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Comparison of volatiles of banana powder dehydrated by vacuum belt drying, freeze-drying and air-drying

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Abstract

Banana puree was dehydrated by using three different drying methods: vacuum belt drying (VBD), freeze-drying (FD) and air-drying (AD) to produce banana powder. Volatiles were extracted from dried banana powder with solid phase micro-extraction (SPME), and separated and identified by gas chromatography–mass spectrometry (GC–MS). SAS (statistical analysis system) was used to evaluate the contribution of the main volatiles. Esters play the most important role in banana powder aroma. The main components detected in banana powder which are responsible for its fruity odor were 3-methylbutanoic acid 3-methylbutyl ester, 3-methylbutyl acetate and butanoic acid 3-methylbutyl ester. Most of the alcohols identified in banana powder were enols and some were of the long chain type. Eugenol and elemicin which give the product its typical mellow aromas were also identified. Alkyls, alkene and alkyne constituted the minor components in banana powder. Basing on the principal component analysis of statistical analysis system, it can be inferred that the preferred method for producing banana powder with the optimum aroma is FD, followed by VBD and then AD.

Keywords: Aroma; Banana; Drying; GC–MS; Powder; Volatiles

1. Introduction

Worldwide production of bananas in 2005 was about 72,464,562 ton; and banana production in China has increased 10-fold over the past 20 years. Although most bananas are consumed fresh, an increasing number of processed products have emerged, such as banana chips, confiture, puree, juice, etc. The great potential of banana products merits further research on the processing of bananas.

Many studies have focused on the volatiles in fresh banana (Jordán, Tandon, Shaw, & Goodner, 2001; Liu & Yang, 2002; Nogueira, Fernandes, & Nascimento, 2003; Pérez, Cert, Ríos, & Olías, 1997; Pilar Cano et al., 1997; Salmon, Martin, Remaud, & Fourel, 1996; Shiota, 1993; Tressl & Jennings, 1972). It is known that banana flavor is mainly due to esters. Salmon et al. (1996) showed that isoamyl acetate, isoamyl butyrate and pentan-2-one are the esters which are characteristic of the geographic origin of the fruit. Early experiments using GC-olfactometry indicated that 3-methylbutylacetate, 3-methyl-butyl butanoate and 3-methylbutyl-3-methyl butanoate are the key components of the banana's fruity odor. Both alcohols and minor carbonyl compounds are referred to as green and woody notes. (*E*) and (*Z*)-hept-4-en-2-one have fatty-green and sweet notes (Miranda Eduardo, Nogueira Regina, Pontes Sérgio, & Rezende Claudia, 2001). However, very few studies have focused on the volatiles of dehydrated banana.

Air-drying and freeze-drying are widely used to dehydrate the fruit. Vacuum belt drying is a new alternative method for dehydrating the fruit, and this continuous drying method has been applied in the production of pure fruit juices (Maltini, Nani, & Bertolo, 1992; Monzini & Maltini, 1990). Dried products produced by vacuum and continu-

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ous drying were of high quality while the process is short, convenient and of low cost. Cesare and Nani (1995) have studied the behavior of aroma compounds in peach juice dried in a vacuum belt drier while Mui, Durance, and Scaman (2002) have studied the flavor of banana chips but no research has been reported on the flavor of banana powder dried by vacuum belt drier. Boudhrioua, Giampaoli, and Bonazzi (2003) have carried out research on the aromatic components of banana during convective air-drying at 40, 60, and 80 °C. Miranda Eduardo et al. (2001) have investigated the odor-active compounds of banana passa which had been dehydrated at 50 °C by forced ventilation. Díaz-Maroto, Soledad Pérez-Coello, González Viñas, and Dolores Cabezudo (2003) studied the influence of three drying methods on the quality of the flavor of spearmint (*Mentha spicata* L.).

So far, no other studies have been reported on the comparison of volatiles in banana powder dehydrated by three different methods, vacuum belt drying (VBD), freeze-drying (FD) and air-drying (AD). Therefore, the purpose of this research was to study the influence of these three drying methods on the flavor of dried bananas.

2. Materials and methods

2.1. Raw materials

Bananas (*Musa* AAA group, Cavendish subgroup) having a yellow peel color and green neck were purchased from a local market. The bananas were peeled and mashed into a puree before drying.

2.2. Vacuum belt drying (VBD)

GZD-S Vacuum Belt Drier designed and manufactured by the Institute of Agricultural Mechanization, Guangdong, China was used. The temperature of the heating board (there are five boards in total), absolute pressure (vacuum degree), velocity of the conveyer belt and revolutions of the pump were all adjustable. The operation parameters used in the current research had been optimized by previous research as shown in Table 1.

2.3. Freeze-drying (FD)

Banana puree was freeze-dried as follows: banana puree → laid on salver (4 mm thickness) → prefreezing → vacuum applied → sublimation drying → packaging → product.

2.4. Air-drying (AD)

Banana puree was air-dried as follows: banana puree → laid on salver (2 mm thickness) → air-drying (75 °C, air velocity 1.5 m/s) → weight invariable → packaging → product.

2.5. Analysis of volatiles

2.5.1. Sample preconcentration (SPME)

The volatile components of banana were isolated by solid phase micro-extraction (SPME), which is widely used to concentrate the aroma fraction of fruit, vegetables, beverages, etc. Dehydrated banana powder was homogenized in a blender, in 1.0-g sample sizes and then placed in a 20-mL vial and sealed. The sample was then extracted on a 100-μm length polydimethyl siloxane (PDMS) fiber column at 40 °C for 30 min and then eluted at 250 °C for 3 min.

2.5.2. Gas chromatography– mass spectrometry analysis (GC–MS)

Analyses were carried out by a TRACE GC-2000 GS-MSTM (Finnigan) using a DB-5(95% of methyl and 5% of phenyl siloxane) column (30 m × 0.25 mm). Helium was used as the carrier gas at a flow rate of 1.0 mL/min. Thermal desorption of the compounds from the column was carried out in the GC splitless injector at 250 °C. The oven temperature was programmed to increase from 40 (5 min) to 60 °C (2 min) at a rate of 2 °C/min. The temperature was then raised to 100 °C (2 min) at a rate of 5 °C/min, and then to 230 °C (20 min) at the same rate. Aroma compounds were analyzed by MS with electronic impact (EI) 70 eV quadripolar filter. The mass range for this acquisition is 35–335 amu. All compounds were identified by comparison to NIST library (including Wiley and Mainlib) spectral data bank. Only compounds whose similarity is more than 750 (the maximum similarity is 1000) were reported here. Quantitative analysis was based on the ratios between the peak area of a particular component in the banana powder and the total peak area of all components in the powder.

2.6. Principal component analysis

SAS (Statistical Analysis System) v8.1 software was used to evaluate the contribution of the main volatiles to the quality of the aroma.

Table 1
Parameters of vacuum belt drying (VBD)

Temperature of five heating board (°C)					Absolute pressure (Pa)	Injection quantity of material (m^3/s)	Velocity of conveyer belt (m/s)
1	2	3	4	5			
210	197	142	120	50	1150 ± 50	5.8×10^{-8}	3.6×10^{-4}

3. Results and discussion

3.1. Volatiles separated and identified by GC–MS

Drying decreases the moisture content and water activity of fruit, but aromatic components are sensitive to heat treatment generally. Chromatograms of banana powder are showed in Fig. 1. It can be clearly seen that the three samples have similar peaks at retention times 21.46 ± 0.01, 23.76 ± 0.02, 28.28 ± 0.01, 29.52 ± 0.01, 35.36, 35.57 ± 0.01, 35.88 min. Nearly 100 compounds were separated by GC but not completely identified by MS. The components identified were esters, alcohols, acids, ketones, phenols, alkyls and so on.

Banana flavor is mainly attributed to esters, although appreciable quantities of free alcohols have also been reported to contribute to the flavor (Blanch, Herraiz, Reglero, & Tabera, 1993). Salmon et al. (1996) have also reported that esters constitute the main fraction of the volatile emission from fresh banana. Table 2 shows several categories of banana powder volatiles. It was shown by VBD, FD and AD that esters were the main components of dehydrated banana. Nearly 30 esters were identified by GC–MS. The aroma was particularly associated with compounds such as 3-methyl, 1-methylhexyl, 2-methylpropyl, 3-methylbutyl, isoamyl, and hexyl esters of acetic, butanoic and isovalerate acids. However, the volatile fractions produced by FD, VBD and AD were dominated by 3-methylbutanoic acid 3-methylbutyl ester (16.11%, 19.30%, 22.39%), followed by isoamyl butyrate (15.83%, 13.69%, 14.75%), butanoic acid 1-methylhexyl ester (7.45%, 6.85%, 5.87%), 3-methylbutyl acetate (7.32%, 3.12%, 0.74%), and hexyl isovalerate (3.23%, 3.29%, 3.20%) respectively. Many researches working on banana aroma (Berger, Drawert, & Kollmansberger, 1986; Miranda Eduardo et al., 2001; Salmon et al., 1996) have reported 3-methylbutyl acetate, butanoic acid 3-methylbutyl ester and 3-methylbutanoic acid 3-methylbutyl ester to be key components of the banana's fruity odor. These esters were also found to be responsible for the aroma of banana powder produced by FD, VBD and AD, and 3-methylbutyl acetate, 3-methylbutanoic acid 3-methylbutyl ester were found to be the major components while butanoic acid 3-methylbutyl ester was found to be a minor component (0.59%, 0.31%, and 0.28% for the respective methods). These results proved that banana powder had the characteristic ester aroma of fresh banana, but the level of flavor in these products was different depending on which method had been used in the drying process. With regard to the volatiles fraction, the most effective drying method for the preservation of 3-methylbutyl acetate, butanoic acid 3-methylbutyl ester was FD, followed by VBD and then AD and with the reverse sequence for the preservation of 3-methylbutanoic acid 3-methylbutyl ester (Table 2). The main volatile of the three products was the same but some esters existed only in the FD product (acetic acid 2-methylpropyl ester, 2-pentanol acetate, butanoic acid butyl ester) and some only in the

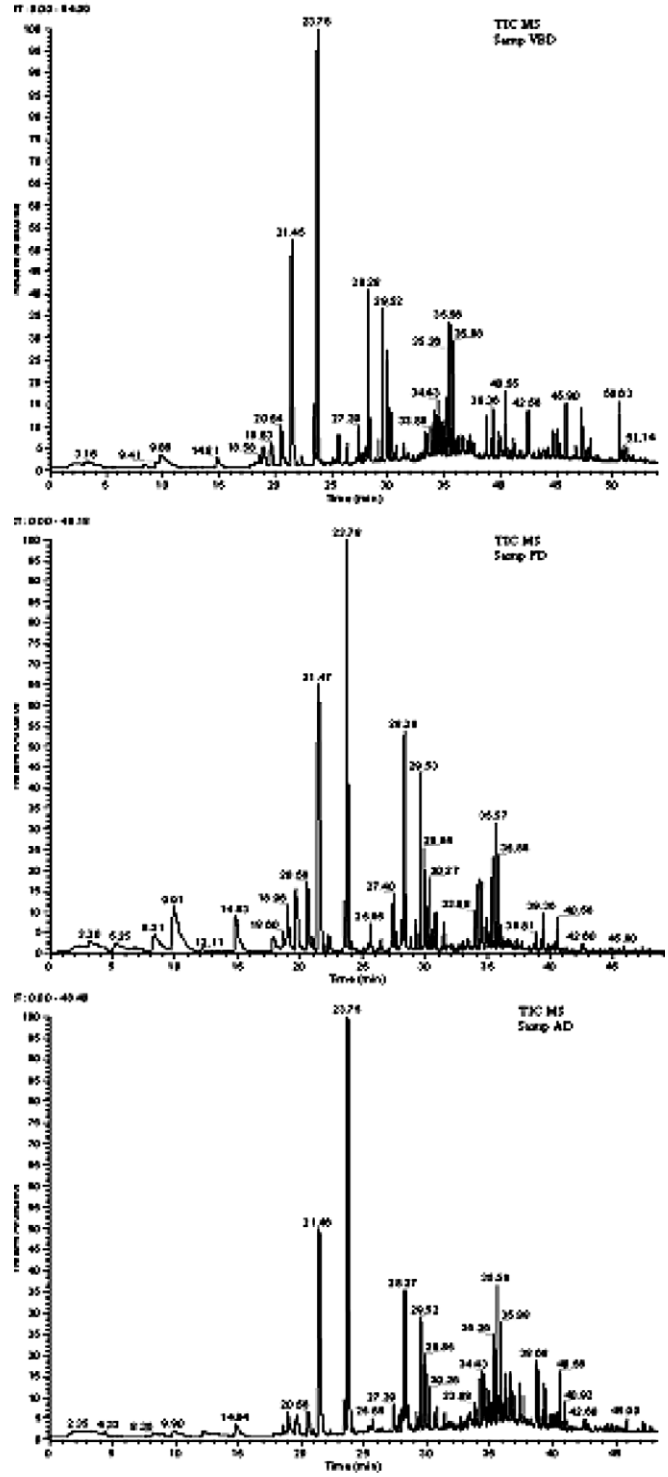

Fig. 1. Chromatograms of banana powder dried by VBD, FD and AD.

VBD or AD product (1,2-benzene dicarboxylic acid diethyl ester, isopropyl myristate). The drying temperature used in VBD and AD was higher than that of FD, so it is likely that some of the original esters had been damaged while some new chemicals had been formed.

Boudhrioua et al. (2003) reported that the most significant compounds making up the characteristic banana smell were two alcohols, nine esters and one phenol. Table 2

Table 2
Volatile compounds of banana powder dried by FD, VBD and AD

Retention time (min)	Components	Fraction[a] (%)		
		FD	VBD	AD
Esters				
5.22	Acetic acid 2-methylpropyl ester	0.61		
8.31	2-Pentanol acetate	2.40		
9.89	3-Methylbutyl acetate	7.32	3.12	0.74
14.83	Butanoic acid 2-methylpropyl ester	4.13	1.12	1.67
17.85	Butanoic acid butyl ester	1.26		
18.96	Isobutyl isoval ester	4.51	1.60	3.23
19.65	Propanoic acid 1,2-dimethylbutyl ester	3.76	1.33	1.69
20.57	2-Heptanol acetate	3.54	2.34	1.67
20.96	Butanoic acid 3-methylbutyl ester	0.59	0.31	0.28
21.47	Isoamyl butyrate	15.83	13.69	14.75
22.33	Isoamyl isovalerate	0.55	0.41	0.21
23.45	Isoamyl -2-methyl butyrate	1.65	2.43	1.66
23.78	3-Methylbutanoic acid 3-methylbutyl ester	16.11	19.30	22.39
24.16	Butanoic acid 1-methyl octyl ester	0.73	0.63	0.59
25.54	Hexanoic acid 2-methyl propyl ester	0.20	0.14	0.22
27.40	Butanoic acid hexyl ester	1.74		0.98
27.77	Butanoic acid 3-hexenyl ester	0.27	0.32	
28.28	Butanoic acid 1-methylhexyl ester	7.45	6.85	5.87
29.53	Hexyl isovalerate	3.23	3.29	3.20
29.85	Octanoic acid 3-methylbutyl ester	2.01	2.07	2.31
34.10	Butanoic acid 1-ethenylhexyl ester	0.87	0.85	0.85
34.43	*E*7-Decenyl acetate	1.02	0.98	1.22
34.55	2-Methyl-5-(1-methylethenyl)-cyclohexanol acetate	1.21	1.28	1.66
34.97	Butanoic acid 2-methyl octyl ester			0.38
39.81	1,2-Benzene dicarboxylic acid diethyl ester		0.54	
39.85	*E*5-Dodecenyl acetate	0.14		
41.22	3-Methylbutyl decanoate			0.25
45.21	Isopropyl myristate		0.49	
45.90	1,2-Benzene dicarboxylic acid bis(2-methyl propyl) ester	0.08	0.95	0.27
Alcohols				
27.59	(*E*)-3-Octen-2-ol	0.44	0.28	
35.11	2-Methyl-5-(1-methylethenyl) cyclohexanol	0.21	0.19	0.51
37.34	3-Methyl-2-propyl-1-pentanol	0.17	0.49	1.12
39.26	(*Z*)-4-Decen-1-ol	0.15	0.28	0.34
39.36	1-Cyclohexyl-2-buten-1-ol (*cis* and *trans*)	0.55	0.80	
40.45	*cis*-9-Tetradecen-1-ol			0.37
Acids				
48.02	*n*-Hexadecanoic acid		0.45	
51.46	(*Z*)-9-Octadecenoic acid		0.16	
Ketones				
26.42	3-Octen-2-one	0.29	0.66	
31.39	2-Undecanone	0.62		0.37
37.49	2-Tridecanone	0.08	0.25	
38.72	1,6-Dioxacyclododecane-7,12-dione	0.37		
Benzenes				
33.40	Eugenol	0.45	1.23	0.76
38.81	Elemicin		0.67	1.26
Others				
35.36	(*Z*,*Z*)-1,4-Cyclooctadiene	1.92	2.20	2.25
35.56	2-Octyne	1.90	2.46	2.78
35.88	*trans*-Bicyclo[4.2.0]octane	1.59	1.78	2.00
40.18	Hexadecane	0.14	0.98	0.54
40.56	7-Propylidene-bicyclo[4.1.0]heptane	0.44	1.00	1.22
44.71	Octadecane		0.48	0.13

[a] Fractions of components in banana powder (%) = peak area of a component in banana powder/total peak area of all components in banana powder.

shows that the alcoholic content of banana powder was not as significant as that of the esters. There were six alcohols identified here. More than half the alcohols were enols with some having a long hydrocarbon chain ($C \geqslant 8$), which probably resulted from the oxidation and degradation of unsaturated fatty acids and the hydrolyzation of esters. A banana-like flavor was assigned to the amyl and isoamyl esters of acetic, propionic and butyric acid, while the alcohols and carbonyls gave odors described as green, woody or musty (McCarthy, Palmer, Shaw, & Anderson, 1963; Pilar Cano et al., 1997). Two carboxylic acids identified as hexadecanoic acid (0.45%) and (*Z*)-9-octadecenoic acid (0.16%) were detected in the VBD product only. With regard to carboxylic compounds, Table 2 shows the presence of several ketones with long hydrocarbon chains and that the FD product contained more ketones than those produced by VBD and AD.

The full-bodied and mellow aroma in ripe banana had been associated with phenolether derivatives, and typical examples are eugenol and elemicin etc. (Berger et al., 1986; Miranda Eduardo et al., 2001). Eugenol is associated with the sweet, phenolic flavor while elemicin is related to the fruity component (Boudhrioua et al., 2003; Miranda Eduardo et al., 2001). Both eugenol (0.45%, 1.23%, 0.76%, respectively) and elemicin (0%, 0.67%, 1.26%, respectively) were discovered in banana powder produced by FD, VBD and AD, but the FD product had comparatively low quantities of these two volatiles. Of the three drying methods the product produced by VBD contained the greatest amount of eugenol, and the AD product contained the greatest amount of elemicin, so it may be inferred that the VBD method was least likely to destroy eugenol and that elemicin was stable to temperature. Moreover, the high vacuum pressure of FD was likely to eliminate elemicin.

3.2. Results of principal component analysis

Five characteristic components of the banana aroma and other volatiles occurring in high quantities were analyzed by SAS software and the results are shown in Table 3. The results of principal component analysis showed that the two principal components together attained 100% (Table 4). Based on eigenvectors of prin1, prin2 (Table 3), their expressions could be calculated.

The value of prin1 and prin2 in three products is shown in Table 5. The values for aroma were greatest for products produced using FD, followed by VBD and AD.

Table 4
Eigenvalues of the correlation matrix

	Eigenvalue	Difference	Proportion	Cumulative
Prin1	7.08701995	4.17403990	0.7087	0.7087
Prin2	2.91298005	2.91298005	0.2913	1.0000

Table 5
Prin1 and prin2 values of the three products

Obs	Type	Prin1 value	Prin2 value
1	FD	3.04968	−0.24732
2	VBD	−1.19075	1.81691
3	AD	−1.85893	−1.56959

4. Conclusion

Banana powder dehydrated by vacuum belt drying (VBD), freeze-drying (FD) and air-drying (AD) has different spectra for the volatile components. The major volatiles of the three products were the same, but some components existed only in FD product and some only in VBD or AD product. The relatively high drying temperature of VBD and AD might damage some of the original compounds while causing others to form.

Esters are considered to be the most important components of the aroma of banana powder. Key components of the banana's fruity odor, 3-methylbutanoic acid 3-methylbutyl ester, 3-methylbutyl acetate and butanoic acid 3-methylbutyl ester, have been separated and identified in banana powder, and the former are the two major components while the latter is a minor component.

More than half the alcohols identified were enols with some having long hydrocarbon chains ($C \geqslant 8$). As the

Table 3
Principal component analysis of 10 volatile compounds

Code	Compounds	Fraction (%)			Eigenvectors	
		FD	VBD	AD	Prin1	Prin2
X1	3-Methylbutyl acetate	7.32	3.12	0.74	0.364922	0.138940
X2	Butanoic acid 3-methylbutyl ester	0.59	0.31	0.28	0.375366	−0.022250
X3	3-Methylbutanoic acid 3-methylbutyl ester	16.11	19.30	22.39	−0.347633	−0.221986
X4	Isoamyl butyrate	15.83	13.69	14.75	0.300390	−0.351794
X5	Butanoic acid 1-methylhexyl ester	7.45	6.85	5.87	0.323006	0.299097
X6	Hexyl isovalerate	3.23	3.29	3.20	−0.024136	0.584700
X7	2-Heptanol acetate	3.54	2.34	1.67	0.365262	0.136753
X8	Isobutyl isoval ester	4.51	1.60	3.23	0.282714	−0.385792
X9	Eugenol	0.45	1.23	0.76	−0.270377	0.406739
X10	Elemicin		0.67	1.26	−0.351407	−0.207021

amounts of acids were very low and only existed in VBD powder, they may have minor influences on the aromatic profile of the banana powder studied. Eugenol and elemicin, responsible for the typical full-bodied and mellow aromas, were detected in banana powder. Other compounds such as alkyls, alkenes, and alkynes were also identified.

From the value of the two principal components, it can be concluded that the best aroma value was achieved in products dried by FD, followed by VBD and AD.

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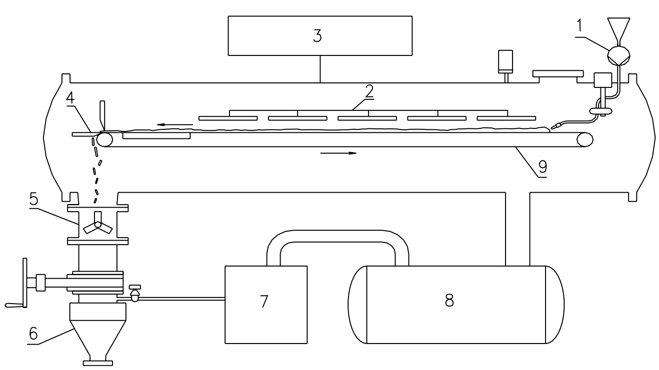
Appendix. Diagram of vacuum belt drier



1 – feed-in and distributing part; 2 – heating zone; 3 – control panel; 4 – part of product peeling off; 5 – product crusher part; 6 – ejector of dried product; 7 – vacuum system; 8 – condensation system; 9 – conveying belt.

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