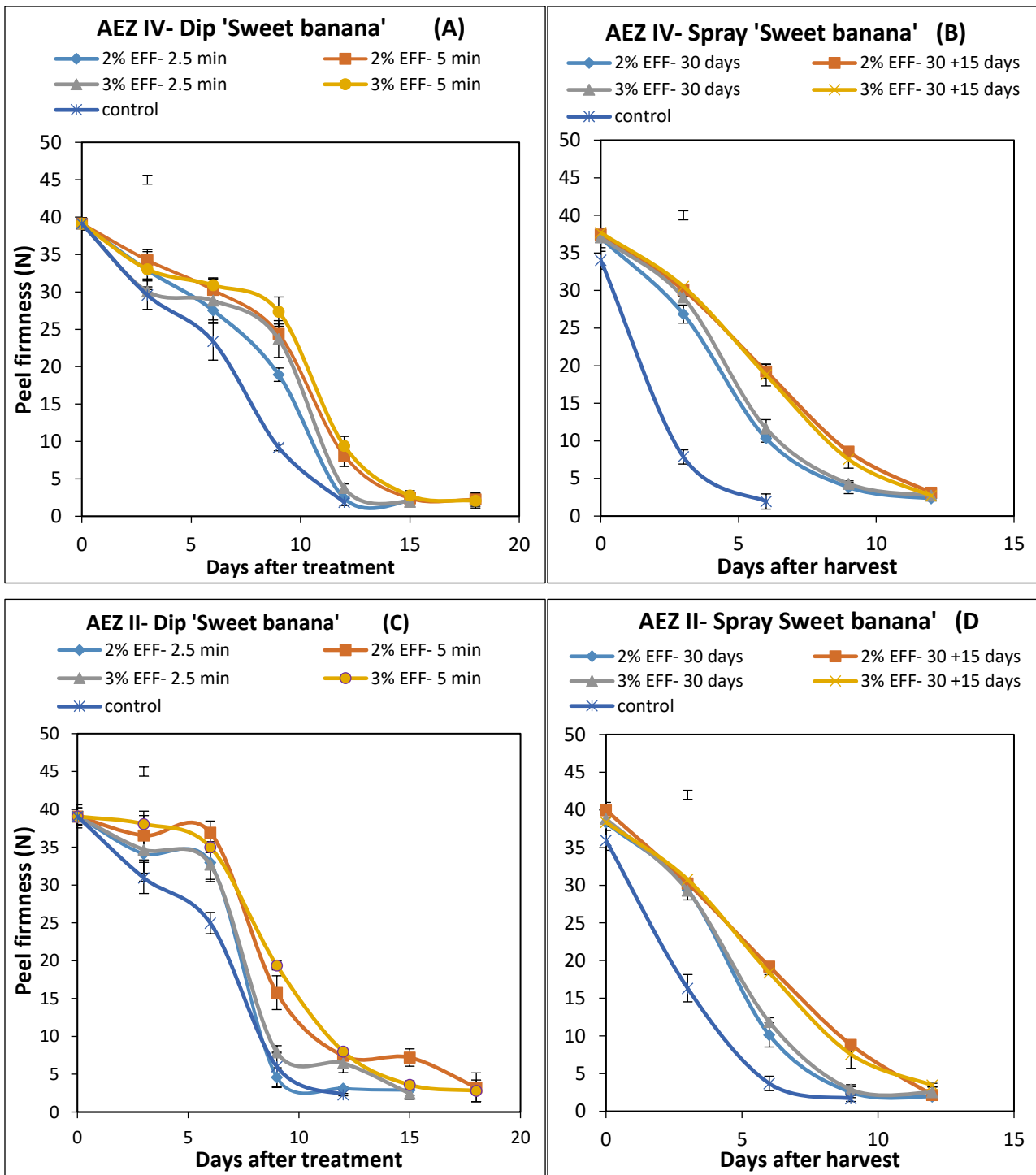
AEZ IV (Machakos County) and AEZ II (Meru County) were compared for cumulative weight loss of 'Sweet banana' fruits from AEZ IV (Machakos County) and AEZ II (Meru County) under different postharvest dip and preharvest spray treatments. The results are presented in Table 6. The cumulative weight loss of 'Sweet banana' fruits from AEZ IV (Machakos County) and AEZ II (Meru County) was significantly higher (p < 0.05) in the 2%-A, 2%-B, 3%-A, 3%-B, 2%-S, 2%-D, 3%-S, and 3%-D treatments compared to the control (Ctrl) treatment. The cumulative weight loss of 'Sweet banana' fruits from AEZ IV (Machakos County) and AEZ II (Meru County) was significantly higher (p < 0.05) in the 2%-A, 2%-B, 3%-A, 3%-B, 2%-S, 2%-D, 3%-S, and 3%-D treatments compared to the control (Ctrl) treatment. The cumulative weight loss of 'Sweet banana' fruits from AEZ IV (Machakos County) and AEZ II (Meru County) was significantly higher (p < 0.05) in the 2%-A, 2%-B, 3%-A, 3%-B, 2%-S, 2%-D, 3%-S, and 3%-D treatments compared to the control (Ctrl) treatment.

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**Figure 14:** Effect of different treatments on peel firmness (N) of 'Sweet banana' over time. The figure consists of four panels (A, B, C, D) showing the decline in peel firmness from 0 to 18 days after treatment or harvest. Treatments include 2% and 3% EFF concentrations with different durations (2.5 min, 5 min) or durations (30 days, 30+15 days) for dip and spray methods. Error bars represent standard deviation. Letters 'I' and 'p' indicate statistical significance.



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**Table 7:** Effect of postharvest and preharvest treatments on the incidence of fruit rot and yield of 'Grand nain' fruits from AEZ IV (Machakos County) and AEZ II (Meru County).

| DAYS           | Postharvest Dip |             |             |             |           | Preharvest spray |            |            |            |            |            |
|----------------|-----------------|-------------|-------------|-------------|-----------|------------------|------------|------------|------------|------------|------------|
|                | Zone IV         | 2%-A        | 2%-B        | 3%-A        | 3%-B      | Ctrl             | 2%-S       | 2%-D       | 3%-S       | 3%-D       | Ctrl       |
| 0              |                 | 2           | 2           | 2           | 2         | 2                | 6.6        |            | 6          | 6          | 6          |
| 3              |                 | 5           |             |             | 6         | 6                | 2          |            |            |            |            |
| 6              |                 | 6.2d        | 6           | 5d          |           |                  | 6d         | 5d         |            | d          | 2d         |
| 9              |                 | 2.5         | 6           |             | 6         |                  |            | d          | 5d         | d          |            |
| 12             |                 | 6           | 5d          | 6           | 6         |                  |            | 2          |            | 2.2        |            |
| 15             |                 | 6           |             | 6           | 2d        |                  |            |            |            |            |            |
| 18             |                 | 5           | 5           | 6           | 6         |                  |            |            |            |            |            |
| 21             |                 |             | 5           |             | 6.2       |                  |            |            |            |            |            |
| 24             |                 |             |             |             |           |                  |            |            |            |            |            |
| <hr/>          |                 |             |             |             |           |                  |            |            |            |            |            |
| <b>Zone II</b> |                 |             |             |             |           |                  |            |            |            |            |            |
| 0              |                 | 2           | 2           | 2           | 2         | 2                | 6          | 6          | 6          | 6          | 6          |
| 3              |                 | 2           | 2           | 2           | 2         | 6                | 6          | 6          | 6.5        | 5.2        | 6          |
| 6              |                 | 2           | 2           |             | 2         |                  |            |            |            |            | d          |
| 9              |                 |             |             |             | 6         | 2.2              | 2          | 2          | 2          |            |            |
| 12             |                 |             | 6           | 2           | 5         |                  |            | 2          | 6          | 2          |            |
| 15             |                 | 5           |             |             |           | 2                |            |            |            | 5          |            |
| 18             |                 |             | 2.6         |             | 2         |                  |            |            |            |            |            |
| 21             |                 |             | 2.2         |             | 2         |                  |            |            |            |            |            |
| 24             |                 |             | 5           |             | 6         |                  |            |            |            |            |            |
| <b>Mean</b>    |                 | <b>12.7</b> | <b>12.8</b> | <b>12.7</b> | <b>13</b> | <b>12.5</b>      | <b>8.0</b> | <b>9.2</b> | <b>9.5</b> | <b>8.9</b> | <b>7.6</b> |
|                |                 |             | 5           |             |           |                  |            |            |            |            |            |
|                |                 |             | 2           |             |           |                  |            |            |            |            |            |
|                |                 |             | 2           |             |           |                  |            |            |            |            |            |
|                |                 |             |             |             |           |                  |            |            |            |            |            |
|                |                 |             | 5           |             |           |                  |            |            |            |            |            |

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Table 8: ‘Sweet banana’ fruits from AEZ IV (Machakos County) and AEZ II (Meru County).

| DAYS           | Postharvest Dip |             |             |             |             | Preharvest spray |             |             |             |            |      |
|----------------|-----------------|-------------|-------------|-------------|-------------|------------------|-------------|-------------|-------------|------------|------|
|                | Zone IV         | 2%-A        | 2%-B        | 3%-A        | 3%-B        | Ctrl             | 2%-S        | 2%-D        | 3%-S        | 3%-D       | Ctrl |
| 0              | 2               | 2           | 2           | 2           | 2           | 2                | 2           | 2           | 2           | 2          | 2    |
| 3              | 2               | 2           | 25          | 26          | 5           | 2                |             | 5           |             |            |      |
| 6              | 2               | 22          | 2           | 22          |             | 6                |             | 5           |             |            |      |
| 9              | 5               |             | 6           | 6           | 2           | 2                |             | 6           | 5           | 5          |      |
| 12             | 2               | 2           | 2           |             |             |                  | 2           |             |             | 2          |      |
| 15             |                 |             |             | 2           |             |                  |             |             |             |            |      |
| 18             |                 | 6           |             | 2           |             |                  |             |             |             |            |      |
| <b>Zone II</b> |                 |             |             |             |             |                  |             |             |             |            |      |
| 0              | 2               | 2           | 2           | 2           | 2           | 2                | 6           | 6           |             |            | 2    |
| 3              | 2               |             | 2           |             | 25          | 6                |             | 5           | 2           | 2          |      |
| 6              | 2               | 2           | 25          | 2           | 22          | 5                |             | 6           | 2           |            |      |
| 9              | 6               | 2           |             | 2           |             | 6                | 2           | 2           | 5           |            |      |
| 12             | 2               | 5           |             |             | 6           |                  |             | 6           | 2           |            |      |
| 15             |                 |             |             | 2           |             |                  |             |             |             |            |      |
| 18             |                 | 6           |             |             |             |                  |             |             |             |            |      |
| <b>Mean</b>    | <b>14.8</b>     | <b>14.6</b> | <b>15.4</b> | <b>15.7</b> | <b>13.3</b> | <b>10.6</b>      | <b>13.4</b> | <b>11.7</b> | <b>14.2</b> | <b>9.9</b> |      |
|                |                 |             |             |             |             |                  |             |             |             |            |      |
|                |                 |             |             |             |             |                  |             |             |             |            |      |
|                |                 |             |             |             |             |                  |             |             |             |            |      |
|                |                 |             |             |             |             |                  |             |             |             |            |      |
|                |                 |             |             |             |             |                  |             |             |             |            |      |

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#### 4.2.2. Measurement of biochemical attributes of banana

##### 4.2.2.1. Total Soluble Solids (TSS/°Brix)

Method 5

$$\% \text{ Brix (dry weight basis)} = \left( \frac{\% \text{ Brix in wet weight basis} * 100}{100 - \text{Moisture content}} \right)$$

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##### 4.2.2.2. Total Titratable Acidity (TTA)

Method 2

$$\text{TTA (dry weight basis)} = \left( \frac{\text{TTA value in wet weight basis} * 100}{100 - \text{Moisture content}} \right)$$

##### 4.2.2.3. Ascorbic acid content

Method 2





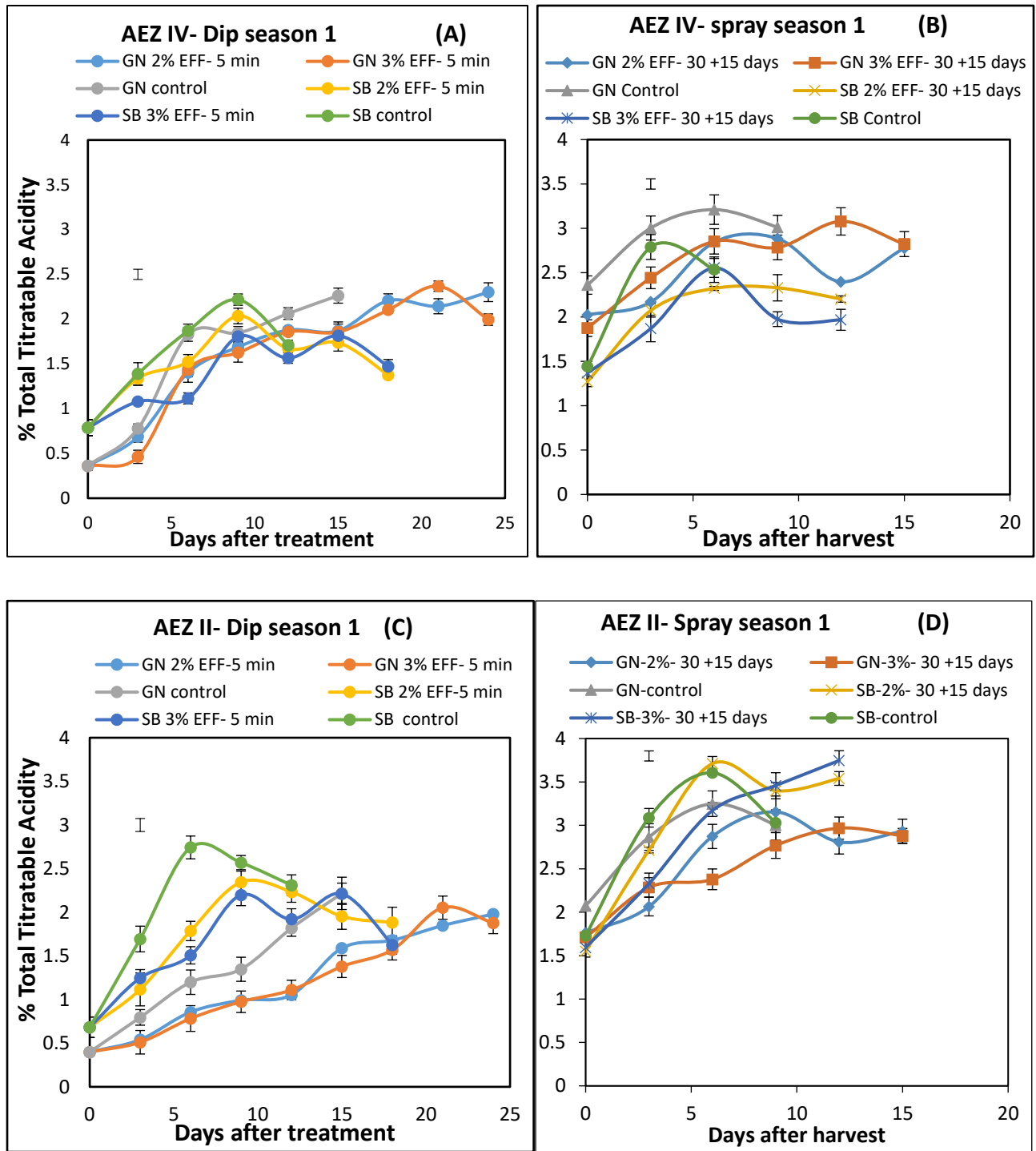




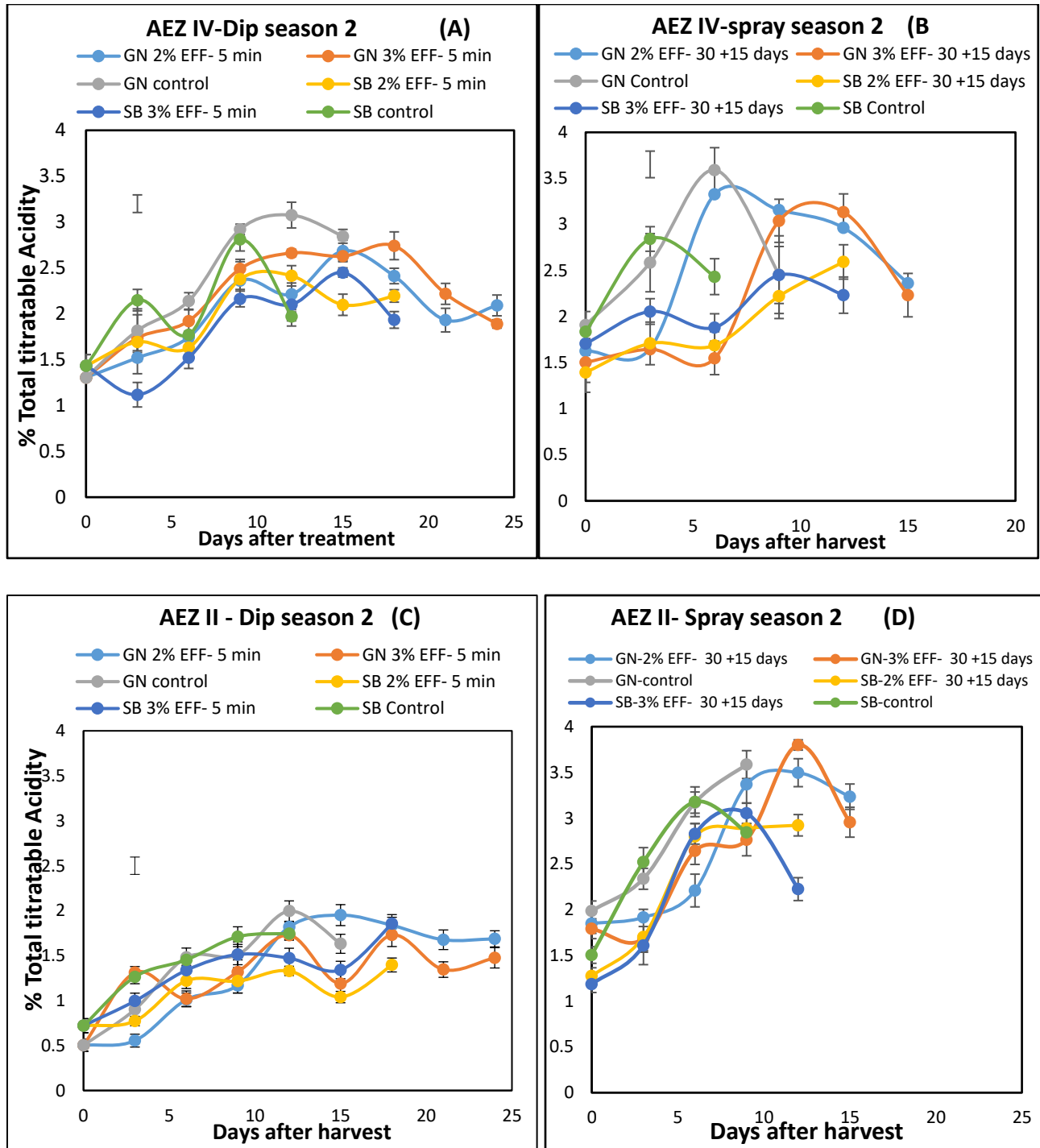








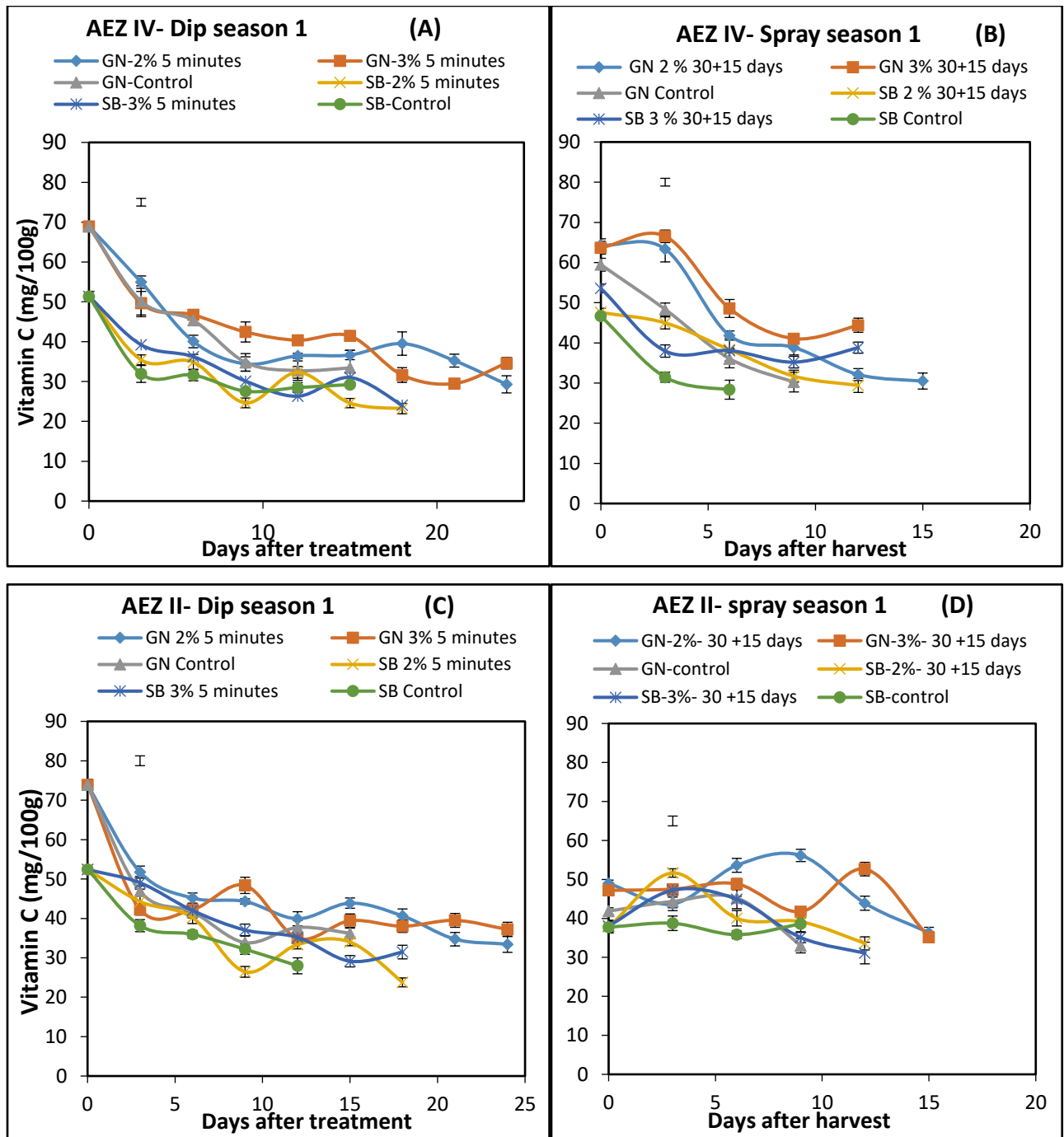
**Figure 17:** Grand nain and Sweet banana. The figure consists of four line graphs (A, B, C, D) showing the percentage of total titratable acidity over time for two banana varieties, Grand nain and Sweet banana, under different treatments and application methods. Graphs A and C show dip treatments, while B and D show spray treatments. Each graph compares Grand nain (GN) and Sweet banana (SB) under various concentrations (2% and 3%) and application methods (5 min and 30 + 15 days). Error bars represent standard deviation.



**Figure 18:** Grand nain and Sweet banana. AEZ IV and AEZ II. Dip and Spray season 2. GN and SB. Control and various EFF treatments (2%, 3%, 5 min, 30+15 days). % Total titratable Acidity vs Days after treatment/harvest. Error bars represent standard deviation. Significant differences are indicated by letters (p < 0.05).

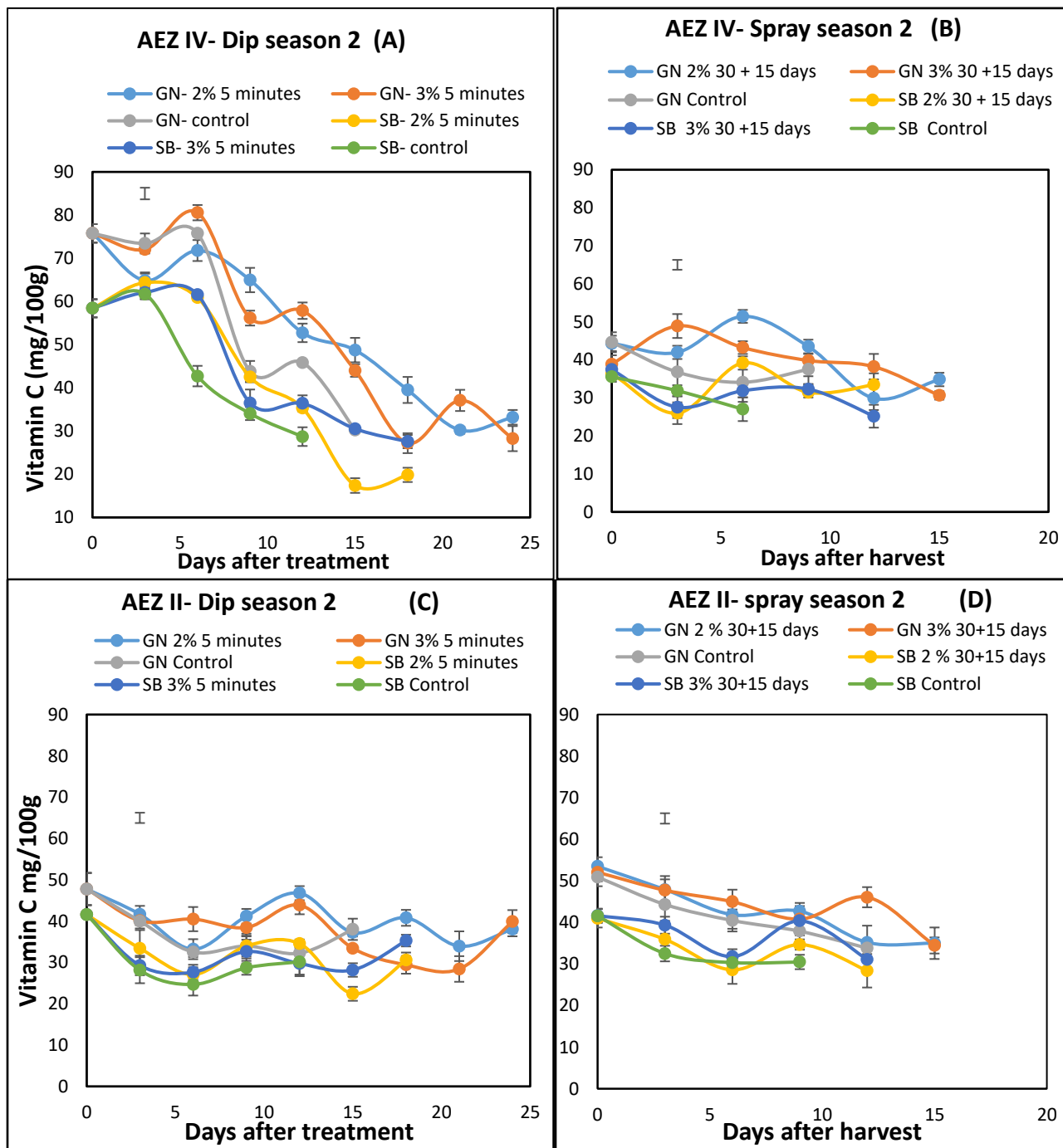


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**Figure 19:** Effect of different treatments on the Vitamin C content of 'Grand nain' and 'Sweet banana' banana varieties. The figure consists of four line graphs (A, B, C, D) showing Vitamin C levels (mg/100g) over time (Days after treatment or Days after harvest). The treatments include different concentrations (2% and 3%) and durations (5 minutes and 30+15 days) of Grand nain (GN) and Sweet banana (SB) varieties. Error bars represent standard deviation. The p-value is 0.05.

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**Figure 20:** Effect of dipping and spraying treatments on the Vitamin C content of 'Grand nain' and 'Sweet banana' banana varieties during AEZ IV and AEZ II seasons. The graphs show Vitamin C (mg/100g) levels over time (Days after treatment or Days after harvest) for different treatments (GN 2%, GN 3%, GN Control, SB 2%, SB 3%, SB Control). Error bars represent standard deviation. Significant differences are indicated by letters 'a', 'b', 'c', 'd', 'e', 'f', 'g', 'h', 'i', 'j', 'k', 'l', 'm', 'n', 'o', 'p', 'q', 'r', 's', 't', 'u', 'v', 'w', 'x', 'y', 'z' above the data points.

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#### 4.3.4. Changes in simple Sugars

##### 4.3.4.1. Fructose

Fructose levels in the untreated 'Grand nain' and 'sweet banana' fruits were significantly higher (p < 0.05) compared to the untreated ones. In the untreated 'Grand nain' fruits, fructose levels increased from 148.6 mg/100g (day 3) to 186.6 mg/100g (day 6) and 212.6 mg/100g (day 9). In the untreated 'sweet banana' fruits, fructose levels increased from 148.6 mg/100g (day 3) to 186.6 mg/100g (day 6) and 212.6 mg/100g (day 9). The fructose levels in the hexanal treated fruits were significantly higher (p < 0.05) compared to the untreated ones. In the hexanal treated 'Grand nain' fruits, fructose levels increased from 148.6 mg/100g (day 3) to 186.6 mg/100g (day 6) and 212.6 mg/100g (day 9). In the hexanal treated 'sweet banana' fruits, fructose levels increased from 148.6 mg/100g (day 3) to 186.6 mg/100g (day 6) and 212.6 mg/100g (day 9).

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Fructose levels in the untreated 'Grand nain' fruits, fructose levels increased from 148.6 mg/100g (day 3) to 186.6 mg/100g (day 6) and 212.6 mg/100g (day 9). In the untreated 'sweet banana' fruits, fructose levels increased from 148.6 mg/100g (day 3) to 186.6 mg/100g (day 6) and 212.6 mg/100g (day 9). The fructose levels in the hexanal treated fruits were significantly higher (p < 0.05) compared to the untreated ones. In the hexanal treated 'Grand nain' fruits, fructose levels increased from 148.6 mg/100g (day 3) to 186.6 mg/100g (day 6) and 212.6 mg/100g (day 9). In the hexanal treated 'sweet banana' fruits, fructose levels increased from 148.6 mg/100g (day 3) to 186.6 mg/100g (day 6) and 212.6 mg/100g (day 9).

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Fructose levels in the 'sweet banana' variety. The fructose levels increased rapidly to 186.6 mg/100g (day 6) and 212.6 mg/100g (day 9). The fructose levels in the hexanal treated fruits assumed a similar trend to that in 'Grand nain' variety with levels of 186.6 mg/100g (day 6) and 212.6 mg/100g (day 9).

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**Table 11A:** Comparison of 'rain' and 'rain' in the M... of 'rain' ...

| M      |              | r           |             |             | r           |             |             |
|--------|--------------|-------------|-------------|-------------|-------------|-------------|-------------|
| □□□□   | □□□□         | □□□□        | 2□□         | □□□         | □□□□        | 2□□         | □□□         |
| □□□□□  | □□           | 5 5□□       | 5 5□□       | 5 5□□       | □5□□□       | □□□□        | □2 6□□      |
| □      | □□           | □□5□□       | □□□□□       | □□□□□       | □5□□□□      | □□□□□       | □□□□□       |
| □      | 6□           | □□□□□       | 25□□□□      | □□□□□       | □2□□2□□     | 65□□□□      | □□□□□       |
| □      | □□           | □□□5d□      | 56□□□□      | 5□□□□□      | □           | □5□5□□      | □6 2□□      |
| □      | □2□          | 2□□□□□      | □□□□□       | 6□□□□□      | □           | □□□2□□      | □2 6□□□     |
| □      | □5□          | □□5□□□□     | 6□2□□□      | □□□□□□      | □           | □□2□□□      | □5□□□□      |
| □      | □□□          | □           | □□□□□□      | □2□□d□      | □           | □           | □           |
| □      | 2□□          | □           | 2□□5□□      | □□□□□□□     | □           | □           | □           |
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| □      | □□           | □2□□□□      | □□□□□□      | □□□□□□      | □5□□d□      | 2□□□□□□     | 2□5□□□      |
| □      | 6□           | 26□□□□      | 22□□□□      | □5□□□□      | □22 5□□     | □□6□□       | □2□□□□      |
| □      | □□           | 5□2□□□      | 2□2□□□      | □□□□□□      | □2 2□□      | □□□□□□      | □□□□□□      |
| □      | □2□          | □□6□□□□     | □□6□□       | 5□□□□□      | □           | □2□□d□      | □□□□d□      |
| □      | □5□          | □□□□□□□     | 6□2□□□      | □□□□□□      | □           | □□6□□□      | □6□□□□      |
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| □      | 2□□          | □           | □□□□□□□     | □□□□□□□     | □           | □           | □           |
|        | <b>Mean</b>  | <b>82.4</b> | <b>75.4</b> | <b>74.2</b> | <b>96.4</b> | <b>83.8</b> | <b>92.6</b> |
| □      | □□□□□□□□     | □□□□        | □           | □           | □□          | □           | □           |
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| □      | □□□□□□□□     | □□□□        | □           | □           | □□          | □           | □           |
| □      | □□□□□□□□□□M□ | □□□□        | □           | □           | □□          | □           | □           |
|        | □□□□□□□      | □□6□        | □□          | □□          | □□□□        | □□          | □□          |

Comparison of 'rain' and 'rain' in the M... of 'rain' ... p=5 ...

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**Table 11B:** Comparison of 'Sweet banana' and 'Grand nain' varieties under different treatments.

| M |             | r           |             |             | r           |             |             |
|---|-------------|-------------|-------------|-------------|-------------|-------------|-------------|
| □ | □           | □           | 2           | □           | □           | 2           | □           |
| □ | □           | 5.5         | 5.5         | 5.5         | 5.5         | 2           | 5           |
| □ | 6           | 5.2d        | □           | 6           | 2.2         | 6           | 2.5         |
| □ | □           | □           | 22.2        | 2.6         | □           | 2           | 2           |
| □ | 2           | □           | □           | 2d          | □           | □           | □           |
| □ | 5           | □           | 2           | 2           | □           | □           | □           |
| □ | □           | □           | 5           | 5.5         | □           | □           | □           |
| □ | □           | □           | □           | □           | □           | □           | □           |
| □ | □           | □           | □           | □           | □           | □           | □           |
| □ | 6           | 5           | 2           | □           | 6           | 52          | 5           |
| □ | □           | □           | 6           | □           | 2d          | 6           | d           |
| □ | 2           | □           | □           | 6           | □           | 2           | □           |
| □ | 5           | □           | 2           | 6           | □           | □           | □           |
| □ | □           | □           | □           | 6d          | □           | □           | □           |
|   | <b>Mean</b> | <b>77.3</b> | <b>59.3</b> | <b>65.9</b> | <b>98.6</b> | <b>68.3</b> | <b>70.5</b> |
| □ | □           | 2           | □           | □           | □           | □           | □           |
| □ | M           | □           | □           | □           | □           | □           | □           |
| □ | □           | 6           | □           | □           | □           | □           | □           |
| □ | M           | 6.2         | □           | □           | □           | □           | □           |
| □ | □           | 6           | □           | □           | □           | □           | □           |

Comparison of 'Sweet banana' and 'Grand nain' varieties under different treatments.  $p < 0.05$  indicates significant differences between treatments.

#### 4.3.4.2. Glucose

Comparison of 'Sweet banana' and 'Grand nain' varieties under different treatments. 'Sweet banana' fruits had significantly high levels of glucose compared to 'Grand nain' variety under 2d treatment.



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□ d d r r r p 5 r r r r  
□ r r d d r p 5 r r M d  
□ d r d

□

**Table 12B:** □ d r r r r r r r r g/100g of 'Sweet banana' from AEZ IV (Machakos County) and AEZ II (Meru County). □

| M d           |                               | r r           |                       |                 | r r r               |                           |                 |
|---------------|-------------------------------|---------------|-----------------------|-----------------|---------------------|---------------------------|-----------------|
| □ □ □ □       | □ □ □ □                       | □ □ □ r □ □   | 2 □ □                 | □ □ □           | □ □ □ r □ □         | 2 □ □                     | □ □ □           |
| □ □ □ □ □     | □ □                           | □ □ □ □ □     | □ □ □ □ □             | □ □ □ □ □       | □ □ 5 □ □           | □ 5 □ □ □ □               | □ □ □ □ □       |
| □             | □ □                           | 22 □ □ □      | □ □ □ □ □             | □ □ □ □ □       | □ □ □ □ 6 □ □       | □ 5 □ 2 □ □               | □ 6 □ □ □ □     |
| □             | 6 □                           | □ □ □ d □     | 22 □ □ □              | 2 □ 6 □ □       | □ □ □ □ □ □ □ □     | □ □ □ □ □ □ □ □           | 55 □ □ d □      |
| □             | □ □                           | □ 5 □ □ □     | 5 □ □ □ □             | 6 □ 2 □ □       | □ □                 | □ 2 □ □ □ □ □ □ □ □       | □ □ □ □ □ □     |
| □             | 2 □                           | □ 6 □ □ □ □ □ | □ □ □ □ d □           | 26 5 d □        | □ □                 | □ □ □ □ 2 □ □ □ □ □ □ □ □ | □ □ □ □ □ □ □ □ |
| □             | 5 □                           | □             | □ 6 □ □ □ □           | □ □ □ □ □ □ □ □ | □ □                 | □ □                       | □ □             |
| □             | □ □                           | □             | □ 6 5 □ □ □ □ □ □ □ □ | □ □ □ □ □ □ □ □ | □ □                 | □ □                       | □ □             |
| □ □ □ □ □ □ □ | □                             | □ □           | □ □                   | □ □             | □ □ □ □             | □ □                       | □ □             |
| □             | □ □                           | □ □ 2 □ □     | □ □ 2 □ □             | □ □ 2 □ □       | □ □ 2 □ □ □ □       | □ □ □ 5 □ □               | □ □ □ □ □ □     |
| □             | □ □                           | 2 □ □ □ □ □   | □ 6 2 □ □ □           | □ □ □ □ □ □ □ □ | □ □ □ □ □ d □       | □ □ □ □ □ □ □             | 25 □ □ □ □ □ □  |
| □             | 6 □                           | □ □ □ □ □ □ □ | □ □ □ □ □ □ □         | □ 2 □ □ □ □     | □ □ □ □ 2 □ □ □ □ □ | □ □ □ □ □ d □             | □ □ □ □ □ □ □ □ |
| □             | □ □                           | □ □ □ □ □ □ □ | □ 5 □ □ □ □ □         | □ □ □ 6 □ □     | □ □ □ □ 6 5 d □     | □ □ □ □ □ □ □ □           | □ □ 2 □ □ □     |
| □             | 2 □                           | □ □ □ □ 5 □ □ | □ □ □ □ 6 d □         | □ 5 □ □ □ □ □   | □ □                 | □ □ □ □ □ □ □ □           | □ □ □ □ □ □ □ □ |
| □             | 5 □                           | □             | □ □ □ □ □ d □         | □ 2 □ □ □ □     | □ □                 | □ □                       | □ □             |
| □             | □ □                           | □             | □ 6 6 □ □ □ □ □       | □ □ □ □ □ □ □ □ | □ □                 | □ □                       | □ □             |
| <b>Mean</b>   |                               | <b>71.6</b>   | <b>72.3</b>           | <b>79.0</b>     | <b>107.5</b>        | <b>78.7</b>               | <b>65.1</b>     |
| □             | □ □ □ □ □ □ □ □               | 6 2 □ □       | □                     | □               | □ □ □               | □                         | □               |
| □             | □ □ □ □ □ □ M □ □             | □ 5 □ □       | □                     | □               | □ □ □               | □                         | □               |
| □             | □ □ □ □ □ □ □ □               | □ 5 □ □       | □                     | □               | □ □ □               | □                         | □               |
| □             | □ □ □ □ □ □ □ □ □ □ □ □ M □ □ | 5 □ □         | □                     | □               | □ □ □               | □                         | □               |
| □             | □ □ □ □ □ □ □ □               | □ 2 □ □ □     | □ □                   | □ □             | □ □ □ □             | □ □                       | □ □             |

□ d d r r r p 5 r r r r  
□ r r d d r p 5 r r M d  
□ d r d



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**Table 13A:**  $\chi^2$  tests of independence for the relationship between 'Grand main' and M. The table shows the number of subjects in each cell and the expected number of subjects in each cell based on the marginal totals. The chi-square test statistic is  $\chi^2(2) = 146.0$ ,  $p < .001$ .

| M           | d            | r            | d            | r           | d           | r            |
|-------------|--------------|--------------|--------------|-------------|-------------|--------------|
| 25          | 265          | 25           | 265          | 25          | 265         | 265          |
| 6           | 25           | 6            | 25           | 6           | 25          | 25           |
| 2           | 25           | 2            | 25           | 2           | 25          | 25           |
| 5           | 25           | 5            | 25           | 5           | 25          | 25           |
| 2           | 25           | 2            | 25           | 2           | 25          | 25           |
| 2           | 25           | 2            | 25           | 2           | 25          | 25           |
| 2           | 25           | 2            | 25           | 2           | 25          | 25           |
| <b>Mean</b> | <b>146.0</b> | <b>126.5</b> | <b>127.9</b> | <b>97.3</b> | <b>99.8</b> | <b>105.2</b> |
| 25          | 25           | 25           | 25           | 25          | 25          | 25           |
| 6           | 25           | 6            | 25           | 6           | 25          | 25           |
| 2           | 25           | 2            | 25           | 2           | 25          | 25           |
| 5           | 25           | 5            | 25           | 5           | 25          | 25           |
| 2           | 25           | 2            | 25           | 2           | 25          | 25           |
| 2           | 25           | 2            | 25           | 2           | 25          | 25           |
| <b>Mean</b> | <b>25</b>    | <b>6</b>     | <b>6.5</b>   | <b>2.5</b>  | <b>6</b>    | <b>6</b>     |

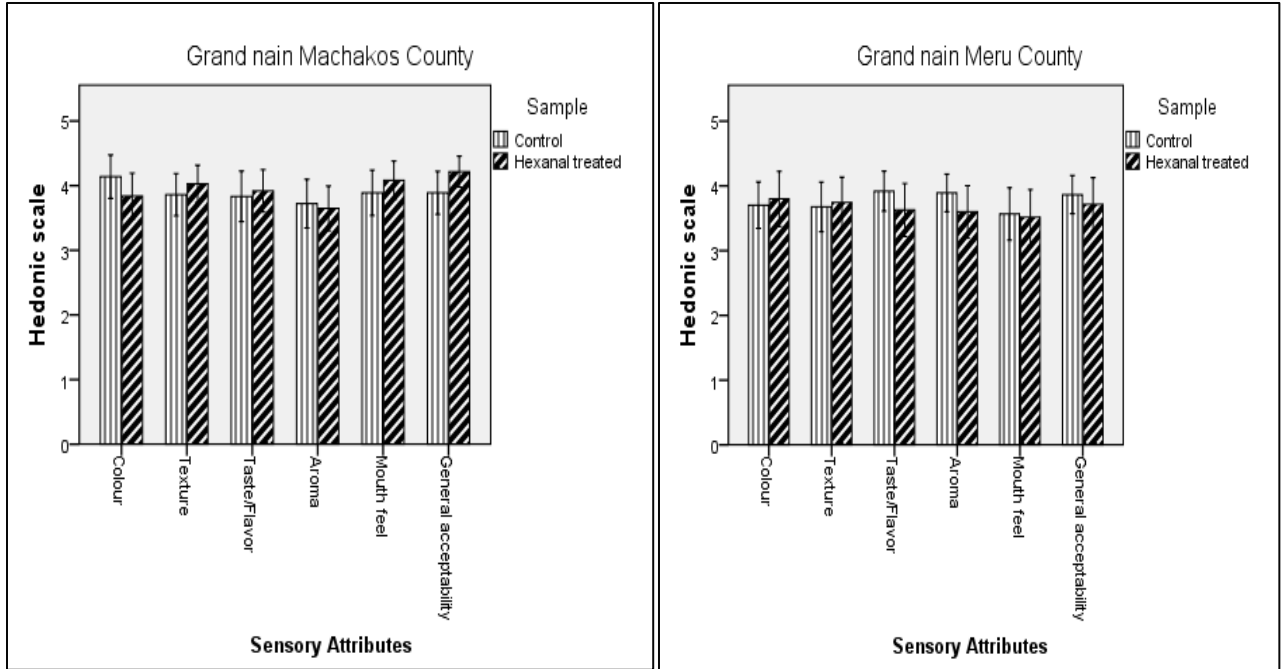
$\chi^2(2) = 146.0$ ,  $p < .001$ . The relationship between 'Grand main' and M is statistically significant. The chi-square test statistic is  $\chi^2(2) = 146.0$ ,  $p < .001$ .





□

□



**Figure 21:** Hedonic scores for sensory quality attributes of ‘Grand nain’ bananas harvested from

Machakos and Meru counties. The figure consists of two bar charts. The left chart is for Machakos County and the right chart is for Meru County. Both charts show hedonic scores for six sensory attributes: Colour, Texture, Taste/Flavor, Aroma, Mouth feel, and General acceptability. For each attribute, two samples are compared: Control (white bars) and Hexanal treated (hatched bars). The y-axis represents the Hedonic scale from 0 to 5. In Machakos County, the Control sample generally scores higher than the Hexanal treated sample, except for Texture. In Meru County, the scores are more similar between the two samples across all attributes.

□

















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The study was designed to evaluate the effect of hexanal on the ripening and quality of 'Grand nain' tomatoes. The experiment was conducted in a glasshouse. The tomatoes were harvested at the peak of ripeness and then treated with hexanal at concentrations of 0, 5, 10, 20, and 30 mg/L. The tomatoes were stored at 25°C for 20 days. The levels of lycopene,  $\beta$ -carotene, and total carotenoids were determined. The results showed that hexanal treatment significantly reduced the ripening rate and the levels of lycopene,  $\beta$ -carotene, and total carotenoids. The most effective concentration was 20 mg/L.

### 5.3. Materials and methods

#### 5.3.1. Plant material and post-harvest treatment

The tomatoes 'Grand nain' were obtained from a commercial nursery. The plants were grown in a glasshouse. The tomatoes were harvested at the peak of ripeness and then treated with hexanal at concentrations of 0, 5, 10, 20, and 30 mg/L. The tomatoes were stored at 25°C for 20 days. The levels of lycopene,  $\beta$ -carotene, and total carotenoids were determined. The results showed that hexanal treatment significantly reduced the ripening rate and the levels of lycopene,  $\beta$ -carotene, and total carotenoids. The most effective concentration was 20 mg/L.





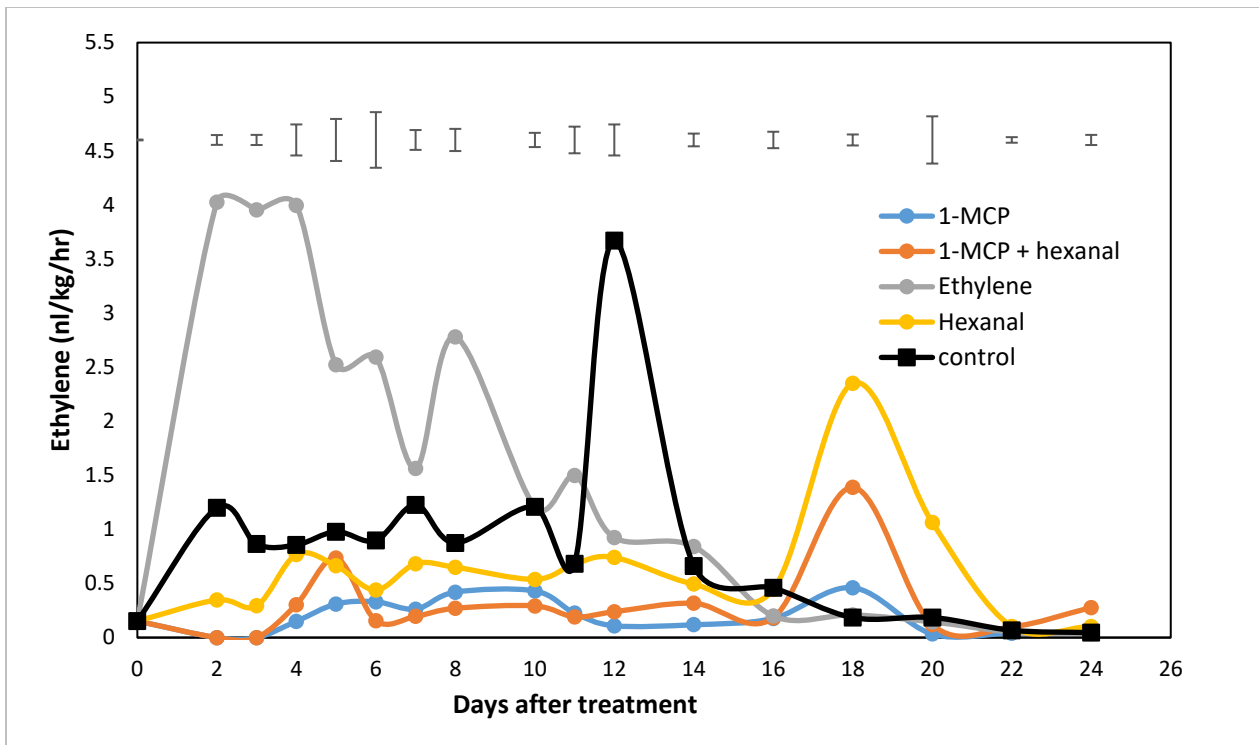








□  
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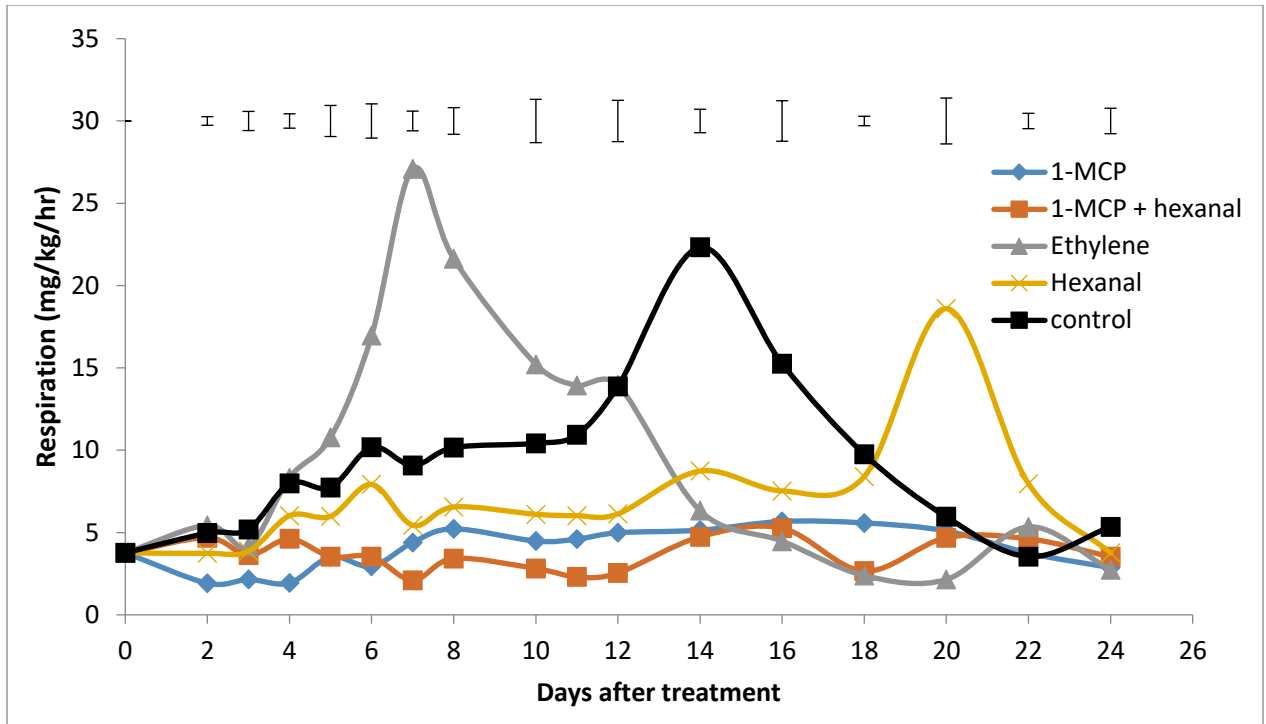


**Figure 23:** Effect of 1-MCP and 1-MCP + hexanal on the rate of ethylene production in 'Grand nain' mango. The graph shows ethylene production (nl/kg/hr) over 26 days for five treatments: 1-MCP, 1-MCP + hexanal, Ethylene, Hexanal, and control. Error bars represent standard deviation. The Ethylene treatment shows the highest peak at day 2, while the Hexanal treatment peaks at day 18.

### 5.4.1.2. Rate of Respiration

The rate of respiration was measured in 'Grand nain' mango fruit. The control treatment showed a steady increase in respiration rate over time. The 1-MCP treatment significantly reduced the respiration rate, which remained low throughout the 26-day period. The 1-MCP + hexanal treatment also showed a lower respiration rate compared to the control. The Hexanal treatment showed a similar trend to the control, with a steady increase in respiration rate. The Ethylene treatment showed a sharp increase in respiration rate, peaking at day 12. Error bars represent standard deviation. The data indicates that 1-MCP and 1-MCP + hexanal treatments effectively reduce the respiration rate in 'Grand nain' mango fruit.

□  
□

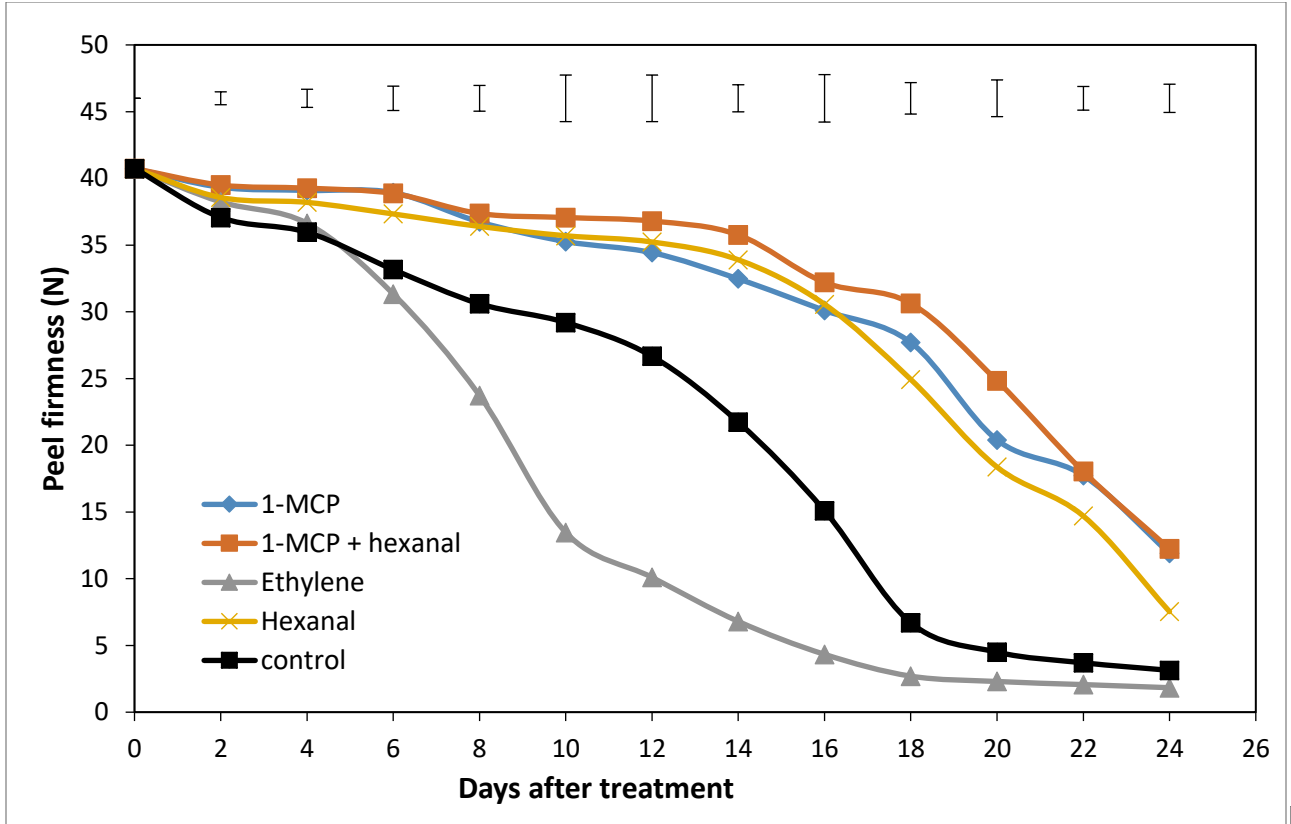


**Figure 24:** Comparison of 1-MCP, 1-MCP + hexanal, Ethylene, and Hexanal treatments compared to control on the rate of respiration in ‘Grand nain’ bananas. Top bars indicate least significant difference (LSD) at  $p < 0.05$ .

### 5.4.1.3. Changes in peel firmness

Changes in peel firmness were measured over time for the five treatments. The control treatment showed the most rapid decline in firmness, reaching a level similar to the 1-MCP + hexanal treatment by day 22. The 1-MCP treatment maintained higher firmness for a longer duration. The Ethylene and Hexanal treatments showed intermediate firmness levels. Statistical significance (LSD) is indicated by top bars in the corresponding graph.

□  
□



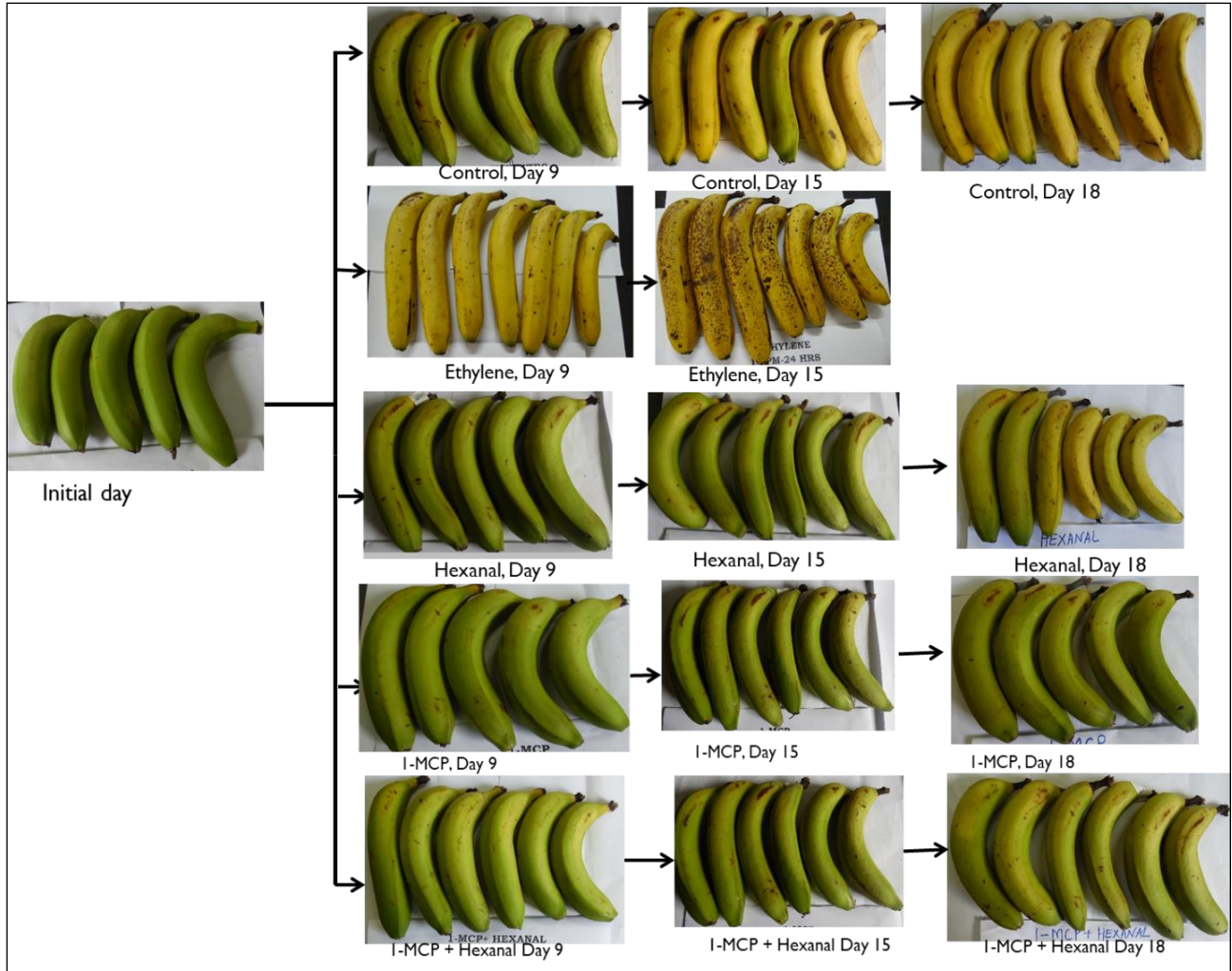
**Figure 25:** Effect of 1-MCP, 1-MCP + hexanal, Ethylene, Hexanal, and control on peel firmness (N) in 'Grand nain' bananas. Top bars indicate least significant differences (LSD) at  $p < 0.05$ .







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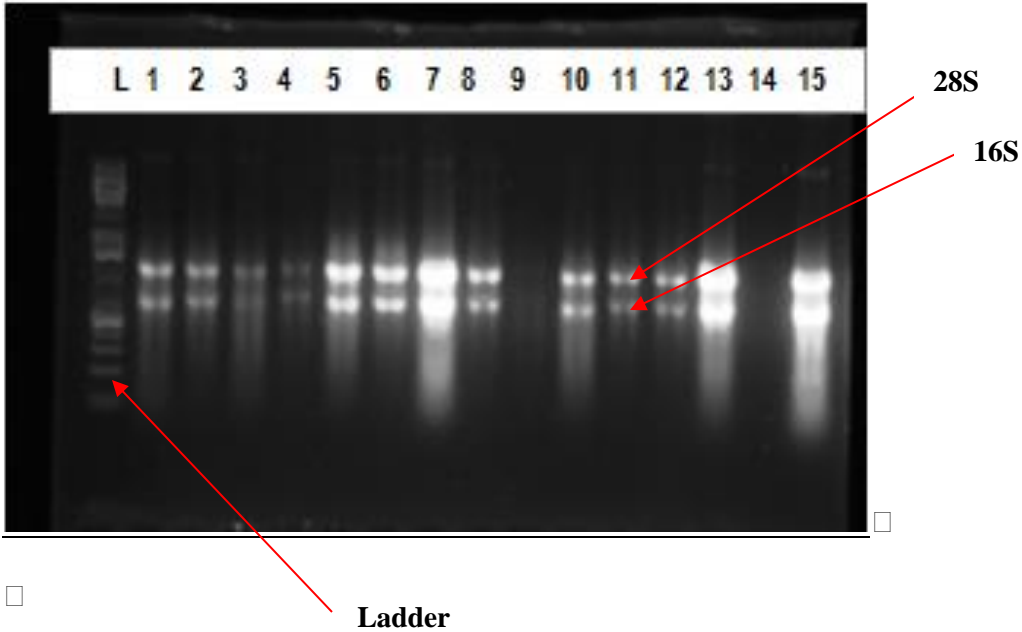
**Figure 28:** Progress of ripening in ‘Grand nain’ banana fruits treated with hexanal, ethylene, 1-MCP, and 1-MCP + Hexanal. The figure shows the ripening progress of banana fruits under five different treatments: Control, Ethylene, Hexanal, 1-MCP, and 1-MCP + Hexanal. The fruits are shown at Day 9, Day 15, and Day 18. The Control group shows the fastest ripening, reaching a yellow color by Day 18. The Ethylene group shows significant darkening and spotting by Day 15. The Hexanal, 1-MCP, and 1-MCP + Hexanal groups show significantly delayed ripening, remaining mostly green through Day 18.

## 5.4.2. Quantitative polymerase chain reaction (qPCR) and Transcriptome analysis

### 5.4.2.1. Quality Check of the extracted RNA

The quality of the extracted RNA was checked using a Nanodrop spectrophotometer. The absorbance ratio of 260 nm/280 nm was found to be 1.8-2.0, indicating the purity of the RNA. The absorbance ratio of 260 nm/230 nm was found to be 1.8-2.0, indicating the absence of contaminants. The RNA concentration was found to be 100-200 µg/ml. The RNA integrity was checked using an Agilent 2100 Bioanalyzer. The RNA integrity number (RIN) was found to be 8.0-9.0, indicating high quality RNA.

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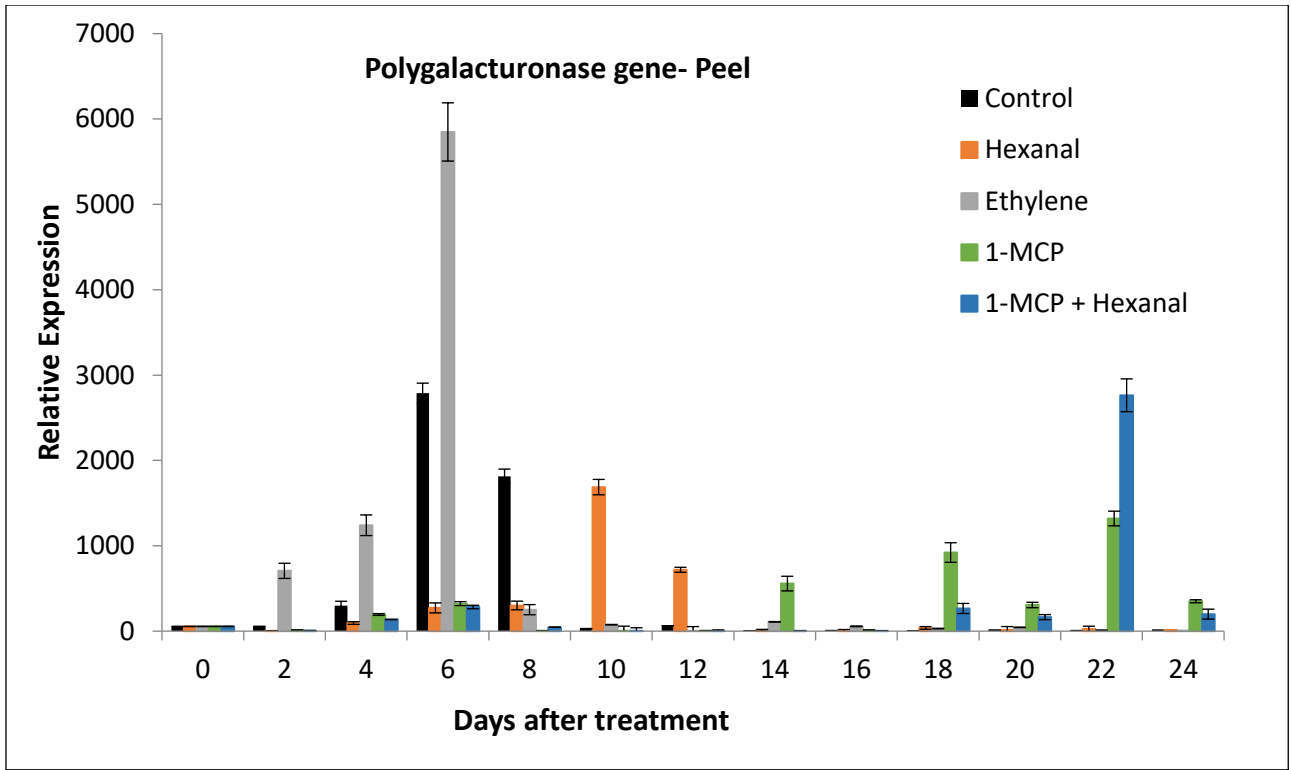
**Figure 29:** Gel electrophoresis image showing PCR products. Lane L is a DNA ladder. Lanes 1-15 show various samples. Red arrows point to bands in lanes 10, 11, 12, and 13, labeled as 28S and 16S. A red arrow also points to the ladder lane, labeled as Ladder.

#### 5.4.2.2 Quantitative PCR Results

**i. Polygalacturonase gene (PG gene)**

Agarose gel electrophoresis image showing PCR products for the Polygalacturonase gene (PG gene). The gel has 16 lanes labeled L, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, and 15. Lane L is the DNA ladder. Lanes 1-15 show various samples. Red arrows point to bands in lanes 10, 11, 12, and 13, labeled as 28S and 16S. A red arrow also points to the ladder lane, labeled as Ladder.

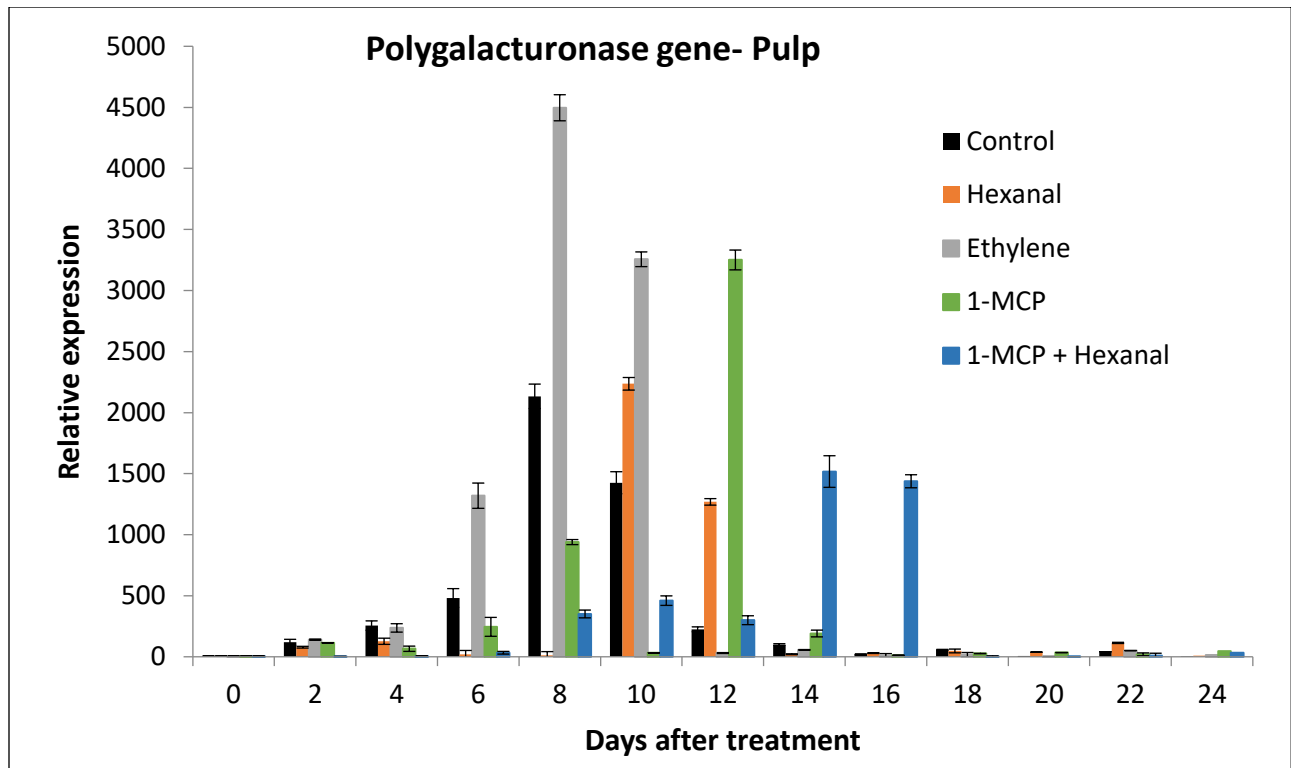
□  
□



**Figure 30:** Bar chart showing the relative expression of the Polygalacturonase gene in peel tissue over 24 days after treatment with Control, Hexanal, Ethylene, 1-MCP, and 1-MCP + Hexanal. The Y-axis represents Relative Expression (0 to 7000) and the X-axis represents Days after treatment (0 to 24). Error bars represent standard deviation.

□  
□

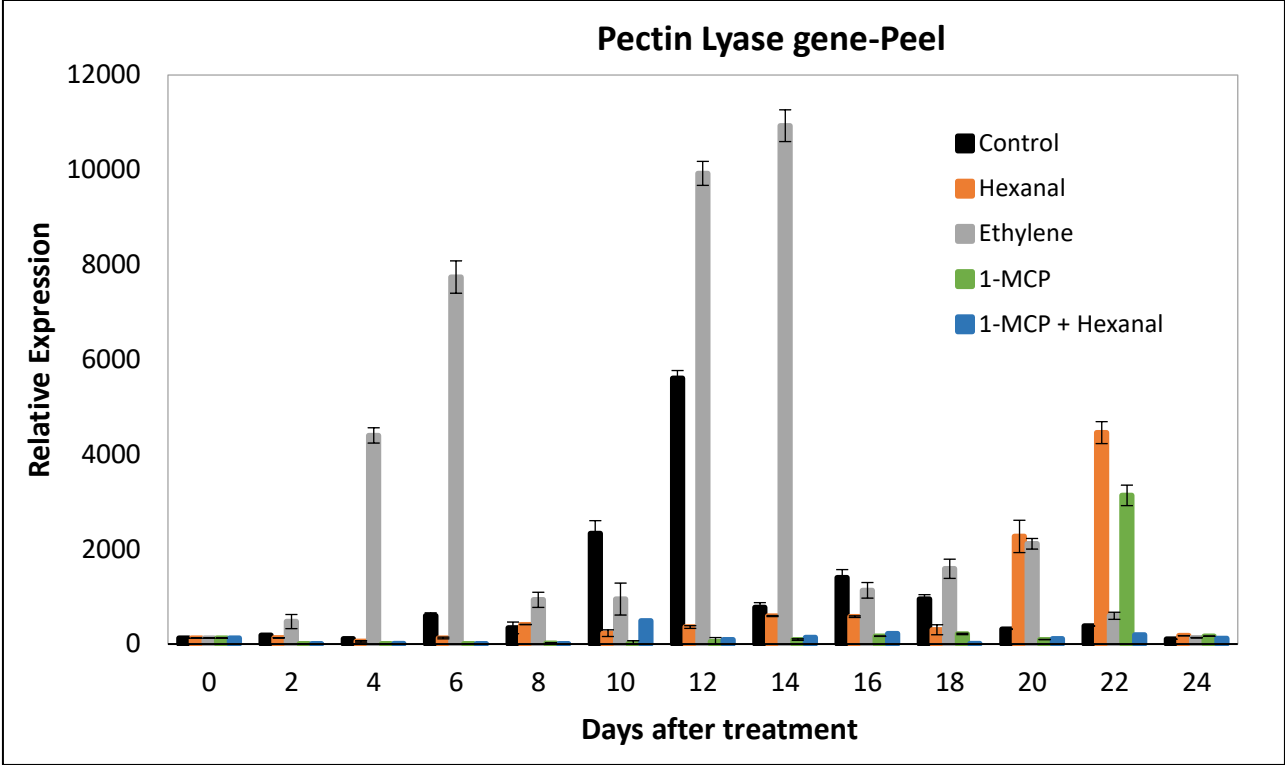
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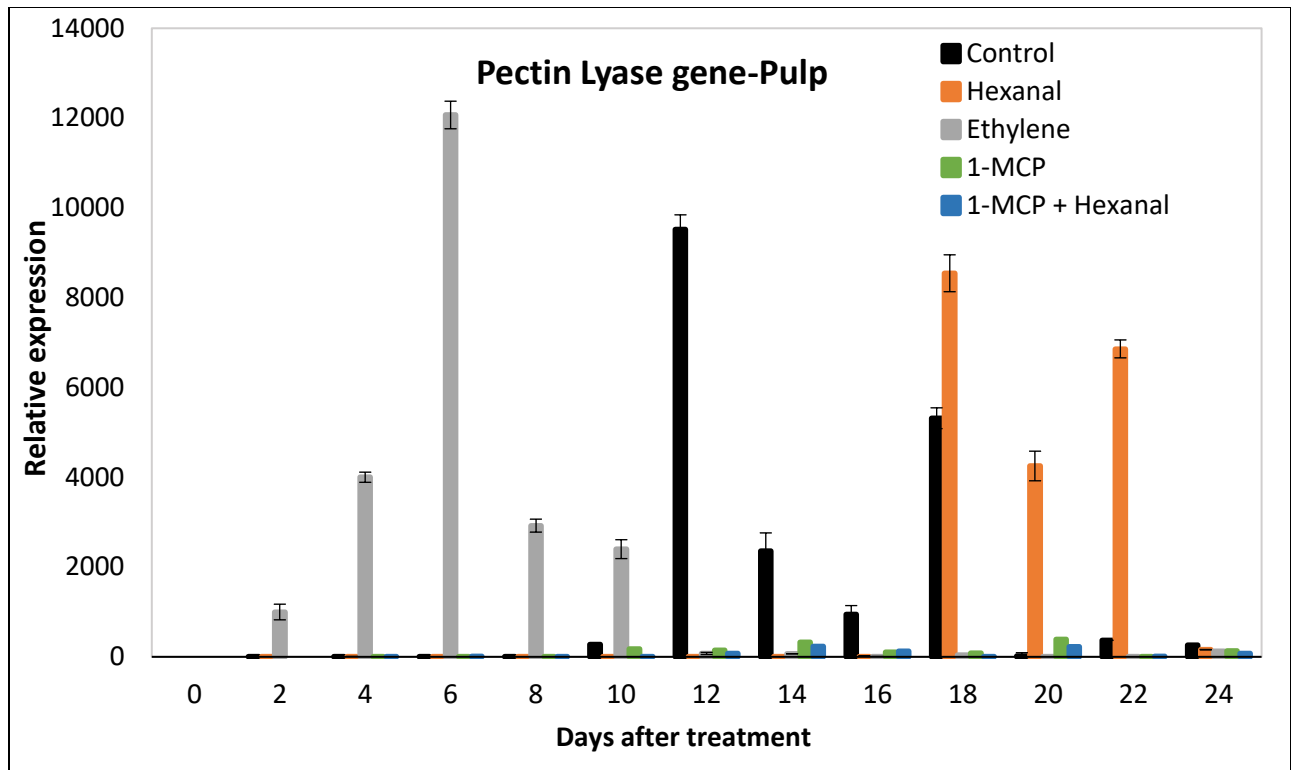
**Figure 31:** Relative expression of Polygalacturonase gene in pulp tissue over 24 days post-treatment under five different conditions: Control, Hexanal, Ethylene, 1-MCP, and 1-MCP + Hexanal. The highest expression was observed in the Ethylene treatment at 8 days.

**ii. Pectate Lyase gene (PL gene)**

Relative expression of Pectate Lyase gene in pulp tissue over 24 days post-treatment under five different conditions: Control, Hexanal, Ethylene, 1-MCP, and 1-MCP + Hexanal. The highest expression was observed in the Ethylene treatment at 8 days.



**Figure 32:** [Placeholder text for Figure 32 description]



**Figure 33:** Bar chart showing the relative expression of the Pectin Lyase gene in pulp over 24 days after treatment with Control, Hexanal, Ethylene, 1-MCP, and 1-MCP + Hexanal. The y-axis represents relative expression (0 to 14000) and the x-axis represents days after treatment (0 to 24). Error bars are shown for each data point.

### iii. Pectin methylesterase gene (PME gene)

Bar chart showing the relative expression of the Pectin methylesterase gene (PME gene) in pulp over 24 days after treatment with Control, Hexanal, Ethylene, 1-MCP, and 1-MCP + Hexanal. The y-axis represents relative expression (0 to 14000) and the x-axis represents days after treatment (0 to 24). Error bars are shown for each data point.



□  
□

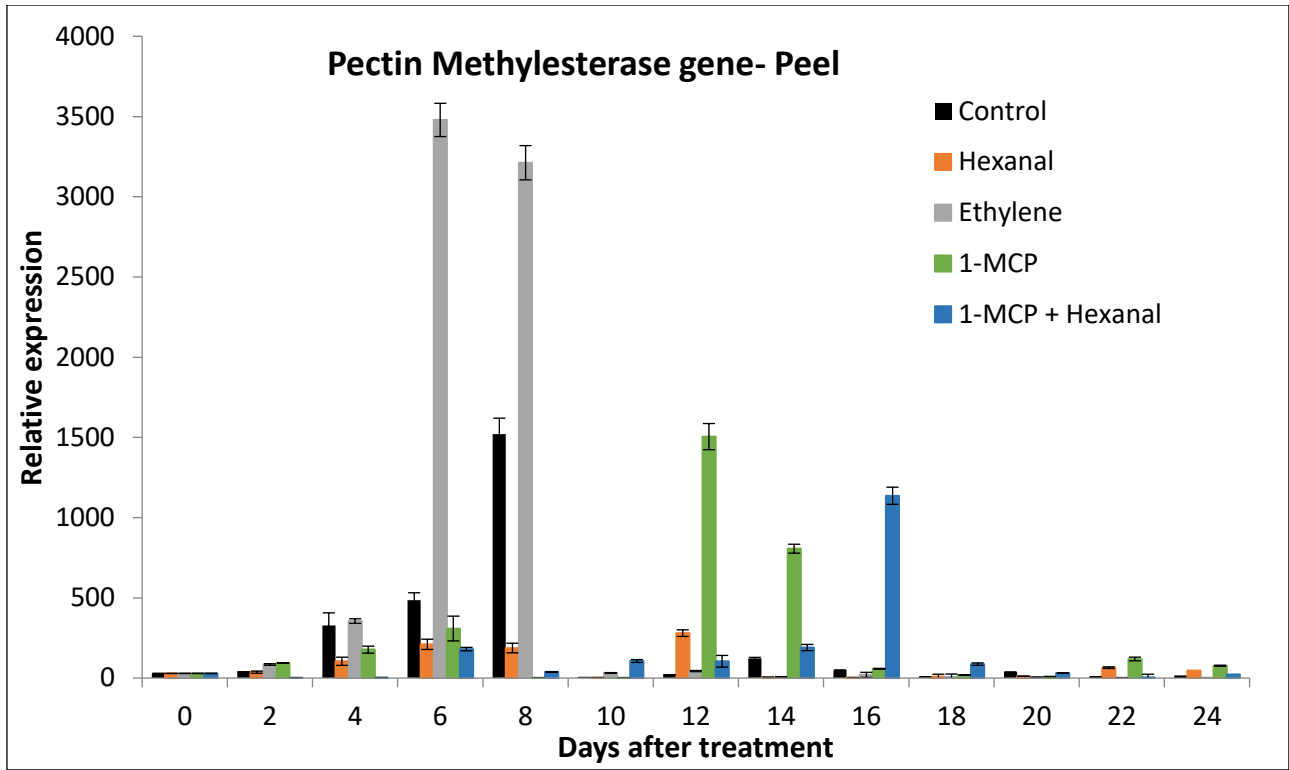
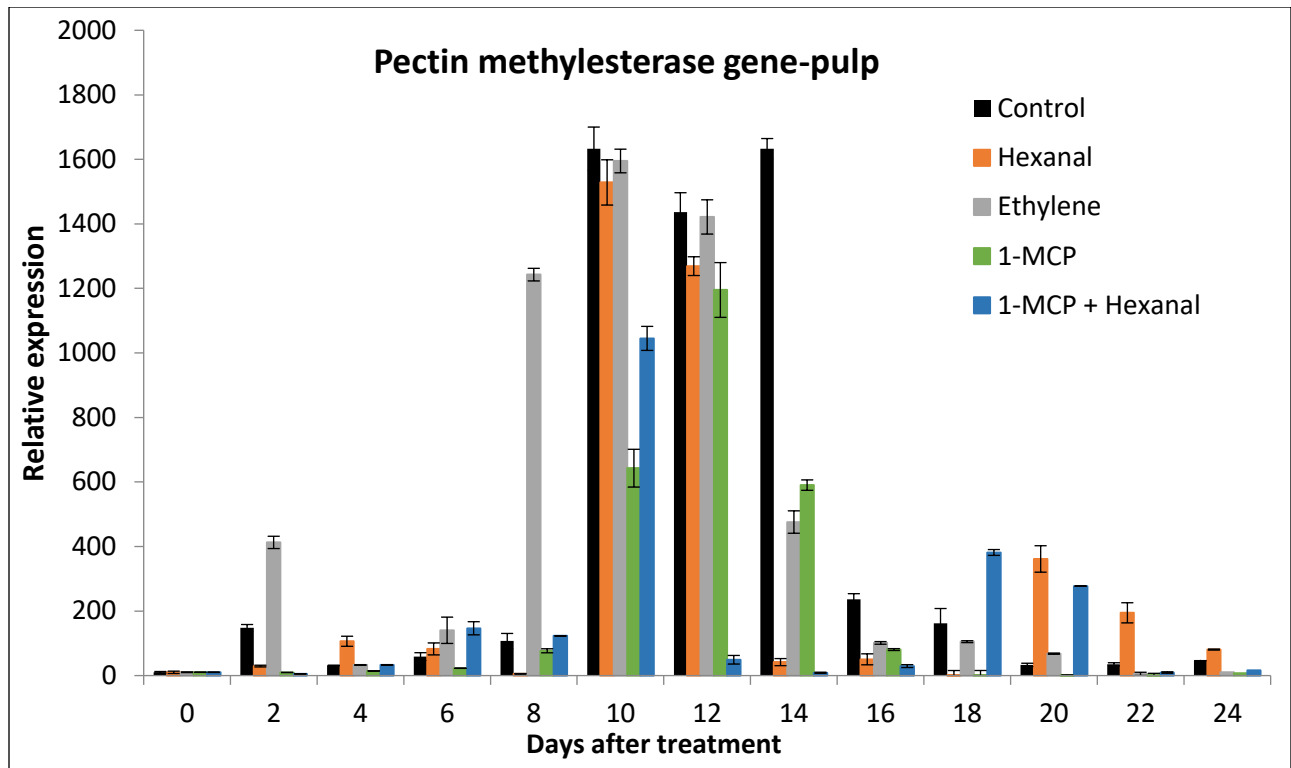


Figure 34: M r d M d r d r r d r r d r d r r d r

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□

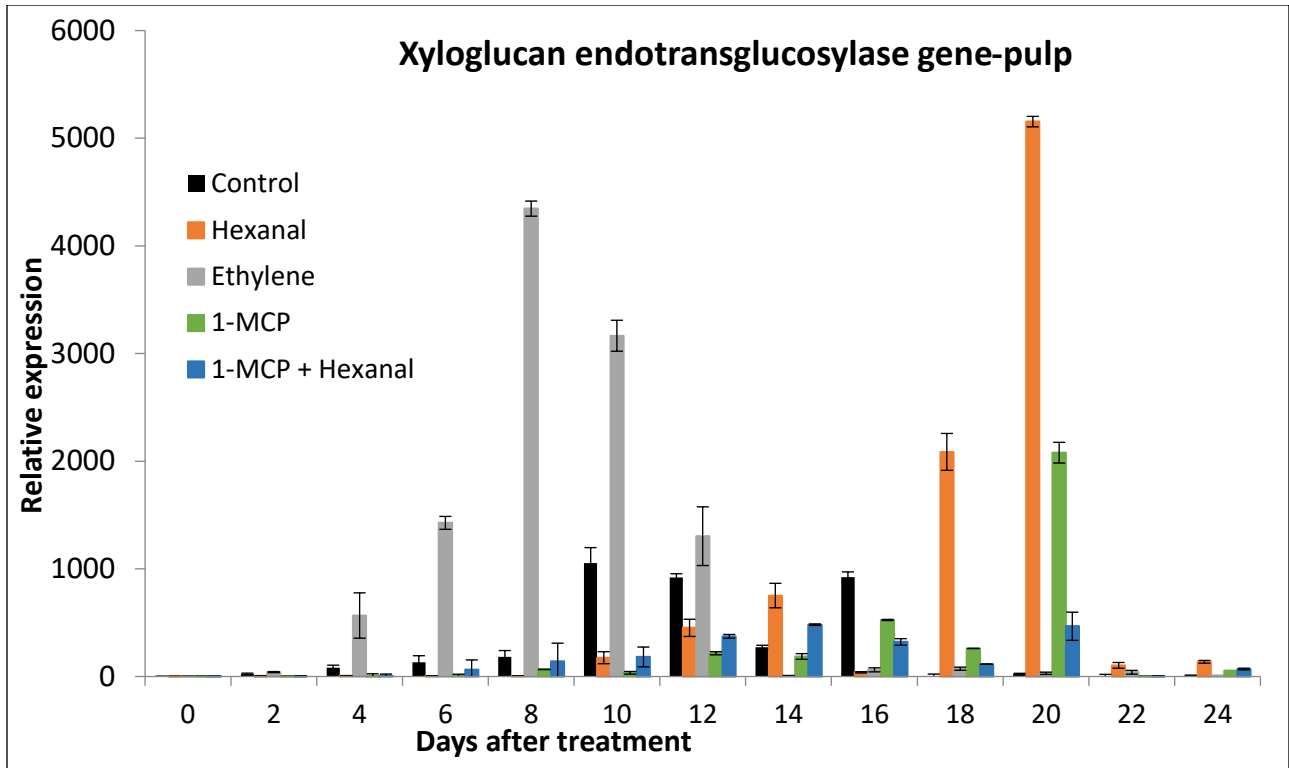


**Figure 35:** Relative expression of Pectin methylesterase gene-pulp in mango pulp over 24 days after treatment with Control, Hexanal, Ethylene, 1-MCP, and 1-MCP + Hexanal. Error bars represent standard deviation.

**iv. Xyloglucan endotransglucosylase gene (XET gene)**

Relative expression of Xyloglucan endotransglucosylase gene (XET gene) in mango pulp over 24 days after treatment with Control, Hexanal, Ethylene, 1-MCP, and 1-MCP + Hexanal. Error bars represent standard deviation.





**Figure 37:** [Placeholder text for Figure 37 description]

**v. 1-Aminocyclopropane-1-Carboxylic Acid Oxidase gene (ACO gene)**

[Placeholder text for ACO gene description]

□  
□

d r r d d 2

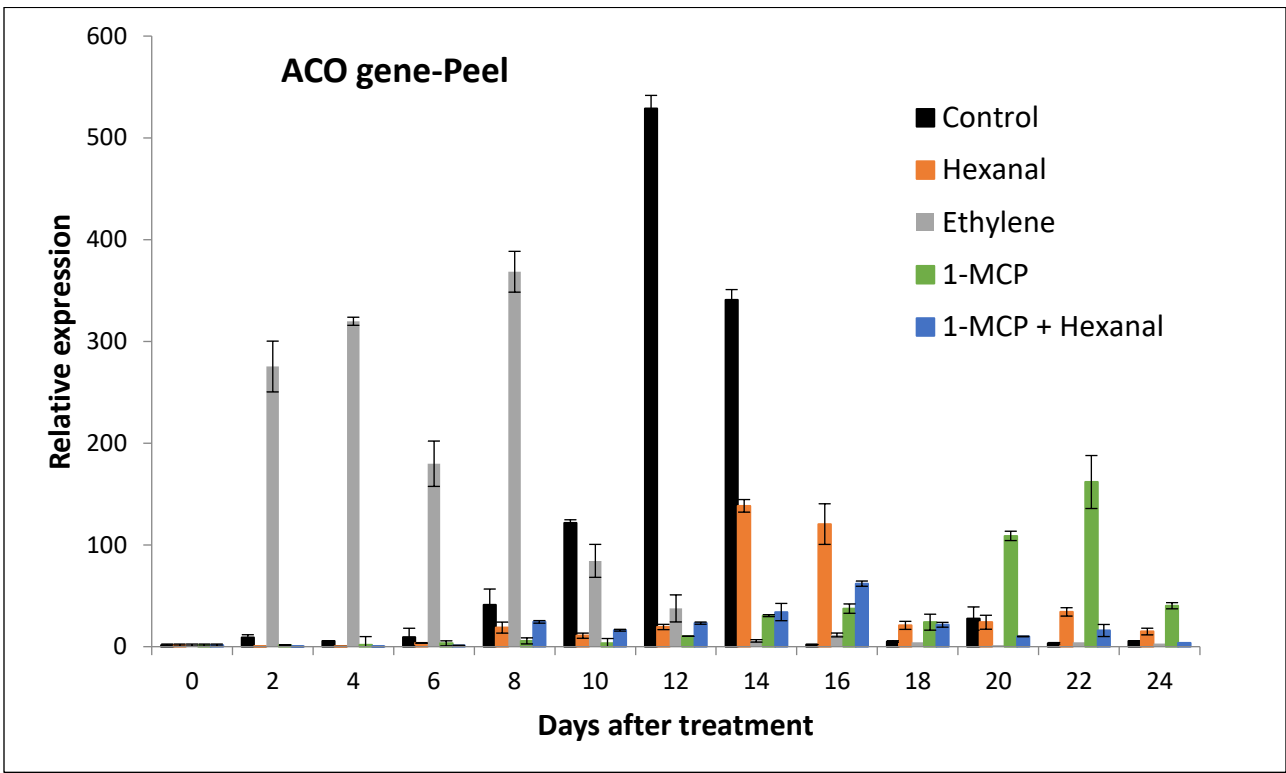
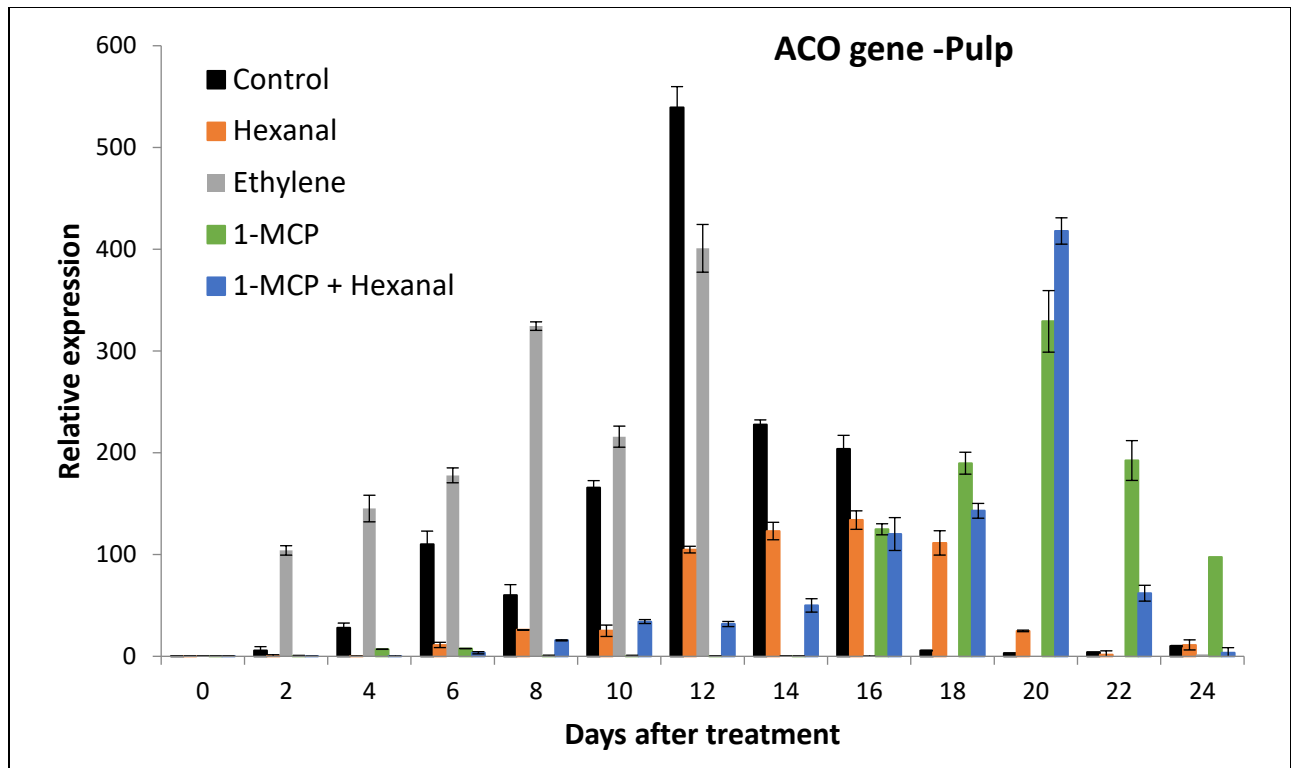


Figure 38: M d M d r d r d d r r r d r r r d r r r

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**Figure 39:** Relative expression of the ACO gene in pulp tissue of 'M' and 'd' genotypes under different treatments (Control, Hexanal, Ethylene, 1-MCP, and 1-MCP + Hexanal) over 24 days. Error bars represent standard deviation.

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### 5.4.3. Next Generation sequencing / Transcriptome analysis

#### 5.4.3.1. Quality control of the prepared libraries

Quality control of the prepared libraries involves several steps, including sequencing and analysis of the libraries. The process typically involves sequencing the libraries and analyzing the resulting data to ensure high quality and accuracy. Key parameters to monitor include sequencing depth, coverage, and the presence of artifacts. The following table summarizes the key parameters and their typical values:

| Parameter        | Typical Value |
|------------------|---------------|
| Sequencing Depth | 25            |
| Coverage         | 25            |
| Artifact Rate    | 25            |

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### Hexanal treated fruits day 1

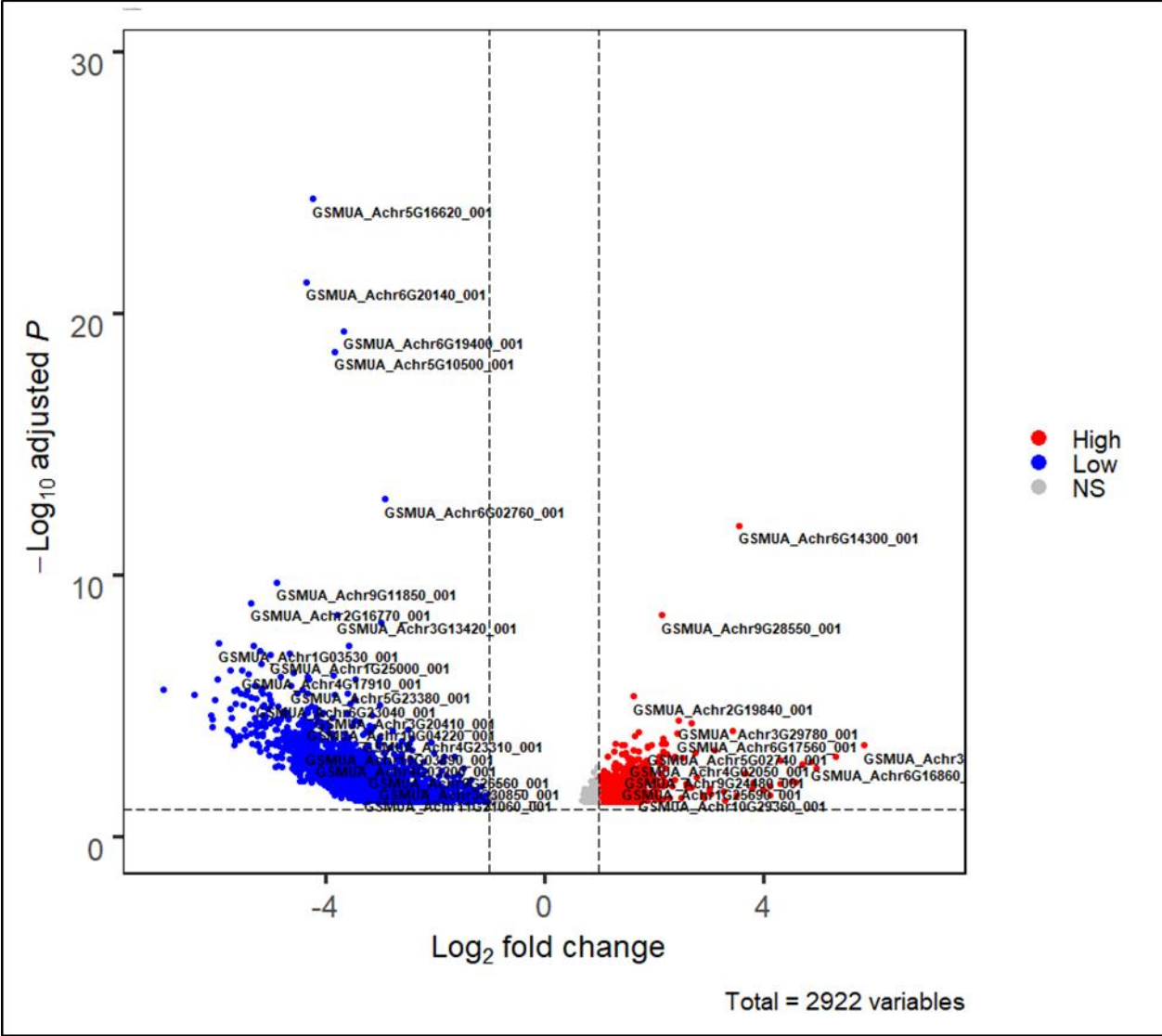
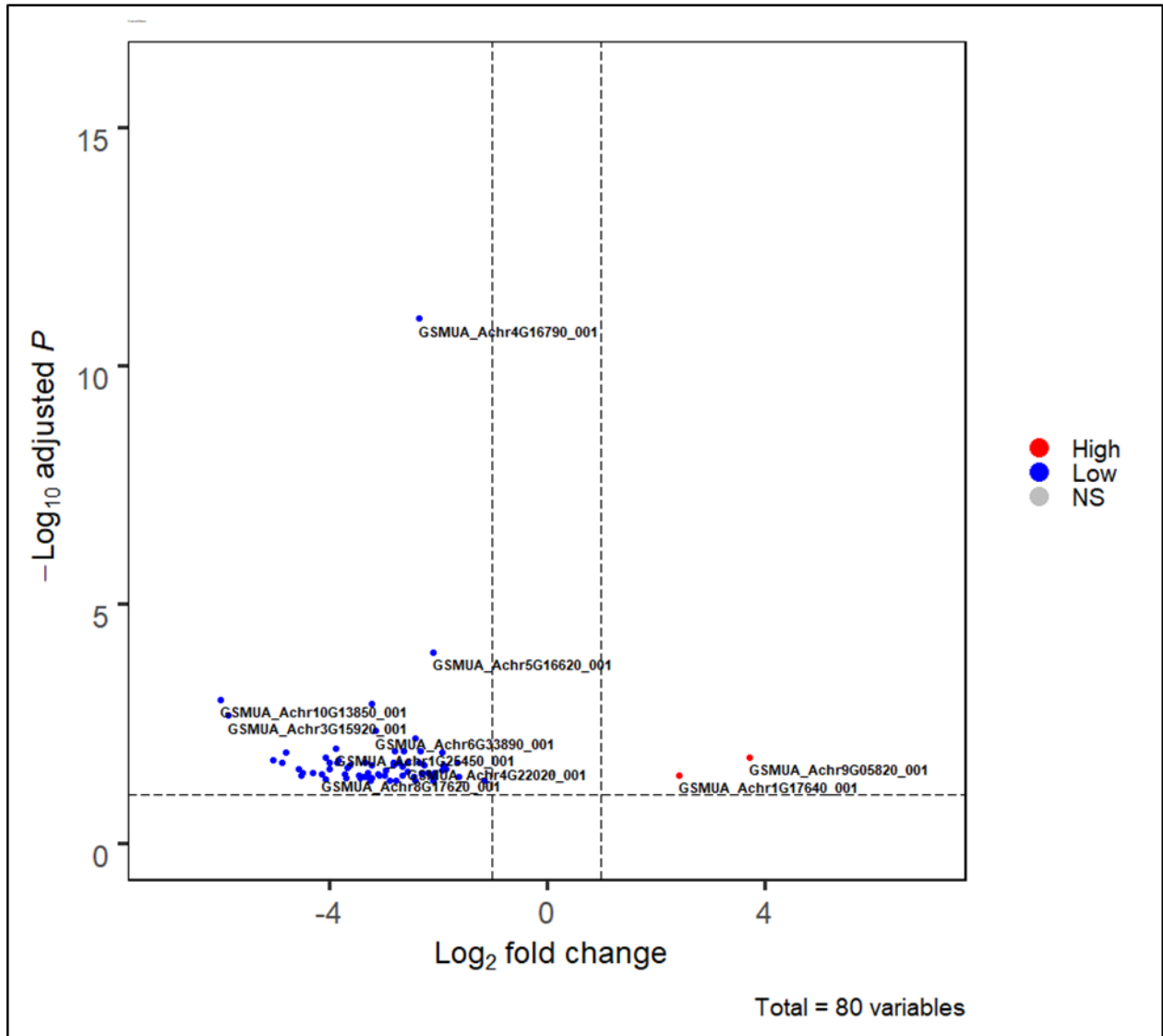


Figure 43: Volcano plot showing differential gene expression in hexanal treated fruits on day 1. The y-axis is  $-\log_{10}$  adjusted P and the x-axis is  $\log_2$  fold ratio. Points are colored red (High), blue (Low), or grey (NS).

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### Ethylene treated fruits day 1



**Figure 44:** Volcano plot showing differential gene expression in ethylene-treated fruits at day 1. The y-axis represents  $-\log_{10}$  adjusted P values, and the x-axis represents  $\log_2$  fold change. Points are colored by significance: High (red), Low (blue), and NS (grey). Significant genes include GSMUA\_Achr4G16790\_001, GSMUA\_Achr5G16620\_001, GSMUA\_Achr10G13850\_001, GSMUA\_Achr3G15920\_001, GSMUA\_Achr6G33890\_001, GSMUA\_Achr1G25450\_001, GSMUA\_Achr4G22020\_001, GSMUA\_Achr8G17620\_001, GSMUA\_Achr9G05820\_001, and GSMUA\_Achr1G17640\_001. Total = 80 variables.

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Ethylene treated fruits day 4

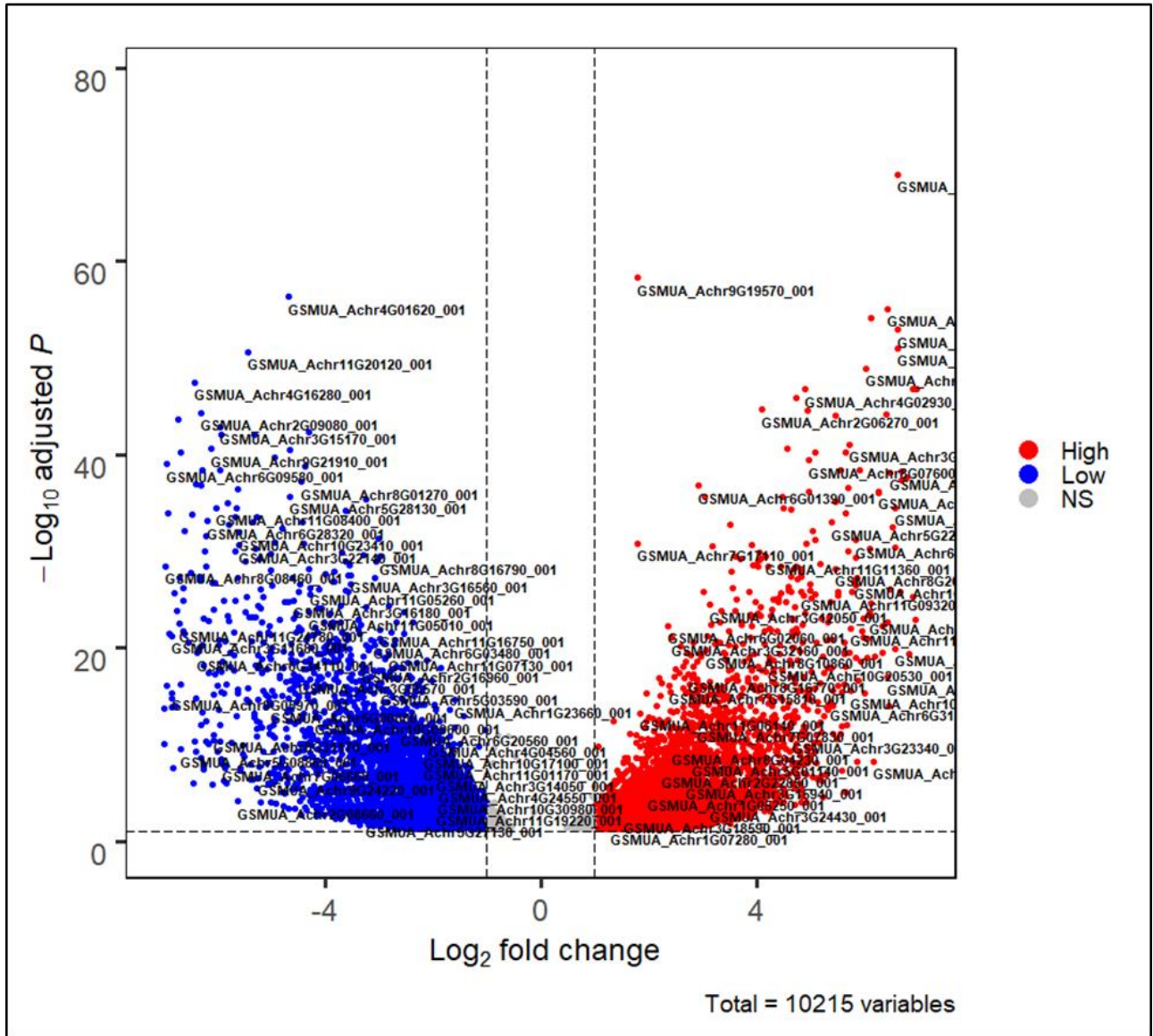


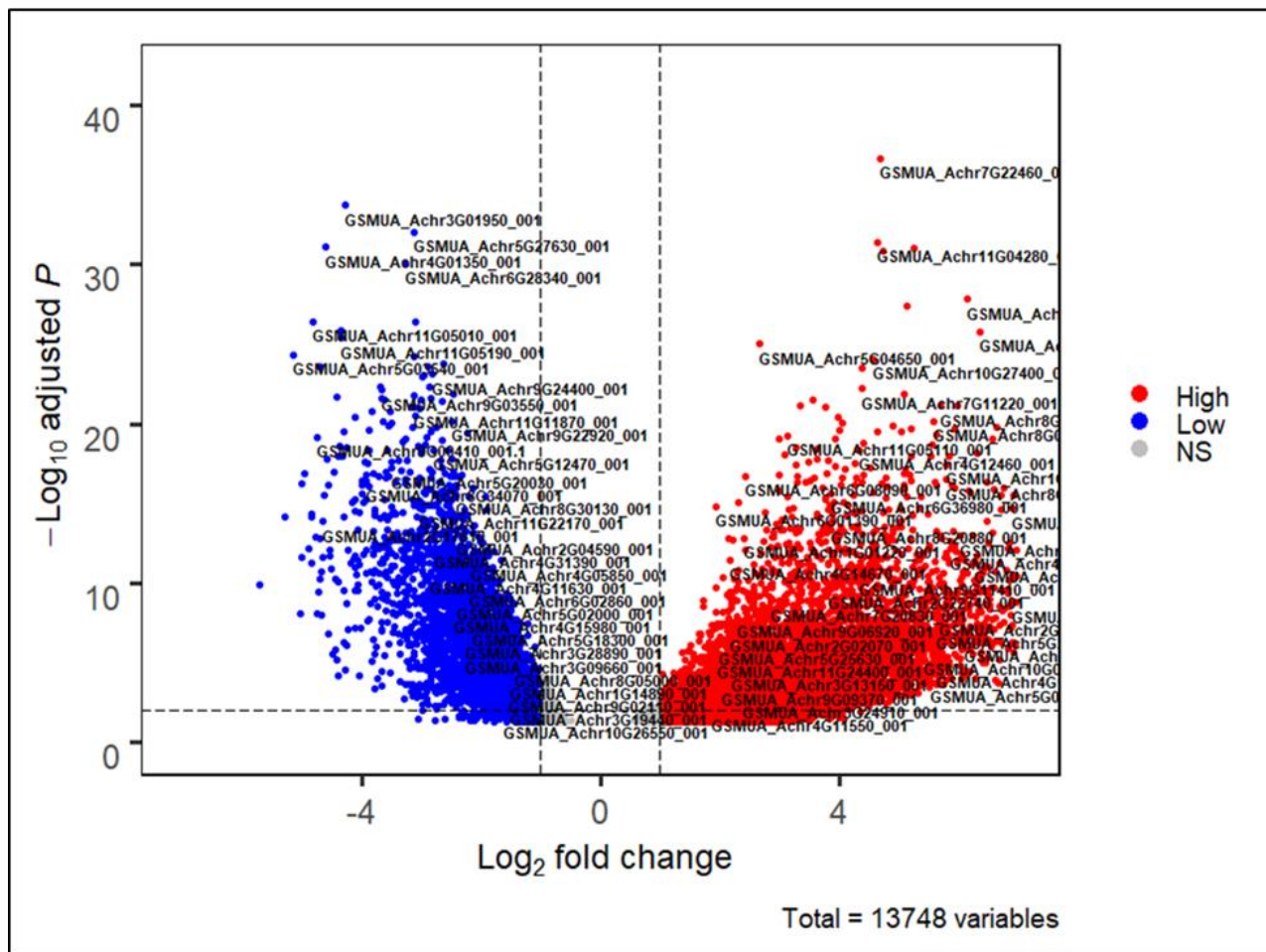
Figure 46: Volcano plot showing differential gene expression in ethylene-treated fruits at day 4 of storage. The y-axis represents the negative logarithm of the adjusted p-value ( $-\text{Log}_{10}$  adjusted P) and the x-axis represents the Log<sub>2</sub> fold change. Points are colored red (High), blue (Low), and grey (NS). Total = 10215 variables.





□  
□

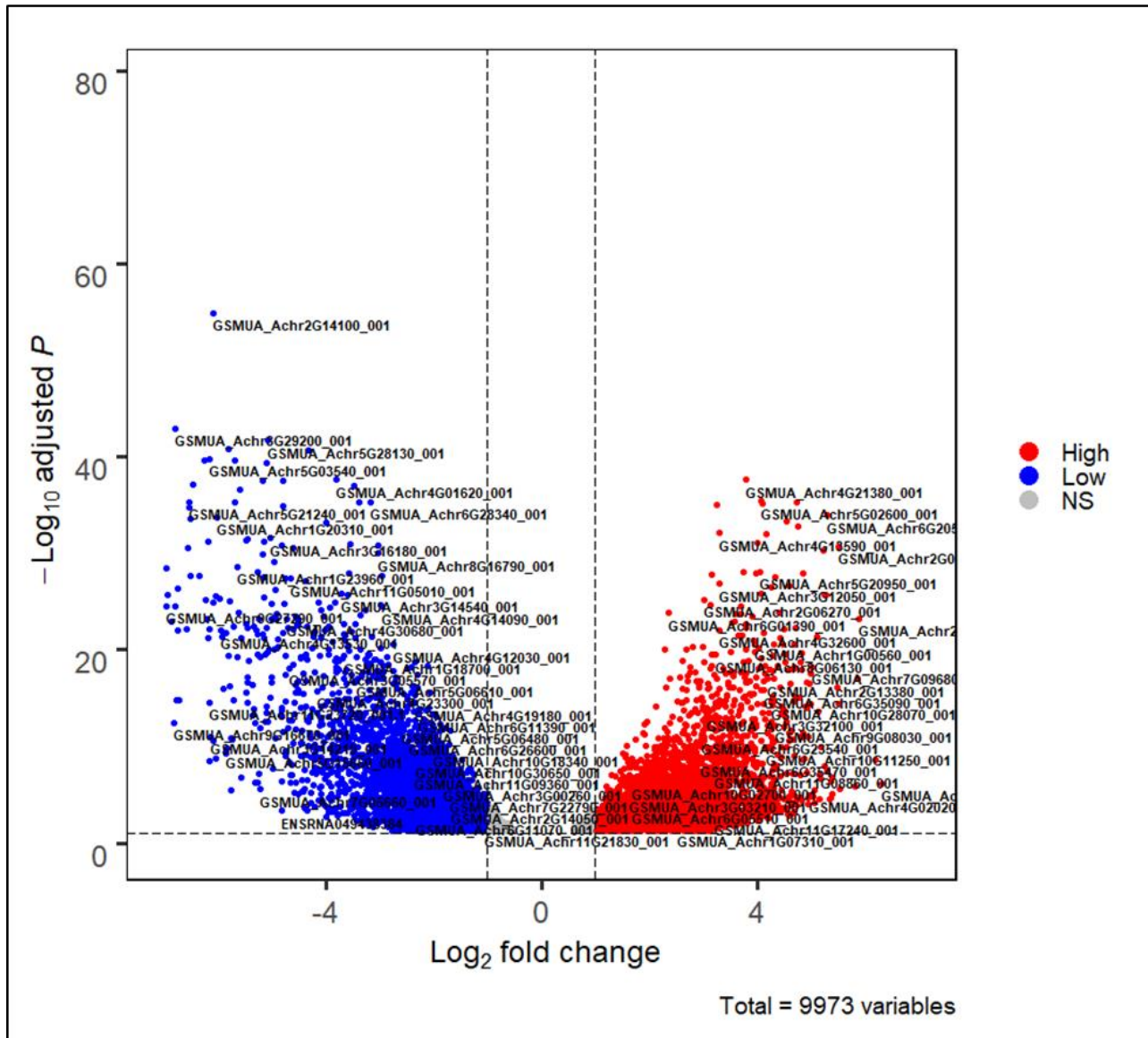
### Hexanal treated fruits day 18



**Figure 47:** Volcano plot showing differentially expressed genes in hexanal treated fruits at day 18 of storage. The plot displays  $-\log_{10}$  adjusted P values on the y-axis and  $\log_2$  fold ratio on the x-axis. Red dots represent up-regulated genes (High), blue dots represent down-regulated genes (Low), and grey dots represent non-significant genes (NS). A horizontal dashed line indicates the significance threshold at  $-\log_{10} P \approx 3.5$ . Vertical dashed lines indicate the fold change threshold at  $\log_2$  fold ratio  $\geq 1$ . Total = 13748 variables.

□

Ethylene treated fruits day 18

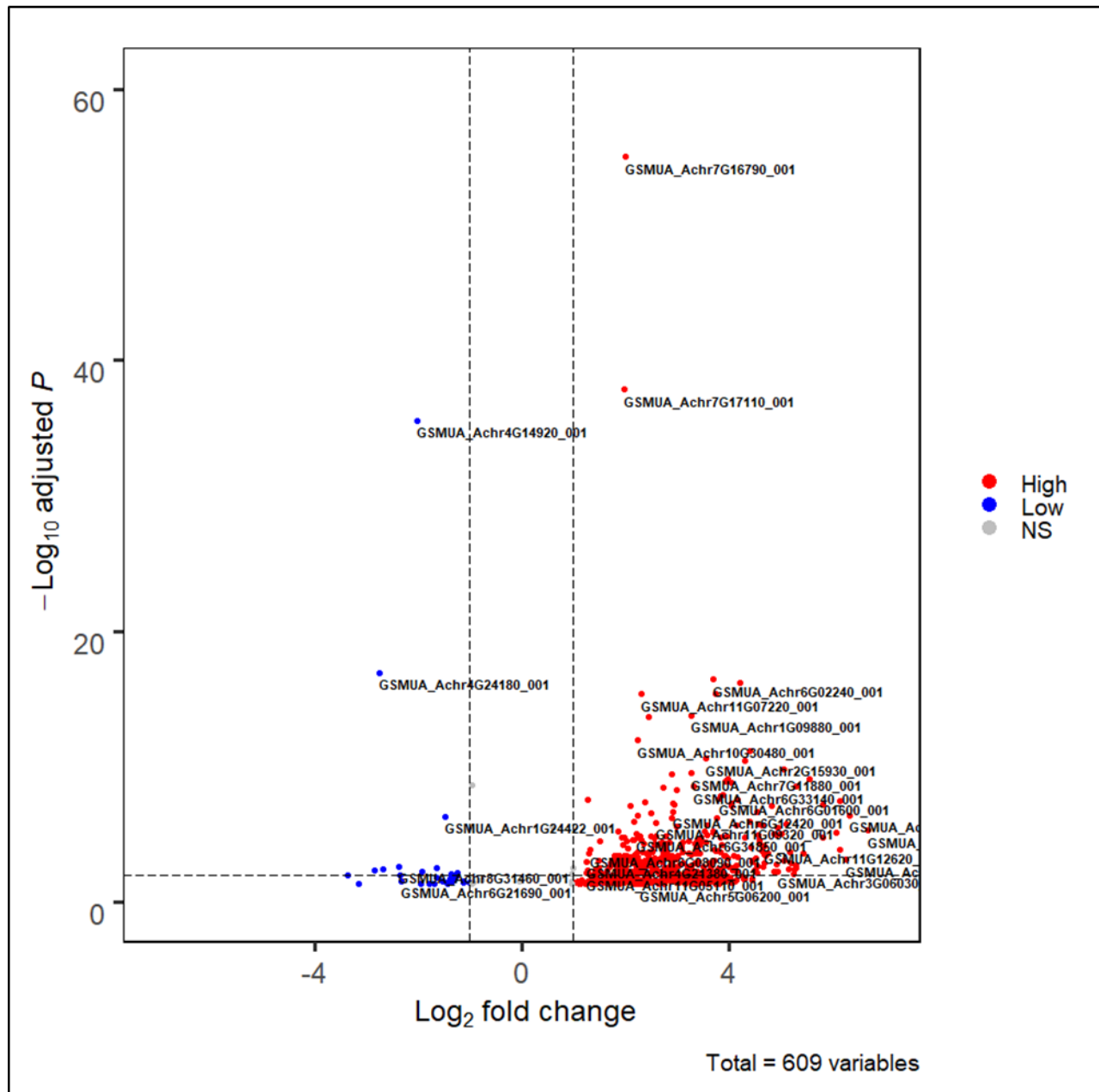


**Figure 48:** Volcano plot showing differential gene expression in ethylene-treated fruits at day 18. The y-axis represents  $-\log_{10}$  adjusted P-value, and the x-axis represents  $\log_2$  fold change. Points are colored red (High), blue (Low), and grey (NS). The plot shows a dense cluster of blue points on the left and red points on the right, with a few grey points near the center. A dashed horizontal line is at  $y=0$ . A dashed vertical line is at  $x=0$ . The total number of variables is 9973.



□  
□

### Hexanal treated fruits day 24



**Figure 49:** Volcano plot showing differential gene expression in hexanal treated fruits at day 24. The y-axis represents  $-\log_{10}$  adjusted P-value, and the x-axis represents  $\log_2$  fold change. Points are colored red (High), blue (Low), and grey (NS). Labeled genes include GSMUA\_Achr7G16790\_001, GSMUA\_Achr7G17110\_001, GSMUA\_Achr4G14920\_001, GSMUA\_Achr4G24180\_001, GSMUA\_Achr1G24422\_001, GSMUA\_Achr6G21690\_001, GSMUA\_Achr6G02240\_001, GSMUA\_Achr11G07220\_001, GSMUA\_Achr1G09880\_001, GSMUA\_Achr10G30480\_001, GSMUA\_Achr2G15930\_001, GSMUA\_Achr7G11880\_001, GSMUA\_Achr6G33140\_001, GSMUA\_Achr6G01600\_001, GSMUA\_Achr6G12420\_001, GSMUA\_Achr1G00820\_001, GSMUA\_Achr6G34860\_001, GSMUA\_Achr6G00930\_001, GSMUA\_Achr11G12620\_001, GSMUA\_Achr1G05110\_001, GSMUA\_Achr3G06030\_001, GSMUA\_Achr5G06200\_001.















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## CHAPTER SIX

### 6.0 GENERAL DISCUSSION, CONCLUSION AND RECOMMENDATIONS

#### 6.1 General Discussion

Bananas are grown in the country and plays a key role in Kenya's economy and food security that is in tandem with 2030 vision of the country. However, bananas' full potential is not fully realized due to various constraints. The major constraints include low yields, poor quality, and limited market access. The Ministry of Agriculture, Livestock and Fisheries (MALF) has identified these constraints and is working to address them through various interventions. These include providing technical support to farmers, improving market access, and promoting value addition. The government is also working to improve the regulatory environment for the banana sector. This will help to attract investment and promote growth in the sector. The government is committed to ensuring that the banana sector is sustainable and contributes to the country's economic development.

The government is also working to improve the regulatory environment for the banana sector. This will help to attract investment and promote growth in the sector. The government is committed to ensuring that the banana sector is sustainable and contributes to the country's economic development. The government is also working to improve the regulatory environment for the banana sector. This will help to attract investment and promote growth in the sector. The government is committed to ensuring that the banana sector is sustainable and contributes to the country's economic development. The government is also working to improve the regulatory environment for the banana sector. This will help to attract investment and promote growth in the sector. The government is committed to ensuring that the banana sector is sustainable and contributes to the country's economic development.















□

□

□  $r$   $d$   $r$   $2$   $M$   $r$   
 $r$   $5$   $6$

□  $d$   $r$   $d$   $r$   $2$   $r$   
 $d$   $r$   $d$   $r$   $d$   $r$   $d$   $r$   $d$   $r$   $6$   $6$   $6$   $2$

□  $r$   $2$   $6$   $r$   $r$   $d$   $r$   $r$   $d$   $r$   
 $r$   $6$ —

□  $r$   $d$   $r$   $M$   $2$   $M$   $r$   $d$   
 $d$   $M$   $r$   $M$

□  $r$   $r$   $M$   $d$   $r$   $r$   $r$   
 $r$   $d$   $r$   $r$   $M$   $6$   $6$

□  $r$   $d$   $r$   $M$   $d$   $r$   $r$   
 $r$   $d$   $r$   $r$   $6$   $5$

□  $d$   $2$   $6$   $M$   $d$   $d$   $r$   
 $d$   $M$   $r$   $r$   $d$   
 $2$

□  $d$   $r$   $d$   $2$   $r$   
 $r$   $d$   $r$   $d$   $r$   $d$   
 $r$   $d$   $5$

□  $d$   $2$   $d$   
 $r$   $d$   $r$   $d$   $r$   
 $5$   $5$   $5$

□  $2$   $r$   $r$   $d$   $r$   $d$   
 $2$   $r$   $d$   $r$   $d$   
 $r$   $d$   $2$

□  $M$   $d$   $M$   $2$   $r$   
 $r$   $d$   $r$   $d$   $r$   $5$   
 $5$



□

□

□  $M$   $d$   $r$   $2$   $5$

$r$   $d$   $r$   $d$

$d$   $d$   $r$   $r$

$r$   $d$   $2$   $22$   $2$   $2$

□  $2$   $M$   $r$   $r$   $d$   $r$

$M$   $52$ ,  $25$

□  $d$   $r$   $M$   $d$   $r$

$d$   $d$   $r$   $r$   $r$   $d$

□  $d$   $r$   $2$   $d$   $r$   $r$   $r$   $r$   $r$

$r$   $r$   $d$   $d$   $d$   $25$

□  $5$   $d$   $d$   $56$

□  $2$   $r$   $r$   $r$   $r$   $r$   $d$

$M$   $r$   $r$   $r$   $2$   $2$

□  $r$   $r$   $r$   $2$   $r$   $r$

$d$   $r$   $r$

$2$

□  $d$   $M$   $2$   $r$

$d$   $d$   $r$   $d$   $d$

$r$   $d$   $M$   $2$   $d$

□  $r$   $r$   $d$   $r$   $5$   $M$   $d$   $d$

$r$   $r$   $d$   $d$   $r$   $r$   $d$

$M$   $d$   $r$   $d$   $r$   $r$

$d$   $r$   $r$   $d$   $r$   $r$   $d$   $r$

$M$   $r$   $2$   $6$

□  $M$   $d$   $r$   $2$   $d$   $r$   $r$

$d$   $r$   $d$   $r$   $r$   $r$

$r$   $r$   $5$



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□ **M** **M** **M** **d** **2** **5** **r** **d** **r**  
**d** **r** **6**

□ **d** **d** **r** **2**  
**d** **r** **d** **rr** **r**  
**r** **2**

□ **d** **2** **r** **d** **r** **r** **d** **r** **d**  
**5**

□ **2** **d** **r** **r** **r** **r** **r** **r** **r** **r** **d**  
**d** **r** **r** **r** **r** **r** **d**  
**r** **r** **d** **M** **d** **d** **M** **r** **2**

□ **d** **d** **d** **d** **M** **2** **5** **r**  
**d** **M** **d** **r** **d**  
**6** **6** **6**

□ **r** **d** **r** **rr** **r**  
**r** **r** **d** **r** **d** **r** **r** **2**  
**r**

□ **d** **M** **r** **d** **r**  
**r** **rr** **d** **r** **2**

□ **d** **r** **d** **M** **2** **d** **d** **r**  
**packaging on quality and shelf life of ‘Robusta’ b** *Musa* **r** **d** **r**  
**r** **d** **d** **2**

□ **r** **d** **r** **2** **r**  
**d** **r** **r** **2** **6**–**55**

□ **r** **r** **d** **2** **d**  
**dr** **r** **d** **d** **d** **M** **d**  
**M** **M** **r** **r** **r** **2** **5**

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Léchaudel, M. and J. Joas. 2006. "Quality and maturation of mango fruits of cv. Cogshall in relation to harvest date and carbon supply." *Australia Journal of Agriculture and Research*, 57:419-426

Quantitative PCR and the  $2^{-\Delta\Delta C_T}$  method for relative gene expression analysis

Relative gene expression analysis using real-time quantitative PCR and the  $2^{-\Delta\Delta C_T}$  method

Relative gene expression analysis using real-time quantitative PCR and the  $2^{-\Delta\Delta C_T}$  method

Relative gene expression analysis using real-time quantitative PCR and the  $2^{-\Delta\Delta C_T}$  method

Relative gene expression analysis using real-time quantitative PCR and the  $2^{-\Delta\Delta C_T}$  method

Relative gene expression analysis using real-time quantitative PCR and the  $2^{-\Delta\Delta C_T}$  method

Relative gene expression analysis using real-time quantitative PCR and the  $2^{-\Delta\Delta C_T}$  method

Relative gene expression analysis using real-time quantitative PCR and the  $2^{-\Delta\Delta C_T}$  method

Relative gene expression analysis using real-time quantitative PCR and the  $2^{-\Delta\Delta C_T}$  method

Relative gene expression analysis using real-time quantitative PCR and the  $2^{-\Delta\Delta C_T}$  method

Relative gene expression analysis using real-time quantitative PCR and the  $2^{-\Delta\Delta C_T}$  method

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M...M...M...d...2...r...  
 □...rd...r...r...r...

M...M...r...r...M...M...  
 □d...d...2...r...r...d...r...  
 d...r...r...d...r...r...dr...r...r...6...  
 2...2...2...

M...M...d...d...5...d...r...d...  
 □r...dr...r...d...r...d...2...5...2...

M...d...r...d...2...d...d...r...r...  
 and maturation of „Carabao“ mango. Animal Husbandr...d...r...r...-6...

M...r...M...d...r...2...d...r...d...  
 ‘Hass’ Fruit Following Treatment w...r...r...M...r...  
 M...d...r...M...d...r...r...d...r...r...56...

M...r...r...d...r...r...2...r...r...d...  
 □rd...r...d...r...d...r...  
 □□□r...d...d...2...56...

M...r...r...d...M...2...5...d...r...r...  
 □□□r...r...d...d...r...r...r...d...62...

□r...r...d...r...2...2...r...d...r...  
 □r...d...r...r...r...r...  
 □□M...r...r...r...d...

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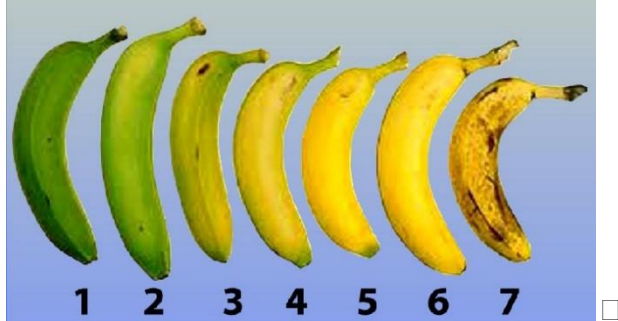


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## APPENDICES

### Appendix 1 Banana ripening chart

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### Appendix 2. Sensory evaluation questionnaire for banana fruits

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Name.....Gender..... Age

r

2 r  25  2 r  5 r  5 r

r r d d  d d  r  r  5  rd

r d d  r

r

2   d r

r r d

d r

5  r

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- r     r d
- d r
- 5     r

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□

### Appendix 3. ANOVA for peel color field □

| Source of variation          | d.f.       | s.s.            | m.s.     | v.r.     | F pr.  |
|------------------------------|------------|-----------------|----------|----------|--------|
| r□□□□ □□□□□                  | □□         | 5□□6□56□        | □□2□□□□□ | □□□□5□   | □□□□□□ |
| □□□□□                        | □□         | 5□6□□□□□        | 5□6□□□□□ | 2□6□□□□□ | □□□□□□ |
| □ r□□□□□                     | □□         | □5□5□□□□        | □5□5□□□□ | 5□□□□□   | □□□□□□ |
| □□□□□                        | □□□        | □□2□6□□         | □□2□□□□  | □□□□5□   | □□□□□□ |
| r□□□□ □□□□□ □□□              | □□         | 2□□6□           | 5□□□□    | 2□2□□    | □□65□  |
| r□□□□ □□□□□□ r□□□□□          | □□         | 62□□□□          | □5□6□□   | □5□□□    | □6□□□  |
| □□□□□ r□□□□□                 | □□         | 5□□□□           | 5□□□□    | 2□22□□   | □□□□□□ |
| r□□□□ □□□□□ □□□□             | □6□        | □□5□6□□         | □□□□□□□  | □2□□□    | □□□□□□ |
| □□□□□ □□□□                   | □□         | 5□□□□□□□        | 6□□□□□□  | 2□□6□□   | □□□□□□ |
| □ r□□□□□□ □□□□               | □□         | 26□□□2□         | □26□2□□  | □2□26□   | □□□□□□ |
| r□□□□ □□□□□ □□□□ r□□□□□      | □□         | 6□□6□           | □□□□□□   | □66□□    | □622□□ |
| r□□□□ □□□□□ □□□□ □□□□        | □□□        | □□□□2□          | 26□□□□   | □□□      | □□□□□  |
| r□□□□ □□□□□ r□□□□□ □□□□      | □□□        | □6□6□□□         | 5□55□□   | 2□□□□    | □□□2□□ |
| □□□□□ r□□□□□ □□□□            | □□         | □□□5□□          | 55□66□   | 2□□□□    | □□□□□□ |
| r□□□□ □□□□□ □□□□ r□□□□□ □□□□ | 2□□        | □25□□□□         | □6□□□□   | □□6□□    | □□□6□□ |
| □□□□ d□□□□                   | □5□□       | □□□□6□□         | 26□6□□   | □□□      | □□□    |
| <b>Total</b>                 | <b>533</b> | <b>47965.63</b> | □□□      | □□□      | □□□    |

□



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**Appendix 4. ANOVA for ethylene production levels**

| Source of variation                 | d.f.       | s.s.           | m.s.      | v.r.    | F pr.  |
|-------------------------------------|------------|----------------|-----------|---------|--------|
| □ □□□□□□□□□□ □d□□                   | □□         | □□2□□          | □□2□6□□   | □□□□2□  | □□□□□□ |
| □r□□□□ □□□□□□                       | □□         | □5□□□□         | □□6□□□    | □□□□6□  | □□□□□□ |
| □ □r□□□□□                           | □□         | □5□□           | □5□□□     | 5□6□□   | □□□□□□ |
| □ □□□□                              | □□         | □□5□□          | □□5□□□□   | □□□□6□  | □□□□□□ |
| □ □□□□□                             | 5□         | □□6□5□□        | 26□□□6□□  | □6□□□□  | □□□□□□ |
| □ □□□□□□□□□□ □d□□□r□□□□□□           | □□         | □62□6□□        | □62□6□□□□ | 5□6□□□□ | □□□□□□ |
| □r□□□□ □□□□□□r□□□□□□                | □□         | □5□6□          | □□□□□5□   | □2□□□□  | □□□□□□ |
| □ □□□□□□□□□□ □d□□□□□□□□             | □□         | □□□□□□□□       | □□□2□□□   | 5□□□□□□ | □□□□□□ |
| □r□□□□ □□□□□□□□□□                   | □□         | □5□□□□         | □6□□2□    | 6□□□□□  | □□□□□□ |
| □ □r□□□□□□□□□□                      | □□         | □6□□□          | □6□□□□5□  | □2□□□□□ | □□□□□□ |
| □ □□□□□□□□□□ □d□□□r□□□□□□□□□□       | □□         | □□6□□          | □□6□25□   | □2□52□  | □□□□□□ |
| □r□□□□ □□□□□□r□□□□□□□□□□            | □□         | □□□□□□□        | □□□□6□    | □□□□□□  | □□□□□□ |
| □ □□□□□□□□□□ □d□□□r□□□□□□□□□□□□     | □□         | □□□□□5□        | 2□□□6□□   | □□□□5□  | □□□□□□ |
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| □ □□□□□□□□□□ □d□□□□□□□□□□□□         | 5□         | □6□□□□         | □2□62□    | 26□26□  | □□□□□□ |
| □r□□□□ □□□□□□□□□□□□□□               | □□□□       | □□□□2□□        | □□□□□□    | □5□□□□  | □□□□□□ |
| □ □r□□□□□□□□□□□□□□                  | 5□         | □□□□6□         | □□52□□    | □5□2□   | □□□□□□ |
| M□d□□r□□□□ □□□□□□r□□□□□□□□□□□□□□□□□ | □□         | □□2□□          | □□2□□□    | □□□65□  | □□□□□□ |
| □r□□□□ □□□□□□r□□□□□□□□□□□□□□        | □□□□       | □□□□□□         | 2□□2□□    | □□□□□   | □□□□□□ |
| □ □□d□□□□                           | □□□□       | □□□□6□□        | □2□□□□    |         | □□     |
| <b>Total</b>                        | <b>650</b> | <b>5159.97</b> |           |         |        |

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### Appendix 6. ANOVA for cumulative weight loss

| Source of variation | d.f.        | s.s.            | m.s.   | v.r.   | F pr.  |
|---------------------|-------------|-----------------|--------|--------|--------|
| M d                 | 1           | 100000          | 100000 | 20000  | 0.0000 |
| r                   | 1           | 50500           | 6620   | 0.0000 | 0.0060 |
| r                   | 1           | 6000            | 6000   | 0.0000 | 0.0000 |
|                     | 1           | 200000          | 200000 | 5050   | 0.0050 |
| M d r               | 1           | 20000           | 20000  | 0.0000 | 0.0000 |
| r r                 | 1           | 5000            | 22000  | 6000   | 0.0000 |
| M d                 | 1           | 6000            | 6000   | 2050   | 0.0000 |
| r                   | 1           | 20000           | 0.0000 | 0.0000 | 0.0520 |
| r                   | 1           | 0               | 0      | 0      | 0.0000 |
| M d r               | 1           | 2000            | 2000   | 0.0000 | 0.0060 |
| r r                 | 1           | 6050            | 0.0000 | 5000   | 0.0000 |
| d                   | 202         | 50000           | 6062   | 0      | 0      |
| <b>Total</b>        | <b>1259</b> | <b>45766.03</b> |        |        |        |

### Appendix 7. ANOVA for peel firmness

| Source of variation | d.f. | s.s.     | m.s.    | v.r.   | F pr.  |
|---------------------|------|----------|---------|--------|--------|
| d                   | 1    | 5050025  | 5050000 | 50000  | 0.0000 |
| r                   | 1    | 256000   | 60200   | 0.0000 | 0.0000 |
| r                   | 1    | 5500006  | 5500006 | 50206  | 0.0000 |
|                     | 1    | 0.0000   | 0.0000  | 5000   | 0.0000 |
|                     | 5    | 500002   | 5000066 | 500000 | 0.0000 |
| d r                 | 1    | 2200000  | 2200000 | 600500 | 0.0000 |
| r r                 | 1    | 52000    | 60000   | 0.0000 | 0.0000 |
| d                   | 1    | 2600006  | 2600006 | 2000   | 0.0000 |
| r                   | 1    | 6000     | 50000   | 2000   | 0.0050 |
| r                   | 1    | 0.0000   | 0.0000  | 0.0000 | 0.0000 |
| d r                 | 1    | 0.00005  | 0.00005 | 5600   | 0.0000 |
| r r                 | 1    | 200000   | 0.0050  | 6000   | 0.0000 |
| d r                 | 5    | 25500000 | 5000562 | 252006 | 0.0000 |
| r r                 | 1    | 0.000062 | 200002  | 20000  | 0.0000 |
| d                   | 5    | 2200002  | 0.00000 | 20000  | 0.0000 |
| r                   | 1    | 500055   | 0.655   | 0060   | 0.0000 |
| r                   | 5    | 60005    | 60002   | 0050   | 0.0000 |
| M d r               | 1    | 20000    | 0.0050  | 5005   | 0.0000 |

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|                         |            |                  |        |       |        |
|-------------------------|------------|------------------|--------|-------|--------|
| □r□□□□ □□□□□□□□□□□□□□□□ | □□□        | 2□5□□□□          | 5□5□□□ | 2□□□□ | □□□□□□ |
| □□□□d□□□□               | □□□□       | □5□□□□□□         | 2□□2□□ | □     | □□     |
| <b>Total</b>            | <b>665</b> | <b>111816.33</b> | □□     | □□    | □□     |

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**Appendix 8. ANOVA for pulp firmness**

| Source of variation             | d.f. | s.s.      | m.s.      | v.r.     | F pr.  |
|---------------------------------|------|-----------|-----------|----------|--------|
| □□□□□□□□□□□□□□□□□□□□□□□□□□□□    | □□   | □□□□5□□□□ | □□□□5□□□□ | 6□□5□□□□ | □□□□□□ |
| □r□□□□□□□□□□                    | □□   | □□□□□□□□□ | □□6□□□□   | 2□□□□□□□ | □□□□□□ |
| □r□□□□□□                        | □□   | □6□□□□    | □6□□□□    | □□26□    | □□□□□□ |
| □□□□□                           | □□   | □5□□□□    | □5□□□□    | □□5□□    | □□□6□  |
| □□□□□                           | 5□   | □2□□2□□   | □5□26□    | 55□2□□□□ | □□□□□□ |
| □□□□□□□□□□□□□□□□□□□□□□□□□□□□    | □□   | □□6□□     | □□6□□     | 55□□□□   | □□□□□□ |
| □r□□□□□□□□□□□□□□□□              | □□   | □56□□□□   | □□□□□□    | □□□□□□   | □□□□□□ |
| □□□□□□□□□□□□□□□□□□□□□□□□□□□□    | □□   | □□□□□□    | □□□□□□    | □226□    | □□□□□□ |
| □r□□□□□□□□□□□□□□□□              | □□   | □5□5□     | □□□□□□    | □□□□□□   | □□□□□□ |
| □r□□□□□□□□□□                    | □□   | 5□□□□     | 5□□□□     | □6□□     | □□5□□  |
| □□□□□□□□□□□□□□□□□□□□□□□□□□□□    | □□   | □□□□□□    | □□□□□□    | 6□□□□    | □□□□□□ |
| □r□□□□□□□□□□□□□□□□□□□□□□□□□□□□  | □□   | 26.5□□    | 2□□5□     | □□5□     | □□5□□  |
| □□□□□□□□□□□□□□□□□□□□□□□□□□□□    | □□   | □2□□6□    | □55□□□□   | 2□6□□□   | □□□□□□ |
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