MICROWAVE AND SPOUTED BED DRYING OF FROZEN BLUEBERRIES: THE EFFECT OF DRYING AND PRETREATMENT METHODS ON PHYSICAL PROPERTIES AND RETENTION OF FLAVOR VOLATILES

HAO FENG and JUMING TANG[1]

Department of Biological Systems Engineering

DENNIS SCOTT MATTINSON and JOHN KEEGAN FELLMAN

Department of Horticulture and Landscape Architecture
Washington State University, Pullman, WA 99164

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ABSTRACT

*Frozen blueberries (*Vaccinium corymbosum L *cv. 'Elliott') were dried in a microwave and spouted bed combined dryer (MWSB) at 70C air temperature and 3.7 W/g microwave power (wet material). The effect of pretreatment using a 2.5% Ethyl Oleate & 0.2 NaOH dipping solution followed by sucrose osmotic treatment was investigated. The drying kinetics of MWSB drying was compared with spouted bed (SB) drying with dipping treatment, and with tray drying. The rehydration ratio, the color, and the bulk density of MWSB dried blueberries were compared with those of freeze, tray, and SB drying. The drying time needed to reduce blueberry moisture content from 82.5% to 15% (wet basis) using MWSB drying was 1/19 and 1/24 (with and without pretreatment) of the time for tray drying. The MWSB drying resulted in a low bulk density and more reddish and less blue color compared with other methods. MWSB dried frozen blueberries exhibited a higher rehydration ratio in short soaking times. Analysis of flavor volatiles by GC/MS identified ten heat-generated compounds. Microwave heating generated three unique flavor compounds (2-Butanone, 2-methyl butanal, and 3-methyl butanal). Freeze-dried frozen blueberries lost several flavor compounds including the typical blueberry aroma, the 1, 8-Cineole.*

[1]Contact author: Dr. Juming Tang, Department of Biological Systems Engineering, Washington State University, Pullman, WA 99164-6120. Tel: 509-335-2140; Fax: 509-335-2722; Email: jtang@mail.wsu.edu

INTRODUCTION

Blueberries are popular in North America because of the unique flavor and nutrition values. Recent studies document their high antioxidant capacity and the benefits of those antioxidants in neutralizing the effects of free radicals that damage DNA in human cells (Anon.). The anthocyanin pigment of blueberries is under study for its links to improved eyesight and reduction in the incidence of age-related diseases. According to a report from The North American Blueberry Council, 163,631 million pounds of cultivated blueberries were produced in 1996 (Anon.). Fresh blueberries are perishable and can only be stored for two weeks under refrigerated conditions after harvesting (Lim *et al.* 1995). Dehydration can be used to extend shelf life at room temperature. Dehydrated blueberries may also impart new functional attributes to final products. Food processors have found that dried cultivated blueberries can provide an added eye and taste appeal to cereals, confections, and bakery goods (Duxburg 1992).

Commercially dried blueberries include dehydrated (moisture level 11-18% wb), freeze dried (moisture level 2-3% wb), and drum dried powders (moisture level 3-5% wb) (Anon.). Current commercial dehydration methods are limited by either high production cost (e.g. freeze drying) or by degraded quality (e.g. sun or hot-air tray drying) because of the long exposure of blueberries to elevated temperatures. Recent research efforts strive to develop appropriate drying methods that result in high quality dehydrated blueberries. The techniques that have been explored include explosion-puffing (Sullivan *et al.* 1982), fluidized bed drying (Kim and Toledo 1987), microwave drying (Yang and Atallah 1985; Venkatachalapathy and Raghavan 1997), high temperature fluidized bed drying (Kim and Toledo 1987), and osmotic dehydration (Kim and Toledo 1987; Yang *et al.* 1987; Venkatachalapathy and Raghavan 1997; Ramaswamy and Nsonzi 1998). The criteria used for evaluating those drying techniques were physical quality attributes such as the rehydration ratio, bulk density, texture, and color (Nsonzi and Ramaswamy 1998). New techniques were reported to yield improved quality when compared to traditional hot air drying. There are no reports concerning aroma volatile retention.

The objective of this study was to investigate the drying characteristics of 'Elliott' blueberries in a microwave and fluidized bed combined (MWSB) dryer and to study the effect of such drying on both the physical and flavor quality attributes.

MATERIALS AND METHODS

Blueberries

Elliott blueberries (*Vaccinium corymbosum L.*), a popular highbush cultivar in North America, grown in northern Idaho and harvested on September 5, 1997, were used in this study. To preserve the aroma volatile, the blueberries were processed immediately after the harvest by the individual quick freeze (IQF) method and kept in refrigeration at -40 to -22C. Before the drying experiments, berries were thawed at 4C for more than 5 h. The moisture content of the thawed blueberries was 82.5% (wb). The drying quality of 'Elliott' blueberries was evaluated by rehydration ratio, bulk density, total color difference, and flavor volatile retention.

Drying Methods

Following drying methods or combination of drying methods were used in this study to reduce berries moisture content to 4 to 13% (wb).

(1) Freeze drying: 400 g frozen berries were freeze dried in a Freezemobile 24-Unitop dryer (Virtis Company, Gardiner, NY) under the following condition: vacuum, 20 millitorr; heating plate temperature, 20C; and condenser temperature, -60C. Since whole berries were used in freeze drying, the drying time to reduce moisture content to 5.1% was 48 h.

(2) Tray drying: 400 g thawed berries were air dried in an UOP-8 tray dryer (Armfield LTD., Hampshire, England) at 70C to a final moisture content of 5.8% (wb). The moisture loss was monitored by periodically weighing the tray.

(3) Microwave and spouted bed combined drying (MWSB): microwave drying was combined with the spouted bed fluidization technique to improve heating uniformity. A spouted bed was used to provide pneumatic agitation to the berries to avoid localized overheating due to the nonuniform distribution of the electromagnetic field inside the microwave cavity. A schematic of the drying apparatus is shown in Fig. 1. Details of the apparatus are reported elsewhere (Feng and Tang 1998a). Thawed blueberries (40 g) were dried at a microwave power level of 3.7 W/g (wet material) and air temperature of 70C. The superficial hot air velocity was 2.1 m/s. The final moisture content of dried berries was 6.9% (wb).

(4) Spouted bed drying (SB) with pretreatment using 2.5% Ethyl Oleate & 0.2% NaOH dipping: In preliminary tests to determine the best dipping

method, three treatment solutions were investigated: 2.5% Ethyl Oleate & 0.2% NaOH solution, 2% NaOH solution, and hot water. The first dipping solution was found to yield the best appearance and highest moisture loss rate. For this treatment, thawed berries were dipped in 2.5% Ethyl Oleate and 0.2% NaOH solution at 60C for 60 s. The dipped samples were then flushed with 40C hot water and extra surface water was removed with paper tissue. Spouted bed air temperature was 70C and air velocity was 2.1 m/s. Blueberries were dried to moisture content of 12.9% (wb).

(5) MWSB drying with osmotic pretreatment: after 2.5% Ethyl Oleate & 0.2% NaOH dipping, 40 g thawed and dipped blueberries were soaked in 800 g saturated sucrose solution at a temperature of 50C for 24 h to reduce moisture levels. After the osmotic treatment, berries were flushed with 40C hot water to remove surface sugar. The moisture content after osmotic treatment was 56.6% (wb). The berries were then MWSB dried under the above-mentioned conditions to a final moisture level of 11.7% (wb).

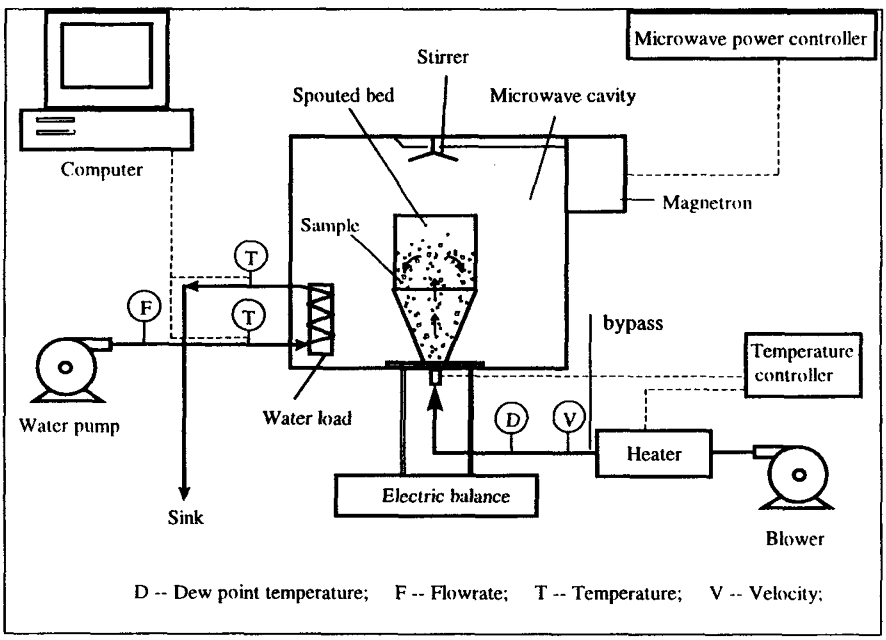

FIG. 1. MICROWAVE AND SPOUTED BED DRYING SETUP

Rehydration Ratio

Rehydration ratio was defined as the total mass of rehydrated blueberries per unit mass of dry matter after rehydration (Kim and Toledo 1987). Since dried blueberries are mainly used in cereal, confections, and bakery goods, a rehydration temperature of 21C (room temperature) was used. Dried blueberries (5 g) were immersed in 100 g tap water and held for 2, 7, 17, 32, and 52 min. The blueberries were then drained on a perforated plate by applying a gentle suction till no water drip could be observed (Prabhanjan *et al.* 1995). The dry matter was determined by the vacuum oven method at 70C and 28 in. Hg (AOAC 1990). Results reported were the means of three determinations.

Bulk Density

Bulk density of dried blueberries was determined as follows (Zogzas *et al.* 1994):

$$\rho_b = \frac{M_s + M_w}{V_s + V_W + V_a} \tag{1}$$

where M and V are mass and volume; subscripts "s", "w", and "a" denote solid, water, and air trapped in the berry, respectively. The bulk density defined in Eq. (1) characterized the internal physical property of the berry and, therefore, is widely used in evaluating quality of dried fruits and vegetables (Feng and Tang 1998b). The mass $M_s + M_w$ was determined by an electronic balance. The volume of dried blueberries, composed of the volume of solid, water, and air, was determined by a water displacement method (Lozano *et al.* 1980). Dried blueberries (5 g) were used for each bulk density measurement and the means of three determinations were reported.

Color

Color measurements were conducted with a Minolta Chroma CR-200 color meter (Minolta Camera Co. LTD, Japan). CIE L*a*b* color system was used to characterize the color changes of blueberries dried with different drying and pretreatment methods. The CIE scales measure the degrees of lightness (L*), redness or greenness (+/- a*), and yellowness or blueness (+/- b*). Total color change ΔE was employed, which was calculated by (Feng and Tang 1998a):

$$\Delta E = \sqrt{(L^* - L_0^*)^2 + (a^* - a_0^*)^2 + (b^* - b_0^*)^2} \tag{2}$$

where subscript "0" represents the color reading of thawed blueberries which serves as a reference for the color comparison. ΔE represents the distance, in three-dimensional CIE color space, between the point representing the thawed blueberries and the point for the blueberries dried with one of the five methods. Color readings of dried blueberries were taken by wrapping a sample of about 40 g with transparent Saran Wrap (Dow Brands L.P., Indianapolis, IN) into a square packet and measuring color at five different locations on the packet. At each location, five readings were taken and the average of 25 readings from five locations was taken as the color of the sample.

Flavor Volatile Analysis

Dehydrated blueberries were rehydrated at room temperature with deionized water. The amount of water used to reconstitute the blueberries was calculated based on the moisture content of the dried blueberries to reach a solid content of 15.6% (g solid/g H_2O) in the mixture. The rehydrated blueberries were then macerated with a blender and the mixture was centrifuged 12-14 min at 8160 g to obtain clarified juice. For thawed blueberries, samples (50 g) were macerated and then diluted in 100 mL distilled deionized water to obtain a mixture. The mixture was centrifuged to collect clarified juice. Flavor volatiles analysis was performed by using 2.5 mL of juice diluted 1:1 with distilled deionized water and injected into a gas chromatography system using purge-and-trap cryofocusing techniques. Samples were purged in a close system for 5 min with helium, and water vapor was condensed from the sampling stream by passing the vapors through a cryostat held at -10C. Samples were injected by cryofocusing at -90C using a commercial purge-and-tap injector (Chrompack International B.V., Middelburg, Netherlands) modeled after that reported by Badings *et al.* (1985). The sample was subsequently injected into a HP-5890 gas chromatographic system, and separations were achieved using conditions reported by Mattheis *et al.* (1991), except that the DB-WAX column diameter was 0.32 mm with 5.0 μM film thickness. Quantitation was achieved using flame-ionization detection. Positive identification of volatile molecules was facilitated by purging the sample onto tenax traps, then using a Tekmar 6000 cryofocusing thermal trap desorber (Tekmar Co., Cincinnati, OH) interfaced to a HP-5890 GC with a HP-5971 Quadrupole Mass Spectrometer. The mass spectrometer operated in the electron ionization mode at 70eV. Identification was via Wiley/NIST library match and injection of standard compounds.

RESULTS AND DISCUSSION

Drying Kinetics

Drying curves for blueberries (Fig. 2a) exhibit a typical exponential decrease, indicating an internal controlled moisture transport (Tulasidas *et al.* 1993). The times needed to reduce moisture from 82.5% (wb) to 15% (wb) were about 40, 50, 200, and 960 min for the MWSB drying, MWSB + dipping + osmosis, SB drying, and tray drying, respectively. A substantial reduction in drying time was achieved by applying microwave energy in the drying process.

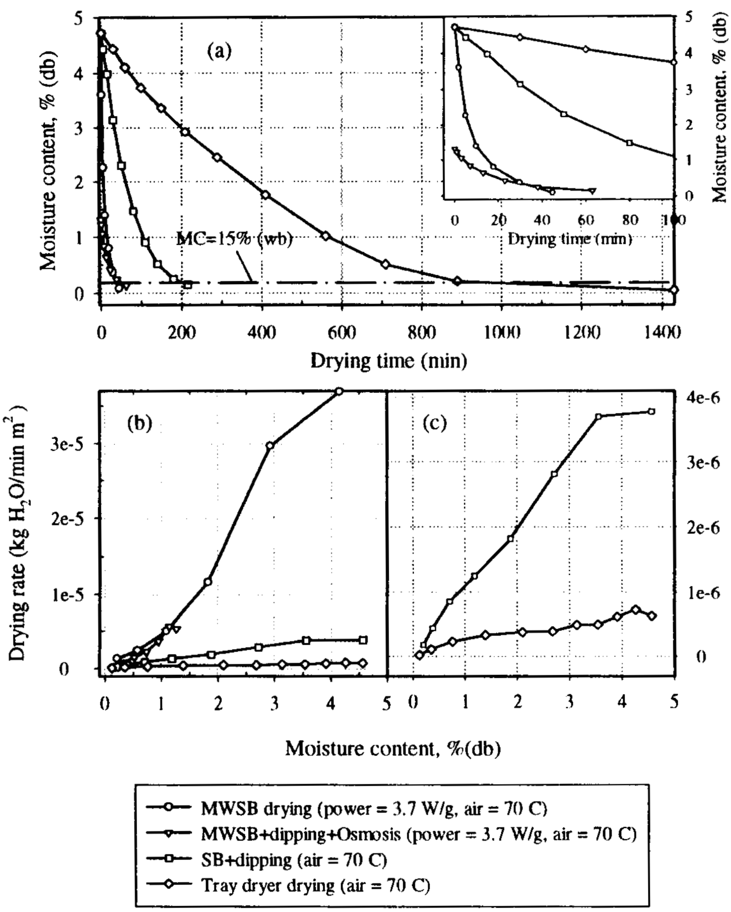

FIG. 2. DRYING KINETICS OF ELLIOTT BLUEBERRIES WITH DIFFERENT DRYING AND PRETREATMENT METHODS

TABLE 1.
BLUEBERRY DRYING TIME COMPARISON

Drying method	Moisture % (wb)	Drying time h	Temperature °C	Reference
MWSB	15	0.7	70	this work
MWSB[e] + dipping[b] + OD[c]	15	0.8	70	this work
OD[c] + HTFB + FB[d]	12[a]	1.2	150 + 60	Kim and Toledo 1987
HTFB + tunnel drying	12[a]	2.1	170 + 60	Kim and Toledo 1987
SB + dipping[b]	15	3.3	70	this work
tunnel drying	12[a]	12.5	60	Kim and Toledo 1987
tray drying	15	16	70	this work
sun drying	16 – 25	72	--	Yang and Atallah 1985

[a] data extracted from sorption isotherm given by Lim et al. (1995). [b] SB (spouted bed); dipping solution: 2.5% EO & 0.2% NaOH. [c] osmotic drying time excluded. [d] OD (osmotic dehydration); HTFB (high temperature fluidized bed, air = 150 & 170°C); FB (fluidized bed). [e] microwave & spouted bed.

With and without pretreatment, the time needed for microwave drying of blueberries to a moisture of 15% (wb) was 1/19 and 1/24 of the time for the tray drying, respectively. Spout bed (SB) fluidization also accelerated the moisture removal as indicated by an almost five fold reduction in drying time compared with the tray drying. A comparison of drying times of blueberries dried with different techniques is shown in Table 1. It has been well recognized that drying time and temperature are the key parameters for the quality degradation of fruits and vegetables during drying (Yang and Atallah 1985; Strumillo *et al.* 1996). Among the newly developed techniques listed in Table 1, microwave and spouted bed combined drying yielded the shortest drying time at a moderate air temperature (70C) and, hence may be a very effective alternative to currently used commercial drying methods for blueberries.

The drying rates (kg H_2O/min m^2 fruit surface area) for four drying methods are shown in Fig. 2(b). In Fig. 2(c), an enlarged drying rate scale was used to show the drying rates of the spouted bed + dipping and the tray drying. All drying of blueberries occurred in the falling rate region. Microwave spouted bed drying rate was about two orders of magnitude higher than SB drying or tray drying. The drying rate for spouted bed approximated three times the rate of tray drying (Fig. 2b & 2C). During the first 5 min in the MWSB drying, the blueberries burst and liquid bled out. The high drying rate of MWSB drying was partially due to bursting which provided openings in the berry epidermis thus allowing moisture to escape. In order to prevent rupture and eliminate its influence on the drying rate, dipping and sucrose osmotic pretreatment were used to reduce moisture to 56.6% (wb). MWSB drying of osmotically pretreated blueberries was slightly slower than the MWSB drying. Our data suggest that microwave heating generates a positive pressure and temperature gradient from sample center to surface thus causing an increase in the drying rate (Torringa *et al.* 1996).

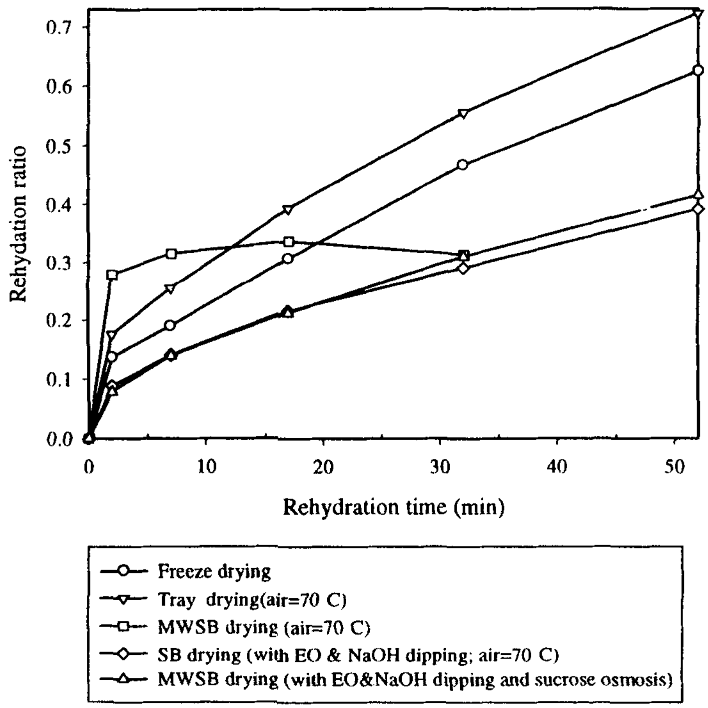

FIG. 3. COMPARISON OF REHYDRATION CAPACITY OF ELLIOTT BLUEBERRIES DRIED WITH DIFFERENT METHODS

Rehydration

The rehydration ratios for dehydrated blueberry are shown in Fig. 3. The effect of drying method on relative water regaining capacity of blueberries was significantly different when measured after 2 min and 32 min soaking. The MWSB dried blueberries yielded the highest rehydration ratio at 2 min while, at 32 min, tray dried samples exhibited the largest water holding capacity. The higher rehydration capacity of MWSB drying at the beginning of the reconstitution process may result from the bursting which created openings in the blueberry skin. The high resistance of berry fruit skin to moisture diffusion has been documented by Venkatachalapathy and Raghavan (1997). The dried blueberries with cracks on the skin could absorb water easier and faster at the beginning and, for the same reason, their water holding capacity would be reduced during long soaking times (Fig. 3). It may be advantageous for dried blueberries to have a high short time reconstitution capacity when used for breakfast cereals, since they are consumed with milk within minutes of mixing. It should be noted that the freeze dried blueberries did not have a higher rehydration capacity compared to tray drying as reported by Yang and Atallah (1985). This may be the consequence of less epicuticular wax decomposition when compared to lengthy thermal tray drying.

Color

Color measurements of dried blueberries are shown in Table 2. The desirable color is the one closest to that of the thawed blueberries. The total color change ΔE values indicated the most severe discoloration in the freeze dried sample while the MWSB dried sample exhibited the smallest color degradation, when compared to the thawed blueberries. MWSB dried blueberries had higher a^* and b^* values, indicating a more reddish but less blue color, possibly caused by a leakage of anthocyanin as a result of bursting. The anthocyanin pigments of blueberries are located in the epidermal and subepidermal cell layers (Sapers and Phillips 1985). Above the epidermal cell layers, the outermost epicuticular wax layer and the underlying cuticle may decrease the perception of anthocyanin pigment colors. The slightly higher L^* value and, therefore, more pale appearance, of freeze dried samples may relate to the intact surface wax layer and altered surface reflection to the incident light of the color meter. A higher ΔE value for freeze dried blueberries was also reported by Nsonzi and Ramaswamy (1998).

Bulk Density

Bulk densities of blueberries dried with different methods are compared in Fig. 4. Compared to thawed blueberries, the bulk density of freeze dried and MWSB dried blueberries is significantly lower, only 49% and 57% of the density of thawed blueberries. The low bulk density of freeze dried product was attributed to the well protected porous structure and minimized shrinkage when

TABLE 2.
BLUEBERRY COLOR MEASUREMENT RESULTS

Treatment	L*	a*	b*	ΔE
thawed	31.07 ± 1.3[a]	1.62 ± 0.3	-0.74 ± 0.1	0
freeze drying	38.52 ± 0.8	0.62 ± 0.3	-0.83 ± 0.1	7.52
tray drying	35.55 ± 0.3	0.51 ± 0.2	-0.06 ± 0.1	4.67
MWSB drying	34.28 ± 0.4	3.11 ± 0.3	0.47 ± 0.1	3.74
SB drying	34.95 ± 0.4	0.48 ± 0.1	-0.03 ± 0.02	4.11
MWSB + dipping + osmosis drying	35.47 ± 0.3	0.21 ± 0.01	-0.13 ± 0.03	4.66

[a]Mean ± standard deviation

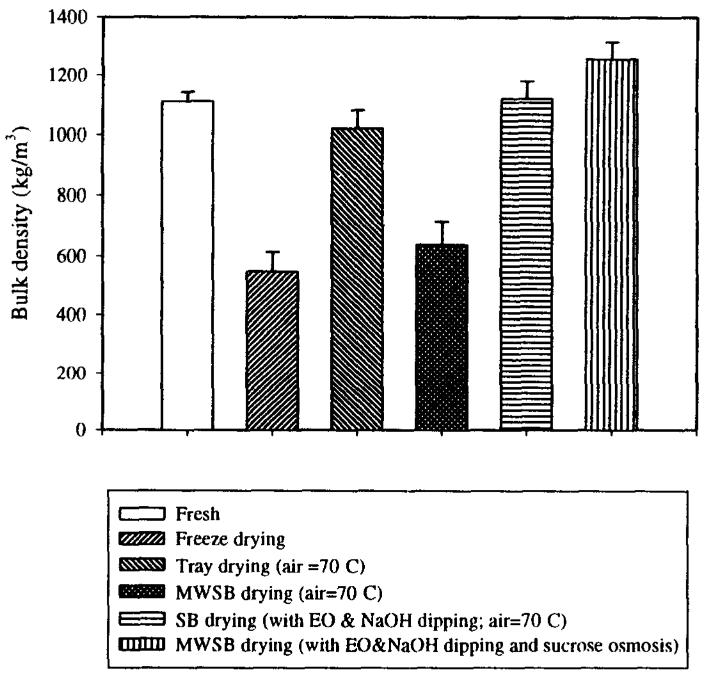

FIG. 4. BULK DENSITY OF ELLIOTT BLUEBERRIES UNDER DIFFERENT PROCESSING AND PRETREATMENT METHODS

freeze-dried (Yang and Atallah 1985). The puffing effect of microwave drying may be responsible for the low bulk density due to MWSB drying. A similar puffing effect was reported by Torringa *et al.* (1996) and Feng and Tang (1998a) in studies regarding the drying of fruits and vegetables. Hot air drying methods (tray and SB drying) were characterized by a high bulk density close to that of the thawed blueberries. In contrast to MWSB drying, the MWSB + dipping + osmotic treatment had the highest bulk density. This is very likely related to the sugar infusion. The introduction of additional sugar may have changed the rheological properties and glass transition temperature of the berry. This may result in a complex internal contracting hygrostress state during drying that may exceed internal pressure produced by the dielectric heating. Our results agree with those of Ertekin and Cakaloz (1996) who reported higher bulk density due to sucrose infusion of dried peas.

Flavor Volatile Analysis

Sample of 'Elliott' blueberries that were dried by different methods was analyzed by GC/FID with purge- and trap injection. The compounds detected are listed in Table 3. A typical chromatogram for microwave dried blueberries is illustrated in Fig. 5. The major findings from Table 3 include: (1) heating caused some aroma compounds, such as acetaldehyde and ethyl 3-methyl butyrate found in thawed juice, to vanish or to decrease until they were undetectable; (2) several aroma volatiles disappeared from freeze-dried samples as a result of prolonged drying; (3) heat treatment altered aroma by creating ten new flavor notes (2-methyl propanol, butanal, 2-butanone, 2-methyl butanal, 3-methyl butanal, 2-pentanone, 2-ethenyltetrahydro 2,6,2h-pyran, 1-limonene, 1,8-cineole, and 2-furancarboxaldehyde). Among the compounds newly detected after heating, limonene and 1,8-cineole have been identified as blueberry aroma in previous studies (Parliment and Koloe 1975; Lugemwa *et al.* 1989; Simon *et al.* 1996). It is likely that the heating increased the intensity of these compounds; (4) microwave heating generated some unique flavor compounds (2-Butanone, 2-methyl butanal, and 3-methyl butanal). The mechanisms under which the flavor volatiles are generated during drying are unknown for both the ordinary heating and the microwave heating. Luning *et al.* (1995), in a study regarding the effect of hot-air drying on the flavor compounds of bell peppers, found that the hot-air drying can release new odor compounds which can be related to the autoxidation of unsaturated fatty acids. Microwave-hot air drying of mushrooms positively affected retention of characteristic aroma compounds (Riva *et al.* 1991). Further study is required to understand the interaction between heat treatment and flavor compound retention/degradation/generation.

TABLE 3.
COMPOUND LIST OF BLUEBERRY SAMPLES DETECTED BY PURGE-AND-TRAP INJECTION WITH GAS CHROMATOGRAPHY/FID UNDER DIFFERING PRETREATMENTS

Compound	Microwave Juice	Hot Air Juice	Freeze Dry Juice	Control Juice
Acetyaldehyde	–	–	–	+
2-Methyl Propanal	+	+	–	–
Propanal	+	–	+	+
Acetone	+	–	–	+
Methyl Acetate	+	–	–	+
Butanal	+	+	+	–
Ethyl Acetate	+	+	+	+
2-Butanone	+	+	–	–
2-Methyl Butanal	+	+	–	–
3-Methyl Butanal	+	+	–	–
Ethanol	+	+	+	+
2-Pentanone	+	+	–	–
2,3-Butadione	+	–	–	–
2-Methyl Propyl Acetate	+	–	–	–
4-Methyl-2-Pentanone	+	–	–	–
Ethyl 3-Methyl Butyrate	–	–	–	+
Hexanal	+	+	+	+
2-Ethenyltetrahydro 2,6, 2H-Pyran	+	+	–	–
l-Limonene	+	+	–	–
1,8-Cineole	+	+	–	+
Trans-2-Hexanal	+	+	+	+
Octanal	+	+	+	–
Nonanal	+	+	+	+
2-Furancarboxaldehyde	+	+	–	–
Decanal	+	+	+	+
Benzaldehyde	+	+	+	+

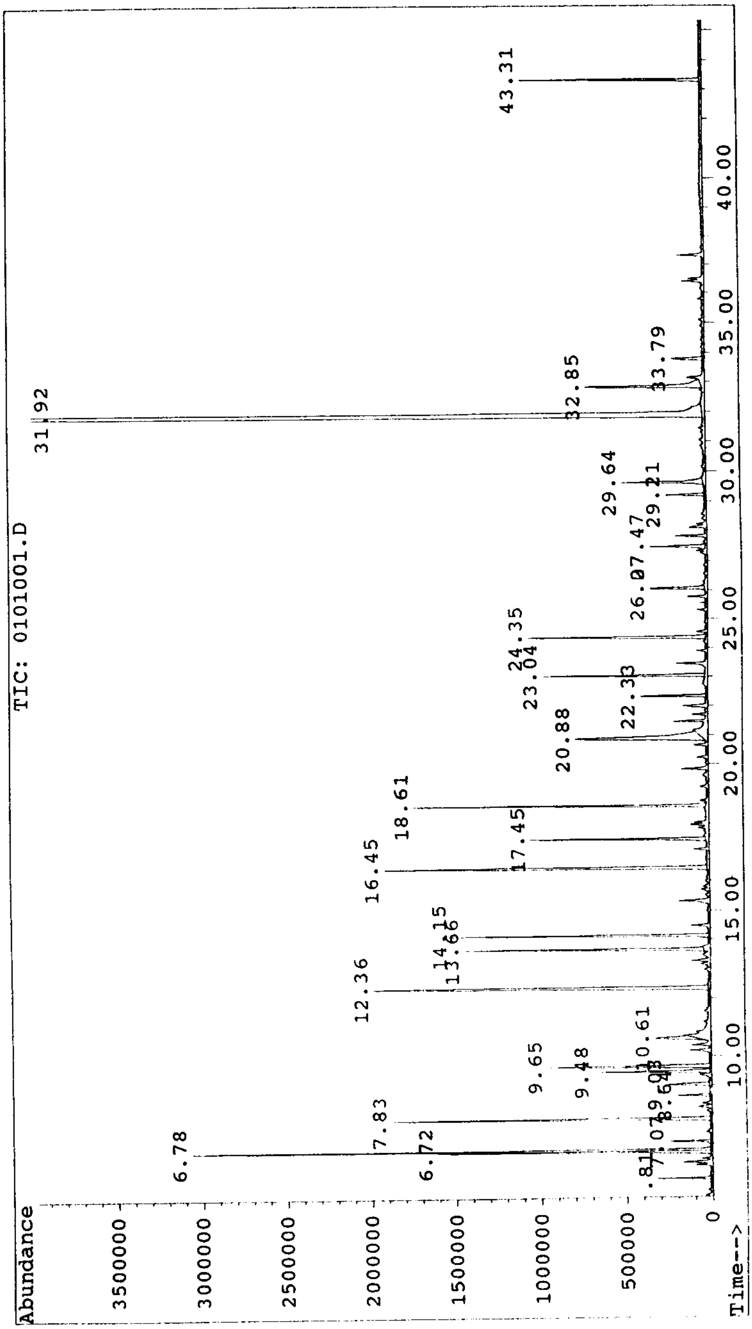

FIG. 5. CHROMATOGRAM SHOWING THE PURGEABLE FLAVOR VOLATILES DETECTED BY PURGING SAMPLES WITH He ONTO TENAX AND THEN PERFORMING PURGE-AND-TRAP GAS CHROMATOGRAPHY WITH MASS SPECTROMETRY

CONCLUSION

MWSB drying of frozen blueberries was characterized by a substantial reduction in drying time and an improved product quality as indicated by a low bulk density, a high short-time rehydration ratio, and a more reddish and less blue color compared to samples freeze dried, tray dried, and SB dried. Pretreatment using 2.5% Ethyl Oleate & 0.2% NaOH dipping followed by sucrose osmotic dehydration can prevent blueberries from bursting when microwaved but resulted in a high bulk density and low rehydration ratio. Freeze drying of frozen blueberries did not yield a high-quality dried product with regard to rehydration ratio and color change.

Characteristics of the flavor volatile compounds of 'Elliott' blueberries were changed by both hot air and microwave heating. Microwave heating produces new volatile compounds not found when blueberries are dried by other methods. Several flavor compounds disappeared from freeze-dried blueberries.

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