EFFECTS OF VACUUM MICROWAVE DRYING
ON THE FLAVOR, TEXTURAL AND COLOR CHARACTERISTICS
OF BANANA CHIPS

By

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Abstract

Bananas were peeled, sliced, and dipped in a solution of 2000 ppm potassium metabisulfite. These slices were next air dried (AD) to remove 60%, 70%, 80% and 90% of the initial moisture respectively and then vacuum microwave dried (VMD) to a final moisture content of about 3% db. The effects of different drying techniques (air drying, air drying / vacuum microwave drying, and freeze drying) on volatile retention in the banana chips were determined using headspace solid-phase microextraction. The effects of these drying techniques on the textural and color characteristics of banana chips were also investigated. Both gas chromatographic and sensory analysis showed that banana chips which underwent more vacuum microwave drying had significantly lower levels of volatile compounds and significantly lower ratings for both the aroma and flavor attributes. 90% AD & 10% VMD chips had significantly higher volatile levels and significantly higher sensory ratings than 100% AD samples. Textural analysis of the banana chips showed that the AD / VMD samples were significantly crisper than the AD and FD samples. Microscopic analysis also showed that vacuum microwave drying exerted a puffing effect on the VMD samples. Color analysis showed that less browning occurred in the VMD and the AD/VMD chips than in the AD samples. The inhibiting effect of five chemicals on banana polyphenoloxidase was studied. 2000 ppm potassium metabisulfite with or without 2% citric acid was the most effective inhibitor. Nevertheless, gas chromatographic analysis showed that bananas dipped in sulfite had significantly lower volatile levels compared to fresh bananas.
<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abstract</td>
<td>ii</td>
</tr>
<tr>
<td>List of Tables</td>
<td>vii</td>
</tr>
<tr>
<td>List of Figures</td>
<td>viii</td>
</tr>
<tr>
<td>Acknowledgements</td>
<td>xiii</td>
</tr>
<tr>
<td>1. Introduction</td>
<td>1</td>
</tr>
<tr>
<td>2. Literature Review</td>
<td>3</td>
</tr>
<tr>
<td>2.1. Bananas</td>
<td>3</td>
</tr>
<tr>
<td>2.1.1. Production of Bananas</td>
<td>4</td>
</tr>
<tr>
<td>2.1.2. Products Processed from Bananas</td>
<td>4</td>
</tr>
<tr>
<td>2.2. Dehydration</td>
<td>5</td>
</tr>
<tr>
<td>2.2.1. Fruit-Based Snack: Dehydrated Fruit</td>
<td>5</td>
</tr>
<tr>
<td>2.2.2. Fruit Dehydration</td>
<td>6</td>
</tr>
<tr>
<td>2.3. Dehydration of Bananas</td>
<td>7</td>
</tr>
<tr>
<td>2.3.1. Pre-Drying Treatments</td>
<td>7</td>
</tr>
<tr>
<td>2.3.1.1. Selection and Sorting for Maturity and Size</td>
<td>7</td>
</tr>
<tr>
<td>2.3.1.2. Sulfuring or Sulfiting</td>
<td>8</td>
</tr>
<tr>
<td>2.3.1.2.1. Commercial Alternatives to Sulfites</td>
<td>10</td>
</tr>
<tr>
<td>2.3.1.2.2. Measurement of Browning and PPO Activity</td>
<td>13</td>
</tr>
<tr>
<td>2.3.2. Drying Methods</td>
<td>14</td>
</tr>
<tr>
<td>2.3.2.1. Deep Fat Frying</td>
<td>14</td>
</tr>
<tr>
<td>2.3.2.2. Sun Drying</td>
<td>14</td>
</tr>
<tr>
<td>2.3.2.3. Solar Drying</td>
<td>15</td>
</tr>
<tr>
<td>2.3.2.4. Air Drying</td>
<td>15</td>
</tr>
<tr>
<td>2.3.2.5. Freeze Drying</td>
<td>16</td>
</tr>
<tr>
<td>2.3.2.6. Osmotic Dehydration</td>
<td>17</td>
</tr>
<tr>
<td>2.3.2.7. Explosion Puffing</td>
<td>18</td>
</tr>
<tr>
<td>2.3.2.8. Vacuum Microwave Drying</td>
<td>19</td>
</tr>
<tr>
<td>2.3.2.8.1. Mechanism of Microwave Heating</td>
<td>19</td>
</tr>
<tr>
<td>2.3.2.8.2. Advantages of Combined Vacuum / Microwave Drying</td>
<td>21</td>
</tr>
<tr>
<td>2.3.2.8.3. When to Apply Vacuum Microwave Drying?</td>
<td>22</td>
</tr>
<tr>
<td>2.3.2.8.4. Flavor Retention during Microwave Heating</td>
<td>23</td>
</tr>
<tr>
<td>2.4. Quality Attributes of Banana Chips</td>
<td>25</td>
</tr>
<tr>
<td>2.4.1. Aroma and Taste of Banana Chips</td>
<td>25</td>
</tr>
<tr>
<td>2.4.1.1. Volatile Constituents of Bananas</td>
<td>26</td>
</tr>
<tr>
<td>2.4.1.2. Determination of Volatile Constituents by GC – MS</td>
<td>26</td>
</tr>
</tbody>
</table>
2.4.1.2.1. Extraction and Concentration of Aroma Compounds
2.4.1.2.1.1. Solvent Extraction
2.4.1.2.1.2. Distillation at Atmospheric and Reduced Pressure
2.4.1.2.1.3. Static or Dynamic Headspace Analysis
2.4.1.2.1.4. Solid-Phase Microextraction
2.4.1.2.1.4.1. How SPME Works
2.4.1.2.1.4.2. Sampling with SPME
2.4.1.2.2. Gas Chromatography (GC)
2.4.1.2.3. Gas Chromatography – Mass Spectrometry (GC – MS)
2.4.1.3. Determination of Aroma and Flavor Attributes by Sensory Evaluation

2.4.2. Texture of Banana Chips
2.4.2.1. Determination of Texture by Acoustical Measurements
2.4.2.2. Determination of Texture by Instrumental Measurements
2.4.2.3. Determination of Structure by Microscopic Techniques

2.4.3. Color and Appearance of Banana Chips
2.4.3.1. Determination of Color by Instrumental Colorimetric Techniques

3. Materials and Methods
3.1. Inhibition of Banana Polyphenoloxidase (PPO)
3.1.1. Raw Materials
3.1.2. PPO Inhibition
3.1.3. PPO Activity

3.2. Effects of Drying Methods and Sulfite on Headspace Volatiles of Banana
3.2.1. Raw Materials
3.2.1.1. Determination of Banana Maturity by Skin Color
3.2.1.2. Determination of Banana Maturity by Starch Content

3.2.2. Sample Preparation
3.2.2.1. Preparation of Vacuum Microwave Dried (VMD) Banana Chips
3.2.2.2. Preparation of 100% VMD Banana Chips
3.2.2.3. Preparation of 100% Air Dried (AD) Banana Chips
3.2.2.4. Preparation of 100% Freeze Dried (FD) Banana Chips

3.2.3. Determination of Water Activity ($a_w$)
3.2.4. Determination of Moisture Content

3.2.5. Flavor Analysis of Banana Chips
3.2.5.1. Selection of Solid-Phase Microextraction (SPME) Fibers
3.2.5.1.1. Preparation of Standard Mixture
3.2.5.1.2. SPME Sampling
3.2.5.1.3. Gas Chromatography
3.2.5.2. Optimization of SPME Parameters 49
  3.2.5.2.1. SPME Sampling 49
  3.2.5.2.2. Optimization Procedures 49
  3.2.5.2.3. Gas Chromatography 50
3.2.5.3. Effect of Drying Methods on Headspace Volatiles of Banana 50
  3.2.5.3.1. SPME Sampling 50
  3.2.5.3.2. Gas Chromatography 50
  3.2.5.3.3. Gas Chromatography – Mass Spectrometry (GC – MS) 50
3.2.5.4. Effect of Sulfite on Headspace Volatiles of Banana 51
  3.2.5.4.1. Sample Preparation 51
  3.2.5.4.2. SPME Sampling 52
  3.2.5.4.3. Gas Chromatography 52
3.2.6. Sensory Analysis of Banana Chips 52
  3.2.6.1. Selection and Training of Sensory Panelists 56
  3.2.6.2. Experimental Design for the Sensory Panel 57
3.2.7. Textural Analysis of Banana Chips 58
  3.2.7.1. Instrumental Measurements 58
3.2.8. Scanning Electron Microscopy (SEM) 58
3.2.9. Color Analysis of Banana Chips 59
3.3. Statistical Analysis 59
  3.3.1. Z-Score Transformation of Data for Sensory Analysis 60
4. Results and Discussion 61
4.1. Inhibition of Banana Polyphenoloxidase (PPO) 61
  4.1.1. PPO Inhibition Using Citric Acid and Sodium Acid Pyrophosphate 61
  4.1.2. PPO Inhibition Using Ascorbic Acid, Citric Acid and 4-Hexylresorcinol 63
    4.1.2.1. Mixture of Ascorbic Acid and Citric Acid 63
    4.1.2.2. Mixtures of Ascorbic Acid, Citric Acid and 4-Hexylresorcinol 66
  4.1.3. PPO Inhibition Using Citric Acid and Potassium Metabisulfite 67
4.2. Flavor Analysis of Banana Chips 69
  4.2.1. Maturity Stage of Bananas 69
  4.2.2. Dynamic Headspace Sampling 69
  4.2.3. Solid Phase Microextraction (SPME) 70
    4.2.3.1. Selection of SPME Fiber 70
    4.2.3.2. Optimization of SPME Parameters 74
  4.2.4. Effects of Drying Methods on Headspace Volatiles of Bananas 75
  4.2.5. Effects of Potassium Metabisulfite on the Headspace Volatiles of Bananas 104
4.3. Sensory Analysis of Banana Chips 110
4.4. Textural Analysis of Banana Chips
   4.4.1. Instrumental Analysis
   4.4.2. Microscopic Analysis

4.5. Color Analysis of Banana Chips

5. Conclusions

6. References
List of Tables

Table 1. Random Centroid Optimization (RCO) of Sampling Temperature & Time, and Results using the Peak Area of Isoamylacetate & 5 Main Peaks...............................76

Table 2. Effect of Drying Methods on the Relative Concentration of Volatile Compounds of Banana Chips..........................................................87

Table 3. Percent Retention of Volatile Components of Banana Chips Prepared from Different Drying Treatments and Their Molecular Weights, Solubility in Water, and Relative Volatilities at Infinite Dilution in Water........................................90

Table 4. Total Heat Units for Each Drying Treatment.........................................102

Table 5. Effect of Potassium Metabisulfite Dip on the Relative Concentration of Fresh Banana Volatiles...............................................................106

Table 6. Peak Areas of Isobutylacetate, Butyl acetate, and Isoamylacetate obtained using the SPME Fiber With and Without Prior Exposed to a 5ppm Potassium Metabisulfite Solution.................................................................108

Table 7. Peak Areas of Isobutylacetate, Butyl acetate, and Isoamylacetate With and Without the 5ppm Potassium Metabisulfite Solution obtained using the SPME Fiber...109

Table 8. Analysis of Variance of Raw Sensory Score of Aroma, Flavor & Off-Flavor of Banana Chips Prepared with Different Drying Methods........................................111

Table 9. Analysis of Variance of Sensory Z Scores of Aroma, Flavor & Off-Flavor of Banana Chips Prepared with Different Drying Methods...........................................119

Table 10. Pearson Correlation Coefficients and Associated Probabilities between Sensory Attributes of Aroma, Flavor & Off-Flavor and Some Volatile Compounds Identified in Freeze-Dried Banana Chips.................................................................120

Table 11. Mean L, a, and b Hunterlab values of Banana Chips Prepared with Different Drying Treatments.................................................................135
List of Figures

Figure 1A. Sensory score sheet used in the study on the effect of drying methods on the aroma intensity of the banana chip samples .................................................................54

Figure 1B. Sensory score sheet used in the study on the effect of drying methods on the flavor and off-flavor intensity of the banana chip samples ........................................55

Figure 2. Effect of Citric Acid and Sodium Acid Pyrophosphate on PPO Activity in Banana
Experiments were done in triplicate. All measurements were performed in triplicate on three samples and recorded as mean + / - standard error mean. % PPO Inhibition was calculated as (PPO activity of control - PPO activity of treated banana slices) / (PPO activity of control) x 100 .................................................................62

Figure 3. Effect of Ascorbic Acid, Citric Acid and 4-Hexylresorcinol on PPO Activity in Banana
Experiments were done in triplicate. All measurements were performed in triplicate on three samples and recorded as mean + / - standard error mean. % PPO Inhibition was calculated as (PPO activity of control - PPO activity of treated banana slices) / (PPO activity of control) x 100 .................................................................64

Figure 4. Effect of Citric Acid and Potassium Metabisulfite on PPO Activity in Banana
Experiments were done in triplicate. All measurements were performed in triplicate on three samples and recorded as mean + / - standard error mean. % PPO Inhibition was calculated as (PPO activity of control - PPO activity of treated banana slices) / (PPO activity of control) x 100. Significant differences between treatments were determined by Tukey's multiple comparison test, and any two value not followed by the same letter are significantly different at p < 0.05 .................................................................68

Figure 5. Gas Chromatogram of Isobutylacetate, 2-Methylbutylacetate and Isoamylacetate adsorbed using 75µm Carboxen / PDMS Fiber
SPME headspace samplings were performed in triplicate at 40°C for 30 minutes ..........72

Figure 6. Effects of Three Types of SPME Fiber on the Adsorption of Isobutylacetate, 2-Methylbutylacetate and Isoamylacetate
SPME headspace samplings were performed in triplicate at 40°C for 30 minutes. All measurements were recorded as mean + / - standard error mean. Significant differences between treatments were determined by Tukey's multiple comparison test, and any two value not followed by the same letter are significantly different at p < 0.05 .................73

Figure 7. Mapping Result of Sampling Temperature and Time using Peak Area of Isoamylacetate by the RCO Program
Figure 7A shows the mapping result of sampling temperature, and figure 7B shows the mapping results of sampling time. All experiments were performed in duplicate ........77
Figure 8. Mapping Result of Sampling Temperature and Time using Peak Area of the 5 Main Peaks by the RCO Program
Figure 8A shows the mapping result of sampling temperature, and figure 8B shows the mapping results of sampling time. All experiments were performed in duplicate.

Figure 9. Gas Chromatogram of 60% Air-Dried & 40% Vacuum-Microwave Dried (60AD/40VMD) Banana Chips
Numbers correspond to compounds identified by GC/MS in Table 2. Caproic acid ethyl ester was used as an internal standard (IS).

Figure 10. Gas Chromatogram of 70% Air-Dried & 30% Vacuum-Microwave Dried (70AD/30VMD) Banana Chips
Numbers correspond to compounds identified by GC/MS in Table 2. Caproic acid ethyl ester was used as an internal standard (IS).

Figure 11. Gas Chromatogram of 80% Air-Dried & 20% Vacuum-Microwave Dried (80AD/20VMD) Banana Chips
Numbers correspond to compounds identified by GC/MS in Table 2. Caproic acid ethyl ester was used as an internal standard (IS).

Figure 12. Gas Chromatogram of 90% Air-Dried & 10% Vacuum-Microwave Dried (90AD/10VMD) Banana Chips
Numbers correspond to compounds identified by GC/MS in Table 2. Caproic acid ethyl ester was used as an internal standard (IS).

Figure 13. Gas Chromatogram of 100% Air-Dried (100AD) Banana Chips
Numbers correspond to compounds identified by GC/MS in Table 2. Caproic acid ethyl ester was used as an internal standard (IS).

Figure 14. Gas Chromatogram of 100% Vacuum-Microwave Dried (100VMD) Banana Chips
Numbers correspond to compounds identified by GC/MS in Table 2. Caproic acid ethyl ester was used as an internal standard (IS).

Figure 15. Gas Chromatogram of 100% Freeze-Dried (100FD) Banana Chips
Numbers correspond to compounds identified by GC/MS in Table 2. Caproic acid ethyl ester was used as an internal standard (IS).

Figure 16. Gas Chromatogram of Fresh Banana
Numbers correspond to compounds identified by GC/MS in Table 2. Caproic acid ethyl ester was used as an internal standard (IS).

Figure 17. Effect of Drying Methods on the Relative Concentration of Total Volatile Compounds of Banana Chips
All headspace SPME samplings were performed at 50°C for 30 minutes in triplicate for each of 3 banana chip samples, and all measurements were analyzed using one way
ANOVA. The results were recorded as mean + / - standard error mean. Significant differences between treatments were determined by Tukey’s multiple comparison test, and any two value not followed by the same letter are significant different at p \leq 0.05. The relative concentration of fresh banana was included here only for comparison.

**Figure 18. Effect of Drying Methods on the Retention of Total Acetates and Esters**
All headspace SPME samplings were performed at 50°C for 30 minutes in triplicate for each of 3 banana chip samples, and all measurements were analyzed using one way ANOVA. The results were recorded as mean + / - standard error mean. Significant differences between treatments were determined by Tukey’s multiple comparison test, and any two value not followed by the same letter are significant different at p \leq 0.05. The relative concentration of fresh banana was included here only for comparison.

**Figure 19. Effect of Drying Methods on the Retention of Isobutylacetate, Butyl acetate and Isoamylacetate**
All headspace SPME samplings were performed at 50°C for 30 minutes in triplicate for each of 3 banana chip samples, and all measurements were analyzed using one way ANOVA. The results were recorded as mean + / - standard error mean. Significant differences between treatments were determined by Tukey’s multiple comparison test, and any two value not followed by the same letter are significant different at p \leq 0.05. The relative concentration of fresh banana was included here only for comparison.

**Figure 20. Time - Temperature Curve of 100% Vacuum Microwave Dried Banana Chips**
10 measurements of temperature were performed each time. All measurements were recorded as mean + / - standard error mean.

**Figure 21. Time - Temperature Curve of 100% Air-Dried Banana Chips**
10 measurements of temperature were performed each time. All measurements were recorded as mean + / - standard error mean.

**Figure 22. Drying Curve of 100% Air-Dried Banana Chips**

**Figure 23. Gas Chromatogram of Sulfited Banana Slices**
Numbers correspond to compounds identified by GC/MS in Table 4. Caproic acid ethyl ester was used as an internal standard (IS).

**Figure 24. Mean, Raw Aroma Intensity Sensory Score of Banana Chips Prepared with Different Drying Methods**
18 measurements were made for each drying treatment, and all measurements were analyzed using general linear model of ANOVA. The results were recorded as mean + / - standard error mean. Significant differences between treatments were determined by Tukey’s multiple comparison test, and any two value not followed by the same letter are significantly different at p \leq 0.05.
Figure 25. Mean, Raw Flavor Intensity Sensory Score of Banana Chips Prepared with Different Drying Methods
18 measurements were made for each drying treatment, and all measurements were analyzed using general linear model of ANOVA. The results were recorded as mean +/- standard error mean. Significant differences between treatments were determined by Tukey's multiple comparison test, and any two value not followed by the same letter are significantly different at p ≤ 0.05. 113

Figure 26. Mean, Raw Off-Flavor Sensory Score of Banana Chips Prepared with Different Drying Methods
18 measurements were made for each drying treatment, and all measurements were analyzed using general linear model of ANOVA. The results were recorded as mean +/- standard error mean. Significant differences between treatments were determined by Tukey's multiple comparison test, and any two value not followed by the same letter are significantly different at p ≤ 0.05. 114

Figure 27. Mean Aroma Z Score of Banana Chips Prepared with Different Drying Methods
18 measurements were made for each drying treatment, and all measurements were analyzed using general linear model of ANOVA. The results were recorded as mean +/- standard error mean. Significant differences between treatments were determined by Tukey's multiple comparison test, and any two value not followed by the same letter are significantly different at p ≤ 0.05. 116

Figure 28. Mean Flavor Z Score of Banana Chips Prepared with Different Drying Methods
18 measurements were made for each drying treatment, and all measurements were analyzed using general linear model of ANOVA. The results were recorded as mean +/- standard error mean. Significant differences between treatments were determined by Tukey's multiple comparison test, and any two value not followed by the same letter are significantly different at p ≤ 0.05. 117

Figure 29. Mean Off-Flavor Z Score of Banana Chips Prepared with Different Drying Methods
18 measurements were made for each drying treatment, and all measurements were analyzed using general linear model of ANOVA. The results were recorded as mean +/- standard error mean. Significant differences between treatments were determined by Tukey's multiple comparison test, and any two value not followed by the same letter are significantly different at p ≤ 0.05. 118

Figure 30. Force vs Deformation of 90% AD & 10% VMD Banana Chips and the Settings of the Texture Analyzer. 123
Figure 31. Mean Slope (g/mm) of Banana Chips Prepared with Different Drying Treatments
The slope of the peak was obtained from the force vs deformation curve of the banana chips prepared with different drying treatments. Experiments were performed in triplicate, and 15 measurements were obtained from each replicate with a total of 45 measurements were made for each drying treatment. All measurements were analyzed using ANOVA. The results were recorded as mean + / - standard error mean. Significant differences between treatments were determined by Tukey’s multiple comparison test, and any two value not followed by the same letter are significantly different at p ≤ 0.05.

Figure 32. Mean Distance (mm) of Banana Chips Prepared with Different Drying Treatments
The distance of the peak was obtained from the force vs deformation curve of the banana chips prepared with different drying treatments. Experiments were performed in triplicate, and 15 measurements were obtained from each replicate with a total of 45 measurements were made for each drying treatment. All measurements were analyzed using ANOVA. The results were recorded as mean + / - standard error mean. Significant differences between treatments were determined by Tukey’s multiple comparison test, and any two value not followed by the same letter are significantly different at p ≤ 0.05.

Figure 33. Mean Peak Force (g) of Banana Chips Prepared with Different Drying Treatments
The peak force of the peak was obtained from the force vs deformation curve of the banana chips prepared with different drying treatments. Experiments were performed in triplicate, and 15 measurements were obtained from each replicate with a total of 45 measurements were made for each drying treatment. All measurements were analyzed using ANOVA. The results were recorded as mean + / - standard error mean. Significant differences between treatments were determined by Tukey’s multiple comparison test, and any two value not followed by the same letter are significantly different at p ≤ 0.05.

Figure 34. Scanning Electron Micrograph of 100%AD Banana Chips with 200x magnification

Figure 35. Scanning Electron Micrograph of 60%AD & 40%VMD Banana Chips with 200x magnification

Figure 36. Scanning Electron Micrograph of 90%AD & 10%VMD Banana Chips with 200x magnification

Figure 37. Scanning Electron Micrograph of 100%FD Banana Chips with 200x magnification
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1. Introduction

Bananas are nutritious with a pleasant flavor and are widely consumed throughout the world (Robinson, 1996a). In the fresh fruit market, bananas are often rejected because of several factors, such as shape, color and dark spots. Also, during the peak production seasons, large quantities of bananas are produced but cannot find immediate use (Stover and Simmonds, 1987a). Therefore, in order to minimize these huge losses, bananas can be preserved using dehydration processes.

Drying is applied to increase product stability and to decrease transport and storage costs by means of volume and weight reduction. In conventional drying procedures, such as deep-fat frying and hot-air drying techniques, a major disadvantage is the thermal degradation of important flavor and nutritional substances (Raghavan et al., 1994; Luning et al., 1995a). Although freeze-drying usually results in good retention of flavor compounds (King, 1970, Gerschenson et al., 1979), this technique is costly and time-consuming (Okos et al., 1992).

Vacuum microwave drying (VMD) may optimally retain volatile compounds sensitive to losses through thermal and oxidative degradation. The microwaves supply energy for rapid heat transfer; the vacuum removes most of the oxygen in the system, lowers the boiling point of water in the material, and hastens the vaporization of moisture from the material (Anon, 1988). VMD has been successfully used for the dehydration of many products such as grapes (Petrucci and Clary, 1989), cranberries (Yongsawatdigul and Gunasekaran, 1996a), potatoes (Durance and Liu, 1996), krill (Durance, 1997), and carrots (Lin et al., 1998); the resulting dried products possessed excellent quality in terms of taste, aroma, texture, color and appearance. Previous research has been done on VMD
of banana slices, and the results showed that the quality of banana slices was excellent with respect to taste, aroma, color and appearance (Drouzas and Schubert, 1996). At this point, factors that influence the retention of volatile compounds during VMD have not been determined. Hence, the volatile retention in vacuum microwave dehydrated banana chips was examined.

Banana is very susceptible to discoloration and flavor deterioration during drying. It contains the enzyme polyphenoloxidase (PPO) and undergoes enzymatic browning as a result of cellular disruption and access of oxygen. In this study, the inhibiting effects of five chemicals on the PPO of banana were studied to determine the most efficient PPO inactivation method. Also, air-drying was used in combination with VMD to produce a crisp and puffed texture in the banana chips. Therefore, the effects of various amounts of air-drying prior to VMD on the retention of volatile components in banana chips were determined. Additionally, the effects of these combinations of air-drying and VMD on the textural and color characteristics of banana chips were investigated.
2. Literature Review

2.1. Bananas

Bananas are tropical fruits belonging to the genus *Musa* and the family *Musaceae* (Palmer, 1971). Bananas are a popular and nutritious fruit, with a pleasant flavor. They are a high-energy fruit rich in carbohydrates and also a good source of potassium, iron, phosphorus, vitamin C and B₆ (Robinson, 1996b). Generally, bananas are eaten raw as a dessert fruit; they are sweet, good-flavored and easily digested in the ripe state.

During ripening, starch constitutes 20 - 25% in the unripe fruit, but is hydrolyzed to 1 - 2% in the ripe fruit. At the same time, sugars, normally 1 - 2% in the unripe pulp, increase to 15 - 20% in the ripe pulp. Sucrose, glucose and fructose are the major sugars in banana, and these sugars increase during ripening, with a nearly constant proportion of 66% sucrose, 20% glucose, and 14% fructose. Also, peel color is closely correlated with the starch-sugar ratio. The green banana peel contains about 50 - 100 µg/g fresh weight of chlorophyll, 5 - 7 µg/g fresh weight of xanthophyll, and 1.5 - 3.5 µg/g fresh weight of carotene. During ripening, the green peel color due to chlorophyll is completely lost, and the yellow peel color due to xanthophyll and carotene remains approximately constant. The interconversion of pectic substances is presumed to be associated with the softening of banana pulp. During fruit ripening, insoluble protopectin decreases from 0.5 to 0.3%, and soluble pectin increases. The characteristic banana aroma develops during ripening and is due to certain esters and alcohols. The main organic acids in banana are malic acid, oxalic acid, and citric acid. During ripening, malic acid increases, whereas oxalic acid is metabolized and decreases (Palmer, 1971; Stover and Simmonds, 1987b; Kotecha and Desai, 1995).
2.1.1. Production of Bananas

Bananas are widely consumed throughout the world and represent 40% by weight of fruit in the world trade. In 1992, the total world production of bananas was 49.6 million tonnes. Asia produced about 40% of the total, South America 30%, Central America 20% and Africa 10%. Most bananas were consumed locally, and only 21.7% were exported, of which 80% came from the Americas and the rest from Africa and Asia. The largest importer of bananas was the USA, and other main importers were the European Union countries, Japan and Canada (Robinson, 1996a).

About one-half of bananas produced are eaten as a raw, fresh fruit; one-half are eaten in the cooked state and termed “plantains”. On average, each person consumes 1 – 2 fresh bananas per week in most countries, and almost all export bananas are eaten as a dessert fruit. Cooked bananas are usually used as a staple foodstuff and consumed locally in most developing countries in which they are produced (Palmer, 1971).

2.1.2. Products Processed from Bananas

In the fresh fruit market, bananas may be rejected because of several factors, such as shape, color and dark spots. Also, during the peak production seasons, large quantities of bananas are produced and cannot be used immediately, and thus are spoiled and wasted by perishing. In order to minimize these huge economic losses, bananas can be preserved and processed by canning, extraction, freezing, drying and frying (Robinson, 1996b; Stover and Simmonds, 1987a).

There are many different products produced from bananas. However, compared with the volume of fresh bananas exports, processed banana products represent a minor
proportion of around 0.003% (Robinson, 1996b). Banana puree is the most important processed product. It consists of canned ripe pulp with no sugar or preservative added and can be used in baking, beverages, dairy products and baby foods. The next most important canned product is sliced ripe bananas in acidified syrup, which are mainly used in bakery products, desserts, fruit salads and toppings (Robinson, 1996b; Stover and Simmonds, 1987a).

Banana essence, extracted from fresh bananas, is a clear liquid with excellent concentrated aroma and is used in drinks and desserts. Frozen bananas are important in the ice cream and bakery trade. Alcoholic beverages are made by brewing ripe bananas into beers with low alcohol content. An important dried banana product is made from drying entire ripe banana slices; flour and powder ground from dried whole green and ripe fruit respectively are other banana products. The most common form of processed products is the banana chip, made from frying thin banana slices in vegetable oil (Robinson, 1996b; Stover and Simmonds, 1987a).

2.2. Dehydration

2.2.1. Fruit-Based Snack: Dehydrated Fruit

Changing lifestyles of modern consumers, especially in the developed world, have lead to a demand for high quality, convenient and healthy foods, with an emphasis on foods that are natural, low in fat, and high in fiber. In the USA, there has been a dramatic increase in new products that claim to be healthy and light. In 1988, 475 reduced / low-calorie / light products were developed; by 1991, 1214 product categories, representing an increase of 155%, were found in supermarkets (Buisson, 1995).
Dehydrated fruits are healthy snacks and a good source of important nutrients, such as carbohydrates, minerals, vitamins and dietary fiber. The process of dehydration hardly affects the main calorie providing constituents and the mineral contents of fruits (Somogyi and Luk, 1986).

2.2.2. Fruit Dehydration

Dehydration is the oldest method of food preservation and involves removal of water from the food material to such an extent that growth of microorganisms is prevented, and many moisture mediated deteriorative reactions are minimized (Jayaraman and Das Gupta, 1992).

Dehydration is an important process in the food industry and is particularly important for the preservation of fruits, which contain a large ratio of water. The main purpose of fruit dehydration is to convert perishable fruits into stable products, thereby reducing post-harvest losses and making them available during times of shortage. Dehydrated fruits, especially with moisture contents below 5%, have an almost unlimited shelf life, because chemical, enzymatic, bacterial, fungi and mold activities are inhibited. Fruit dehydration also brings about substantial reduction in weight and volume and requires no refrigeration during storage and transport, thus lowering packing, storage and transportation costs. Dehydration can develop fruit products into new or more usable sizes, shapes and forms, and therefore make them more convenient to prepare as industrial and foodservice ingredients. This process can provide consistent fruit products; consequently, seasonal variations in quality can be minimized (Somogyi and Luh, 1986).
2.3. Dehydration of Bananas

2.3.1. Pre-Drying Treatments

The general procedures for the preparation of bananas prior to drying are: selection and sorting for maturity and size; peeling by hand; cutting into slices; and sulfuring.

2.3.1.1. Selection and Sorting for Maturity and Size

Fully ripe and mature bananas are most suitable for the production of the best quality dehydrated products (McBean et al., 1971). Banana is a climacteric fruit; when fully mature, the fruit's green colored peel, caused by chlorophyll, is completely lost; and the characteristic yellow color, caused by xanthophyll and carotene, reaches its maximum intensity. Starch in the pulp has been converted to soluble sugars with the formation of sucrose, glucose and fructose. Also, flavor compounds are at their best and near their peak concentration (Kotecha and Desai, 1995; McBean et al., 1971).

The most common indexes used commercially to assess the optimum maturity stages of bananas are the shape of fruit fingers, the ratio of fruit length to diameter and the ratio of pulp to peel weight (Von Loesecke, 1949). For experimental purposes, the ripening stages of bananas can be evaluated by measuring the peel color against a set of standard color plates (United Fruit Sales Corp., 1964), by determining the ratio of starch to sugar content using the starch-iodine staining technique (Blankenship et al., 1993), and the amount of soluble solids using a refractometer (McBean et al., 1971).
2.3.1.2. Sulfuring or Sulfiting

Banana is very susceptible to discoloration during processing; it contains the enzyme polyphenoloxidase (PPO) and undergoes rapid browning as a result of cellular disruption and access of oxygen during the peeling and slicing operations (Cano et al., 1997). PPO is widely distributed in nature; it can be found in plants and microorganisms, especially in fungi and some animal organs. The role of PPO in nature is manifold; it was found to be participated in the respiratory chain of higher plants as one of the terminal oxidases and more importantly in the resistance of plants to microbial or viral infections, and probably, to adverse climate (Vamos-Vigyazo, 1981).

Enzymatic browning is the result of the PPO-catalyzed oxidation of monophenols and diphenols (colorless) to o-quinones (red or reddish brown), which then polymerize spontaneously to form high molecular weight compounds, melanins (brown), or react with amino acids and proteins to enhance the formation of brown pigments. In uncut or undamaged fruits, the PPO is separated from the phenolic substrates, and browning does not occur. However, when fruits have been subjected to surface or tissue damage, such as during the peeling, cutting or slicing typical of food processing, browning occurs rapidly. Browning is a major problem in the food industry; it causes deleterious changes to the appearance of food products and is often accompanied by undesirable changes in flavor, texture, and loss of nutrients via the oxidation of ascorbic acid and essential amino acids, e.g. lysine. This discoloration decreases the commercial value and consumer acceptance of the food products, and therefore is usually highly undesirable from the point of view of food processors (McEvily et al., 1992; Sapers, 1993).
Anti-browning agents are commonly used for the prevention of browning in the food industry; their uses are constrained by issues such as toxicity, costs, effects on taste, flavor, texture and color (Iyengar and McEvily, 1992). Sulfites are highly effective in controlling browning and are widely used as browning inhibitors in the food industry. Sulfiting agents include sulfur dioxide, sodium sulfite, sodium and potassium bisulfites and metabisulfites (Sapers, 1993). In addition to controlling the enzymatic browning reaction, these agents can act as antimicrobial agents, bleaching agents, antioxidants and reducing agents (Sayavedra and Montgomery, 1986). However, these agents cannot completely stop the enzymatic browning reaction; still, they can retard the reaction sufficiently to allow the dehydrated products to remain acceptable for about a year at 21°C (McBean et al., 1971).

Sulfiting can be carried out either by gas treatment with sulfur dioxide prepared by burning elemental sulfur, or by dipping in a solution of sodium sulfite, sodium bisulfite or potassium metabisulfite (Saravacos, 1993). Dipping banana after peeling and slicing in a 1 – 2% solution of sodium metabisulfite inhibited the surface enzymes and prevented the surface blackening, thereby improving the color of the dehydrated products (Mowlah et al., 1982a). The Food and Drug Administration (FDA) has proposed that the maximum level of residual sulfite concentration in dehydrated fruits should be 2,000 ppm (FDA, 1988).

Sulfiting agents are generally regarded as safe (GRAS) by the FDA. However, the safety of using these agents has been questioned within the last ten years. Sulfites are known to cause adverse allergic-type reactions in certain sensitive individuals, especially asthmatics. More than 20 cases of death have been reported due to consumption of foods
containing sulfites among this highly sensitive group (Taylor, 1993). Also, sulfites can induce off-flavor, destroy some of the important nutrients, such as vitamin B1, of the treated products, and can cause corrosion of equipment (Saravacos, 1993).

Due to these negative effects, the FDA has established new regulations regarding the use of sulfiting agents. The FDA has banned using sulfites in fresh fruits and vegetables; the FDA has further ruled that all processed foods containing 10 ppm or more of sulfites are required to disclose their presence on the label and the package. In addition, sulfiting agents are not GRAS in meats which are recognized as a major source of vitamin B1 (Sapers, 1993). Furthermore, some importing countries, such as Japan and Germany, have special regulations regarding sulfite levels in specific dehydrated fruits; moreover, there is an increasing demand for sulfite-free dehydrated fruits by consumers in the USA (Somogyi and Luh, 1986). Therefore, alternative anti-browning agents should be found to replace sulfites in order to control the enzymatic browning of fruits.

2.3.1.2.1. Commercial Alternatives to Sulfites

Enzymatic browning can be inhibited by the use of heat treatments, such as steam and water blanching. However, these heat treatments can cause tissue softening and can adversely affect the flavor and texture of the products (Cano et al., 1997). Instead of blanching, chemical additives, such as ascorbic acid-based compounds, sulphydryl compounds, phosphate-based compounds, acidulants, 4-substituted resorcinols and other minor browning inhibitors, can be used as anti-browning agents in controlling enzymatic browning of fruits (McEvily et al., 1992).
Ascorbic acid and its isomer erythorbic acid are frequently used as anti-browning agents in controlling enzymatic browning in fresh-cut and frozen fruits, such as apples and peaches (Sapers, 1993). These compounds act as a reducing agent in the prevention of enzymatic browning by chemically reducing the o-quinones back to the di-phenols (McEvily et al., 1992). Ascorbic acid was found to be the most effective browning inhibitor in bananas (Galeazzi and Sgarbieri, 1981); a mixture of ascorbic and citric acids was found to be 90 - 100% effective in inhibiting browning in apple cubes (Pizzocaro et al., 1993). Ascorbic acid-2-phosphate and ascorbic acid-2-triphosphate were reported to be stable alternatives to ascorbic acid for inhibiting the browning of the cut surfaces of raw apples, potatoes, and in fruit juices (Sapers and Douglas, 1987; Sapers et al., 1989; Liao and Seib, 1990). Sulfhydryl compounds, such as reduced glutathione, are more effective than ascorbic acid; these compounds prevent the formation of brown pigments by reacting with the o-quinone intermediates to form stable, colorless adducts. However, these sulfhydryl compounds are too expensive to be commercially practical. Alternatives include sulfur-containing amino acids, such as L-cysteine, L-cystine, and D, L-methionine. Unfortunately, the concentrations of cysteine and other thiols necessary to achieve acceptable levels of browning inhibition may have negative effects on taste (Sapers, 1993). Kahn (1985) found that 0.32mM L-cysteine was effective in controlling banana and avocado browning. Zawistowski et al. (1987) reported that 10mM L-cysteine was more effective than sodium bisulfite at the same concentration in inhibiting browning in Jerusalem artichoke extracts. Phosphate-based compounds, such as sodium acid pyrophosphate, polyphosphate and metaphosphate, are used as anti-browning agents for freshly peeled fruits and vegetables. Citric acid is the most widely used acid in the food
industry in controlling enzymatic browning. Phosphate-based compounds and citric acid both inhibit the enzyme PPO by chelating the copper prosthetic group at the enzyme active site. Citric acid also inhibits the enzyme PPO by lowering the pH below 3 where the enzyme is inactive. Both phosphate-based compounds and citric acid are usually used at levels of 0.5 - 2% or in combination with other anti-browning agents. Other acidulants include organic acids, such as malic, tartaric, and malonic acids, and inorganic acids, such as phosphoric and hydrochloric acids. These acidulants are inferior to citric acid with respect to their limited availability, and negative impact on taste and price (Iyengar and McEvily, 1992). In addition, cinnamic acid and benzoic acid were found to be effective in inhibiting browning of the cut surfaces of raw apples and in apple juices, notably in combination with ascorbic acid (Sapers et al., 1989). 4-substituted resorcinols were found to be browning inhibitors isolated from fig extracts. Of the 4-substituted resorcinols, 4-hexylresorcinol has the greatest potential to inhibit enzymatic browning in the food industry. This compound is nontoxic and is GRAS for use in the prevention of shrimp melanosis (McEvily et al., 1991). Also, laboratory studies showed that 4-hexylresorcinol inhibited the enzyme PPO, and therefore inhibited the browning of fresh and air-dried apple slices (Monsalve-Gonzalez et al., 1993; Luo and Barbosa-Canovas, 1995). Other browning inhibitors include inorganic halides and honey. Inorganic halides were reported to be PPO inhibitors in the prevention of enzymatic browning (Lerner, 1952). The order of decreasing inhibitory power of the halides was found to be exactly the order of decreasing ionic radii of the compounds. It may be that the halides inhibit the enzyme PPO by either sterically hindering the enzyme or binding to the copper prosthetic group at the enzyme active site, thereby rendering the enzyme incapable of catalyzing the
enzymatic browning reaction. Inorganic halides, include sodium chloride, which is a component of some commercial browning inhibitors, and zinc chloride, which is a highly effective browning inhibitor, especially in combination with calcium chloride, ascorbic acid and citric acid (Sapers, 1993; Bolin and Huxsoll, 1989). Honey was found to be effective in inhibiting enzymatic browning in apple slice, grape juice, and model systems; this effect was probably due to the presence of a small peptide with a molecular weight of about 600 dalton (Oszmianski and Lee, 1990).

2.3.1.2.2. Measurement of Browning and PPO Activity

In order to evaluate the effectiveness of these anti-browning agents in controlling enzymatic browning of bananas, tristimulus reflectance colorimetry and absorption spectrophotometry can be used to measure the extent of browning of the treated fruits (Sapers et al., 1989).

Tristimulus reflectance colorimetry, involving the measurements of Hunter L and a values, has been used to determine the extent of enzymatic browning in apple slices (Ponting, 1972). Although this reflectance method is rapid and nondestructive, it is limited in terms of its accuracy and precision (Sapers, 1985). On the other hand, absorption spectrophotometry has been successfully used in several studies to determine the rate of enzymatic browning by measuring the PPO activity of the macerated fruits at an absorbance of 420nm (Pizzocaro et al., 1993; Almeida and Nogueira 1995).
2.3.2. Drying Methods

Bananas can be dried by different methods; the quality of dehydrated banana slices depends primarily on the method of drying used, the temperature and duration of the drying process.

2.3.2.1. Deep Fat Frying

Deep fat frying is a conventional drying technique for banana chip production, in which the banana slices are dried by means of frying in a vegetable oil at a temperature of around 110 – 160°C (Kotecha and Desai, 1995). Deep-frying is a fast drying technique because of the high conductivity of oil and the high temperature during drying (Salunkhe et al., 1973). However, the oily flavors and textures of the deep-fried fruit pieces are usually not compatible with those of the fresh fruit. Also, these deep-fried products possess enhanced calorie values because the oil used during frying becomes an ingredient of the products. Hence, off-flavors or non-typical flavors may develop, especially rancid flavors during storage, due to the oxidation of the incorporated oil (Matz, 1993).

2.3.2.2. Sun Drying

Sun drying is a traditional method to produce dehydrated banana slices, and it is still in use in many parts of the world, especially in developing countries (Ihekoronye and Ngoddy, 1985; Potter, 1986). Sun drying is by far the cheapest method but is limited to hot, sunny, dry climates. During drying, the banana slices are simply spread on wooden trays and exposed to the sun until dry. This drying process is slow and unsuitable for producing good quality products. The moisture content of the sun dried products is
generally no lower than 15%; thus, the shelf life of such products does not exceed a year (Somogyi and Luh, 1986). In addition, sun drying incurs the risk of excessive losses due to inclement weather and contamination of the products with dust, dirt, insects and bacteria (Somogyi and Luh, 1986).

2.3.2.3. Solar Drying

Solar drying is an improved alternative to sun drying; the principal energy source of this method is the radiation of the sun. Solar drying, compared with sun drying, provides higher air temperature and lower relative humidity, thereby resulting in a faster drying rate and a dehydrated product with a lower final moisture content. Furthermore, solar drying is carried out in an enclosed structure, in which solar energy is collected by a solar collector that heats the air, which in turn is channeled into the dehydration chamber. Also, the enclosed system protects the fruits against rain, dust, dirt, insects and other contaminants, thereby resulting in a product with a longer shelf life (United Nations, 1986a). Bowrey et al. (1980) used solar drier cabinets to dehydrate bananas. This drying process required about 72 hours, and the moisture content of the bananas reached around 14 – 15%.

2.3.2.4. Air Drying

Presently, most dehydrated fruits are produced by hot air dehydration, which is the simplest, the most economical, and the most frequently used operation among various drying methods (Jayaraman and Das Gupta, 1992). Air-drying requires high temperatures and long periods of time. The drying rate depends on the air temperature, the rate of air
circulation, and the relative humidity of air (Mowlah et al., 1983). This drying process involves simultaneous occurrences of heat transfer and mass transfer, in which heat penetrates into the food product, and moisture is removed from the product in the form of water vapor. The air-drying process consists of two periods, the constant-rate period and the falling-rate period. During the constant-rate period, water evaporates from the surface of the product, and the moisture is then transferred slowly from the interior to the surface using a combined mechanism of diffusion and capillary suction caused by a concentration gradient set up within the product. During the falling-rate period, the drying rate continually decreases, and a prolonged drying time is required to obtain a low moisture content (Saravacos and Charm, 1962). Additionally, the diffusion of solutes during drying causes the formation of a tough and leathery skin described as "case hardening" (Holdsworth, 1986). The air-dried products are characterized by poor retention of nutrients and flavor due to volatilization of some important volatile compounds and are also characterized by a shrunken structure and a dark brown color due to excessive thermal damage during drying (Johnson et al., 1998). Commercially, banana slices are dried in a single layer at 60 – 75°C until the slices are hard and brittle, with a moisture content of around 12% (United Nations, 1986b).

2.3.2.5. Freeze Drying

Freeze drying is one of the most advanced dehydration techniques, in which bananas are frozen, and the moisture is removed from frozen fruits under vacuum by sublimation, i.e. converting ice to water vapor without melting (Somogyi and Luh, 1986). During freeze-drying, ice crystals sublime from the surface of the frozen fruits, and the
ice layer gradually recedes towards the center of the products, leaving vacant pores in the fruit products. Thus, the water vapor diffuses from the interior of the fruit matrix and escapes from the fruit product through the pores (Lorentzen, 1974; Somogyi and Luh, 1986). The freeze-dried products are characterized by maximum retention of flavor and nutrients, minimum damage to structure and minimum changes in color, shape and appearance, thereby resulting in fresh-like products with a porous structure having little or no shrinkage. Further, the low processing temperature decreases various degradative reactions, such as enzymatic and non-enzymatic browning. Nevertheless, this drying process is expensive, and the use of vacuum adds to the cost. Additionally, the drying rate is slow, and the porous structure and low moisture content of the products require special packaging to avoid oxidation and moisture pick up (Okos et al., 1992).

2.3.2.6. Osmotic Dehydration

Osmotic dehydration of bananas can be achieved by immersing the banana slices in a concentrated sugar solution, thereby allowing the water to diffuse out and the sugar solutes to diffuse into the slices via osmosis. This process reduces the moisture content of the fruit slices to about 50%, and the partially dehydrated slices can then be further dried by other conventional methods, such as air drying and vacuum drying. The extent of dehydration depends on the concentration and temperature of the sugar solution, the time of immersion, and the area of the fruit slices exposed to the solution (Holdsworth, 1986).

Osmovac drying can be used commercially to produce dehydrated banana slices that have a porous crisp texture, as well as a good retention of the fresh fruit's flavor and color. The banana slices are dehydrated by being immersed in sugar syrup at about 70°
Brix for around 8 – 10 hours, and the fruit slices are then vacuum dried at 66 – 71°C and 10mm Hg until the moisture content of the slices is reduced to 2.5% or less (Somogyi and Luh, 1986). This drying process is energy efficient, and the non-thermal dehydration of the fruit slices by osmosis minimizes heat damage to the flavor of the fruit products. Furthermore, the sugar syrup surrounding the fruit slices prevents enzymatic browning of the fruit and thus retains the color of the products with little or no use of anti-browning agents (Brekke and Ponting, 1970). However, the economics of this drying technique probably depend upon the availability and possibility of reusing the sugar solution (Salunkhe et al., 1973).

### 2.3.2.7. Explosion Puffing

In explosion puffing, the banana slices are partially dehydrated by conventional drying methods, and then sealed in a metal cylinder, known as a “gun.” When the water within the fruit slices is heated above its atmospheric boiling point and a predetermined pressure has been established inside the cylinder, the fruit pieces are discharged instantly to atmospheric pressure. This sudden change in pressure causes some of the water within the slices to vaporize, creating a highly porous structure inside the fruit pieces, in turn allowing the final dehydration to be achieved much more rapidly until the moisture content of the fruit pieces reaches about 4 – 5% (Somogyi and Luh, 1986; Saca and Lozano, 1992). This drying technique produces many of the desired attributes of freeze-dried fruit products, but at a significantly reduced cost, and is comparable to the cost of conventional air drying (Okos et al., 1992).
2.3.2.8. Vacuum Microwave Drying

Vacuum microwave drying offers an alternative way to improve the quality of dehydrated fruit products and to produce unique, puffed dehydrated banana slices. This system includes a microwave power supply, a vacuum pump, an airtight chamber and associated controls. The microwave power supplies the energy for heating the fruits in order to accelerate drying. The vacuum applied in the chamber lowers the boiling point of the water molecules within the fruit pieces and allows the vaporization of moisture at a lower temperature than that experienced at atmospheric condition, thereby minimizing any thermal damage to the fruit products. In addition, the vacuum environment removes most of the oxygen, thereby diminishing oxidation reactions and preserving the flavor and color of the dried fruits (Anon, 1988; Yongsawatdigul and Gunasekaran, 1996a).

2.3.2.8.1. Mechanism of Microwave Heating

Microwaves are electromagnetic waves generated by magnetrons; they are composed of an electrical field and a magnetic field (Datta, 1990). The two most popular microwave frequencies used in the United States are 915 MHz for industrial purposes and 2450 MHz for domestic purposes (Shaath and Azzo, 1989).

There are two major mechanisms that govern microwave heating of food material: ionic polarization and dipole rotation. Ions, such as salts, carry an electric charge; when ions move in response to an electric field, ionic polarization occurs. Ions are accelerated by the field alternating at the microwave frequencies and thus collide with others, thereby converting kinetic energy into heat (Decareau and Peterson, 1986).
The main mechanism that governs microwave heating of fruits is dipole rotation. Water is the major component in fruits, and it has a permanent dipole and an asymmetric charge distribution. When the microwave energy penetrates into the fruit slices, the water molecules oscillate back and forth to align themselves with the changing microwave field at a frequency of many millions of times per second, resulting in molecular friction, and thus producing heat (Decareau and Peterson, 1986; Datta, 1990; Ramaswamy and van de Voort, 1990; Nijhuis et al., 1998).

Additionally, microwaves can easily penetrate the dry surface layer and can preferentially be absorbed by the water molecules within the fruit pieces. This absorption of energy rapidly vaporizes the water molecules, thereby generating a gas pressure gradient within the fruit slices, and thus expelling the moisture from the interior of the fruits (Bouraoui et al., 1993; Prabhanjan et al., 1995). This pressure gradient can also prevent the collapse of the tissue structure and thus maintain the porous structure of dehydrated fruit products, thereby facilitating moisture transport and improving the drying rate (Marousis et al., 1991; Prabhanjan et al., 1995).

One unique feature of microwave energy is its ability to penetrate a food material and its efficiency in being converted into heat (Ramaswamy and van de Voort, 1990). The penetration ability of microwave energy is often expressed as the penetration depth, which is defined as the depth into the material at which the energy has been reduced to 37% at the surface (Salunkhe et al., 1973). The depth of penetration can be determined by the following equation:

\[
dp = \frac{\lambda_0 \sqrt{\varepsilon'}}{2\pi\varepsilon''}.
\]
where \( dp \) (m) is the depth of penetration, \( \lambda \) (m) the wavelength in space, \( \varepsilon' \) the dielectric constant and \( \varepsilon'' \) the loss factor of the material (Buffler, 1993). This equation is accurate for most food materials within plus or minus 5% accuracy. Also, the penetration depth depends on the microwave frequency and the type of material being exposed. Penetration usually increases as the microwave frequency decreases or as the moisture content of the material decreases. Further, penetration is infinite in perfectly transparent material and zero in reflecting material; penetration is finite in most absorptive materials, such as food (Salunkhe et al., 1973).

Microwave absorption by a food material depends on the dielectric constant and the loss factor of the material. The dielectric constant is a measure of the material’s ability to store electric energy, while the loss factor is a measure of its ability to dissipate energy in the form of heat. Thus, materials with a high loss factor, such as water and salt, absorb microwave energy efficiently; materials with a low loss factor generate little heat (Ramaswamy and van de Voort, 1990). Therefore, materials with high salt and water content absorb microwave energy efficiently.

Microwaves have been employed to dehydrate apples (Huxsoll and Morgan, 1968), berries (Jepsson, 1964), carrots (Sobiech, 1979) and potatoes (Gerling, 1968; Huxsoll and Morgan, 1968). The quality of these products was reported to be excellent, in some cases superior to that of freeze-dried products.

**2.3.2.8.2. Advantages of Combined Vacuum / Microwave Drying**

Applying microwave energy under vacuum combines the advantages of both microwave drying and vacuum drying. Microwave heating vaporizes the water molecules
and generates a pressure gradient within the fruit pieces. Then, the water molecules rapidly diffuse to the surface and thus quickly desorb to the reduced pressure atmosphere, thereby accelerating moisture removal. Also, the reduced pressure enables the fruit slices to be dried at a lower temperature than would be required at atmospheric pressure. Therefore, this combined microwave / vacuum drying system permits rapid dehydration at a low temperature that significantly reduces any thermal damage to the fruit products and retains the original flavor, color and shape of the fresh fruits (Anon, 1988; Krokida and Maroulis, 1999).

Vacuum microwave drying has been successfully used to dehydrate raisin grapes, apples, bananas, cranberries, apricots, peaches, strawberries, raspberries, corn, peanuts, rice, wheat, carrots, parsley, peppers, potatoes, tomatoes, soy protein, and milk powder (Elias, 1979). This drying system was first applied to grapes in 1978 in order to improve the efficiency of grape dehydration for raisin production (Anon, 1988). Banana slices dried by vacuum microwave drying possessed excellent quality with respect to taste, aroma, texture, color and appearance (Drouzas and Schubert, 1996). Vacuum microwave dried cranberries were redder in color and softer in texture when compared to those dried by conventional methods (Yongsawatdigul and Gunasekaran, 1996b). In addition to high retention of vitamin C, vacuum microwave drying of orange and grape juices had less effect on the volatile components than either spray or freeze drying (Decareau, 1985).

2.3.2.8.3. When to Apply Vacuum Microwave Drying?

In order to decrease energy costs and to increase the efficiency of vacuum microwave drying, alternative drying procedures can first be used to remove the high levels of
water from the fresh fruits; vacuum microwave drying can then be used to remove the remaining water (Anon, 1988). Additionally, when the fruit pieces are first conventionally dried to about 50% moisture, forming a hard dry crust on the outside with a wet core inside, the vacuum microwave drying can then be applied (Huxsoll and Morgan, 1968). At this moisture level, the case hardened layer has developed to such an extent that the outer layer of the fruit piece has been set, and yet a substantial portion of the solids remains in the wet core. When the microwave power is applied to such a fruit piece, the internal vapor pressure exerts an outward force on the case hardened layer, causing an open porous structure to develop (Huxsoll and Morgan, 1968; Riva et al., 1991). These dehydrated fruit products would be best for snack items that have a crisp texture similar to that produced by frying (Huxsoll and Morgan, 1968; Lin et al., 1998).

Apple and potato slices have been dried in this manner (Huxsoll and Morgan, 1968). The vacuum microwave finish dehydrated apple slices and potato slices possessed puffed and porous structures, and the final volumes of these dehydrated slices were three and one-half times greater than those dried by conventional manners.

2.3.2.8.4. Flavor Retention during Microwave Heating

The behavior of flavor compounds during microwave heating has been described by two different theories, the delta T' theory and the vapor pressure theory.

Delta T' is the ratio of the temperature increase of a pure flavor compound to the temperature increase of the standard (water) at the same microwave power level. Compounds with a high delta T' value absorb more microwave energy and thus are more susceptible to evaporation, while compounds with a low delta T' value absorb less micro-
wave energy and thus are less prone to vaporization and distortion, and are therefore likely to have superior retention. However, this theory was developed from experiments using pure flavor compounds (Shaath and Azzo, 1989) and was completely irrelevant to the diluted flavor compounds in the actual food systems. Li et al. (1994) reported that no relationship was found between delta T' and flavor volatilization when tested in the actual food systems. Also, Lindstrom and Parliment (1994) and Stanford and McGorrin (1994) reported that compounds with higher microwave adsorption and higher microwave heating rates were not preferentially volatilized by microwave heating in water/oil mixture. Therefore, the delta T' theory is not applicable to flavor compounds in foods because the properties of the food, and not those of the flavor compound, influence the volatilization of the flavor compounds during microwave heating.

The vapor pressure theory, on the other hand, states that flavor compounds are lost from foods according to their vapor pressures in the respective media (Steinke et al., 1989). In a study of the microwave volatilization of organic acids, a clear relationship was found to exist between volatility and flavor loss. Likewise, Risch (1989) stated that the release of the aroma compounds during microwave heating depends on the volatility of the compounds. Up to 95% of the flavor-contributing compounds can be lost during microwave cooking, and the percent loss ranges from 10% for low volatile compounds to 95% for very volatile compounds. Also, the volatilization of individual flavor compounds was controlled by the chemical and physical properties of the food system. Stanford and McGorrin (1994) demonstrated that the release of the volatile compound was related to its solubility / hydrophobicity and its interaction with other compounds in the system, and they showed that the loss of the volatile compounds during microwave heating increased
as the water solubility of these compounds increased. Further, Lindstorm and Parliment (1994) reported that the release of aroma compounds during microwave heating mainly depended on the temperature of the food system but not on the dielectric properties of the individual flavor compounds.

2.4. Quality Attributes of Banana Chips

Banana chips produced from fully ripe bananas are popular as a snack food in many countries. Consumers' acceptance of banana chips is based on the quality attributes of the product, which are aroma, flavor, texture and color (Godavari and Narayana, 1969).

2.4.1. Aroma and Taste of Banana Chips

Flavor plays an important role in food acceptability and thus in food marketing. Analysis of volatile compounds is essential to gain knowledge of the nature of flavor affected by processing and storage, and can be done by combined gas chromatography – mass spectrometry (GC – MS) and sensory evaluation (Cronin, 1982).

In order to determine the effect of processing on the volatile constituents of dehydrated banana slices, the volatile constituents can be extracted and concentrated by using appropriate techniques to obtain compounds having maximum quality and quantity. The isolated volatile constituents can then be separated by gas chromatography (GC), and the important volatile compounds can be identified by combined gas chromatography – mass spectrometry (GC – MS). Sensory evaluation of food aromas is of fundamental importance in studies of the flavors of food products. Since the human nose and mind
control decisions about the acceptability or unacceptability of a flavor, sensory evaluation should be done to correlate the data obtained by panelists with those obtained by GC analysis. In addition, the human sensory receptors integrate the effect of the entire range of compounds present in the food product; as compared to the analytical methods (GC), which only evaluate the single constituent of the product (Mannheim and Passy, 1975).

2.4.1.1. Volatile Constituents of Bananas

Banana is a tropical fruit with a pleasant flavor that develops during ripening (Ali et al., 1984). The characteristic aroma of banana consists of a combination of volatile components, including esters, acetates, butyrates, alcohols and carbonyl compounds. Acetates and butyrates are described as fruity and estery odors, whereas alcohols and carbonyl compounds have odors described as green, woody or musty (Kotecha and Desai, 1995). In ripe bananas, the major volatile constituents are isoamylacetate, isobutylacetate, n-butyl acetate, isoamylbutyrate, isobutyrlbutyrate, butyl butyrate and isoamyl alcohol (Stover and Simmonds, 1987b). McCarthy (1963) assigned a banana-like flavor to the amyl and isoamyl esters of acetic, propionic and butyric acids.

2.4.1.2. Determination of Volatile Constituents by GC – MS

2.4.1.2.1. Extraction and Concentration of Aroma Compounds

Solvent extraction, distillation, solid-phase extraction, the purge and trap method, and static or dynamic headspace analysis can be used to extract and concentrate aroma compounds prior to GC analysis.
2.4.1.2.1.1. Solvent Extraction

Solvent extraction is the simplest method for isolating aroma compounds based on solubility. In this technique, a large number of volatile compounds can be extracted by simply shaking the food with the solvents in a separating funnel at room temperature or in a Soxhlet extractor at an elevated temperature. The solvents commonly used include ether, pentane, hexane and isooctane. Usually, rotary evaporation can be used to remove solvent selectively and thus to concentrate the isolated volatile compounds (Maga, 1990).

2.4.1.2.1.2. Distillation at Atmospheric and Reduced Pressure

Historically, distillation at atmospheric pressure is a popular isolation technique. The volatile compounds are isolated by dispersing the food sample in boiling water, and the resulting condensate is collected, extracted with solvents, and then concentrated. However, as most volatile compounds are thermally unstable, prolonged heating at an elevated temperature involved in this system is not an ideal approach (Maga, 1990).

Steam distillation under reduced pressure can be used as an alternative technique. The reduced pressure lowers the boiling point of the system, and therefore reduces both the time required and artefact formation. Normally, distillation is performed at 10 – 20 torr, sometimes in conjunction with a Likens – Nickerson apparatus which combines distillation, extraction and concentration in one continuous step (Maga, 1990). Fractional distillation at atmospheric or reduced pressures can also be used. Usually, the distillation is carried out by using a Vigreux-type column in conjunction with traps operating at −20° and −40°C (Maga, 1990).
2.4.1.2.1.3. Static or Dynamic Headspace Analysis

Headspace analysis is the most popular sampling technique (Nunez et al., 1984). The major advantage of this technique is that the headspace of the food sample contains aroma compounds in the same relative proportions as those experienced by a human consumer, and thus this measure represents the effective odor of the food product (Cronin, 1982). Dynamic headspace analysis is an improvement over static headspace analysis. Dynamic headspace analysis is sensitive and involves flushing the system with purified air and adsorbing the aroma compounds onto polymer traps, which can exclude any water vapor being adsorbed from the headspace. The adsorbed compounds are then eluted and concentrated for GC analysis. Conversely, static headspace analysis is insensitive and involves injecting a very dilute sample, which contains water vapor that causes damage to the GC stationary phase (Maga, 1990).

Recently, various porous polymers have been developed; they have the ability to retain most volatile compounds at ambient temperature, while displaying little affinity for water. Porapak Q, a non-polar copolymer of ethylvinylbenzene and divinylbenzene, is the most widely used adsorbent for trapping the volatile components of a food sample. Chromosorb Century polymers are also popular for their low susceptibility to both oxidative and thermal decomposition. Tenax polymers, based on 2,6-diphenylene oxide, are also commonly used for the trapping of volatiles and semi-volatiles in liquid or solid samples (Cronin, 1982; Maier and Fieber, 1988; Maga, 1990).

In practice, 100 – 500mg of polymer is packed into a glass tube and conditioned at a temperature of around 180 – 225°C by purging with purified oxygen-free nitrogen. Then, the polymer trap is attached to the sampling apparatus containing the food sample,
and it collects the headspace volatiles by purging the apparatus with a stream of purified air or nitrogen at a flow rate of around 50ml /min to 300ml /min. After trapping the volatiles, the polymer trap is then disconnected and purged with purified nitrogen to remove most of the water vapor. The adsorbed volatiles can easily be transported in a stable form and be desorbed from the trap, either by dissolving the volatiles in a small volume of solvent for sample injection, or by applying heat for direct thermal desorption into the GC column (Cronin, 1982; Maga, 1990). This sampling method is commonly used in extracting and concentrating the volatile compounds of fresh fruit juices (Rizzolo et al., 1992), such as grapefruit juice (Nunez and Maarse, 1986) and orange juice (Elmore et al., 1994); Perez et al. (1997) used this method to sample the volatile components from two banana cultivars.

Isolation of aroma compounds by headspace analysis is a useful alternative to solvent extraction and distillation. Headspace sampling usually achieves better recovery of the more volatile components of the food sample, whereas either solvent extraction or distillation yields good recovery of less or non-volatile components (Maga, 1990).

2.4.1.2.1.4. Solid-Phase Microextraction

Solid-phase microextraction (SPME) is a recently developed sampling technique. It consists of a fused-silica fiber coated with a polymeric stationary phase. For sampling, the fiber is exposed to the headspace of the food sample and adsorbs the volatile compounds through partitioning the analytes between the fiber coating and the food sample for a predetermined period of time. Immediately after sampling, the adsorbed volatile compounds can be thermally desorbed in the GC injector and thus separated in
the GC column (Penton, 1997). SPME is fast (with extractions completed in less than 30 minutes) and less labor intensive (with a handling time of only about 3 minutes per sample). This technique requires only small amounts of samples and eliminates the use of solvents or complicated apparatus for concentrating volatile or non-volatile compounds during headspace or liquid sampling. This technique is compatible with any packed or capillary column or gas chromatograph or gas chromatograph – mass spectrometer system and can be used with split / splitless or direct / packed injectors (Zhang et al., 1994). In addition, SPME provides linear results over wide concentrations of analytes, and the detection limit of the headspace SPME was claimed to be at the subpicogram level (Zhang and Pawliszyn, 1995).

4.2.1.2.1.4.1. How SPME Works

The SPME device consists of a 1-cm length of fused silica fiber, coated with an adsorbent film or a stationary phase, bonded to a stainless steel plunger, and installed in a modified syringe holder. This fiber can be drawn into and out of a hollow needle by using the plunger on the holder. During sampling, the needle is pierced through the septum that seals the sample vial; the plunger is depressed, and the fiber is exposed to the sample or to the headspace above the sample. The organic analytes are then adsorbed to the phase coating on the fiber until the adsorption equilibrium is attained usually in 2 to 30 minutes. After adsorption, the fiber is drawn into the needle, withdrawn from the sample vial, and introduced into the gas chromatograph injector where the adsorbed analytes are thermally desorbed and delivered to the capillary column (Zhang et al., 1994).
SPME is an equilibrium process established among the concentration of analytes in the sample, in the headspace above the sample, and in the phase coating on the fiber. The principle of SPME is the partitioning process of the analyte between the fiber coating and the sample; the higher the partition coefficient of the analyte, the higher the fiber's affinity for the compound (Zhang and Pawliszyn, 1993). The selectivity of the process can be modified by changing the type of adsorbent phase and the thickness of coating on the fiber to match the characteristics of the analytes of interest. In general, a non-polar fiber coating is most effective for extracting non-polar analytes, and a polar coating is most effective for polar analytes. A thick coating is most efficient for adsorbing/desorbing volatile compounds, and a thin coating is most efficient for semi-volatile compounds. Therefore, the selection of a suitable fiber coating is important to obtain a maximum extraction of analytes. Additionally, the amount of analyte adsorbed by the fiber depends on the thickness of the coating and also on the distribution constant of the analyte. Generally, a thick fiber coating, compared to a thin fiber coating, extracts more of a given volatile compound (Boyd-Boland et al., 1994; Zhang et al., 1994).

4.2.1.2.1.4.2. Sampling with SPME

SPME can be used to examine the quality of samples, and it can also be used to quantify the analytes in samples, especially when used with internal standards under consistent sampling conditions. In order to ensure high accuracy and precision with this technique, neither complete extraction of analytes nor full equilibrium is necessary, but consistent sampling time, temperature, and fiber immersion depth, constant sample vial size and sample volume are critical. The number of extractions that can be performed by
a fiber is governed by the care given to the fiber and the nature of the components in the samples being analyzed; under most conditions, a fiber can perform 50 – 100 extractions (Zhang et al., 1994).

SPME is a useful technique for flavor analysis. This technique has been recently applied to the analysis of volatile compounds in foods (Page and Lacroix, 1993; Yang and Peppard, 1994) and beverages (Constant and Collier, 1997; Gandini and Riguzzi, 1997; Yang and Peppard, 1994). Headspace SPME has been applied to the analysis of volatile compounds in fruits, such as strawberries, raspberries, blackberries, bananas and mangos, and the chromatograms obtained include compounds typically found in these fresh fruits (Ibanez et al., 1998). Also, this technique has been employed to quantitatively determine volatile components in certain food products, such as kiwi fruits (Wan et al., 1999), tomatoes (Song et al., 1998) and tobacco (Clark and Bunch, 1997).

2.4.1.2.2. Gas Chromatography (GC)

GC achieves separation of aroma compounds by partitioning the components between a stationary phase and a mobile gas phase. In most applications, the separation is made to determine the identity and the quantity of each component of the food sample. Further, the aroma compounds must be stable, have significant volatility at the analytical temperature, and interact with the stationary phase and the mobile gas phase. Nowadays, GC is not the only technique considered in the analysis of food products. In particular, high-performance liquid chromatography (HPLC) is an alternative applied to the analysis of a wide range of food components. GC is suitable for analyzing volatile compounds,
whereas HPLC is preferred for completely non-volatile or thermally liable components (Littlewood, 1962; Gordon, 1990; Grob, 1995).

The elution technique is the commonest technique in achieving separation of aroma components of the food sample. In this technique, the sample, either as a gas or a liquid form, is introduced at the beginning of the column and is evaporated to a vapor form if it is introduced as a liquid form. The sample is then swept by the inert carrier gas through the column, and the vapor of the aroma component is adsorbed in an equilibrium set up between the gas phase and the stationary phase of the column. Another portion of the aroma vapor always remains in the gas phase and again equilibrates with the column when this portion moves a little further along the column. At the same time, the portion of the aroma vapor already adsorbed in the column again equilibrates with the gas phase that follows the zone of vapor. The process in which the carrier gas containing the aroma vapor is adsorbed by the column in front of the zone while the aroma vapor enters the carrier gas at the rear of the zone proceeds continuously. This process results in the zone of vapor moving along the column in a more or less compact zone. Further, the speed at which the zone moves along the column depends on two factors: the flow rate of carrier gas and the extent to which the aroma vapor is adsorbed by the column. Hence, the faster the flow rate of the carrier gas, the faster the zone moves along the column. Additionally, the aroma components in the sample behave independently. Therefore, the stronger the aroma vapor is adsorbed by the column, the slower the zone moves along the column, and the slower the zone is eluted from the column. Consequently, a gas chromatogram of aroma components is obtained; the position of the peak identifies the components and the
peak area is proportional to the amount of each component (Littlewood, 1962; Grob, 1995).

GC columns are usually divided into two categories: packed and open tubular (or capillary). Packed columns are larger in diameter and are capable of accommodating a large sample size. However, these columns require a carrier gas with a relatively high flow rate, and are thus not appropriate for use in combination with the mass spectrometer. Instead, open tubular columns or capillary columns are often used; they achieve a much better resolution and shorter analysis times. There are two types of capillary columns: wall-coated and porous-layer open tubular. Wall-coated open tubular columns are most commonly used; they contain the stationary phase coated or chemically bonded onto the inside wall of a long glass or fused-silica capillary (Merritt and Robinson, 1982; Gordon, 1990).

The selection of a stationary phase depends on the chemical structures of the volatile components to be separated. In general, polar stationary phases are used for analyzing polar components based on dipole-dipole, dipole-induced dipole and hydrogen-bonding interactions. Non-polar stationary phases are used to separate non-polar components mainly on the basis of the boiling point (Klee, 1985; Gordon, 1990).

GC detectors are used to convert the flow of the volatile compounds eluting from a GC column to a voltage that can be monitored by a data capturing device. The flame ionization detector (FID) is the most common detector in GC analysis, and this detector consists of a mixture of gases, containing air, hydrogen, and carrier gas, burning at the tip of a jet. Also, an electrostatic potential is applied between the jet, which is grounded, and the collector, which operates at a voltage of about 400V. The collector is connected to an
electrometer for current measurement. When volatile / organic compounds are eluted from the column and introduced into the flame, radicals are formed by ionization. Then, these electrically charged molecules are collected; the resulting current is amplified by an electrometer, and the magnitude of the current increases as the mass of the molecule increases. Conversely, when carrier gas is eluted from the column, no signal is formed and a stable baseline is achieved. Most organic compounds burn in the flame and produce a response, which is proportional to the number of carbon atoms eluted from the column. On the other hand, most carrier gas impurities, such as water and CO₂, do not produce a response. The detection limits of the FID are approximately 5pgs⁻¹ for light organic compounds, increasing up to 10pgs⁻¹ for higher molecular weight organic molecules (Gordon, 1990).

2.4.1.2.3. Gas Chromatography – Mass Spectrometry (GC – MS)

GC – MS is a powerful technique for separation and identification of the volatile components of food products (Gerhardt, 1990). In mass spectrometers, the ion source, the mass analyzer and the output system are the three major functional parts (Merritt and Robinson, 1982).

The first functional part of the mass spectrometer is the ion source, and the most commonly used ion source is the electron impact (EI). In practice, the volatile molecules are bombarded by an electron beam; the extent of fragmentation of the molecule is dependent on the chemical structure of the molecules and the energy of the electron beam. The second functional part of the mass spectrometer is the mass analyzer, which provides the means for separating the ions that have been formed in the ion source. Magnetic
deflection is the most common mass analyzer used in the GC/MS, in which the ions are introduced into a static magnetic field and are segregated by the field on the basis of the mass: charge ratio. At last, these ions are displayed as a function of their mass and relative abundance, and therefore constitute a profile called the mass spectrum that is uniquely diagnostic for a particular chemical compound (Merritt and Robinson, 1982).

2.4.1.3. Determination of Aroma and Flavor Attributes by Sensory Evaluation

The three basic types of sensory tests are affective tests, discriminative tests, and descriptive tests. Affective tests generally require a large number of untrained panelists to indicate liking, acceptance or preference of the test product; the attitudes of panelists towards the product are measured on the basis of its sensory properties (Poste et al., 1991). Both discriminative and descriptive tests generally require trained panelists. Discriminative tests can be used to determine any detectable difference among products but cannot indicate how large or what kind of difference exists (Jellinek, 1985).

Descriptive tests can be used to identify the important sensory characteristics and to examine the nature and intensity of these characteristics of a food product. This test is most widely used in identifying the effect of processing variables on the sensory attributes of a product (Poste et al., 1991). Unstructured scaling is commonly used in studies of flavor; Shamaila et al. (1996) used this type of scaling to rate the aroma intensity of water blanched carrots. The unstructured scale consists of a horizontal line with anchor points at each end indicating extremes of the sensory attributes to be measured. Panelists are asked to record each evaluation by marking a vertical line across the horizontal line at
the point that best reflects their perception of the magnitude of the attributes (Poste et al., 1991).

2.4.2. Texture of Banana Chips

Texture is a key quality attribute of a snack food, and crispness is an important textural characteristic. Based on the perception of consumers, crispness is defined as food that is firm, snaps easily and emits a cracking sound when broken (Szczesniak, 1988). Acoustical and force-deformation instrumental measurements can be used to determine sensory crispness (Vickers, 1987). Also, as structural organization dictates food texture, microstructural knowledge is useful in predicting and explaining the texture of food (Stanley, 1987).

2.4.2.1. Determination of Texture by Acoustical Measurements

Drake (1963) was the first to examine the role of sound on judgement of food texture. He showed that sounds produced by crushing a variety of foods differed in amplitude, frequency and temporal characteristics. Vickers and Bourne (1976) suggested that acoustical sensations were involved in the perception of food crispness. They showed that a characteristic acoustical profile was produced when biting a crisp food, and they hypothesized that the amplitude of the sound produced was the most important dimension of food crispness. Furthermore, Sherman and Deghaidy (1978) reported that the loudness of the biting sound, particularly during the first bite, was an auditory cue to determine food crispness. The above studies revealed that the loudness of the sound produced when
biting crisp foods, particularly during the first bites, was very important in quantifying the sensation of crispness.

2.4.2.2. Determination of Texture by Instrumental Measurements

Various investigators have examined the crispness of snack foods by using different instrumental measurements. Bourne et al. (1966) studied the crispness of potato chips at different moisture contents by using a punch test; they found that the crispness of the chip increased with the initial slope of the force-deformation curve. Iles and Elson (1972) and Vickers (1987) studied the crispness of potato chips and gingersnaps by using a punch test, with a 4.3-mm diameter punch and a needle respectively. They both found that the sensory crispness of these products again increased with the initial slopes of their force-deformation curves. Furthermore, Vickers and Bourne (1976) identified two instrumental textural measures derived from a snap test: bend deformation to fracture and the slope of a force-deformation curve. These two measures correlated well with the sensory crispness of a variety of crisp foods. Hence, the initial slope of the force-deformation curve is a good indicator of the food and sensory crispness.

2.4.2.3. Determination of Structure by Microscopic Techniques

The microstructure of food can be examined by various microscopic techniques, such as light microscopy (LM), transmission electron microscopy (TEM), and scanning electron microscopy (SEM) (Postek et al., 1980). Among these microscopic techniques, SEM is an important magnifying tool for examining food microstructure and has been
recognized by scientists as the primary source in determining microstructural information on food (Aguilera and Stanley, 1990).

SEM's outstanding contribution is its ability to combine high magnification and great depth of field. SEM can produce images with a wide variety of magnifications, ranging from 20x to 100,000x, thus bridging the magnification gap between LM and TEM. SEM can also achieve a depth of field approximately 500x that of LM at equivalent magnifications, and its electron induced signals can yield a great deal of physical, chemical and morphological information about a food sample (Postek et al., 1980).

SEM uses a focused beam of high-energy electrons; the beam scans across the surface of the food sample repeatedly. When the electron beam strikes the sample, some of the incident electrons will be transmitted and others will be reflected; as a result, secondary electrons are generated near the surface of the sample. These secondary electrons are gathered by a collector, conveyed to an amplifier, and then displayed onto the screen of a cathode ray tube, producing a magnified image characterizing the sample topography (Aguilera and Stanley, 1990). SEM has been used to study the microstructural changes of certain processed fruits, such as apples (Lee et al., 1967), bananas (Saca and Lozano, 1992) and peaches (Lee et al., 1966a).

2.4.3. Color and Appearance of Banana Chips

2.4.3.1. Determination of Color by Instrumental Colorimetric Techniques

Scientific color measurement is based on numerical representations of three-color response mechanisms of the human eyes. Different methodologies can be used to analyze
the color of food samples. The most common methods are RGB, XYZ and LAB scales that analyze color in terms of three parameters; each composite color can be easily quantified by a set of three numbers (Hunt, 1977).

The measurement of color is done through colorimetric techniques by analyzing the spectrum of light reflected from the sample’s surface and detected by the instrument. The RGB scale is the primary system developed to measure color, and the R, G, B values represent the amounts of red, green and blue light respectively required to simulate the color of a food sample (Hunt, 1977). However, this RGB scale often results in negative R, G and B values. The XYZ scale is resolve from the manipulations of the R, G, and B values, and this system can be used to eliminate the negative values.

The LAB scale, developed through transformation of the XYZ scale, is based on the opponent-colors theory. In this theory, the a and b values represent the two color dimensions: the a value is associated with the red-to-green dimension generated by comparing red responses with green responses, and the b value is associated with the yellow-to-blue dimension generated by comparing green (or red and green) responses with blue responses. The L value is associated with the third color dimension, lightness. This system is widely used to measure the color of certain processed fruits and vegetables, such as apples (Krokida and Maroulis, 1999), bananas (Saca and Kizano, 1992; Krokida and Maroulis, 1999) and carrots (Lin et al., 1998). Additionally, the ratio of redness and yellowness of the sample can be expressed as hue ($\tan^{-1} (b/a)$); the level of saturation of the color can be expressed as chroma ($\sqrt{a^2 + b^2}$).
3. Materials and Methods

3.1. Inhibition of Banana Polyphenoloxidase (PPO)

The % PPO inhibition was determined using the method as described below by Galeazzi et al. (1981), Pizzocaro et al. (1993), and Almeida and Nogueira (1995)

3.1.1. Raw Materials

Bananas were purchased from a local supermarket. All reagents were of food grade. Ascorbic acid was obtained from Galloway's Vancouver, BC, Canada; potassium meta-bisulfite from Wine Art Inc., Markhem, ON, Canada; 4-hexylresorcinol and sodium acid pyrophosphate from Western Basic Ingredients Ltd., Coquitlam, BC, Canada.

3.1.2. PPO Inhibition

Yellow bananas were peeled and sliced to an approximately thickness of 6mm using a mechanical slicer. A 50g sample of the banana slices was then dipped in one of the following aqueous solutions (w/v basis) for 2.5 minutes:

- 1% or 2% (w/v basis) Citric acid
- 1% & 2% Citric acid + 0.2% Tetra-sodium pyrophosphate
- 1% & 2% Citric acid + 1% & 2% Ascorbic acid
- 1% & 2% Citric acid + 1% & 2% Ascorbic acid + 0.2% 4-Hexylresorcinol
- 250, 500, 1000, 2000ppm Potassium metabisulfite
- 1% & 2% Citric acid + 250, 500, 1000, 2000ppm Potassium metabisulfite
All treatments were performed in triplicate. After dipping, the banana slices were left to drip for about 15 minutes at 4°C prior to analysis. As a control, the banana slices were dipped in distilled water for 2.5 minutes.

3.1.3. PPO Activity

50g of the treated banana slices was homogenized at 4°C with 100ml of the pre-cooled (4°C) 0.2M sodium phosphate (Fisher Scientific Company, NJ) pH 6.5 in a blender that had previously been cooled in an ice bath. The homogenate was then immediately centrifuged (Sorvall RC 5B Plus, Mandel Scientific Co. Ltd., USA) at 12,000 x g at 4°C for 30 minutes.

The PPO activity was determined by measuring the rate of increase in absorbance at 420nm using an UV-160 visible recording spectrophotometer (Shimadzu, Tekscience Hadley, Oakville, ON, Canada) at 25°C. The reaction contained 25μl of the supernatant (the enzyme extract), 0.25ml of 0.2M catechol and 1.225ml of 0.2M sodium phosphate pH 6.5. The reference contained 25μl of distilled water, 0.25ml of 0.2M catechol and 1.225ml of 0.2M sodium phosphate pH 6.5. All measurements were done in triplicate. The absorbance was read at 420nm every 10 seconds for 10 minutes, and the enzyme activity was determined on the basis of the slope of the linear portion of the curve plotted with A420 against time (up to 1.5 and 3 minutes for the control and the treated samples respectively). The % inhibition of PPO was calculated by using the following equation:

\[
\% \text{ Inhibition} = \frac{\text{PPO Activity (control)} - \text{PPO Activity (treated banana slices)}}{\text{PPO Activity (control)}} \times 100
\] (2)
3.2. Effects of Drying Methods and Sulfite on Headspace Volatiles of Banana

3.2.1. Raw Materials

Bananas were purchased from a local supermarket and stored at around 20°C until the bananas were fully ripe reaching a stage having a yellow color with little brown spots. The bananas were carefully matched according to degree of ripeness. As examined by a preliminary study, the maturity of the bananas was determined by measuring skin color and starch content as described by Perez et al. (1997) and Blankening et al. (1993) respectively.

3.2.1.1. Determination of Banana Maturity by Skin Color

Banana skin color was evaluated using a Hunter LabScan II Spectrocolorimeter (Hunter Lab., Reston, VA) with a 1.27 cm aperture and expressed as Hunter L (lightness / darkness), a (redness / greenness) and b (yellowness / blueness) values. The middle finger of outer whorl for each bunch was chosen. Six measurements of Hunter L, a and b value were performed for each side of each finger, and a total of twelve measurements were obtained and averaged. The L value of 50.0 – 60.0, a value of 8.0 – 9.0, and b value of 20.0 – 25.0 was used as the maturity standard. The instrument, equipped with a D65 illuminant and 2°-observer optical position, was standardized using a black plate and a white plate (No. LS-13685, X = 79.8, Y = 84.67, Z = 91.23).

3.2.1.2. Determination of Banana Maturity by Starch Content

Banana starch content was determined by iodine staining method. A starch-iodine staining solution of 1.0-% potassium iodide (Baker’s Analyzer, Phillipsburg, NJ, USA)
and 0.1% iodine in distilled water was used. After measuring the skin color as mentioned in section 3.2.1.2., two cross-sectional cuts were made across the center of the unpeeled banana and the cut surfaces were immersed in the staining solution for about 5 minutes. The cut surfaces were then transferred to a 10-cm Petri dish. The color of the cut surfaces was evaluated using a Hunter LabScan II Spectrocolorimeter (Hunter Lab., Reston, VA) with a 1.27cm aperture. Six measurements of Hunter L, a and b value were performed for each cut surface by rotating the Petri dish 60° to the right, and the measurements were then averaged. The L value of 40.0 – 50.0, a value of 4.0 – 5.0, and b value of 14.0 – 16.0 were used as the maturity standard. The instrument, equipped with a D65 illuminant and 2°-observer optical position, was standardized using a black plate and a white plate (No. LS-13685, X = 79.8, Y = 84.67, Z = 91.23).

3.2.2. Sample Preparation
3.2.2.1. Preparation of Vacuum Microwave Dried (VMD) Banana Chips

650g of fully ripe bananas was prepared for each drying process. Bananas were peeled, sliced to a thickness of 6mm and dipped in a solution of 2000ppm potassium metabisulfite for 2.5 minutes to inhibit enzymatic browning. These banana slices were first air dried on a Vers-a-belt dryer (Wal-Dor Industries Ltd., New Hamburg, ON, Canada) at 70°C, with an air flow rate of 1.1m³/min and relative humidity of 15 ± 3% to remove 60%, 70%, 80% and 90% of the initial moisture respectively on a wet weight basis (wb). These partially air dried banana slices were then transferred to a high density polyethylene drying drum and vacuum microwave dried in a 2 kW maximum power vacuum microwave dryer (EnWave Corporation, Vancouver, BC, Canada). The drying
drum was rotated at a rate of 4 revolutions per minute. After a vacuum of 28 inches of Hg was achieved, the partially air dried banana slices were vacuum microwave dried at a microwave power of 1.5 kW for approximately 7.5, 6.5, 5.5 and 4.5 minutes respectively to a final moisture content of around 3% on a dry weight basis (db), corresponding to a water activity of approximately 0.25. All experiments were performed in triplicate.

3.2.2.2. Preparation of 100% VMD Banana Chips

650g of fully ripe bananas was first prepared as mentioned in section 3.2.2.1. These banana slices were then positioned in a plastic tray and vacuum microwave dried at a vacuum of 28 mm Hg and a microwave power of 1.5 kW to a final moisture content of around 3% db. All experiments were performed in triplicate.

During drying, the banana slices were taken out from vacuum microwave dryer every minute. The temperatures of these banana slices were measured immediately using an Infrared Thermometer (model 39650-04, Cole Parmer Instruments Co., Chicago, IL, USA), and ten measurements were done for each minute.

3.2.2.3. Preparation of 100% Air Dried (AD) Banana Chips

650g of fully ripe bananas was first prepared as mentioned in section 3.2.2.1. These banana slices were then air dried at 70°C with an air flow rate of 1.1 m³/min on a Vers-a-belt dryer for about 3 hours until the final moisture content of the air-dried banana chips reached around 3% db. All experiments were performed in triplicate.

During drying, the banana slices were taken out from the air dryer. The weights of these banana slices were recorded to construct a drying curve, and their temperatures
were measured immediately using an Infrared Thermometer (model 39650-04, Cole Parmer Instruments Co., Chicago, IL, USA), and ten measurements were done each time.

3.2.2.4. Preparation of 100% Freeze Dried (FD) Banana Chips

650g of fully ripe bananas was first prepared as mentioned in section 3.2.2.1. These banana slices were frozen at –35°C and then freeze-dried to a moisture content of around 3% db under a vacuum of 1.6 inches of Hg with a chamber temperature of 20°C and a condenser temperature of –55°C. All experiments were performed in triplicate.

3.2.3. Determination of Water Activity ($a_w$)

Water activity of all dried banana chip samples was determined in triplicate using the Aqualab meter (model CX-2, Decagon Devices, Inc., Pullman, WA, USA). Approximately 1g of banana chip sample was put in a miniature plastic dish provided and then placed into the chamber of the water activity meter. The water activity of the sample was then recorded when equilibrium was obtained.

3.2.4. Determination of Moisture Content

Moisture content of all banana chip samples was determined in triplicate using a laboratory vacuum oven (National Appliance Co., Portland, OR). The chip sample was weighed in a labeled, pre-weighed aluminum weighing boat and then dried in the vacuum oven at 70°C with a vacuum level of 27 inches of Hg for 16 hours. Upon completion of drying, the weighing boat containing the dried sample was taken out from the oven,
cooled in a desiccator and then re-weighed. The moisture content of the sample on a dry weight basis (db) was calculated using the following equation:

\[
\% \text{ Moisture (db)} = \frac{\text{Wet weight of banana chip} - \text{Dry weight of banana chip}}{\text{Dry weight of banana chip}} \times 100
\]  

(3)

3.2.5. Flavor Analysis of Banana Chips

3.2.5.1. Selection of Solid-Phase Microextraction (SPME) Fibers

3.2.5.1.1. Preparation of Standard Mixture

Three standard volatile compounds were analyzed: isobutylacetate, 2-methylbutylacetate and isoamylacetate. The standard solutions of these volatile compounds were purchased from Aldrich Chemical Co. Inc. (Milwaukee, WI, USA).

The standard mixture was prepared by adding 1\(\mu\)l of isobutylacetate and 1\(\mu\)l of the standard solution containing 30% 2-methylbutylacetate and 70% isoamylacetate into 10\(\mu\)l of distilled deionized water in a 15-\(\mu\)l vial with a Teflon septum lid.

3.2.5.1.2. SPME Sampling

A 1cm long 100\(\mu\)m polydimethylsiloxane (PDMS) – coated SPME fiber, a 65\(\mu\)m polydimethylsiloxane/divinylbenzene (PDMS/DVB) – coated fiber and a 75\(\mu\)m carboxen/polydimethylsiloxane (Carboxen/PDMS) – coated fiber (Supelco, Inc., Toronto, ON, Canada) were used for this analysis. These fibers were conditioned in a GC injection port prior to use at 250\(^\circ\)C for 2 hours, at 260\(^\circ\)C for 1 hour and at 280\(^\circ\)C for 1 hour respectively.

The vial containing the standard mixture was placed in a 40\(^\circ\)C water bath. Then, the needle of the SPME device was pierced through the septum of the vial, and the fiber
was exposed to the headspace of the standard mixture for 30 minutes. After sampling, the fiber was withdrawn into the needle and then transferred to the injection port of the GC. When the needle of the SPME device penetrated through the septum of the GC inlet, and the fiber was exposed in the hot injection port, the volatile compounds adsorbed onto the fiber were thermally desorbed into the column for gas chromatographic analysis. All SPME samplings were performed in triplicate.

3.2.5.1.3. Gas Chromatography

Gas chromatographic analysis was performed using a Varian 3700 gas chromatograph (Varian Associates, Inc., Palo Alto, CA, USA) equipped with a flame ionization detector (FID) coupled to a Supelcowax-10 fused silica capillary column (30m, 0.25mm i.d., 0.25μm film thickness, Supelco Inc., Toronto, ON, Canada). Volatile compounds adsorbed on the SPME fiber were immediately thermally desorbed in the injector port at 250°C for 5 minutes in a split mode, and the detector port was set at 280°C. The column temperature was held at 35°C for 5 minutes and increased to 180°C at 3°C/min. Flow rates of the helium make-up gas and the hydrogen gas were set at 30ml/min and for air at 60ml/min. The head pressure of the column was set at 15 psi, and the flow rate of the helium carrier gas was 1.7ml/min. Data were collected and processed with the JCL 6000 Chromatography Data System for PC (Jones Chromatography, Lakewood, CO, USA).
3.2.5.2. Optimization of SPME Parameters

3.2.5.2.1. SPME Sampling

Banana chips (80%AD & 20%VMD) were ground by mortar and pestle, and 5g of banana chip powder was made as a slurry with 5ml of distilled water in a 15ml Teflon septum-closed vial. SPME sampling was carried out as mentioned in section 3.2.5.1.2. except that sampling was performed at various times and temperatures as suggested from the Random Centroid Optimization (RCO) program and the Carboxen/PDMS fiber was used. All samplings were performed in duplicate.

3.2.5.2.2. Optimization Procedures

The SPME parameters, the sampling time and temperature, were optimized using RCO program. Sampling times ranging from 15 to 60 minutes and temperatures ranging from 40 to 60°C were chosen on the basis of parameters suggested by the manufacturer. Also, nine random sampling time and temperature combinations were suggested from the RCO program. After sampling and GC analysis as mentioned in section 3.2.5.2.2 and 3.2.5.2.3, the peak area of isoamylacetate and the total peak areas of the 5 main peaks were optimized using the program.

Then, another two random combinations of sampling time and temperature were proposed from the RCO program. After sampling, analysis, and mapping, the optimum sampling time and temperature, that provided extraction having maximum peak areas of the isoamylacetate and of the 5 main peaks, were chosen.
3.2.5.2.3. Gas Chromatography

Gas chromatographic analysis was carried out as described in section 3.2.5.1.3. except that the volatile compounds adsorbed on the fiber were thermally desorbed in a splitless mode and the column temperature was held at 35°C for 5 minutes, increased to 120°C at 3°C/min, and then to 180°C at 6°C/min.

3.2.5.3. Effect of Drying Methods on Headspace Volatiles of Banana

3.2.5.3.1. SPME Sampling

Banana chips were ground by mortar and pestle, and 5g of banana chip powder was made as a slurry with 5ml of distilled water in a 15-ml Teflon septum-closed vial. 2μl of capric acid ethyl ester (Sigma Co., St. Louis, MO, USA) in methanol (0.1%, V/V) was added as an internal standard using a syringe just under the surface of the slurry. SPME sampling was performed as mentioned in section 3.2.5.1.2. except that the sampling was performed at 50°C for 30 minutes and the Carboxen/PDMS fiber was used. All samplings were performed in triplicate (i.e. 5g of banana chips for 3 trials).

3.2.5.3.2. Gas Chromatography

Gas chromatographic analysis was carried out as mentioned in section 3.2.5.2.3.

3.2.5.3.3. Gas Chromatography – Mass Spectrometry (GC – MS)

The volatile components of the banana chip samples were identified by performing gas chromatography – mass spectrometry (GC – MS), which was generously performed
by Dr. T. Cottrell at the AgriFood and Agricultural Canada Research Station, Summerland, BC.

5g of freeze-dried banana chip sample was used in the sampling as mentioned in section 3.2.5.3.1. The SPME fiber with the adsorbed volatile components was ice-packed in a Styrofoam box and sent to the Research Station. The adsorbed volatile components were thermally desorbed using a 0.75mm-i.d. SPME liner (Supelco Inc., Toronto, ON, Canada) in the injection port at 250°C for 5 minutes in a splitless mode. The volatile components were then separated using a Supelcowax-10 fused silica capillary column (60m, 0.25mm i.d., .025μm film thickness, Supelco Inc., Toronto, ON, Canada) that was housed in the Hewlett-Packard 5890-5970 GC – MSD system. The column temperature was held at 35°C for 5 minutes, increased to 120°C at 3°C/min and to 180°C at 6°C/min. The head pressure of the column was set at 200kPa, and the flow rate of the helium carrier gas was 24.9cm³/sec. The MSD was operated in a scan mode from 40 – 400 amu, and the sample rate was at 1.7 scans/sec. The mass spectral identification was obtained with a G1034C MS Chemstation containing a Wiley 138K MS library.

3.2.5.4. Effect of Sulfite on Headspace Volatiles of Banana

3.2.5.4.1. Sample Preparation

10g of fresh banana was sliced to a thickness of 6mm and dipped in a solution of 2000ppm potassium metabisulfite for 2.5 minutes. After dipping, the slices were left to drip for approximately 15 minutes. As a control, the banana slices from the same banana were dipped in distilled water for 2.5 minutes.
3.2.5.4.2. SPME Sampling

The banana slices were ground to slush by mortar and pestle and placed in a 15-ml vial with a Teflon septum lid. 2µl of capric acid ethyl ester (Sigma Co., St. Louis, MO, USA) in methanol (0.1%, V/V) was added as an internal standard. SPME sampling was carried out as mentioned in section 3.2.5.1.2. except that the sampling was performed at 50°C for 30 minutes and the Carboxen/PDMS fiber was used. All samplings were performed in triplicate (i.e. 10g of banana samples for 3 trials).

3.2.5.4.3. Gas Chromatography

Gas chromatographic analysis was carried out as mentioned in section 3.2.5.1.3. except that the volatile compounds adsorbed on the fiber were thermally desorbed in a splitless mode and the column temperature was held at 35°C for 5 minutes, increased to 120°C at 3°C/min, and then to 180°C at 6°C/min.

3.2.6. Sensory Analysis of Banana Chips

Sensory descriptive evaluation (Poste et al., 1991) was carried out to determine the effect of drying methods on the aroma and flavor intensity of banana chip samples. Sensory analysis was performed in triplicate, with one panel session per week and with a total of three panel sessions per study. All panels were performed from 10:00 am to 12:00 am in the morning. In each session, panelists were asked to evaluate the aroma and flavor intensity of a complete set of banana chip samples once. A sensory score sheet with a 15-cm unstructured line scale, each with anchor points at 1.5cm from each end and at the midpoint, was provided to evaluate each sensory attribute of the chip samples. Panelists
were asked to mark a vertical line across the unstructured line at the point that best reflected their evaluation of the intensity of each attribute. The sensory score sheets used in this study are shown in figure 1A and 1B.
Sensory evaluation of VMD banana chips

Name: ___________________________ Date: ___________________________

Please evaluate the aroma of these samples of banana chips. Make a vertical line on the horizontal line to indicate your rating of the banana aroma of each sample. Label each vertical line with the code number of the sample it represents.

Please bring the container to your nose, remove the lid and take 3 short sniffs to evaluate the banana aroma. Then, replace the lid on the container for headspace saturation in case you want to reevaluate the sample. As a blank, please sniff fresh air for about 15 seconds between samples. A reference standard of strong banana aroma has been given, please feel free to refer back to it whenever you need.

Please evaluate the samples in the following order:

________, ________, ________, ________, ________, ________

Aroma:

1. Banana aroma

   (reference)

   weak           moderate          strong

Comments:

Figure 1A. Sensory score sheet used in the study on the effect of drying methods on the aroma intensity of the banana chip samples.
Sensory evaluation of VMD banana chips

Please evaluate the flavor of these samples of banana chips in terms of banana flavor and off flavor. Make a vertical line on the horizontal line to indicate your rating of each sample. Label each vertical line with the code number of the sample it represents.

Please taste the banana chip and then chew at least five times to evaluate the banana flavor and off flavor. Please rinse your mouth with water before you begin tasting and also between each sample. Crackers are also provided to clear the mouth between samples. A reference standard has been given, please feel free to refer back to it whenever you need.

Please evaluate the samples in the following order:

__________________________

Flavor:

1. Banana flavor

   (reference)

   none               moderate               strong

2. Off flavor

   (reference)

   none               moderate               strong

Comments:

Figure 1B. Sensory score sheet used in the study on the effect of drying methods on the flavor and off-flavor intensity of the banana chip samples.
3.2.6.1. Selection and Training of Sensory Panelists

A group of six panelists with sensory evaluation experience were recruited from the students of the Food Science Program at the University of British Columbia. These selected panelists generally enjoyed eating snacks and showed interest in the experiment.

A total of four training sessions were conducted. The purposes of training were to familiarize the panelists with the sensory test method, the sensory score sheet, the scale and the descriptive terms used on the score sheet, the techniques used in the evaluation, and the utilization of the reference standards. The training sessions were also intended to determine whether evaluation of seven chip samples per sensory session would induce fatigue in the panelists.

Training sessions were conducted in a round table format (Rutledge and Hudson, 1990), and open discussions among the panelists were encouraged. During the sessions, fresh banana slices and chip samples with various degree of aroma and flavor intensity were presented to the panelists. Slices of unripe (green), ripe (yellow) and fully ripe (yellow with few brown spots) banana, were presented to familiarize the panelists with banana flavor and to expose the panelists to a range of aroma and flavor intensities. Slices of fully ripe bananas were used as reference standards for strong banana aroma, for a level midway between moderate and strong banana flavor and for 'none' on the scale of off-flavor.

During training, the panelists were asked to bring the container to their noses, remove the container lid, take three sniffs, and evaluate and record the aroma intensity of the chip samples using the sensory score sheet. Subsequently, the panelists were asked to take a bite and chew the samples at least five times in the mouth to assess the flavor and
off-flavor attributes. Spring water and crackers were provided to the panelists for rinsing their mouths and cleansing their palates between samples.

Also, in order to determine whether evaluation of seven chip samples per sensory session would induce fatigue in the panelists, the chip samples prepared from the drying treatments were divided into two batches and four chip samples per batch were presented to the panelists at a time. However, the panelists found that this presentation of samples make them difficult to compare the aroma and flavor intensity of all the seven samples. When the panelists evaluated all seven treatment samples at the same time, they found that it would be easy for them to compare the samples and would not induce any fatigue.

3.2.6.2. Experimental Design for the Sensory Panel

The sensory tests were conducted in the sensory panel room of the Food Science Building at the University of British Columbia. The sensory panels were conducted under red fluorescent light to minimize the effect of the banana chip color on the assessment of the aroma and flavor attributes. During preparation, three banana chips from each of the seven drying treatments were placed in a lid-closed small plastic container that was labeled with a random three-digit code. During the sensory panel, each panelist received all seven treatment samples at the same time on a paper plate. Panelists were asked to evaluate the banana chip samples using the same techniques as in the training sessions except that the evaluations were carried out individually in booths and no communication was allowed. Slices of fully ripe banana were provided as reference standards. After each panel session, a small treat was given to the panelists.
3.2.7. Textural Analysis of Banana Chips

The banana chip samples from the replicates of the seven drying treatments were packed in individual cheesecloth bags, which were then sealed in an airtight plastic bag. The chip samples were allowed to equilibrate at room temperature for fourteen days until the samples reached the same water activity prior to analysis.

3.2.7.1. Instrumental Measurements

The texture of the banana chip samples was measured using a Texture Analyzer (TAXT2, Stable Micro System Ltd., Surrey, England). Prior to the beginning of analyses, the texture analyzer was calibrated using a 5.0kg load. The test speed was set at 7.0mm/s, and the penetration depth of probe was at 12.0mm. Each chip sample was centered on a 10.1cm x 8.8cm metal base with a 1cm hole at the center of the base, and the sample was then fractured using a No. 5 flat-ended probe. The slope (g/mm), the peak force (g) and the distance (mm) of the first peak were recorded. Fifteen measurements of the slope, the peak force and the distance were obtained from each replicate of the seven drying treatments. A total of 45 measurements were obtained and then averaged.

3.2.8. Scanning Electron Microscopy (SEM)

The microstructure of the banana chip samples was examined in duplicate using SEM. The chip sample was first dipped in liquid nitrogen for about five seconds and then fragmented into small pieces using forceps. The chip fragment was attached onto a SEM stub and subsequently coated with gold (~25nm) using the Nanotech SEMPREP II Sputter Gold Coater, and then examined using the scanning electron microscope.
(Stereoscan 250, Cambridge Instruments Ltd., Cambridge, UK). Polaroid pictures were taken and processed as specified by the manufacturer.

3.2.9. Color Analysis of Banana Chips

The color of banana chip samples was evaluated in triplicate using a Hunter LabScan II Spectrocolorimeter (Hunter Lab, Reston, VA) with a 2.50cm aperture. A 10g sample of banana chips was ground by mortar and pestle, and the banana chip powder was placed in a 10-cm Petri dish and positioned over the viewing area of the colorimeter. Six measurements of Hunter L, a and b value **Godavari** were performed for each sample by rotating the Petri dish 60° to the right, and the measurements were then averaged. The instrument, equipped with a D_65_ illuminant and 2°-observer optical position, was standardized using a black plate and a white plate (No. LS-13685, X = 79.8, Y = 84.67, Z = 91.23).

3.3. Statistical Analysis

Minitab statistical software, version 12.1, was used to perform statistical analyses of the data collected from the experiments. Two-sample t test was performed to examine the effect of sulfite on the headspace volatiles of banana, and the confidence level was set at 95%. One-way analysis of variance was performed to examine the effects of drying method on the flavor, texture and color of banana. Differences among treatments were further assessed using Tukey's multiple comparison test, and the treatments were considered significantly different when p ≤ 0.05.
3.3.1. Z-Score Transformation of Data for Sensory Analysis

General linear model of analysis of variance was performed to examine the effects of drying method, replicate and panelist on the aroma and flavor attributes of the banana chip samples. However, a significant panelist effect was observed, suggesting that the panelists were using different parts of the scale during the panels. Therefore, the sensory scores were transformed using the following equation in order to standardize the scores obtained from different panelists (Reid and Durance, 1992).

\[ Z = \frac{(x - X)}{s.d.} \]  

where \( Z \) is the transformed score, \( x \) is the actual sensory scores obtained from a panelist for a specific sensory attribute; \( X \) and \( s.d. \) are the mean and the standard deviation of all the scores from the same panelists for the sensory attribute, respectively. A general linear model of analysis of variance was again performed using the Z-scores to determine the effects of drying method, replicate and panelist on the sensory attributes of the samples. Differences among treatments were further assessed using Tukey's multiple comparison test, and the treatments were considered significantly different when \( p \leq 0.05 \).
4. Results and Discussion

4.1. Inhibition of Banana Polyphenoloxidase (PPO)

Polyphenoloxidase (PPO) is a multifunctional oxidase that catalyzes the oxidation of mono- and di-phenols (colorless) to o-quinones (red or reddish brown), which then polymerize spontaneously to form high molecular weight compounds, melanins (brown), or react with amino acids or proteins to enhance the formation of brown pigments.

PPO is mostly located in the inner portion of banana pulp (Galeazzi et al., 1981). It is a copper-containing enzyme (Richardson and Hyslop, 1985), and the optimum pH for its activity is between pH 5 and 7 (Sapers, 1993). The enzyme is relatively heat labile and can be inhibited by agents such as chelators, acidifiers and reducing agents (Sapers, 1993).

In this experiment, the banana slices were dipped into anti-browning agents for 2.5 minutes but the amount of dipping time has not been optimized. Since different anti-browning agents diffuse into the cellular matrix of the banana tissues at different degrees, the amount of dipping time could be a factor in determining the inhibitory effect of the anti-browning agent on the PPO activity.

4.1.1. PPO Inhibition Using Citric Acid and Sodium Acid Pyrophosphate

Figure 2 shows the effect of citric acid and mixtures of citric acid and sodium acid pyrophosphate on the PPO activity in bananas. The 1% & 2% citric acid and mixtures of 1% & 2% citric acid with 0.2% pyrophosphate only had a minimal inhibiting effect on banana PPO. The pH of the banana slices after being dipped into these solution mixtures was measured using pH paper and was found to be around pH 2.0, irrespective of the acid
Figure 2. Effect of Citric Acid and Sodium Acid Pyrophosphate on PPO Activity in Banana

Experiments were done in triplicate. All measurements were performed in triplicate on three samples and recorded as mean ± standard error mean. % PPO Inhibition was calculated as (PPO activity of control - PPO activity of treated banana slices) / (PPO activity of control) x 100
concentrations. In addition, these acidic solutions can only be used at low concentration because they may impart an off or sour taste to the fruit slices (Vamos-Vigyazo, 1995). Therefore, citric acid and sodium acid pyrophosphate could act as both acidulent and chelating agents to decrease the pH of the food system to below 3 where PPO is inactive and to either complex the copper prosthetic group, which is essential to the function of the enzyme PPO, or reduce the level of copper available in the food system for incorporation into the enzyme (McEvily et al., 1992). However, the 1% & 2% citric acid and mixtures of 1% & 2% citric acid with 0.2% pyrophosphate only had a minimal inhibiting effect on the PPO activity in bananas. This observation could be explained by the fact that the chelating agents could only slow down the enzymatic browning reaction but could not completely eliminate the occurrence of the browning reaction (Lambrecht, 1995).

4.1.2. PPO Inhibition Using Ascorbic Acid, Citric Acid and 4-Hexylresorcinol

4.1.2.1. Mixture of Ascorbic Acid and Citric Acid

Ascorbic acid is frequently used as an anti-browning agent in the food industry, and it acts as a reducing agent in the prevention of enzymatic browning by chemically reducing the o-quinones back to the di-phenols (McEvily et al., 1992).

Figure 3 shows the effect of mixtures of ascorbic acid and citric acid on the PPO activity in banana. Mixtures of 1% ascorbic acid with 1% & 2% citric acid did not inhibit, but rather activated PPO. This phenomenon could be due to an insufficient concentration of ascorbic acid, which at a low concentration, might promote oxidation or act as a prooxidant. Pizzocaro et al. (1993) reported that ascorbic acid in concentrations between
Figure 3. Effect of Ascorbic Acid, Citric Acid and 4-Hexylresorcinol on PPO Activity in Banana

Experiments were done in triplicate. All measurements were performed in triplicate on three samples and recorded as mean + / - standard error mean. % PPO Inhibition was calculated as (PPO activity of control - PPO activity of treated banana slices) / (PPO activity of control) x 100.
0.02% & 1% did not inhibit but rather activated PPO in apple. Olsen and Brown (1942) reported that ascorbic acid promoted oxidation in milk products. Kanner et al. (1977) also reported that ascorbic acid, especially in the presence of transition metal ions, exhibited a prooxidant effect on the linoleate-mediated oxidation of beta-carotene. Previous studies also reported that ascorbic acid acted as a prooxidant at low concentrations, but acted as an antioxidant at high concentrations, when added to milk cream (Bauernfeind and Pinkert, 1970) and meat (Sato and Hegarty, 1971).

The effect of ascorbic acid on the prevention of browning was only temporary, especially when this reducing agent was at a low concentration, because this compound was oxidized irreversibly when reacting with the o-quinones. Ascorbic acid could easily be oxidized by the enzyme polyphenoloxidase. Once all the ascorbic acid was oxidized, the o-quinones could no longer be reduced and could undergo oxidative polymerization to yield brown melanin pigments. In addition, ascorbic acid could easily be oxidized by iron or copper-catalyzed auto-oxidation to form dehydroascorbic acid, which could then react with amino acids via the Maillard reaction, a non-enzymatic reaction, to yield brown pigments. Furthermore, ascorbic acid was reported to insufficiently penetrate into the cellular matrix of fruits, thus limiting the efficiency of this agent in the prevention of browning (Iyengar and McEvily, 1992; McEvily et al., 1992; Sapers, 1993).

According to Figure 3, mixtures of 2% ascorbic acid with 1% & 2% citric acid inhibited PPO by 13.5% and 21.8% respectively. In addition to the reducing effect of ascorbic acid and the acidulent and chelating effects of citric acid in controlling enzymatic browning as mentioned above, citric acid could exert a protective effect on
ascorbic acid by chelating trace metals, such as iron and copper, to slow down the auto-oxidation of ascorbic acid (Langdon, 1987).

4.1.2.2. Mixtures of Ascorbic Acid, Citric Acid and 4-Hexylresorcinol

4-Hexylresorcinol is the active ingredient in Everfresh™, and sodium chloride is the carrier agent in this patented product (Lambrecht, 1995). 4-Hexylresorcinol is used as an anti-browning agent in controlling enzymatic browning in crustaceans (Sapers, 1993), and this compound was also proposed for using in various fruits and vegetables (McEvily et al., 1991). Both 4-hexylresorcinol and sodium chloride are PPO inhibitors and can exert an inhibiting effect on the enzyme PPO in the prevention of enzymatic browning (Sapers, 1993).

Figure 3 shows the effect of mixtures of ascorbic acid, citric acid and 4-hexylresorcinol on PPO activity in bananas; mixtures of ascorbic acid, citric acid and 4-hexylresorcinol inhibited PPO activity. 4-Hexylresorcinol increased the inhibiting effect of ascorbic acid and citric acid; when 0.2% 4-hexylresorcinol was added to the mixtures of ascorbic acid and citric acid, the PPO inhibition increased from approx. -10% to 20%, to 50% to 60%. In addition to the reducing effect of ascorbic acid and the acidulent and chelating effects of citric acid, 4-hexylresorcinol could interact with PPO and therefore render the enzyme incapable of catalyzing the enzymatic browning reaction (Lambrecht, 1995). Further, 4-hexylresorcinol could prolong the retention and thus the reducing effect of ascorbic acid by suppressing the activity of PPO (Luo and Barbosa-Canovas, 1995). Still, this compound cannot be used at high concentrations in combination with citric acid and ascorbic acid to obtain a 100% PPO inhibition, because it may impart an off or salty
flavor to the fruit slices (McEvily et al., 1992). Additionally, sodium chloride could exert an inhibiting effect on the enzymatic browning of banana slices. The inhibitory effect of sodium chloride was attributed to the chloride anion, which could inhibit PPO by either sterically hindering the enzyme or binding to the copper prosthetic group at the enzyme active site, thereby rendering the enzyme incapable of catalyzing the browning reaction (Lambrecht, 1995).

4.1.3. PPO Inhibition Using Citric Acid and Potassium metabisulfite

Figure 4 shows the effect of potassium metabisulfite and mixtures of citric acid and potassium metabisulfite on PPO activity in bananas. According to this Figure, potassium metabisulfite inhibited PPO activity. The concentration of potassium metabisulfite was positively related to the inhibition of the PPO; 2000 ppm metabisulfite inhibited 85.3% PPO activity.

Sulfites can control enzymatic browning in several ways. Firstly, sulfites could act as reducing agents to reduce the colored o-quinones back to the colorless di-phenols (Iyengar and McEvily, 1992). Secondly, sulfites might interact with the intermediates in the reaction, such as o-quinones to form sulfite-quinone complexes, and thus remove these intermediates from the reaction, and hence prevent the formation of brown pigment (Sayavedra-Soto and Montgomery, 1986; Taylor et al., 1986). Lastly, sulfites might irreversibly inhibit the enzyme PPO by modifying the protein structure of the enzyme (Sayavedra-Soto and Montgomery, 1986).

According to Figure 4, mixtures of citric acid and potassium metabisulfite inhibited PPO activity. Citric acid increased the inhibiting effect of potassium
Figure 4. Effect of Citric Acid and Potassium Metabisulfite on PPO Activity in Banana

Experiments were done in triplicate. All measurements were performed in triplicate on three samples and recorded as mean ± standard error mean. % PPO Inhibition was calculated as (PPO activity of control - PPO activity of treated banana slices) / (PPO activity of control) x 100. Significant differences between treatments were determined by Tukey’s multiple comparison test, and any two value not followed by the same letter are significant different at p ≤ 0.05.
metabisulfite, and with a mixture of 2% citric acid and 2000 ppm metabisulfite, completely inhibited PPO activity. Thus, the solution of 2% citric acid and 2000 ppm potassium metabisulfite was preliminarily used as an anti-browning agent to control enzymatic browning in the preparation of banana chips. However, this solution imparted an off and sour taste to the dried products. Therefore, the solution of 2000 ppm potassium metabisulfite was used instead in the preparation of banana chips for the remainder of the experiment.

4.2. Flavor Analysis of Banana Chips

4.2.1. Maturity Stage of Bananas

The maturity stage of the banana samples was assessed by measuring skin color and by determining starch content using the iodine-staining method. The banana samples with skin colors having L values of $52.1 \pm 1.8$, $a$ values of $8.83 \pm 0.59$, and $b$ values of $22.6 \pm 1.4$ were used, and the samples with starch contents having L values of $41.3 \pm 1.5$, $a$ values of $4.73 \pm 0.44$, and $b$ values of $14.9 \pm 0.9$ were used.

4.2.2. Dynamic Headspace Sampling

Dynamic headspace sampling technique was initially employed to extract and concentrate the volatile compounds of the banana chip samples. However, this sampling technique was not sensitive enough to extract adequate volatile components for carrying out a gas chromatographic analysis. Firstly, only trace amounts of aroma compounds were retained in the banana slices after being dried. Secondly, some extracted volatile
components might also be lost during the removal of diethyl ether in the concentration step.

4.2.3. Solid Phase Microextraction (SPME)

Solid phase microextraction (SPME) can be a satisfactory alternative technique to the dynamic headspace technique in extracting and concentrating the volatile components of the banana chip samples. Solid phase microextraction (SPME) is an adsorption and desorption technique. SPME is fast and not too labor intensive. This technique eliminates the use of solvents or complicated apparatus for concentrating volatile or non-volatile compounds during headspace or liquid sampling. This technique is compatible with any packed or capillary column or gas chromatograph or gas chromatograph - mass spectrometer system (Zhang et al., 1994).

4.2.3.1. Selection of SPME Fiber

Three types of SPME fibers are recommended by the manufacturer to carry out flavor and odor analysis; they are the 100μm polydimethylsiloxane (PDMS) fiber, the 65μm polydimethylsiloxane / divinylbenzene (PDMS / DVB) fiber, and the 75μm carboxen / polydimethylsiloxane (Carboxen / PDMS) fiber.

Since these fibers are coated with different adsorbents, they adsorb the headspace volatiles of the VMD banana chip samples selectively. PDMS is a non-polar coating that extracts a wide range of volatile compounds, both polar and non-polar (Boyd-Boland et al., 1994). This coating is often used as the stationary phase of the capillary GC column and can withstand temperatures up to 300°C (Elsert and Pawliszyn, 1997). PDMS / DVB
is a more polar coating that extracts more polar volatile compounds, such as alcohols and amines. This thin coating allows the adsorption and desorption of volatile compounds to occur more efficiently. Carboxen / PDMS is a coating claimed for trace-level volatile analysis. This coating is made by adding the carboxen adsorbent material to the PDMS, thereby increasing the available surface area and improving the extraction of small volatile components; the small pores in carboxen are particularly effective in extracting C2 – C5 molecules (Elsert and Pawliszyn, 1997). Compared to the adsorbent material used in dynamic headspace sampling, Tenax is a porous polymer based on 2,6-diphenylene oxide and designed for the trapping of volatiles and semi-volatiles in liquid or solid samples. Nevertheless, the selectivity of this adsorbent material is not as great as that of the SPME fibers (Maier and Fieber, 1988).

In order to select the most efficient fiber to adsorb the headspace volatiles of the banana chip samples, three volatile compounds commonly found in fully ripe bananas were used in this study; these compounds were isobutylacetate, 2-methylbutylacetate and isoamylacetate. A typical gas chromatogram of these three volatile compounds adsorbed using Carboxen / PDMS fiber is shown in Figure 5. The peak areas of these three volatile compounds adsorbed using PDMS, PDMS / DVB and Carboxen / PDMS fibers are compared in Figure 6.

According to these Figures, the Carboxen / PDMS was the most efficient fiber for adsorbing all three volatile compounds; this result showed that the partitioning of these volatile compounds into the Carboxen / PDMS fiber coating was greater compared to the PDMS and PDMS / DVB coatings. As mentioned above, Carboxen / PDMS coating is made by adding the carboxen adsorbent material onto the PDMS, and thus increases the
Figure 5. Gas Chromatogram of Isobutylacetate, 2-Methylbutylacetate and Isoamylacetate adsorbed using 75μm Carboxen / PDMS Fiber

SPME headspace samplings were performed in triplicate at 40°C for 30 minutes.
Figure 6. Effects of Three Types of SPME Fiber on the Adsorption of Isobutylacetate, 2-Methylbutyl-acetate and ISOamylacetate

SPME headspace samplings were performed in triplicate at 40°C for 30 minutes. All measurements were recorded as mean + / - standard error mean. Significant differences between treatments were determined by Tukey's multiple comparison test, and any two value not followed by the same letter are significantly different at p < 0.05.
surface areas available for adsorption and hence can extract more small volatile compounds. Also, since most volatile components in bananas are small polar components, and since the Carboxen / PDMS fiber is especially effective in extracting C2–C5 polar compounds, this fiber was used in the remainder of the experiment to analyze the headspace volatile compounds of the banana chip samples.

4.2.3.2. Optimization of SPME Parameters

Sampling temperature and time are the two SPME parameters known to affect the sensitivity of the SPME procedure (Clark and Bunch, 1997). As mentioned before, the principle of SPME is the partition of the volatile compound between the fiber coating and the sample matrix; the partition coefficient of the analyte is strongly dependent on temperature and time (Zhang and Pawliszyn, 1993; Zhang et al., 1994). Therefore, heating the sample matrix releases more analytes into the headspace, thereby facilitating the SPME extraction. However, as the sampling temperature increases, the fiber coating begins to lose its ability to adsorb analytes. Additionally, as the sampling time increases, this effect will become significant. Therefore, the sampling temperature and time should be optimized to determine optimum conditions, thereby obtaining a maximum extraction of analytes. In this study, Random Centroid Optimization (RCO) was used to optimize these two SPME parameters. This program was employed to optimize two sets of data. The first set of data was obtained using the peak area of isoamylacetate; the second set was obtained using the total peak areas of the 5 main peaks, in which 3 of the 5 peaks were identified by comparing the retention times of the three standard solutions.
These two sets of data are listed in Table 1. The mappings of these data are shown in Figures 7 and 8; the mapping lines were found to converge to a point where maximum extraction of analytes was obtained and the optimum sampling temperature and time were found to be 50°C and 30 minutes respectively. These optimum parameters were used to analyze the headspace volatile compounds of the banana chip samples in the remainder of the experiments.

4.2.4. Effects of Drying Methods on Headspace Volatiles of Bananas

The gas chromatograms of banana chips prepared from different drying technique (i.e. 60AD/40VMD, 70AD/30VMD, 80AD/20VMD, 90AD/10VMD, 100AD, 100VMD, and 100FD) are given in Figures 9, 10, 11, 12, 13, 14 and 15 respectively. The gas chromatogram of fresh bananas is given in Figure 16. A total of 16 volatile compounds was extracted from 100FD banana chip samples and identified by GC/MS (Table 2), and several high boiling point volatile compounds were also extracted but were not identified. The 16 volatile compounds, were mainly esters of acetates and butanoates, and also included alcohol and carbonyl compounds. No unreported compound was identified. Esters accounted for 49.8% of the total volatile compounds extracted from fresh bananas and represented the dominant group of compounds in ripe banana fruit (Table 2). Acetates accounted for 36.9% of the total volatile compounds, with ethyl acetate (16.3%) being the major component. Perez et al. (1997) reported that ethyl acetate was the major component in Valery banana. Isoamylacetate (9.6%) imparted the characteristic aroma typical of fresh bananas (Issenberg and Wick, 1963; McCarthy et al., 1964; Murray et al., 1968; Ali et al., 1984; Perez et al., 1997), while butyl acetate (8.1%) and isobutylacetate
Table 1. Random Centroid Optimization (RCO) of Sampling Temperature & Time, and Results using the Peak Area of Isoamylacetate & 5 Main Peaks

<table>
<thead>
<tr>
<th>Trial #</th>
<th>Temperature (°C)</th>
<th>Time (min)</th>
<th>Peak Area</th>
<th>5 main peaks</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>40</td>
<td>25</td>
<td>17000</td>
<td>74000</td>
</tr>
<tr>
<td>2</td>
<td>50</td>
<td>30</td>
<td>62200</td>
<td>206000</td>
</tr>
<tr>
<td>3</td>
<td>55</td>
<td>15</td>
<td>27000</td>
<td>107100</td>
</tr>
<tr>
<td>4</td>
<td>55</td>
<td>60</td>
<td>40000</td>
<td>125000</td>
</tr>
<tr>
<td>5</td>
<td>50</td>
<td>40</td>
<td>57200</td>
<td>188300</td>
</tr>
<tr>
<td>6</td>
<td>45</td>
<td>20</td>
<td>26300</td>
<td>95000</td>
</tr>
<tr>
<td>7</td>
<td>60</td>
<td>30</td>
<td>31800</td>
<td>84600</td>
</tr>
<tr>
<td>8</td>
<td>43</td>
<td>50</td>
<td>35500</td>
<td>147000</td>
</tr>
<tr>
<td>9</td>
<td>40</td>
<td>45</td>
<td>40600</td>
<td>179900</td>
</tr>
<tr>
<td>10</td>
<td>50</td>
<td>33</td>
<td>34400</td>
<td>122000</td>
</tr>
<tr>
<td>11</td>
<td>45</td>
<td>35</td>
<td>14100</td>
<td>57600</td>
</tr>
</tbody>
</table>

1 11 random combinations of sampling temperature and time were suggested from RCO.
2 Sampling temperature ranging from 40 to 60°C, and sampling time ranging from 15 to 60 minutes were chosen to carry out RCO.
3 All experiments were performed in duplicate. All peak areas were recorded as mean.
Figure 7. Mapping Result of Sampling Temperature and Time using Peak Area of Isoamylacetate by the RCO Program. The Arrow Represents the Maximum Temperature or Time

Figure 7A shows the mapping result of sampling temperature. The x-axis represents the sampling temperature and the y-axis represents the peak area of Isoamylacetate obtained from gas chromatograms.

Figure 7B shows the mapping result of sampling time. The x-axis represents the sampling time and the y-axis represents the peak area of Isoamylacetate obtained from gas chromatograms.
Figure 8. Mapping Result of Sampling Temperature and Time using Peak Area of the 5 Main Peaks by the RCO Program. The Arrow Represents the Maximum Temperature or Time.

Figure 8A shows the mapping result of sampling temperature. The x-axis represents the sampling temperature and the y-axis represents the peak areas of the 5 main peaks obtained from gas chromatograms.

Figure 8B shows the mapping results of sampling time. The x-axis represents the sampling time and the y-axis represents the peak areas of the 5 main peaks obtained from gas chromatograms.
Figure 9. Gas Chromatogram of 60% Air-Dried & 40% Vacuum-Microwave Dried (60AD/40VMD) Banana Chips

Numbers correspond to compounds identified by GC/MS in Table 2. Caproic acid ethyl ester was used as an internal standard (IS).
Figure 10. Gas Chromatogram of 70% Air-Dried & 30% Vacuum-Microwave Dried (70AD/30VMD) Banana Chips

Numbers correspond to compounds identified by GC/MS in Table 2. Caproic acid ethyl ester was used as an internal standard (IS).
Figure 11. Gas Chromatogram of 80% Air-Dried & 20% Vacuum-Microwave Dried (80AD/20VMD) Banana Chips

Numbers correspond to compounds identified by GC/MS in Table 2. Caproic acid ethyl ester was used as an internal standard (IS).
Figure 12. Gas Chromatogram of 90% Air-Dried & 10% Vacuum-Microwave Dried (90AD/10VMD) Banana Chips

Numbers correspond to compounds identified by GC/MS in Table 2. Caproic acid ethyl ester was used as an internal standard (IS).
Figure 13. Gas Chromatogram of 100% Air-Dried (100AD) Banana Chips

Numbers correspond to compounds identified by GC/MS in Table 2. Caproic acid ethyl ester was used as an internal standard (IS).
Figure 14. Gas Chromatogram of 100% Vacuum-Microwave Dried (100VMD) Banana Chips

Numbers correspond to compounds identified by GC/MS in Table 2. Caproic acid ethyl ester was used as an internal standard (IS).
Figure 15. Gas Chromatogram of 100% Freeze-Dried (100FD) Banana Chips.

Numbers correspond to compounds identified by GC/MS in Table 2. Caproic acid ethyl ester was used as an internal standard (IS).
Figure 16. Gas Chromatogram of Fresh Banana

Numbers correspond to compounds identified by GC/MS in Table 2. Caproic acid ethyl ester was used as an internal standard (IS).
Table 2. Effect of Drying Methods on the Relative Concentration of Volatile Compounds of Banana Chips

<table>
<thead>
<tr>
<th>Peak #</th>
<th>Volatile compounds</th>
<th>60AD / 40VMD</th>
<th>70AD / 30VMD</th>
<th>80AD / 20VMD</th>
<th>90AD / 10VMD</th>
<th>100AD</th>
<th>100VMD</th>
<th>100FD</th>
<th>p</th>
<th>Fresh Banana 5</th>
<th>% of each cmpd to the total volatile cmpd of fresh banana</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Ethyl acetate</td>
<td>0.25 d</td>
<td>0.38 cd</td>
<td>0.25 d</td>
<td>0.61 b</td>
<td>0.57 bc</td>
<td>0.38 cd</td>
<td>1.62 a</td>
<td>0.00</td>
<td>(0.20)</td>
<td>3.26</td>
</tr>
<tr>
<td>2</td>
<td>3-Methyl butanal</td>
<td>0.34 b</td>
<td>0.21 bcd</td>
<td>0.28 bc</td>
<td>0.10 d</td>
<td>0.50 a</td>
<td>0.17 cd</td>
<td>0.52 a</td>
<td>0.00</td>
<td>(0.01)</td>
<td>1.29</td>
</tr>
<tr>
<td>3</td>
<td>2-Pentanone</td>
<td>1.01 b</td>
<td>1.32 a</td>
<td>0.77 bc</td>
<td>0.55 cd</td>
<td>0.41 d</td>
<td>0.54 cd</td>
<td>1.33 a</td>
<td>0.00</td>
<td>(0.09)</td>
<td>1.95</td>
</tr>
<tr>
<td>4</td>
<td>Isobutyl acetate</td>
<td>0.025 c</td>
<td>0.085 b</td>
<td>0.097 b</td>
<td>0.10 b</td>
<td>0.024 c</td>
<td>0.000 c</td>
<td>0.20 a</td>
<td>0.00</td>
<td>(0.01)</td>
<td>0.28</td>
</tr>
<tr>
<td>5</td>
<td>Ethyl butanoate</td>
<td>0.000 c</td>
<td>0.000 c</td>
<td>0.000 c</td>
<td>0.012 b</td>
<td>0.017 b</td>
<td>0.000 c</td>
<td>0.036 a</td>
<td>0.00</td>
<td>(0.01)</td>
<td>0.054</td>
</tr>
<tr>
<td>6</td>
<td>Butyl acetate</td>
<td>0.043 de</td>
<td>0.11 d</td>
<td>0.19 c</td>
<td>0.32 b</td>
<td>0.082 de</td>
<td>0.017 e</td>
<td>0.69 a</td>
<td>0.00</td>
<td>(0.04)</td>
<td>1.63</td>
</tr>
<tr>
<td>7</td>
<td>Isoamyl acetate</td>
<td>0.15 d</td>
<td>0.39 c</td>
<td>0.45 c</td>
<td>0.69 b</td>
<td>0.23 d</td>
<td>0.016 e</td>
<td>1.20 a</td>
<td>0.00</td>
<td>(0.07)</td>
<td>1.92</td>
</tr>
<tr>
<td>8</td>
<td>1-Butanol</td>
<td>0.0088 d</td>
<td>0.019 d</td>
<td>0.024 cd</td>
<td>0.062 b</td>
<td>0.049 bc</td>
<td>0.000 d</td>
<td>0.11 a</td>
<td>0.00</td>
<td>(0.05)</td>
<td>0.15</td>
</tr>
<tr>
<td>9</td>
<td>Isobutyl butanoate</td>
<td>0.023 cd</td>
<td>0.028 c</td>
<td>0.032 c</td>
<td>0.13 a</td>
<td>0.076 b</td>
<td>0.000 d</td>
<td>0.094 b</td>
<td>0.00</td>
<td>(0.01)</td>
<td>0.31</td>
</tr>
<tr>
<td>10</td>
<td>2-Heptanoate</td>
<td>0.000 c</td>
<td>0.000 c</td>
<td>0.000 c</td>
<td>0.000 c</td>
<td>0.054 a</td>
<td>0.000 c</td>
<td>0.012 b</td>
<td>0.00</td>
<td>(0.04)</td>
<td>0.054</td>
</tr>
<tr>
<td>11</td>
<td>Methyl hexanoate</td>
<td>0.14 c</td>
<td>0.19 b</td>
<td>0.096 cd</td>
<td>0.087 d</td>
<td>0.22 ab</td>
<td>0.25 a</td>
<td>0.097 cd</td>
<td>0.00</td>
<td>(0.07)</td>
<td>1.4</td>
</tr>
<tr>
<td>12</td>
<td>2-Hexenal</td>
<td>0.16 bc</td>
<td>0.32 bc</td>
<td>0.31 bc</td>
<td>0.39 bc</td>
<td>0.54 b</td>
<td>0.006 c</td>
<td>3.77 a</td>
<td>0.00</td>
<td>(0.14)</td>
<td>4.00</td>
</tr>
<tr>
<td>13</td>
<td>Isoamyl butanoate</td>
<td>0.11 c</td>
<td>0.39 b</td>
<td>0.66 a</td>
<td>0.83 a</td>
<td>0.29 b</td>
<td>0.031 c</td>
<td>0.30 b</td>
<td>0.00</td>
<td>(0.10)</td>
<td>1.51</td>
</tr>
<tr>
<td>14</td>
<td>Hexyl acetate</td>
<td>0.067 b</td>
<td>0.13 a</td>
<td>0.10 a</td>
<td>0.10 a</td>
<td>0.036 bc</td>
<td>0.016 c</td>
<td>0.12 a</td>
<td>0.00</td>
<td>(0.02)</td>
<td>0.29</td>
</tr>
<tr>
<td>15</td>
<td>3-Hydroxy-2-butanoate</td>
<td>0.13 bc</td>
<td>0.16 b</td>
<td>0.16 b</td>
<td>0.21 a</td>
<td>0.096 c</td>
<td>0.018 d</td>
<td>0.10 c</td>
<td>0.00</td>
<td>(0.01)</td>
<td>0.47</td>
</tr>
<tr>
<td>16</td>
<td>1-Hexanol</td>
<td>0.049 de</td>
<td>0.10 cd</td>
<td>0.12 c</td>
<td>0.22 b</td>
<td>0.15 c</td>
<td>0.020 e</td>
<td>0.43 a</td>
<td>0.00</td>
<td>(0.02)</td>
<td>0.55</td>
</tr>
</tbody>
</table>
Table 2 (Continued)

<table>
<thead>
<tr>
<th>---</th>
<th>Total Acetate</th>
<th>0.54 d</th>
<th>1.093 c</th>
<th>1.095 c</th>
<th>1.82 b</th>
<th>0.94 c</th>
<th>0.42 d</th>
<th>3.84 a</th>
<th>0.000</th>
<th>7.38</th>
<th>36.9</th>
</tr>
</thead>
<tbody>
<tr>
<td>---</td>
<td>Total Butanoate</td>
<td>0.14 c</td>
<td>0.41 b</td>
<td>0.69 a</td>
<td>0.97 a</td>
<td>0.39 b</td>
<td>0.030 c</td>
<td>0.43 b</td>
<td>0.000</td>
<td>1.87</td>
<td>9.3</td>
</tr>
<tr>
<td>---</td>
<td>Total Ester</td>
<td>0.81 d</td>
<td>1.70 c</td>
<td>1.88 c</td>
<td>2.88 b</td>
<td>1.55 c</td>
<td>0.71 d</td>
<td>4.36 a</td>
<td>0.000</td>
<td>10.6</td>
<td>53.2</td>
</tr>
<tr>
<td>---</td>
<td>Total of 16 volatile compounds</td>
<td>2.52 d</td>
<td>3.83 bc</td>
<td>3.54 c</td>
<td>4.41 b</td>
<td>3.35 c</td>
<td>1.45 d</td>
<td>10.6 a</td>
<td>0.000</td>
<td>19.1</td>
<td>95.6</td>
</tr>
<tr>
<td>---</td>
<td>Total volatile compounds</td>
<td>3.41 d</td>
<td>5.16 bc</td>
<td>4.84 c</td>
<td>6.37 b</td>
<td>4.02 cd</td>
<td>1.62 e</td>
<td>13.5 a</td>
<td>0.000</td>
<td>20.0</td>
<td>---</td>
</tr>
</tbody>
</table>

1 Relative amount – peak area of volatile compound divided by peak area of internal standard
2 All headspace SPME samplings were performed at 50°C for 30 minutes in triplicate on three banana chip samples, and all measurements were recorded as mean + / - standard error mean
3 Results are considered significantly different at p ≤ 0.050
4 Significant differences between measurements were determined by Tukey’s multiple comparison test, and any two values not followed by the same letter are significant different at p ≤ 0.050
5 All headspace SPME samplings were performed in triplicate at 50°C for 30 minutes for fresh banana and all measurements were recorded as mean + / - standard error mean
6 The relative amounts of volatile components extracted from fresh banana were indicated here only for comparison
(1.4%) were considered to be character impact compounds of banana flavor. Butanoates accounted for 9.3% of the total volatile compounds, including ethyl butanoate (0.3%), isobutylbutanoate (1.5%), and isoamylbutanoate (7.5%). Alcohol and carbonyl compounds also contributed to banana flavor and imparted green-woody notes, including 1-butanol (0.7%), 1-hexanol (2.7%), 2-heptanone (0.3%), 3-hydroxy-2-butanone (2.3%), 3-methylbutanal (6.4%), 2-pentanone (9.7%), and 2-hexenal (20.0%).

Relative amounts of volatile compounds extracted from banana chips prepared using different drying techniques are given in Table 2, and percent retention of volatiles relative to fresh banana is given in Table 3. During SPME sampling, volatile components of banana chips were extracted from 5g of chip samples, i.e. 20g on a wet weight basis, whereas volatile components of fresh banana were extracted from only 10g of banana. Therefore, the relative amounts of volatile compounds extracted from fresh bananas were indicated in Table 2 & 3 only for comparison. According to Table 2, the drying treatment was found to affect the relative amounts of volatile compounds significantly. Almost all volatile compounds decreased as the extent of vacuum microwave drying increased, with the least total volatile compounds, esters, and acetates found in 100VMD banana chips (Figures 17 & 18). 100FD banana chips retained the most total volatile compounds, esters, acetates; 90AD/10VMD banana chips were second in retaining these volatile compounds; lastly 100AD banana chips, compared with 90AD/10VMD banana chips, retained less of these volatile compounds (Figures 17 & 18). Among acetates, isobutylacetate, butyl acetate, and isoamylacetate were considered to be the impact compounds in banana flavor (Issenberg et al., 1963; McCarthy et al., 1964; Murray et al., 1968; Ali et al., 1984; Perez et al., 1997). These volatile compounds followed the same
Table 3. Percent Retention\(^1\) of Volatile Components of Banana Chips Prepared from Different Drying Treatments and Their Molecular Weights, Solubility in Water & Relative Volatilities at Infinite Dilution in Water

<table>
<thead>
<tr>
<th>Peak #</th>
<th>Volatile components</th>
<th>Molecular Weight</th>
<th>Solubility(^2) (g/100ml)</th>
<th>(\alpha_{av}) (^3)</th>
<th>60AD / 40VMD</th>
<th>70AD / 30VMD</th>
<th>80AD / 20VMD</th>
<th>90AD / 10VMD</th>
<th>100AD</th>
<th>100VMD</th>
<th>100FD</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Ethyl acetate</td>
<td>88.11</td>
<td>8</td>
<td>270</td>
<td>7.67</td>
<td>11.7</td>
<td>7.67</td>
<td>18.7</td>
<td>17.5</td>
<td>11.7</td>
<td>49.7</td>
</tr>
<tr>
<td>2</td>
<td>3-Methyl butanal</td>
<td>100.16</td>
<td>N/A (^4)</td>
<td>26.4</td>
<td>16.3</td>
<td>21.7</td>
<td>7.75</td>
<td>38.8</td>
<td>13.2</td>
<td>40.3</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>2-Pentanone</td>
<td>86.14</td>
<td>4.30</td>
<td>110</td>
<td>51.8</td>
<td>67.7</td>
<td>39.5</td>
<td>28.2</td>
<td>21.0</td>
<td>27.7</td>
<td>68.2</td>
</tr>
<tr>
<td>4</td>
<td>Isobutyl acetate</td>
<td>116.16</td>
<td>0.67</td>
<td>N/A</td>
<td>8.93</td>
<td>30.4</td>
<td>34.6</td>
<td>35.7</td>
<td>8.57</td>
<td>0.00</td>
<td>71.4</td>
</tr>
<tr>
<td>5</td>
<td>Ethyl butanoate</td>
<td>116.16</td>
<td>0.68</td>
<td>620</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>22.2</td>
<td>31.5</td>
<td>0.00</td>
<td>66.7</td>
</tr>
<tr>
<td>6</td>
<td>Butyl acetate</td>
<td>116.16</td>
<td>0.68</td>
<td>689</td>
<td>2.64</td>
<td>6.75</td>
<td>11.7</td>
<td>19.6</td>
<td>5.03</td>
<td>1.04</td>
<td>42.3</td>
</tr>
<tr>
<td>7</td>
<td>Isoamyl acetate</td>
<td>130.19</td>
<td>0.20</td>
<td>N/A</td>
<td>7.81</td>
<td>20.3</td>
<td>23.4</td>
<td>35.9</td>
<td>12.0</td>
<td>0.83</td>
<td>62.5</td>
</tr>
<tr>
<td>8</td>
<td>1-Butanol</td>
<td>74.12</td>
<td>6.32</td>
<td>27</td>
<td>5.87</td>
<td>12.7</td>
<td>16.0</td>
<td>41.3</td>
<td>32.7</td>
<td>0.00</td>
<td>73.3</td>
</tr>
<tr>
<td>9</td>
<td>Isobutyl butanoate</td>
<td>144.21</td>
<td>N/A</td>
<td>1160</td>
<td>7.42</td>
<td>9.03</td>
<td>10.3</td>
<td>41.9</td>
<td>24.5</td>
<td>0.00</td>
<td>30.3</td>
</tr>
<tr>
<td>10</td>
<td>2-Heptanone</td>
<td>114.19</td>
<td>0.43</td>
<td>260</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>100.0</td>
<td>0.00</td>
<td>0.00</td>
<td>22.2</td>
</tr>
<tr>
<td>11</td>
<td>Methyl hexanoate</td>
<td>130.19</td>
<td>&lt; 0.1</td>
<td>650</td>
<td>10.0</td>
<td>13.6</td>
<td>6.86</td>
<td>6.21</td>
<td>15.7</td>
<td>17.9</td>
<td>6.93</td>
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<tr>
<td>12</td>
<td>2-Hexenal</td>
<td>98.15</td>
<td>N/A</td>
<td>1460</td>
<td>4.00</td>
<td>8.00</td>
<td>7.75</td>
<td>9.75</td>
<td>13.5</td>
<td>0.15</td>
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</tr>
<tr>
<td>13</td>
<td>Isoamyl butanoate</td>
<td>158.24</td>
<td>N/A</td>
<td>1260</td>
<td>7.28</td>
<td>25.8</td>
<td>43.7</td>
<td>54.9</td>
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<td>2.05</td>
<td>19.9</td>
</tr>
<tr>
<td>14</td>
<td>Hexyl acetate</td>
<td>144.22</td>
<td>N/A</td>
<td>1580</td>
<td>23.1</td>
<td>44.8</td>
<td>34.5</td>
<td>34.5</td>
<td>12.4</td>
<td>5.52</td>
<td>41.4</td>
</tr>
<tr>
<td>15</td>
<td>3-Hydroxy-2-butanol</td>
<td>88.11</td>
<td>Slightly Soluble</td>
<td>N/A</td>
<td>27.7</td>
<td>34.0</td>
<td>34.0</td>
<td>44.7</td>
<td>20.4</td>
<td>3.83</td>
<td>21.3</td>
</tr>
<tr>
<td>16</td>
<td>1-Hexanol</td>
<td>102.18</td>
<td>Slightly Soluble</td>
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<td>8.91</td>
<td>18.2</td>
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<td>40.0</td>
<td>27.3</td>
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<td>Total Butanoate</td>
<td>Total Ester</td>
<td>Total of 16 volatile compounds</td>
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<td>7.64</td>
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<td>17.5</td>
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</tr>
<tr>
<td>17.0</td>
<td>25.8</td>
<td>24.2</td>
<td>31.8</td>
<td>20.1</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1 % Retention of the volatile component was calculated on the basis of the peak area of the component in the banana chip relative to the peak area in the fresh banana.
2 Butler and Ramchandani (1935)
3 Bretty et al. (1969)
4 N/A stands for not available
Figure 17. Effect of Drying Methods on the Relative Concentration of Total Volatile Compounds of Banana Chips

All headspace SPME samplings were performed at 50°C for 30 minutes in triplicate for each of 3 banana chip samples, and all measurements were analyzed using one way ANOVA. The results were recorded as mean ± standard error mean. Significant differences between treatments were determined by Tukey’s multiple comparison test, and any two value not followed by the same letter are significantly different at $p \leq 0.05$. The relative concentration of fresh banana was included here only for comparison.
Figure 18. Effect of Drying Methods on the Retention of Total Acetates and Esters

All headspace SPME samplings were performed at 50°C for 30 minutes in triplicate for each of 3 banana chip samples, and all measurements were analyzed using one way ANOVA. The results were recorded as mean +/− standard error mean. Significant differences between treatments were determined by Tukey’s multiple comparison test, and any two value not followed by the same letter are significantly different at p ≤ 0.05. The relative concentration of fresh banana was included here only for comparison.
trend of decline with increasing amounts of vacuum microwave drying; again, the least was found in 100VMD banana chips and the most was found in 100FD banana chips (Figure 19). Additionally, all volatile compounds decreased for all drying treatments in relation to fresh bananas (Figures 17, 18 & 19).

Retention of aroma compounds is of importance in fruit dehydration, because fruit flavor consists largely of volatile compounds, such as esters, acids, alcohols, and various essential oils. During fruit dehydration, a significant amount of these compounds may be evaporated, resulting in a product with a poor flavor. For the banana chips prepared using different drying treatments, almost all the volatile compounds decreased as the extent of vacuum microwave drying increased, with the least amount retained in 100VMD banana chip samples (Table 2). The retention of fruit aroma during vacuum microwave drying can be influenced by a number of factors, including the drying temperature, the total amount of heat input, the vapor pressure of each aroma compound, its volatility relative to water, and its molecular weight and solubility. During microwave heating, the product temperature is low. The region of maximum temperature, and consequently maximum vapor pressure, was located in the interior of the fruit piece. Thus, the main driving force for moisture migration was directed toward the surface. Also, water vapor generated within the fruit piece, along with other volatile compounds, migrated toward the surface. Then, these compounds were vaporized to the atmosphere and lost from the fruit piece. Moreover, fruit aromas are often quite hydrophilic compounds. Therefore, most of these aroma compounds might dissolve into the aqueous phase of the fruit piece, which absorb microwave energy selectively; thus, these compounds might easily be vaporized during vacuum microwave drying (Shaath and Azzo, 1989; van Eijk, 1994). Further, at the end
Figure 19. Effect of Drying Methods on the Retention of Isobutylacetate, Butylacetate and Isoamylacetate

All headspace SPME samplings were performed at 50°C for 30 minutes in triplicate for each of 3 banana chip samples, and all measurements were analyzed using one way ANOVA. The results were recorded as mean + / - standard error mean. Significant differences between treatments were determined by Tukey’s multiple comparison test, and any two value not followed by the same letter are significantly different at p ≤ 0.05. The relative concentration of fresh banana was included here only for comparison.
of vacuum microwave drying, the temperature of the fruit piece was no longer controlled by the operating pressure due to the limited amount of water available inside the fruit product. At the same time, the specific heat of the fruit piece was sharply decreased; hence, the temperature of the banana slice reached a maximum value at around 70 – 75°C (Figure 20). Therefore, the aroma compounds might be thermally degraded at the end of the drying process. Furthermore, during the preparation of the 100VMD banana chips, the banana slices were VMD by placing on a plastic tray and the fruit slices were taken out from the vacuum microwave dryer every minute in order to measure the temperature of the slices. This drying process may allow the banana slices to be VMD for a much longer time; thus the fruit slices would experience excessive oxidation and flavor loss.

Retention of volatile compounds during vacuum microwave drying depends on the relative volatility, molecular weight, and solubility of the compound. According to Table 3, there was no retention in the 100VMD banana chips for isobutylacetate, ethyl butanoate, 1-butanol, isobutylbutanoate, 2-heptanone, and 2-hexenal. This result could be due to their high volatility relative to water (Steinke et al. 1989), which was estimated to be 620 for ethyl butanoate, 1160 for isobutylbutanoate, and 1460 for 2-hexenal. Although the relative volatility of 1-butanol is low (27), none of this compound was retained in the 100VMD banana chips, probably because of its low molecular weight (74.12g/mol) and high water solubility (6.32g/100ml) and thus its high diffusivity and high vaporization during vacuum microwave drying. Van Eijk (1994) reported that volatile compounds with low molecular weights were microwave unstable. Furthermore, isobutylacetate and 2-heptanone were not retained; this result could probably be due to their moderate solubility in water, which was estimated to be 0.67g/100ml for isobutylacetate and
Figure 20. Time - Temperature Curve of 100% Vacuum Microwave Dried Banana Chips
10 measurements of temperature were performed each time. All measurements were recorded as mean +/- standard error mean.
0.43g/100ml for 2-heptanone. Van Eijk (1994) reported that volatile compounds with high water solubilities could easily be vaporized during microwave heating. Conversely, 2-pentanone was retained the most in the 100VMD banana chips; this result could be due to its low relative volatility (110).

By comparing the volatile retention of the banana chips prepared using different drying treatments, higher levels of volatile compounds were retained when banana fruits underwent more extensive air drying, prior to vacuum microwave drying (Table 2). The selective diffusion theory has been proposed to explain the retention of volatile compounds during the air-drying process (Thijssen, 1971). This theory has been used by Luning et al. (1995b) and Mazza and LeMaguer (1979) to explain the volatile retention during the air-drying of bell peppers and onions respectively. According to this theory, the migration of water and aroma compounds in the drying fruit piece is governed by molecular diffusion. At the beginning of air drying, i.e. during the constant-rate period of drying, water evaporates freely and volatile compounds are lost rapidly, depending on their relative volatility to water. The aroma loss during air-drying is mainly controlled by the length of constant-rate period (Thijssen, 1979). As air drying progresses, water, along with fruit sugars and other solutes, diffuses from the interior to the surface of fruit piece. When the surface water concentration falls below a critical moisture content, a thin layer of these sugars and solutes is formed, thereby covering the drying fruit slice. This thin layer is selectively permeable to water and becomes increasingly impermeable to the diffusing aroma compounds. When the water concentration decreases, the diffusion coefficients of water and aroma compounds decrease, with the diffusion coefficient of aroma compound decreasing much more sharply than that of water. Hence, the thin layer
is virtually impermeable to aroma compounds and retains the banana aromas still present in the drying fruit slice. Therefore, as the banana fruits underwent more air drying and less vacuum microwave drying, banana aromas were less susceptible to vaporization during vacuum microwave drying; hence, more banana aromas were retained in the fruit product. Additionally, the temperature of the banana slices was found to maintain at approximately 55°C during air drying (Figure 21) and did not reach the approximately 70 – 75°C that occurred during vacuum microwave drying; hence, the banana aromas were less prone to thermal degradation during air drying.

On the contrary, 100AD banana chips retained less total volatile compounds when compared with 90AD/10VMD, 80AD/20VMD, 70AD/30VMD and 60AD/40VMD chips (Table 2, Figure 17). This can be explained by the fact that the 100AD banana chips were dried for about 3 hours (Figure 22) and exposed to approximately 7620 heat units (Table 4). Still, the 90AD/10VMD, 80AD/20VMD, 70AD/30VMD and 60AD/40VMD chips were only air-dried for about 80, 60, 50 and 40 minutes (Figure 22) and exposed to approximately 3520, 2780, 2300 and 1830 total heat units respectively (Table 4). As the 100AD banana chips were dried at approximately 55°C for a long period and exposed to a large number of heat units, the banana aroma was vaporized with water vapor and / or thermally degraded, causing a significant loss of aroma compounds from the fruit slices. However, the AD/VMD chips retained more total volatile compounds when they underwent more extensive air-drying, carried out prior to vacuum microwave drying. Clearly, volatile retention in the AD/VMD chips did not correlate with total heat unit exposure during the drying processes but could be explained by the selective diffusion theory. Moreover, according to Table 3, a high percentage of 2-heptanone (100.0%) was retained
Figure 21. Time - Temperature Curve of 100% Air-Dried Banana Chips

10 measurements of temperature were performed each time. All measurements were recorded as mean ± standard error mean.
Figure 22. Drying Curve of 100% Air-Dried Banana Chips
<table>
<thead>
<tr>
<th>Drying Treatments</th>
<th>Total Heat Units</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>100VMD</td>
<td>850 (10)</td>
<td></td>
</tr>
<tr>
<td>60AD / 40VMD</td>
<td>1840 (70)</td>
<td></td>
</tr>
<tr>
<td>70AD / 30VMD</td>
<td>2320 (60)</td>
<td></td>
</tr>
<tr>
<td>80AD / 20VMD</td>
<td>2760 (70)</td>
<td></td>
</tr>
<tr>
<td>90AD / 10VMD</td>
<td>3550 (50)</td>
<td></td>
</tr>
<tr>
<td>100AD</td>
<td>7650 (50)</td>
<td></td>
</tr>
</tbody>
</table>

1 The total heat unit was obtained by calculating the area under the time-temperature curve (Figure 20 & 21) for the corresponding drying treatments, and all calculations were recorded as mean (standard error mean).

2 The 100VMD banana chips were VMD for 20.5 minutes
3 The 60AD / 40VMD banana chips were AD for 38 minutes and VMD for 7.5 minutes
4 The 70AD / 30VMD banana chips were AD for 50 minutes and VMD for 6.5 minutes
5 The 80AD / 20VMD banana chips were AD for 62 minutes and VMD for 5.5 minutes
6 The 90AD / 10VMD banana chips were AD for 80 minutes and VMD for 4.5 minutes
7 The 100AD banana chips were AD at around 50°C for 180 minutes
in the 100AD chips. As mentioned before, the retention of volatile compounds during air-drying depends mainly on the relative volatility of the compound; therefore, the high retention of 2-heptanone in the 100AD chips was probably due to its low relative volatility (260).

Among the seven drying treatments, freeze-drying was the best drying treatment for the retention of volatile compounds in bananas (Table 2, Figures 17, 18 & 19). Freeze-drying is a process of sublimation, involving the removal of water from the frozen state to the vapor state without passing through the liquid state (Ryan, 1965). This process involves the simultaneous removal of ice from the frozen fruit pieces by sublimation and the removal of water from the concentrated fruit matrix by evaporation (King, 1970). Significantly, the low processing temperature minimizes the thermal degradation of fruit aromas. Additionally, the microregion entrapment theory, proposed by Flink and Karel (1970), has been used to explain volatile retention in freeze-drying; this theory has been used by Gerschenson et al. (1979) to explain volatile retention during freeze-drying of tomato juice. According to this theory, during the freezing of banana slices, crystallization of water results in the formation of microregions containing highly concentrated solutions of banana aroma compounds and carbohydrates. The structure of these microregions, as well as their permeability to volatile compounds and water, depends upon their local moisture content. During the early stages of drying, water sublimes freely from the surface of the fruit slices at a fairly constant rate; most of the volatile compounds are rapidly lost, depending upon their volatility (Saravacos and Moyer, 1968). As drying progresses, the local moisture content within the microregions decreases, and the molecular association of carbohydrates occurs via hydrogen bonds;
thus, the loss of the volatile compounds decreases. As the local moisture content reaches a critical level, the microregion is sealed, volatile loss ceases, and water loss still occurs, probably because of the small size of water molecules. According to Table 3, the final retention in the 100FD banana chips was high for most volatile compounds, except methyl hexanoate and isoamylbutanoate. Since the retention of volatile compounds during freeze-drying depends on their relative volatility, the low retention of methyl hexanoate and isoamylbutanoate in the 100FD chips was probably due to their high relative volatility, which was estimated to be 650 for methyl hexanoate and 1260 for isoamylbutanoate. Also, although vacuum is applied in both vacuum microwave drying and freeze drying, the 100VMD banana chips retained the least volatile compounds and the 100FD chips retained the most volatile compounds. Therefore, the least retention of volatile compounds in the 100VMD chips is mainly due to the mechanism of microwave heating but not to the application of vacuum during vacuum microwave drying.

4.2.5. Effects of Potassium Metabisulfite on the Headspace Volatiles of Bananas

The gas chromatogram of sulfited banana is given in Figure 23; the relative amounts of volatile compounds in the sulfited and the fresh banana are compared in Table 5. Significant differences were found concerning most of the volatile compounds in the sulfited and the fresh bananas. All volatile compounds decreased for the sulfited banana in relation to the fresh banana. Also, total volatile compounds, total esters, and especially aldehydes, including 3-methyl butanal and 2-hexenal, decreased for the sulfited banana. The three characteristic impact compounds in banana flavor, isobutylacetate, butyl acetate, and isoamylacetate, also decreased for the sulfited banana.
Figure 23. Gas Chromatogram of Sulfited Banana Slices

Numbers correspond to compounds identified by GC/MS in Table 4. Caproic acid ethyl ester was used as an internal standard (IS).
### Table 5. Effect of Potassium Metabisulfite Dip on the Relative Concentration of Fresh Banana Volatiles

<table>
<thead>
<tr>
<th>Peak #</th>
<th>Volatile Compounds</th>
<th>Relative amounts of volatile compounds</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Sulfited</td>
<td>Control</td>
</tr>
<tr>
<td>1</td>
<td>Ethyl acetate</td>
<td>1.77</td>
<td>3.26</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.06)</td>
<td>(0.20)</td>
</tr>
<tr>
<td>2</td>
<td>3-Methyl butanal</td>
<td>0.82</td>
<td>1.29</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.04)</td>
<td>(0.01)</td>
</tr>
<tr>
<td>3</td>
<td>2-Pentanone</td>
<td>0.43</td>
<td>1.95</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.02)</td>
<td>(0.01)</td>
</tr>
<tr>
<td>4</td>
<td>Isobutyl acetate</td>
<td>0.15</td>
<td>0.28</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.01)</td>
<td>(0.01)</td>
</tr>
<tr>
<td>5</td>
<td>Ethyl butanoate</td>
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<td>0.054</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.004)</td>
<td>(0.002)</td>
</tr>
<tr>
<td>6</td>
<td>Butyl acetate</td>
<td>0.72</td>
<td>1.63</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.01)</td>
<td>(0.07)</td>
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<tr>
<td>7</td>
<td>Isoamyl acetate</td>
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<td>1.92</td>
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<tr>
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<td>(0.03)</td>
<td>(0.05)</td>
</tr>
<tr>
<td>8</td>
<td>1-Butanol</td>
<td>0.071</td>
<td>0.15</td>
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<td></td>
<td></td>
<td>(0.007)</td>
<td>(0.01)</td>
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<tr>
<td>9</td>
<td>Isobutyl butanoate</td>
<td>0.12</td>
<td>0.31</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.01)</td>
<td>(0.04)</td>
</tr>
<tr>
<td>10</td>
<td>2-Heptanone</td>
<td>0.037</td>
<td>0.054</td>
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<tr>
<td></td>
<td></td>
<td>(0.005)</td>
<td>(0.004)</td>
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<tr>
<td>11</td>
<td>Methyl hexanoate</td>
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<td>1.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.01)</td>
<td>(0.1)</td>
</tr>
<tr>
<td>12</td>
<td>2-Hexenal</td>
<td>1.22</td>
<td>4.00</td>
</tr>
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<td></td>
<td></td>
<td>(0.03)</td>
<td>(0.14)</td>
</tr>
<tr>
<td>13</td>
<td>Isoamyl butanoate</td>
<td>1.04</td>
<td>1.51</td>
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<td></td>
<td></td>
<td>(0.03)</td>
<td>(0.10)</td>
</tr>
<tr>
<td>14</td>
<td>Hexyl acetate</td>
<td>0.14</td>
<td>0.29</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.01)</td>
<td>(0.02)</td>
</tr>
<tr>
<td>15</td>
<td>3-Hydroxy-2-butanone</td>
<td>0.38</td>
<td>0.47</td>
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<td></td>
<td></td>
<td>(0.02)</td>
<td>(0.01)</td>
</tr>
<tr>
<td>16</td>
<td>1-Hexanol</td>
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<td>0.55</td>
</tr>
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<td></td>
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<td>(0.01)</td>
<td>(0.02)</td>
</tr>
<tr>
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<td>Total Acetate</td>
<td>3.66</td>
<td>7.38</td>
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<td>(0.05)</td>
<td>(0.26)</td>
</tr>
<tr>
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<td>Total Butanoate</td>
<td>1.19</td>
<td>1.87</td>
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<td></td>
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<td>(0.04)</td>
<td>(0.10)</td>
</tr>
<tr>
<td>---</td>
<td>Total Ester</td>
<td>5.29</td>
<td>10.6</td>
</tr>
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<td>(0.05)</td>
<td>(0.5)</td>
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<tr>
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<td>Total of 16 volatile</td>
<td>8.45</td>
<td>19.1</td>
</tr>
<tr>
<td></td>
<td>compounds</td>
<td>(0.08)</td>
<td>(0.7)</td>
</tr>
<tr>
<td>---</td>
<td>Total volatile</td>
<td>10.2</td>
<td>20.0</td>
</tr>
<tr>
<td></td>
<td>compounds</td>
<td>(0.4)</td>
<td>(0.9)</td>
</tr>
</tbody>
</table>

1 Relative amounts – peak area of volatile compound divided by peak area of internal standard
2 All SPME headspace samplings were done in triplicate at 50°C for 30 minutes, and all measurements were recorded as mean (standard error mean).
3 Values are considered significantly different at p ≤ 0.050
Dipping in sulfite decreased the relative amount of volatile compounds in banana. As sulfites bind to aldehydes via available carbonyl groups (Lindsay, 1996), the decline in volatiles could be explained by the fact that sulfite might bind to the aroma compounds of banana, especially esters, which in turn affects volatilization. Another possibility could be that the sulfur vapor might be adsorbed onto the SPME fiber during sampling, thereby hindering the adsorption sites of the fiber in adsorbing the aroma compounds of banana. In order to verify this possibility, an experiment was performed, in which the SPME fiber was first used to sample the 5 ppm sulfite solution at 50°C for 30 minutes; the same fiber was then used to sample the standard solution containing isobutylacetate, 2-methylbutylacetate and isoamylacetate. As a control, the fiber was used to sample the standard solution. Only 5 ppm sulfite solution was used because this is the estimated concentration that covered the surface area of the banana slice after it was dipped into the sulfite solution. According to Table 6, no significant difference was found between the experimental data and the control concerning the peak areas of the three standard compounds. Thus, the possibility that sulfite was binding preferentially to the fiber, over aroma compounds, was not confirmed.

Another experiment was therefore performed, in which the SPME fiber was used to sample the solution containing both the 5 ppm sulfite and the 3 standard compounds, including isobutylacetate, 2-methylbutylacetate and isoamylacetate. Again, as a control, the fiber was used to sample the solution containing only the 3 standard compounds. According to Table 7, significant differences were found between the experimental data and the control concerning the peak areas of the three standard compounds. Therefore,
Table 6. Peak Areas of Isobutylacetate, Butyl acetate, and Isoamylacetate obtained using the SPME Fiber With and Without Prior Exposed to a 5ppm Potassium Metabisulfite Solution

<table>
<thead>
<tr>
<th>Volatile Compounds</th>
<th>5 ppm Sulfite / Standard Solution ¹</th>
<th>Standard Solution ¹</th>
<th>p ²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Isobutylacetate</td>
<td>326000 (2330)</td>
<td>337010 (7280)</td>
<td>0.29</td>
</tr>
<tr>
<td>Butyl acetate</td>
<td>30050 (640)</td>
<td>31750 (910)</td>
<td>0.22</td>
</tr>
<tr>
<td>Isoamylacetate</td>
<td>340780 (7930)</td>
<td>334720 (10210)</td>
<td>0.67</td>
</tr>
</tbody>
</table>

¹ All SPME headspace samplings were done in triplicate at 50°C for 30 minutes, and all measurements were recorded as mean (standard error mean).

² Values are considered significantly different at p ≤ 0.050
Table 7. Peak Areas of Isobutylacetate, Butyl acetate, and Isoamylacetate With and Without the 5ppm Potassium Metabisulfite Solution obtained using the SPME Fiber

<table>
<thead>
<tr>
<th>Volatile Compounds</th>
<th>Standard Solution 1</th>
<th>Standard Solution 1</th>
<th>P 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Isobutylacetate</td>
<td>209300 (1500)</td>
<td>337010 (7280)</td>
<td>0.0034</td>
</tr>
<tr>
<td>Butyl acetate</td>
<td>23220 (570)</td>
<td>31750 (910)</td>
<td>0.0042</td>
</tr>
<tr>
<td>Isoamylacetate</td>
<td>214160 (4980)</td>
<td>334720 (10210)</td>
<td>0.0088</td>
</tr>
</tbody>
</table>

1 All SPME headspace samplings were done in triplicate at 50°C for 30 minutes, and all measurements were recorded as mean (standard error mean).
2 Values are considered significantly different at p ≤ 0.050
sulfite did affect the volatilization of the three standard compounds and thus the amount of volatile compounds of banana chips.

Additionally, the active polyphenoloxidase in the fresh/unsulfited bananas might catalyze the enzymatic browning reaction, in which o-quinones are formed and react with the amino groups of the amino acids of the bananas. This could result in the formation of aldehydes which contributed to the development of extra volatile compounds in the fresh banana (Whitaker, 1996).

4.3. Sensory Analysis of Banana Chips

Sensory analysis was performed in triplicates, and analysis of variance (ANOVA) was carried out by using the results collected from these three sensory panel sessions. ANOVA of raw sensory scores was shown in Table 8. The variance ratio or the F value for a variable (treatment, panelist or replicate) is determined by dividing the mean square (MS) for that variable by the MS for error. Further, the MS for error is determined by dividing the sum of square (SS) for error by the degree of freedom for error, in which the SS for error is calculated by subtracting the SS values obtained from the variables (treatment and panelist) from the SS for the total. Finally, the F value can be used to determine whether the difference among the variables (treatment, panelist or replicate) is significant or not.

Analysis of variance (ANOVA) of raw sensory scores indicated significant differences among seven drying treatments for all sensory attributes, banana aroma, banana flavor, and off-flavor (Figures 24, 25 & 26). The sensory ratings for both banana aroma and flavor intensities decreased as the extent of vacuum microwave drying
Table 8. Analysis of Variance of Raw Sensory Score of Aroma, Flavor & Off-Flavor of Banana Chips Prepared with Different Drying Methods

<table>
<thead>
<tr>
<th></th>
<th>DF</th>
<th>Aroma</th>
<th>Flavor</th>
<th>Off-Flavor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drying Treatment</td>
<td>6</td>
<td>88.42</td>
<td>24.35</td>
<td>16.92</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>Panelist</td>
<td>5</td>
<td>14.05</td>
<td>8.77</td>
<td>3.84</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.000</td>
<td>0.000</td>
<td>0.004</td>
</tr>
<tr>
<td>Replicate</td>
<td>2</td>
<td>0.57</td>
<td>0.07</td>
<td>5.12</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.571</td>
<td>0.934</td>
<td>0.009</td>
</tr>
<tr>
<td>Drying Treatment x Panelist</td>
<td>30</td>
<td>3.40</td>
<td>1.80</td>
<td>1.00</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.000</td>
<td>0.027</td>
<td>0.482</td>
</tr>
<tr>
<td>Replicate x Panelist</td>
<td>10</td>
<td>3.55</td>
<td>3.17</td>
<td>2.16</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.001</td>
<td>0.003</td>
<td>0.033</td>
</tr>
</tbody>
</table>

1 Values are considered significantly different at p ≤ 0.05
Figure 24. Mean, Raw Aroma Intensity Sensory Score of Banana Chips Prepared with Different Drying Methods

18 measurements were made for each drying treatment, and all measurements were analyzed using general linear model of ANOVA. The results were recorded as mean ± standard error mean. Significant differences between treatments were determined by Tukey's multiple comparison test, and any two value not followed by the same letter are significantly different at p ≤ 0.05.
Figure 25. Mean, Raw Flavor Intensity Sensory Score of Banana Chips Prepared with Different Drying Methods

18 measurements were made for each drying treatment, and all measurements were analyzed using general linear model of ANOVA. The results were recorded as mean ± standard error mean. Significant differences between treatments were determined by Tukey's multiple comparison test, and any two value not followed by the same letter are significantly different at p ≤ 0.05.
Figure 26. Mean, Raw Off-Flavor Sensory Score of Banana Chips Prepared with Different Drying Methods

18 measurements were made for each drying treatment, and all measurements were analyzed using general linear model of ANOVA. The results were recorded as mean +/- standard error mean. Significant differences between treatments were determined by Tukey's multiple comparison test, and any two value not followed by the same letter are significantly different at $p \leq 0.05$. 
increased, with the lowest rating in 100VMD banana chips, the second lowest in 100AD banana chips, and the highest in 100FD banana chips (Figures 24 & 25). The off-flavor rating was almost none for all drying treatments, except a slightly higher rating in 100AD banana chips (Figure 26).

Variations among replicates of the three panel sessions were not significant for both the aroma and flavor attributes, but significant for the off-flavor attribute (Table 8). Also, the panelist effect, the replicate by panelist interaction, and the drying treatment by panelist interaction were significant for all sensory attributes, indicating that despite training and the use of reference samples, panelists displayed a similar trend of ratings but tended to use different portions of the linear scale. Hence, z transformation was performed to standardize the raw sensory scores within each panelist, thereby forcing all panelist scores onto the same scale (Reid and Durance, 1992).

ANOVA of z scores also showed significant differences among drying treatments for the banana aroma, banana flavor, and off-flavor attributes (Figures 27, 28 & 29). Also, ANOVA of standardized scores resulted in a slight increase in the power of the analysis; the panelist effect was removed, the drying treatment by panelist interaction and the replicate by panelist interaction were not significant (Table 9). However, the mean standardized score of the off-flavor attribute showed a much higher rating intensity for the 100%AD banana chips, compared to other banana chips (Figure 29).

Correlation coefficients were determined between the sensory attributes and the volatile compounds known to contribute to the characteristic banana aroma (Table 10). Both the sensory attributes of aroma and flavor highly correlated with the peak areas of the volatile compounds obtained from the gas chromatograms of the banana chips. The
Figure 27. Mean Aroma Z Score of Banana Chips Prepared with Different Drying Methods

18 measurements were made for each drying treatment, and all measurements were analyzed using general linear model of ANOVA. The results were recorded as mean +/- standard error mean. Significant differences between treatments were determined by Tukey's multiple comparison test, and any two value not followed by the same letter are significantly different at p ≤ 0.05.
Figure 28. Mean Flavor Z Score of Banana Chips Prepared with Different Drying Methods

18 measurements were made for each drying treatment, and all measurements were analyzed using general linear model of ANOVA. The results were recorded as mean +/- standard error mean. Significant differences between treatments were determined by Tukey's multiple comparison test, and any two value not followed by the same letter are significantly different at $p \leq 0.05$. 
Figure 29. Mean Off-Flavor Z Score of Banana Chips Prepared with Different Drying Methods

18 measurements were made for each drying treatment, and all measurements were analyzed using general linear model of ANOVA. The results were recorded as mean + / - standard error mean. Significant differences between treatments were determined by Tukey’s multiple comparison test, and any two value not followed by the same letter are significantly different at p ≤ 0.05.
Table 9. Analysis of Variance of Sensory Z Scores of Aroma, Flavor & Off-Flavor of Banana Chips Prepared with Different Drying Methods

<table>
<thead>
<tr>
<th></th>
<th>DF</th>
<th>Aroma</th>
<th>Flavor</th>
<th>Off-Flavor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drying Treatment</td>
<td>6</td>
<td>84.60</td>
<td>34.43</td>
<td>27.19</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>Panelist</td>
<td>5</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1.000</td>
<td>1.000</td>
<td>1.000</td>
</tr>
<tr>
<td>Replicate</td>
<td>2</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1.000</td>
<td>1.000</td>
<td>1.000</td>
</tr>
<tr>
<td>Drying Treatment x Panelist</td>
<td>30</td>
<td>1.40</td>
<td>1.53</td>
<td>1.40</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.133</td>
<td>0.081</td>
<td>0.132</td>
</tr>
<tr>
<td>Replicate x Panelist</td>
<td>10</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1.000</td>
<td>1.000</td>
<td>1.000</td>
</tr>
</tbody>
</table>

1 Values are considered significantly different at p ≤ 0.05
Table 10. Pearson Correlation Coefficients and Associated Probabilities between Sensory Attributes of Aroma, Flavor & Off-Flavor and Some Volatile Compounds Identified in Freeze-Dried Banana Chips

<table>
<thead>
<tr>
<th>Volatile 2</th>
<th>Aroma 1</th>
<th>Flavor 1</th>
<th>Off-Flavor 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Isobutylacetate</td>
<td>+0.825</td>
<td>+0.896</td>
<td>-0.413</td>
</tr>
<tr>
<td></td>
<td>0.022</td>
<td>0.006</td>
<td>0.357</td>
</tr>
<tr>
<td>Butyl acetate</td>
<td>+0.925</td>
<td>+0.982</td>
<td>-0.298</td>
</tr>
<tr>
<td></td>
<td>0.003</td>
<td>0.000</td>
<td>0.516</td>
</tr>
<tr>
<td>Isoamylacetate</td>
<td>+0.894</td>
<td>+0.934</td>
<td>-0.310</td>
</tr>
<tr>
<td></td>
<td>0.007</td>
<td>0.002</td>
<td>0.499</td>
</tr>
<tr>
<td>Total Acetate</td>
<td>+0.950</td>
<td>+0.975</td>
<td>-0.235</td>
</tr>
<tr>
<td></td>
<td>0.001</td>
<td>0.000</td>
<td>0.611</td>
</tr>
<tr>
<td>Total Ester</td>
<td>+0.920</td>
<td>+0.932</td>
<td>-0.222</td>
</tr>
<tr>
<td></td>
<td>0.003</td>
<td>0.002</td>
<td>0.632</td>
</tr>
<tr>
<td>Total Volatile</td>
<td>+0.909</td>
<td>+0.955</td>
<td>-0.239</td>
</tr>
<tr>
<td></td>
<td>0.005</td>
<td>0.001</td>
<td>0.605</td>
</tr>
</tbody>
</table>

1 Cell Contents: Correlation Coefficient P-value

2 The peak areas of the volatile compounds were obtained from the gas chromatogram of the banana chips.
sensory aroma correlated positively with isobutylacetate (+0.825), butyl acetate (+0.925), isoamylacetate (+0.894), total acetate (+0.950), total ester (+0.920), and total volatile compounds (+0.909). Similarly, sensory flavor correlated positively with isobutyl-acetate (+0.896), butyl acetate (+0.982), isoamylacetate (+0.934), total acetate (+0.975), total ester (+0.932), and total volatile compounds (+0.955). However, sensory off-flavor attribute did not correlate with these volatile compounds; thus, this sensory attribute occurred regardless of the drying treatments, and the banana chips did not have much off-flavor.

4.4. Textural Analysis of Banana Chips

4.4.1. Instrumental Analysis

The texture of the banana chips prepared from different drying treatments was measured in terms of the slope, distance, and peak force. By personal assessment, the 100VMD banana chips were hard and chewy and were not crispy at all. The texture of 100VMD banana chips was not measured. Because these banana chips were VMD by being placed on the plastic tray instead of being rotated in the drying drum, these banana chips might experience non-uniform microwave heating: some chips might receive more microwave energy but some chips might receive less energy. Hence, these banana chips might experience different degrees of puffing effect, and the texture of specific chips might vary greatly. Nonetheless, the flavor of 100VMD banana chips was measured by gas chromatographic (GC) and sensory analysis. During GC analysis, the banana chips were ground and 5g of these banana chip powders were used during SPME sampling. Also, three batches of 100VMD banana chip were made. For each batch, three replicates
of GC analysis were performed. Hence, variations between chips could be averaged out. Further, during sensory analysis, six panelists were used; for each panelist, three banana chips were sampled. Therefore, the results should also be reliable.

A typical force-deformation curve of the 90AD/10VMD banana chips is shown in Figure 30. At the same water activity of 0.25 at 25°C, the slopes of the VMD banana chips increased with vacuum microwave drying and were significantly greater than those of the 100AD and the 100FD chips (Figure 31). On the contrary, the distances of the VMD chips decreased when vacuum microwave drying increased and were significantly smaller than those of the 100AD and the 100FD chips (Figure 32). The initial slope of the force-deformation curve has been reported as an indicator of the food and sensory crispness. Bourne et al. (1966) studied the crispness of potato chips at different moisture contents; they demonstrated that the crispness of the chips increased with the initial slope of the force-deformation curve. Similarly, Vickers and Bourne (1976) observed that the sensory crispness of a variety of crisp foods correlated well with the initial slopes of their force-deformation curves. The distance of the force-deformation curve has been reported as an indicator of the food firmness (Vickers, 1980). In other words, the VMD banana chips were crisper and less firm than the 100AD and the 100FD chips. During vacuum microwave heating, the microwave energy was preferentially absorbed by water molecules in the interior of banana slice. This absorption of microwave energy generated heat within the fruit slice, thereby creating a large vapor pressure differential between the center and the surface of the fruit product. Under the low chamber pressure provided by the vacuum condition, this high internal vapor pressure produced by the microwave heating resulted in an outward force, causing the structure of the fruit slice to expand and
Slope of the line from a to b = slope of the peak = 3980g/mm

Distance from a to c = distance to peak = 0.63mm

Force at b = peak force = 2515g

Figure 30. Force vs Deformation of 90%AD & 10%VMD Banana Chips and the Settings of the Texture Analyzer
**Figure 31. Mean Slope (g/mm) of Banana Chips Prepared with Different Drying Treatments**

The slope of the peak was obtained from the force vs deformation curve of the banana chips prepared with different drying treatments. Experiments were performed in triplicate, and 15 measurements were obtained from each replicate with a total of 45 measurements were made for each drying treatment. All measurements were analyzed using ANOVA. The results were recorded as mean +/− standard error mean. Significant differences between treatments were determined by Tukey’s multiple comparison test, and any two value not followed by the same letter are significantly different at p < 0.05.
Figure 32. Mean Distance (mm) of Banana Chips Prepared with Different Drying Treatments

The distance of the peak was obtained from the force vs deformation curve of the banana chips prepared with different drying treatments. Experiments were performed in triplicate, and 15 measurements were obtained from each replicate with a total of 45 measurements were made for each drying treatment. All measurements were analyzed using ANOVA. The results were recorded as mean ± standard error mean. Significant differences between treatments were determined by Tukey’s multiple comparison test, and any two value not followed by the same letter are significantly different at p < 0.05.
puff. Durance and Liu (1996) and Lin et al. (1998) also demonstrated that the structures of potato and carrot slices were expanded and puffed by vacuum microwave drying. Therefore, as the banana slices underwent more vacuum microwave drying, a greater puffing effect was obtained; thus, the banana chips were crisper.

The peak force of the 100AD banana chips was significantly larger than either the VMD chips or the 100FD chips. On the contrary, the least peak force was found in the 100FD chips (Figure 33). The peak force of the force-deformation curve measures the hardness of the surface of the fruit product; this parameter has been reported as an indicator of the extent of case hardening that has occurred during drying (Kim and Toledo, 1987). The results indicated that the 100AD banana chips had the most case hardening. Conversely, the VMD chips and the 100FD chips, compared to the 100AD chips, had less case hardening. During air-drying, water evaporated freely from the surface of the banana slice. At the same time, moisture diffused from the interior to the surface of the fruit slice, carrying fruit sugars and other solutes. As drying progressed, the rate of water evaporation from the fruit surface was faster than the rate of water diffusion to the surface. Thus, a thin layer of fruit sugars and other solutes formed, thereby covering the fruit surface, acting as a water barrier, and causing a wet interior (Lin et al., 1998). However, during vacuum microwave drying, heat was generated within the banana slice, thereby resulting in in situ vaporization of water that was expelled out of the fruit piece without carrying any fruit sugar or solute. Therefore, less case hardening occurred with the VMD chips. Lin et al. (1998) also demonstrated that the VMD carrot slices, compared to the AD ones, had less case hardening. Moreover, during freeze-drying, the structure of the banana slice was maintained by freezing and the moisture was
Figure 33. Mean Peak Force (g) of Banana Chips Prepared with Different Drying Treatments

The peak force of the peak was obtained from the force vs deformation curve of the banana chips prepared with different drying treatments. Experiments were performed in triplicate, and 15 measurements were obtained from each replicate with a total of 45 measurements were made for each drying treatment. All measurements were analyzed using ANOVA. The results were recorded as mean + / - standard error mean. Significant differences between treatments were determined by Tukey’s multiple comparison test, and any two value not followed by the same letter are significantly different at p 0.05.
sublimed from the frozen state to the vapor state without passing through the liquid state. This drying process prevented the collapse of the fruit matrix and maintained the porous structure of the fruit piece (King, 1970). Hence, the 100FD banana chips were the least crispy. Moreover, since no liquid phase was involved, there was no migration of water along with other soluble components to the fruit surface (Li-Shing-Tat and Jelen, 1987). Therefore, the 100FD chips had the least case hardening.

4.4.2. Microscopic Analysis

Effects of different drying treatments on banana chip structure were observed with the scanning electron microscope. After air drying, banana chips exhibited severe tissue shrinkage; the tissues were elongated and severely collapsed, and several cavities had formed as a result of the heat-induced expansion of intercellular gases (Lee et al., 1966a; Lee et al., 1966b; Lee et al., 1967) (Figure 34). During air drying, the fruit tissues were pulled together under the influence of the surface tension as water evaporated from the wet surface. As drying progressed, the tissue further crumbled and folded, thereby causing a shrinking volume (Li Shing Tat and Jelen, 1987). On the contrary, the tissues of the 60AD/40VMD and the 90AD/10VMD banana chips were less affected by the drying process as judged by the extent of shrinkage; the tissues were expanded and puffed, and open structures were formed (Figures 35 & 36). Further, the tissues of the 60AD/40VMD banana chips, compared with those of the 90AD/10VMD banana chips, were more expanded and more puffed (Figures 35 & 36). During vacuum microwave drying, the low chamber pressure provided by the vacuum and the high internal vapor pressure produced by the microwave heating resulted in an outward force causing the structure of the banana
Figure 34. Scanning Electron Micrograph of 100%AD Banana Chips with 200x magnification
Figure 35. Scanning Electron Micrograph of 60%AD & 40%VMD Banana Chips
with 200x magnification
Figure 36. Scanning Electron Micrograph of 90%AD & 10%VMD Banana Chips

with 200x magnification
slice to expand and puff. Further, the low temperature during vacuum microwave drying minimized the collapsing forces caused by heat, thereby causing the slices to retain their open structures. Additionally, the collapse resulting from air-drying was proportional to the moisture lost during the drying process (Lozano et al., 1983). Therefore, as the banana slices underwent less air-drying and more vacuum microwave drying, a greater puffing effect was attained. On the contrary, after freeze drying, banana chips exhibited open porous structures with the least amount of tissue shrinkage or cell collapse among all the chip samples (Figure 37). During freeze drying, the structure of the banana slice was maintained by freezing, and the moisture was sublimed from the frozen state to the vapor state without passing via the liquid state. This process prevented the collapse of the fruit matrix, thereby leaving numerous voids within the matrix, thus maintaining the porous structure of the fruit piece (King, 1970). Also, for the VMD banana chip samples, a gelatinous mass was observed to fill the spaces between the cells, giving them a grayish cast as compared to the white intercellular space perceived in the 100FD samples. This observation could be due to the gelatinization of starch granules in the banana slices during vacuum microwave drying. The gelatinization temperature of banana starch was reported to be between 70 – 85°C (Stover and Simmonds, 1987a). Also, the temperature of banana slices reached around 70 – 75°C during vacuum microwave drying (Figure 20); thus, the temperature was high enough to gelatinize the starch granules of the VMD banana chips. Similarly, Lee et al. (1967) and Sterling (1955) reported the gelatinization of starch granules in apples during air drying and blanching. They confirmed the starch gelatinization by using the starch-iodine staining test, in which the starch granules that underwent gelatinization did not react with the iodine reagent.
Figure 37. Scanning Electron Micrograph of 100%FD Banana Chips with 200x magnification
Nevertheless, during the preparation steps, the banana chips were first dipped into liquid nitrogen and then fragmented into small pieces. However, the liquid nitrogen might exert some artifacts onto the chip samples and thus might slightly affect the structure of the chip samples.

4.5. Color Analysis of Banana Chips

The Hunter L, a, b values, hue saturation, and hue angle of banana chips prepared using different drying treatments are given in Table 11. All the VMD banana chips had higher lightness but lower redness, yellowness, and saturation than the 100AD samples. Also, as the banana slices underwent more vacuum microwave drying and less air drying, the banana chips were lighter and had less red and yellow hues and saturation. Further, the 100FD samples had the highest degree of lightness but the lowest degree of redness, yellowness, and saturation, while the 100AD samples had the lowest degree of lightness but the highest degree of redness, yellowness, and saturation. The hue angle was reported to be an indicator of browning in apple cubes; higher values of hue angle indicate less browning (O’Neill, 1998). In the case of VMD banana chips, hue angle increased as the extent of vacuum microwave drying increased. In addition, the 100FD chip samples had the highest hue angle, whereas the 100AD chip samples had the lowest hue angle.

Discoloration of fruit product during drying is always due to certain reactions, such as enzymatic browning and non-enzymatic browning reaction (Soriano et al., 1976). Non-enzymatic / Maillard browning involves condensation between the carbonyl groups of reducing sugars and the amino groups of amino acids, peptides and proteins. The rate of browning increases as the reaction temperature and time increase (BeMiller and
### Table 11. Mean L, a, and b Hunterlab values of Banana Chips Prepared with Different Drying Treatments

<table>
<thead>
<tr>
<th>Drying Treatments</th>
<th>L-value (^{1,2})</th>
<th>a-value (^{1,2})</th>
<th>b-value (^{1,2})</th>
<th>Hue Saturation (^{1,2,3})</th>
<th>Hue Angle (^{1,2,4})</th>
</tr>
</thead>
<tbody>
<tr>
<td>60AD/40VMD</td>
<td>62.52 bc</td>
<td>4.82 c</td>
<td>19.52 e</td>
<td>20.11 e</td>
<td>76.14 c</td>
</tr>
<tr>
<td></td>
<td>(0.12)</td>
<td>(0.06)</td>
<td>(0.07)</td>
<td>(0.08)</td>
<td>(0.14)</td>
</tr>
<tr>
<td>70AD/30VMD</td>
<td>61.24 cd</td>
<td>4.86 c</td>
<td>20.07 d</td>
<td>20.66 d</td>
<td>76.39 bc</td>
</tr>
<tr>
<td></td>
<td>(0.07)</td>
<td>(0.09)</td>
<td>(0.10)</td>
<td>(0.11)</td>
<td>(0.24)</td>
</tr>
<tr>
<td>80AD/20VMD</td>
<td>57.10 e</td>
<td>5.54 b</td>
<td>21.96 b</td>
<td>22.65 b</td>
<td>75.85 ed</td>
</tr>
<tr>
<td></td>
<td>(0.33)</td>
<td>(0.05)</td>
<td>(0.05)</td>
<td>(0.06)</td>
<td>(0.12)</td>
</tr>
<tr>
<td>90AD/10VMD</td>
<td>60.54 d</td>
<td>5.34 b</td>
<td>21.03 c</td>
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<td>75.75 ed</td>
</tr>
<tr>
<td></td>
<td>(0.43)</td>
<td>(0.07)</td>
<td>(0.14)</td>
<td>(0.15)</td>
<td>(0.11)</td>
</tr>
<tr>
<td>100AD</td>
<td>54.95 e</td>
<td>5.98 a</td>
<td>22.47 a</td>
<td>23.25 a</td>
<td>75.09 d</td>
</tr>
<tr>
<td></td>
<td>(0.57)</td>
<td>(0.13)</td>
<td>(0.12)</td>
<td>(0.10)</td>
<td>(0.34)</td>
</tr>
<tr>
<td>100VMD</td>
<td>63.60 b</td>
<td>4.05 d</td>
<td>17.83 f</td>
<td>18.28 f</td>
<td>77.19 b</td>
</tr>
<tr>
<td></td>
<td>(0.21)</td>
<td>(0.08)</td>
<td>(0.08)</td>
<td>(0.09)</td>
<td>(0.21)</td>
</tr>
<tr>
<td>100FD</td>
<td>82.85 a</td>
<td>0.92 e</td>
<td>14.95 g</td>
<td>14.98 g</td>
<td>84.50 a</td>
</tr>
<tr>
<td></td>
<td>(0.15)</td>
<td>(0.02)</td>
<td>(0.03)</td>
<td>(0.03)</td>
<td>(0.07)</td>
</tr>
</tbody>
</table>

---

1. 21 measurements were made for each drying treatment and were recorded as mean (standard error mean).
2. Significant differences between measurements were determined by Tukey's multiple comparison test, and two values not followed by the same letter are significant different at \(p \leq 0.05\).
3. Hue Saturation = \((a^2 + b^2)^{1/2}\)
4. Hue Angle = \(\tan^{-1}(b/a)\)
Whistler, 1996). During air drying, the banana slices were exposed to oxygen and high
temperature for long times; therefore, the fruit slices were more susceptible to these
browning reactions, thereby displaying the highest degree of redness, yellowness, and
saturation and the lowest hue angle among all the samples. Moreover, in this study,
majority (85%) of the enzyme PPO was inactivated using the sulfiting agent; therefore,
non-enzymatic browning was responsible for most of the discoloration during air drying
of banana slices. Mowlah et al. (1982b) also reported that non-enzymatic browning was
responsible for the discoloration that occurred while air dehydrating the banana slices.
However, the 15% of the PPO that was left could catalyze the enzymatic browning
reaction of the banana slices during the air-drying process. Furthermore, enzymatic
browning might also occur during the preparation steps, i.e. right after the banana fruits
were sliced and before these slices were dipped into the potassium metabisulfite solution.
Therefore, enzymatic browning of these banana slices could be catalyzed by the oxygen
and the high temperatures during the lengthy air drying period. Conversely, during
vacuum microwave and freeze drying, the low chamber oxygen provided by the vacuum
and the low temperature maintained during the dryings made the banana slices less prone
to these browning reactions. Hence, the fruit products displayed less red, yellow hues and
saturation but higher hue angles. Krokida and Maroulis (1999) reported that vacuum
microwave drying of banana slices prevented damage to color during drying.
Furthermore, by visual assessment, after the banana chips were stored for about 12
months, the color of the chips became darker. This observation could probably be due to
the 15% of the active PPO left in the banana chips that could catalyze the enzymatic
browning reaction during the long storage period. Additionally, structural changes during
drying play an important role in color changes of banana slices. After air drying, the tissues of fruit slices were severely shrunken, and the cells were extensively folded. Hence, the density of the slices was increased, thereby yielding a higher concentration of pigment per volume of tissue and a darker color (Lin et al., 1998). Conversely, the cells of the fruit slices were puffed during vacuum microwave drying. Hence, the density of the slices was decreased, thereby yielding a lighter color. Furthermore, the 100FD fruit slices possessed the most open porous structure; thus this fruit product displayed the highest degree of lightness.
5. Conclusions

Five anti-browning agents were used, singly and in various combinations, to determine the most effective treatment for inhibition of banana polyphenoloxidase (PPO). 2000ppm potassium metabisulfite with or without 2% citric acid was found to be the most effective PPO inhibitor. Nevertheless, gas chromatographic analysis showed that bananas dipped in sulfite had significantly lower levels of volatile compounds compared to fresh bananas. Hence, a minimum amount of potassium metabisulfite should be used to prepare banana chips in order to maximally retain the volatile compounds and obtain an acceptable appearance of the banana chips, especially during storage.

A total of 16 identified volatile compounds were extracted from the freeze-dried (FD) banana chips; several high boiling point volatile compounds were also extracted but were not identified. Results from gas chromatographic analysis showed that banana chips that underwent more vacuum microwave drying had significantly lower levels of volatile compounds. 90% air-dried (AD) and 10% vacuum microwave dried (VMD) banana chips had significantly higher levels of volatile compounds than the 100% AD banana chips. Conversely, the 100% FD banana chips retained the most volatile compounds among all the chip samples. Results from sensory analysis also showed that banana chips which underwent more vacuum microwave drying had significantly lower ratings for both the banana aroma and flavor intensities and the 100% FD banana chips received the highest sensory ratings for both aroma and flavor intensities. Furthermore, the partially VMD and the 100% VMD banana chips had no off-flavor. Therefore, in this study, the general behavior of a range of low boiling point volatile compounds during vacuum microwave drying was characterized.
Textural analysis showed that the banana chips which underwent more vacuum microwave drying had greater puffing effects and significantly crisper textures. 90% AD and 10% VMD banana chips were the crispest among all the chip samples. Although the 100% FD banana chips retained the most volatile compounds among all the chip samples, the texture of the 100% FD banana chips were over soft or rather “cotton-woolly” and thus not suitable for commercialize as chips. Color analysis showed that the lightness, redness, yellowness, and hue saturation of the partially VMD and the 100% VMD banana chips were significantly lower than those of the 100% AD chip samples. Also, the hue angle of the partially VMD and the 100% VMD banana chips was significantly higher than that of the 100% AD samples. Hence, less browning had occurred in the VMD banana chips than in the 100% AD samples.

Vacuum microwave drying, which occurs rapidly at low atmospheric pressure and at low temperatures, was used in combination with air drying to yield banana chips with a crisp and puffed texture. 10% VMD and 90% AD banana chips were found to have higher levels of volatile compounds, crisper texture and less browning than the 100% AD chips. Clearly, this combination of drying techniques can be used to produce high quality banana chips.
6. References


