Flavor Volatiles and Physical Properties of Vacuum-Microwave- and Air-Dried Sweet Basil (*Ocimum basilicum* L.)

Alex N. Yousif,[†] Christine H. Scaman,[†] Timothy D. Durance,*[,†] and Benoit Girard[‡]

Department of Food Science, University of British Columbia, 6650 North West Marine Drive, Vancouver, British Columbia V6T 1Z4, Canada, and Pacific Agri-Food Research Center, Agriculture and Agri-Food Canada, 4200 Highway 97, Summerland, British Columbia V0H 1Z0, Canada

Basil (*Ocimum basilicum* L.) was dried using conventional hot air or the recently developed vacuum-microwave dryers. The effect of the drying method on the relative abundance of major flavor volatiles, rehydration rate, color, and structural integrity of the plant was evaluated. Dynamic headspace analysis of volatiles present in fresh or dried basil revealed that linalool and methylchavicol (estragole) were the two major headspace volatile compounds of the plant sample. Vacuum-microwave dehydrated basil yielded approximately 2.5 times the linalool and 1.5 times the methylchavicol of the air-dried samples. Furthermore, the vacuum-microwave-treated samples yielded more volatiles than fresh basil, due to chemical reactions during drying. Air-dried samples of basil had darker and fewer green hues than those prepared by vacuum microwave. Vacuum-microwave-dried samples had a higher rehydration rate, whereas the potential of the plant material to rehydrate was hindered in air-dried samples. This is likely attributed to the dramatic and pronounced structural collapse of the air-dried cells as revealed by the scanning electron microscope.

Keywords: *Basil; Ocimum basilicum; air-drying; vacuum-microwave-drying; volatiles; scanning electron microscopy; color; rehydration*

INTRODUCTION

Sweet basil (*Ocimum basilicum* L.) is a popular aromatic and annual herb that grows in several regions of the world. Basil is marketed as the fresh or dried plant. The air-dried plant and its extract, basil oil, have been used extensively from the earliest times for perfumery and flavor purposes, to enhance product acceptance.

Drying of basil is an effective method that inhibits the growth of microorganisms and delays the onset of some biochemical reactions in the final product. Hot-air-drying, however, can cause heat damage and severely modifies the physical and chemical characteristics of the marketed plant. Although freeze-drying can be used to circumvent heat damage and produce a product with superior physical and chemical qualities, it is considered a costly process.

Vacuum-microwave-drying offers an alternative way to improve the quality of dehydrated products. The low temperature and fast mass transfer conferred by vacuum (Huxsoll and Morgan, 1968), combined with the rapid energy transfer by microwave heating, generate a rapid, low-temperature drying. Moreover, the absence of air during drying may inhibit oxidation. Therefore, physical properties such as structure, color, and sensory qualities of products can be largely preserved. To date, vacuum-microwave-drying has been successfully used in dehydration of animal materials such as shrimp (Lin et al., 1998b) and krill (Durance, 1997) as well as plant materials, for example, potato chips (Durance and Liu, 1996), carrots (Lin et al., 1998a), and cranberry (Yongsawatdiguul and Gunasekaran, 1996a,b). Regardless of its nature, vacuum-microwave-dried foods showed better retention of key constituents and sensory properties than their air-dried counterparts.

This study was undertaken to investigate the potential use of vacuum microwave in drying basil and to compare the effect of factors associated with the drying method on the physical and chemical properties of the final product.

MATERIALS AND METHODS

Plant Source. Sweet basil (*O. basilicum* L.) was purchased from a local wholesale market in Surrey, BC, but originally it was imported by air from Israel. The herb was generally available with the stems and leaves attached. In all experiments, the leaves were selected and used. The initial moisture of the plant material was measured at 89.9% on a wet weight basis.

Drying. A sample (600 g) of fresh basil leaves was placed in the drying drum of a 4 kW maximum power microwave vacuum chamber (26 in. in diameter and 20 in. long, DRI Dehydration Research, Vancouver, BC, Canada). The drum was rotated at a rate of 11 rotations per minute. After a vacuum of 27 in. of Hg was achieved, the magnetron was powered at 3.2 kW for 12 min, followed by 1 kW for 6 min and then 0.5 kW for 5 min. Microwave power was measured by the IMPI 2-liter test (Buffler, 1993). The product temperature was maintained at 45 °C. Ambient air flow rate through the chamber was 3 L/min. The final moisture content and water activity of the plant material were measured at 7.1% and 0.37, respectively.

Fresh basil from the same source used in the preceding drying method was air-dried using a commercial dryer as follows: 1 kg of fresh basil leaves was loaded on a Vers-a-belt dryer (Wal-Dor Industries Ltd., New Hamburg, ON, Canada).

* Author to whom correspondence should be addressed [telephone (604) 822-4425; fax (604) 822-3959; e-mail durance@interchange.ubc.ca].

[†] University of British Columbia.

[‡] Agriculture and Agri-Food Canada.

10.1021/jf990484m CCC: $18.00
Published on Web 10/08/1999

The dryer temperature was set at 48 °C with an air flow rate of 2.3 m^3/s and a relative humidity of 25%. After 11.5 h in the dryer, moisture content and water activity of the plant material were measured at 7.8% and 0.34, respectively.

Water Activity (a_w) and Moisture Content Determinations. The water activity (a_w) of all dried samples was determined using the Aqualab (Model CX-2, Decagon Devices Inc., Pullman, WA) for water activity determination. Moisture content of dry samples was determined (in triplicates) using a laboratory oven at 103 °C. Samples were dried to a constant weight, and the moisture content was calculated from the difference between the wet and dry weights divided by the wet weight.

Headspace Volatile Compound Analysis. Volatile compounds of basil were extracted by a dynamic headspace technique, separated on a Varian 3700 gas chromatograph (Varian Associates Inc., Palo Alto, CA), and identified by gas chromatography/mass spectrometry (GC/MS).

Six samples of fresh or dried basil were weighed in clean zip-lock bags so that the content of each bag delivered a final concentration of 0.6% (dry w/v) when suspended in the preheated (60 °C) distilled water contained in a 1 L purge and trap apparatus (Wheaton, Millville, NJ). The temperature of the apparatus was held at 60 °C throughout the course of the experiment by circulating water from a water bath. Fresh samples were blended (Sunbeam blender) in 100 mL of preheated (60 °C) distilled water until completely homogenized (30 s). Dried samples of the herb, however, were crushed while inside the sealed plastic bag, and the flakes were immediately added to the purge and trap vessels. An internal standard, tetradecane (Aldrich Chemicals, Milwaukee, WI) dissolved (1:100) in diethyl ether (BDH Chemicals, Toronto, ON) was added (500 μL) to each of the vessels that were attached to a horizontal shaking platform. The headspace of the shaken herb-containing vessels was purged with purified N_2 (Linde Specialty Gas, Vancouver, BC, Canada) at 50 mL/min for 2 h and subsequently passed through an adsorbent trap containing Tenax GC (60−80 mesh, Alltech Associates, Deerfield, IL). About 100 mg of Tenax GC was packed into each glass tube (18 cm, 6 mm o.d., 4 mm i.d.), which was secured at both ends with glass wool deactivated with Sylon-CT (Supelco Inc., Toronto, ON, Canada). The Tenax GC was conditioned prior to first use as recommended by the manufacturer. Subsequent use of the traps was preceded by stripping the adsorbent with diethyl ether and drying at 60 °C with N_2 flowing at 30 mL/min for 30 min. Diethyl ether was used to elute the volatile compounds from the Tenax GC, and the extract was concentrated to ~300 μL by directing a gentle stream of N_2 onto the surface. A sample (1 μL) of the concentrated extract was injected into the GC that was equipped with a flame ionization detector (FID) coupled to a polyethylene glycol (PEG) capillary Supelcowax-10 column (30 m, 0.25 mm i.d., 0.25 μm film thickness; Supelco Inc., Toronto, ON, Canada). The column temperature was held at 35 °C for 5 min, programmed at 4 °C/min to 200 °C, and held at 200 °C for 5 min. The injector port and detector were set at 220 and 250 °C, respectively. The flow rates for helium (carrier gas) and hydrogen gas were set at 30 mL/min and that for air at 300 mL/min. Splitless injection was employed. Data were collected and processed with the JCL 6000 Chromatography Data System for PC (Jones Chromatography, Lakewood, CO). The relative amount of major volatile compounds was determined by dividing the area of a compound by peak area of the internal standard (10^{-2}).

For volatile identification, the same sample preparation was used, but separation was performed using a longer (60 m) Supelcowax-10 fused silica capillary column housed in a Hewlett-Packard 5890-5970 GC/MSD system (Hewlett-Packard, Avondale, PA). Oven temperature was initially held at 35 °C and then increased by 3 °C /min to 200 °C with a final hold time of 10 min. The carrier gas was helium, and the column head pressure was maintained at 30 psi. The MSD operating conditions were scan mode 25−200 amu, threshold = 400, sample rate = 2.7 scan/s, and EM voltage = 1800. Mass spectral identification was obtained with an HP G1034C MS Chem Station containing an HP G1035A Wiley (138.1) PBM library.

Table 1. Volatile Compounds from Sweet Basil *O. basilicum* Leaves, Extracted by Headspace Procedure, Analyzed and Identified by GC/MS

peak[a]	compound	peak	compound
1	β-thujene	12	terpinen-1-ol
2	β-myrcene	13	decyl acetate
3	α-terpinene	14	linalool
4	limonene	15	bornyl acetate
5	1,8-cineole (+ β-phellandrene)	16	terpinen-4-ol
6	γ-terpinene	17	methylchavicol
7	*trans*-ocimene	18	α-terpineol
8	*p*-cymene	19	geraniol
9	α-terpinolene	20	thymol
10	tetradecane (internal standard)	21	carvacrol
11	1-octen-3-ol		

[a] The peak numbers correspond to the numbers in Figure 1.

Color. All dried samples were subjected to a colorimetric analysis. Triplicates of 5 g of each treatment were ground in a household coffee grinder for 10 s to produce a powder of a uniform color. The samples were then transferred to a 10 cm Petri dish and subsequently read by a Hunter LabScan II Spectrocolorimeter (HunterLab, Reston, VA). The instrument, equipped with a D_{65} illuminant and 2 degree observer optical position, was standardized using a black plate and a standard white plate (No. LS-13685, $X = 79.8$, $Y = 84.67$, $Z = 91.23$). The results were expressed as HunterLab L (whiteness/darkness), a (red/green), and b (yellow/blue) values. Color of air- or vacuum-microwave-dried basil was compared to that of a commercial sample of basil, which had a moisture content of 9.6%.

Rehydration. The rehydration potential of dried basil leaves was evaluated by immersing preweighed samples, held by plastic netting, in small glass containers in water at (1) 30 °C and (2) 100 °C. The samples (triplicates for each time interval and treatment temperature) were drained under vacuum (in a Büchner funnel, for 30 s) and reweighed at 0, 10, and 20 min for samples rehydrated at 30 °C and at 0.5 and 1 min for samples rehydrated at 100 °C. The water absorbed (grams) divided by the dry sample weight (grams) was expressed as the rehydration ratio. The slope of the rehydration ratio versus rehydration time was defined as the rehydration rate.

Scanning Electron Microscopy (SEM). Dried whole leaves of approximately similar size and moisture content were chosen at random from the various drying methods for SEM examination. The leaves were fragmented, under a dissection microscope, into smaller pieces. Leaf fragments were then attached to SEM stubs, subsequently coated with gold (~25 nm) using the Nanotech SEMPREP II Sputter Gold Coater, and finally stored under desiccation until examined by the SEM (Stereoscan 250, Cambridge Instruments Ltd., Cambridge, U.K.). Polaroid pictures were taken and processed as specified by the manufacturer.

Statistical Analysis. Statistical analysis software (InStat for Macintosh, version 2.01, 1992−1993) was used to evaluate the significance of the difference between the various treatment groups. Student's t test was used to compare the mean values of the various treatments. Mean values were considered significantly different when $p < 0.05$.

RESULTS AND DISCUSSION

The literature shows a wide range of variation in the essential oil composition and concentration of basil. In particular, the contents of two major compounds, linalool and methylchavicol, show an interesting pattern depending on the region where the basil was produced. Basil used in this research was classified as belonging to chemotype AB, a cultivar indigenous to Europe and

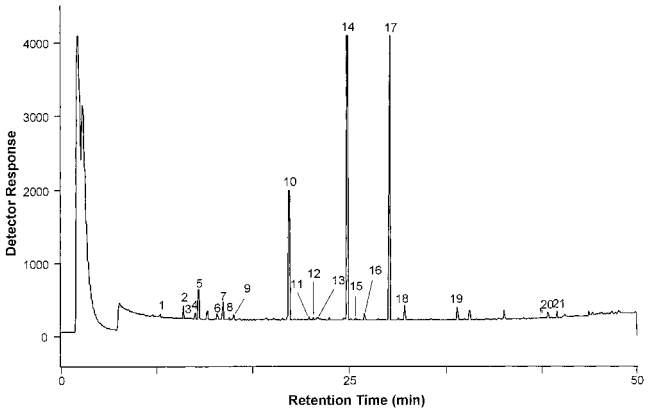

Figure 1. Typical chromatogram of volatile compounds extracted from fresh sweet basil *O. basilicum* leaves by purge and trap technique. (Peak 10 = C14, tetradecane internal standard; numbers correspond to compounds identified by GC/MS in Table 1.)

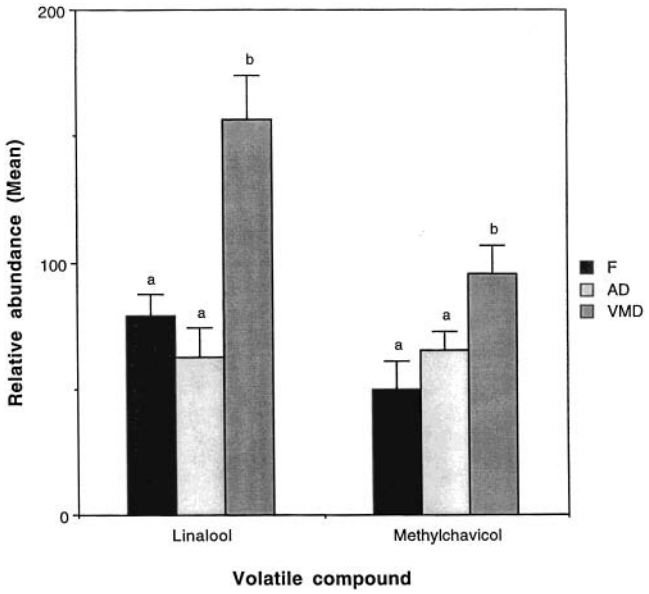

Figure 2. Effect of drying method on relative abundance of linalool and methylchavicol of sweet basil *O. basilicum* leaves. F, fresh; AD, air-dried; VMD, vacuum-microwave-dried. Different letters above bars indicate a significant difference ($p < 0.05$).

the Mediterranean, which is characterized by its high content of linalool and the presence of an appreciable concentration of methylchavicol (Baritaux et al., 1992).

The result of volatile analysis of the basil used in this study is shown in Table 1. Twenty volatile compounds were identified as monoterpenes and oxygenated terpenes. As expected, the two major volatile compounds in our samples were linalool and methylchavicol. Eugenol, a common constituent of basil, was not detected in the samples analyzed in this study, most likely because its concentration is known to vary from trace quantities to 11% depending on the strain and place of origin (Baritaux et al., 1992). Noteworthy was the presence of thymol and carvacrol. Thymol is not a common volatile compound of basil; however, it has been identified in some cultivars of basil tissues (Stahl-Biskup, 1987).

Several other compounds were also separated but were not identified. A typical chromatogram of headspace flavor volatiles of fresh basil leaves is shown in Figure 1. In this study, the abundance of the volatiles

Table 2. HunterLab Color Values of Dried Basil *O. basilicum*[a]

	AD	VMD	commercial
L	28.70 ± 1.15	35.43 ± 0.10	32.56 ± 0.73
a	−1.06 ± 0.35	−6.55 ± 0.20	−0.23 ± 0.08
b	9.89 ± 0.61	10.52 ± 2.17	10.52 ± 0.46

[a] Values are mean ± standard deviation. AD, air-dried; VMD, vacuum-microwave-dried.

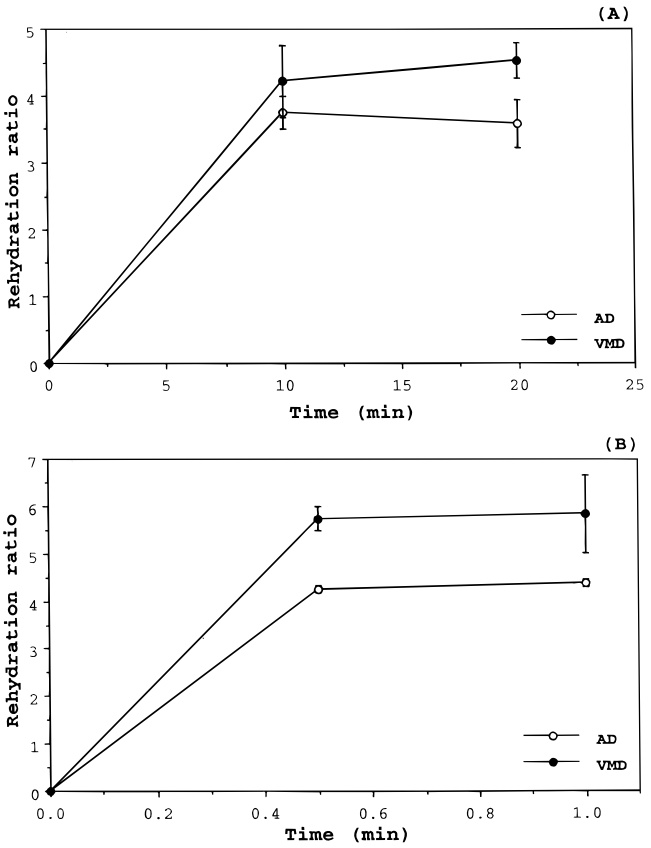

Figure 3. Rehydration curve of air-dried (AD) and vacuum-microwave-dried (VMD) sweet basil *O. basilicum* leaves at 30 °C (A) and 100 °C (B).

linalool and methylchavicol was chosen for quantitative and comparative analyses because they are the character-impact components of basil and constitute ~60−70% of the total volatiles of the herb (Baritaux et al., 1992).

Figure 2 shows the effect of the drying method on the abundance of linalool and methylchavicol. In this study, air-drying did not have an apparent effect on the level of these two compounds; a comparison of concentrations (on a dry weight basis) with those present in fresh samples showed insignificant differences. These results are different from those of others (see below). This may possibly be a consequence of our particular method of air-drying, in which a slightly higher drying temperature (48 versus 45 °C) was used. More likely, however, it was due to the high air flow rate (2.3 versus 0.4 m^3/s) employed in this experiment, which subsequently affected the moisture content of the final product (7.8 versus 10%).

Major flavor volatiles of vacuum-microwave-prepared samples showed a substantial and statistically significant increase of approximately 2.5-fold for linalool and 1.5-fold for methylchavicol, compared to that present in air-dried samples. This may be due to the rapid rate of vacuum-drying that reduced the time for diffusion of

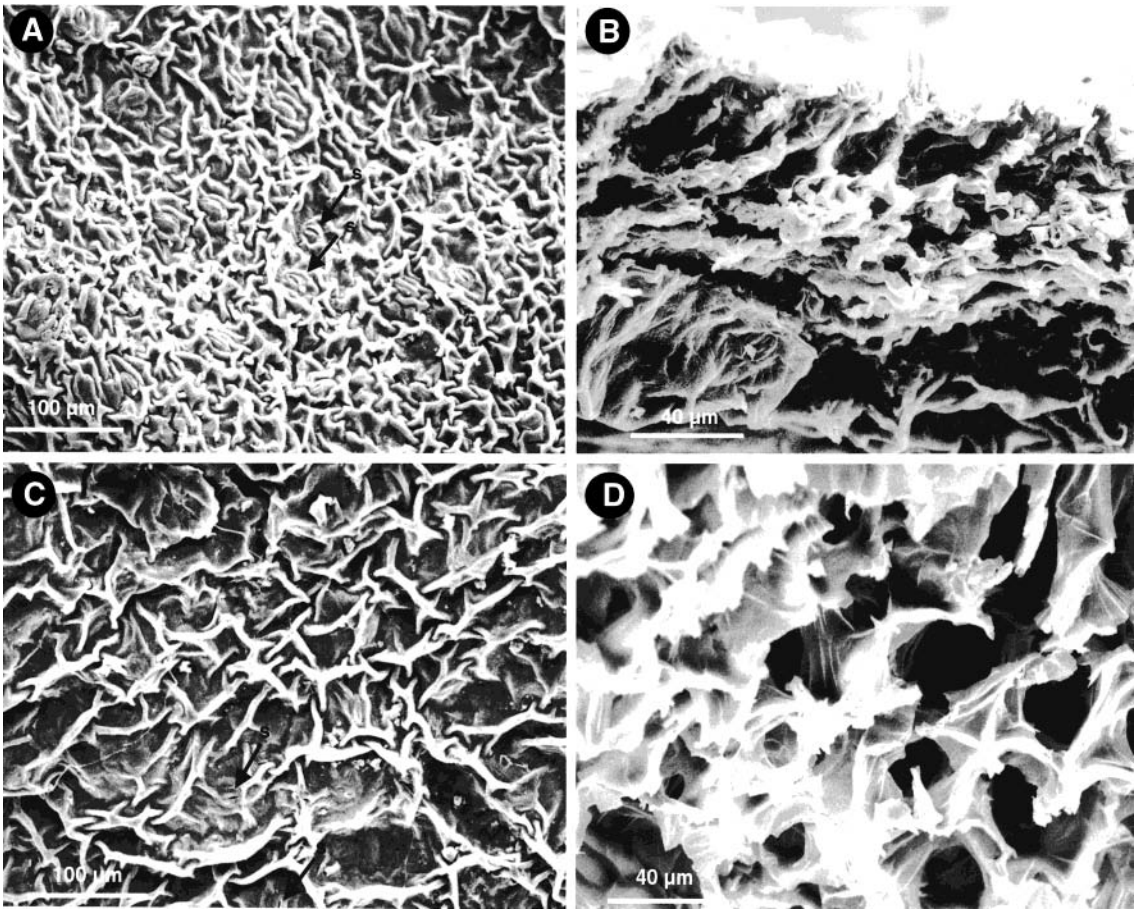

Figure 4. Sweet basil *O. basilicum* leaf: scanning electron micrographs of upper epidermis ×200 (A, air-dried; C, vacuum-microwave-dried), and cross-sectional view ×500 (B, air-dried; D, vacuum-microwave-dried). (Figure is reproduced here at 67% of the original.) S, stomata.

volatiles out of the tissue. Overall, the vacuum-microwave-treated samples exhibited a higher concentration (by a magnitude of ~2) of volatiles than fresh basil. A combination of enhanced loss of volatiles during air-drying compared to vacuum-microwave-drying and/or greater hydrolysis of nonvolatile conjugates of the vacuum-microwave-dried samples during the volatiles' extraction in the purge and trap apparatus may be responsible for this difference. The observed unequivocal increase in concentration of flavor volatiles upon vacuum-microwave-drying is not surprising. Linalool in coriander (*Coriander sativum*) seeds increased 3-fold upon drying (Braja et al., 1989). Following hot-air-drying, Baritaux et al. (1992) also observed an increase in the concentration of several flavor volatiles of basil, including linalool. These authors concluded that the increase in oxygenated monoterpenes was likely due to hydrolysis of glycosides and the conversion of linalyl acetate into linalool.

During the long hours of air-drying, heat is conducted from the surface to the interior of the product and the rate of water evaporation on the surface is faster than the rate of diffusion to the surface. Furthermore, the prevailing conditions of heat and atmospheric oxygen in air-drying facilitate the high enzymatic activity of polyphenol oxidase (PPO), which results in the browning effect that characterizes many air-dried food materials (Howard et al., 1996). During the shorter period of drying in the vacuum-microwave and the greatly reduced oxygen, less browning (higher L values) was observed (Table 2).

Vacuum-microwave-drying offers an advantage over air-drying in appearance of the herbs. The effect of drying temperature on the concentration of chlorophyll was not assessed in this study. Color analysis, however, indicated that vacuum-microwave-dried samples were greener (smaller a values) in color than either our own air-dried basil or commercially dried basil. A similar effect on color during vacuum-microwave- and air-drying was also evident in dry carrot chips. Lin et al. (1998a) observed that air-dried carrot slices were darker and had fewer red and yellow hues than vacuum-microwave-dried samples.

The rehydration curves of dried basil at 30 and 100 °C are shown in Figure 3. At both temperatures, vacuum-microwave-dried basil exhibited a higher rehydration rate than air-dried basil. When the water temperature was increased, however, less time was required for reconstitution. Similarly, Lin et al. (1998a,b) observed better rehydration of vacuum-microwave-dried carrot slices and shrimps. Furthermore, at high temperatures higher rates occurred at the beginning of rehydration. This was especially noted in the vacuum-microwave-dried samples.

The effect of each drying method on leaf structure was observed under the SEM. After air-drying, basil leaves exhibited severe shrinkage of their cuticle layer (Figure 4A). Internally, the epidermis and mesophyllic cells of the palisade layer were extremely affected and looked collapsed (Figure 4B). The structure of cuticle of vacuum-microwave-dried samples was less affected by heat as judged from the extent of shrinkage to that layer (Figure

4C), and cells of the epidermis and palisade layers looked "stretched" or "puffed" (Figure 4D). Therefore, it is reasonable to propose that the surface of a puffed material would have a lighter hue than that of a shrunk one because extensive folding in general intensifies and deepens colors. This is consistent with the HunterLab *L* values, which indicated that air-dried samples had a darker appearance (Table 2).

It was previously reported that the structure of carrot (Lin et al., 1998a) and potato (Durance and Liu, 1996) slices could be "puffed" or expanded by vacuum-microwave-drying because the chamber pressure was kept low during drying, while the internal steam pressure within products was elevated. This pressure differential generates an outward force, causing the material to expand beyond its original dimensions, resulting in a "puffing" effect. Alternatively, the low temperature that is maintained during vacuum-microwave-drying may minimize the destructive forces of heat during drying. Under both circumstances the original open structure is retained.

In summary, the quality of dried basil depends on the drying method. Vacuum-microwave-drying is a very rapid drying process (0.4 versus 11.5 h for air-drying) that resulted in a better quality product in terms of flavor, color, rehydration, and appearance than conventional hot-air-drying.

LITERATURE CITED

Baritaux, O.; Richard, H.; Touche, J.; Derbesy, M. Effects of drying and storage of herbs and spices on the essential oil. Part I. Basil, *Ocimum basilicum* L. *Flavor Fragrance J.* **1992**, *7*, 267−271.

Braja, D. M.; Richard, A. W.; Robert, W. T.; Michael, J. Z.; Keith, P. S. New dimensions in flavor research. In *Flavor Chemistry: Trends and Developments*; Teranishi, R., Buttery, R. G., Shahidi, F., Eds.; ACS Symposium Series 388; American Chemical Society: Washington, DC, 1989; pp 176−187.

Buffler, C. P. Microwave cooking and processing. In *Engineering Fundamentals for the Food Scientist*; AVI Van Nostrand Reinhold: New York, 1993; p 157.

Durance, T. D. Vacuum microwave drying of krill. Presented at the Annual Meeting of the Institute of Pacific Fisheries Technologists, Astoria, OR, June 1997.

Durance, T. D.; Liu, F. Production of potato chips. U.S. Patent 5,676,989, 1996.

Howard, L. R.; Braswell, D. D.; Aselage, J. Chemical composition and color of strained carrots as affected by processing. *J. Food Sci.* **1996**, *61*, 327−330.

Huxsoll, C. C.; Morgan, Jr., A. I. Microwave dehydration of potatoes and apples. *J. Food Sci.* **1968**, *22*, 47−52.

Lin, T. M.; Durance, T. D.; Scaman, C. H. Characterization of vacuum microwave, air, and freeze-dried carrot slices. *Food Res. Int.* **1998a**, in press.

Lin, T. M.; Durance, T. D.; Scaman, C. H. Physical and sensory properties of vacuum microwave dehydrated shrimp. *J. Aquat. Food Prod. Technol.* **1998b**, in press.

Stahl-Biskup, E. Monoterpene glycosides, state-of-the-art. *Flavor Fragrance J.* **1987**, *2* (2), 75−82.

Yongsawatdiguul, J.; Gunasekaran, S. Microwave vacuum-drying of cranberries: Part I: Energy use and efficiency. *J. Food Process. Preserv.* **1996a**, *20*, 121−143.

Yongsawatdiguul, J.; Gunasekaran, S. Microwave vacuum-drying of cranberries: Part II: Quality evaluation. *J. Food Process. Preserv.* **1996b**, *20*, 145−156.

Received for review May 7, 1999. Revised manuscript received August 5, 1999. Accepted August 16, 1999. We acknowledge the financial support of Agriculture and Agri-Food Canada and the Natural Sciences and Engineering Research Council of Canada.

JF990484M