# Quality Retention in Strawberry and Carrot Purees Dried with Refractance Window™ System

B.I. ABONYI, H. FENG, J. TANG, C.G. EDWARDS, B.P. CHEW, D.S. MATTINSON, AND J.K. FELLMAN

**ABSTRACT:The quality retention characteristics of strawberry and carrot purees dried using the Refractance Window™ (RW) drying method were evaluated against freeze drying, drum drying, and spray drying methods. Ascorbic acid retention of the strawberry purees (94.0%) after RW drying was comparable to 93.6% in freeze-drying. The carotene losses for RW drying were 8.7% (total carotene), 7.4% (α-carotene), and 9.9% (β-carotene), which were comparable to losses of 4.0% (total carotene), 2.4% (α-carotene), and 5.4% (β-carotene) for freeze-dried carrot purees. The color of the RW-dried carrot purees was comparable to fresh puree. For RW-dried strawberry purees, the color retention was comparable to freeze-dried products. RW drying altered the overall perception of aroma in strawberries.**

**Keywords: Refractance Window™ drying, quality, strawberries, carrots, ascorbic acid, carotene, aroma**

## Introduction

REFRACTANCE WINDOW DRYING system is a novel drying method developed by MCD Technologies, Inc. (Tacoma, Wash., U.S.A.). It utilizes circulating water at 95 to 97 °C as a means to carry thermal energy to materials to be dehydrated. Pureed products are spread on a transparent plastic conveyer belt that moves over circulating water in a shallow trough. The unused heat in the circulating water is recycled (Figure 1). The dried products are then moved over a cold water trough before being scrapped off the belt. The product is tempered as cold water circulates under the belt, which enables easy separation of the product from the belt by a scraper device. Products on the moving belt dry rapidly. The residence time of the product on the drying belt is typically 3 to 5 min, contrary to tray or tunnel drying which takes several hours, or freeze drying which may take more than 12 h. Refractance Window drying is similar to drum drying in that the product is dried in a thin layer on a heated surface, except that the heated surface is at much lower temperature (70 to 85 °C as compared with 120 to 150 °C).

β-carotene (pro-vitamin A) and ascorbic acid (vitamin C) are among the most heat-sensitive nutrients that suffer sugnificant losses during conventional drying operations. Losses of vitamin A and ascorbic acid are commonly studied as indices to evaluate quality retention and the effects of heating in different drying methods.

The carotene in carrots is an important source of vitamin A in typical U.S. diet (Simon 1987). β-carotene theoretically possesses 100% vitamin A activity and provides 80% of the vitamin A value of fruits and vegetables (Chou and Breene 1972). Concerns have been raised in recent years about β-carotene loss during food processing (Bushway and Wilson 1982). Rukimini and others (1985) documented 82% and 72% losses of α- and β-carotene in sliced fresh carrots that were air dried at 60 to 70 °C. Desobry and others (1997) observed 8% β-carotene loss in carrots during freeze-drying.

Strawberries are high in ascorbic acid (AA) content (Nunes and others 1998). Strawberries deteriorate quickly due to bruise damage, rapid growth of surface molds, and high rate of respiration (Heath 1981). Dried strawberries may be stored for a long time and are used in the preparation of many products, such as bakery products and cereals. The main factors that control the rate of AA degradation during drying include temperature, pH, oxygen concentration, light intensity, and presence of metal ions (Lin and Agalloco 1979).

Strawberry aroma contains over 360 identified volatile compounds (Latrasse 1991). But only a small number of the compounds are important for characteristic odors and several are odor-active at extremely low concentrations. The major compounds detected in strawberry aroma include methyl butanoate, ethyl butanoate, ethyl hexanoate (Perez and others 1992; Gomez de Silva and Chaves das Neves 1999), and 2,5-dimethyl-4-methoxy-3(2H)-furanone (Hirvi 1983). Recent studies by Song and others (1998) using

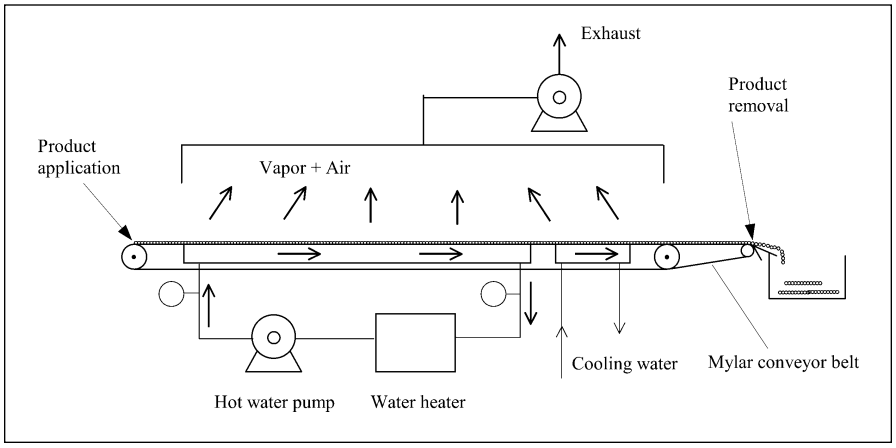


**Figure 1—Schematic of Refractance Window drying system**

solid phase micro extraction (SPME) with gas chromatography/time-of-flight mass spectrometry detected several odor active strawberry compounds in the headspace of whole, ripe fruit. The use of SPME with GC/MS allows the measurement of odor-active aroma compounds in strawberry samples at extremely low levels.

The objective of the present study was to study quality retention characteristics of Refractance Window drying system, in comparison with spray-drying, drum-drying, and freeze-drying methods. The quality attributes compared were color and β-carotene for carrots, and color, vitamin C, and flavor volatile content for strawberries.

**Table 1—Carotene losses in carrots among control and samples dried by drum, freeze, and Refractance Window† drying methods.**

| | Total carotene | | alpha carotene | | β carotene | |
|---|---|---|---|---|---|---|
| Sample | g/g solid | Loss (%) | g/g solid | Loss (%) | g/g solid | Loss (%) |
| Control | 1.77 ± 0.09[†a] | | 0.85 ± 0.04[a] | | 0.92 ± 0.05[a] | |
| Drum dried | 0.78 ± 0.18[b] | 56.0 ± 1.2 | 0.38 ± 0.09[b] | 55.0 ± 1.1 | 0.39 ± 0.08[b] | 57.1 ± 1.3 |
| RW* dried | 1.62 ± 0.33[a] | 8.7 ± 2.0 | 0.79 ± 0.16[a] | 7.4 ± 2.2 | 0.83± 0.17[a] | 9.9 ± 1.8 |
| Freeze dried | 1.70 ± 0.06[a] | 4.0 ± 3.6 | 0.83 ± 0.03[a] | 2.4 ± 3.7 | 0.87 ± 0.03[a] | 5.4 ± 3.5 |

Refractance Window™. +: average of three replicates.
[abcd]Different letters in the same column indicate a significant difference ($p \leq 0.05$)

## Materials and Methods

### Drying sample preparation

Frozen strawberry purees were purchased from a commercial supplier (Stahlbush Island Farms, Inc., Corvallis, Ore., U.S.A.). The strawberries (*Fragaria annanasa* cv. Totem) were grown in the Willamette Valley, Ore., U.S.A. and harvested in June, 1998. In preparing the frozen purees, strawberries were washed, inspected, pureed, pasteurized (74 °C), and then cooled (3 °C) before being frozen to –20 °C. The total processing time was 20 min. The strawberry puree had average moisture content of 93.6% (wb).

Frozen carrot purees were purchased from the same supplier. Carrots (*Daucvs carta L* cv. Navajo) were grown in the Columbia Basin, Wash., U.S.A. and harvested in July, 1998. The processing of the carrots included washing, scrubbing/peeling, blanching, pureeing, pasteurizing (85 °C), acidifying (using citric acid solution), cooling (2 °C), and freezing (–20 °C) The total time taken in carrot puree proparation was 33 min. Carrot puree had average moisture content of 89.4% (wb). The samples were thawed overnight in a storage room at 4 °C before drying tests.

### Drying experiments

Carrot purees were dried by Refractance Window, freeze drying, and drum drying methods. Similarly, strawberry purees were dried by Refractance Window drying, freeze drying, and spray drying. All tests were conducted in triplicate. The conditions for the drying tests were as follows:

**Spray-drying.** A pilot-scale spray dryer (Anhydro Attleboro Falls Mass, Copenhagen, Denmark) was used in drying tests. The inlet air temperature was 190 ± 5 °C and the outlet air temperature 95 ± 5 °C. In preliminary tests, it was found that strawberry purees could not be spray-dried without adding a carrier due to its high sugar content. Hence, maltodextrin (DE = 10) was used as a carrier during the spray drying experiments (Hui 1992). 70% maltodextrin carrier was added to strawberry puree and samples were dried to moisture content of 2.3 % (wb).

**Drum drying.** A pilot-scale double-drum dryer was used. This dryer had 2 counter-rotating drums, which had a dia of 19 cm and rotated at 0.3 rpm, giving a residence time of 3 min. Carrot puree was fed into the gap between the drum rolls. The drum surface temperature was maintained at 138 °C by pressurized steam. The final moisture content of carrots was 5.0% (wb).

**Freeze drying.** The strawberry and carrot samples were quick-frozen at –35 °C. A freeze dryer (Virtis Co., Gardiner, N.Y., U.S.A.) was operated at an absolute pressure of 3.3 kPa. The temperature of the heating plate was 20 °C, while the condenser temperature was –64 °C. The drying time to reduce moisture content to 8.2% (wb) (carrot), 3.9% (wb) (strawberry purees with 70% maltodextrin as carrier), and 12.1% (wb) (strawberry purees without carrier) was 24 h.

**Refractance Window drying.** A pilot scale Refractance Window dryer with an effective length of 1.83 m was used (Figure 1). Air at 20 °C and 52% relative humidity (RH) was forced over the bed at an average air velocity of 0.7 m/s to remove the moisture. The water temperature was 95 °C while the belt speed was in the range of 0.45 to 0.58 m/min. The thickness of the puree application was about 1 mm. Residence times of the material on the drying bed were controlled between 3 and 5 min by adjusting the belt speed. Carrot puree was dried to 6.1 % (wb), strawberry puree to 9.9% (wb), and strawberry puree with maltodextrin carrier to 5.7% (wb).

After the drying tests, the products were packed in aluminum-coated polyethylene bags, flushed with nitrogen, heat sealed, and stored at –20°C prior to analyses.

### Color measurement

The color of samples (L*, a*, and b*) was measured with a Minolta Chroma CR-200 color meter. To prepare the samples for color measurement, purees were poured into a 35-mm Petri dish and carefully covered with a Saran Wrap transparent film (Dow Brands L.P., Indianapolis, Ind., U.S.A.) which was carefully pressed against surface to remove air bubbles. Color of the purees was measured by contacting the color meter with the film-covered sample. Measurements were taken at 5 different locations on the sample. At each location 5 readings were taken. The mean of 25 readings was reported. Dried samples were ground and rehydrated to make slurries with the same moisture content as the fresh purees. Measurements were made on the slurry following the same procedure as described for fresh purees. A darkness factor b*/a* was used to quantify possible color changes (Tulasidas and others 1993). The hue angle, H*, and chroma C*, which are given by $H^* = \tan^{-1}(b^*/a^*)$ and $C^* = (a^{*2} + b^{*2})^{1/2}$ were also calculated.

### Moisture content determination

The sample moisture contents were determined using the vacuum oven method at 70°C and absolute pressure of 13.3 kPa (AOAC 1996). The means of 3 measurements are reported.

### Product temperature

Product temperature during drying was measured with a thermometer (Omega Engineering, Inc., Stamford, Conn., U.S.A.) which used a type T thermocouple with a response time of 0.8 s. The measurements were made by promptly scraping off small amount of sample from the drying belt and probing the thermal couple into the sample to obtain readings.

### Carotene analysis

Samples were prepared from commercial carrot purees following a standard procedure (method 941.15, AOAC 1996) with

modifications. Upon thawing overnight at room temperature, 5-g puree was blended using a Sorvall Omni-Mixer (Ivan Sorvall Inc., Newtown, Conn., U.S.A.) with 40 ml acetone, 60 ml hexane, and 0.1 g $MgCO_3$ for 5 min. The mixture was drawn under gentle vacuum through a 5.8 cm diameter Büchner funnel containing Whatman #4 filter paper and filter aid (Celite 545, Fisher Co., Pa., U.S.A.). The residue was placed in a separate funnel and washed with two 25-ml portions of acetone, followed by washing with 25 ml hexane. The extract was combined with the filtrate, transferred into a 250 ml separatory funnel covered with aluminum foil, and kept in the dark for 1 h. The lower phase was released into a flat bottom flask. The upper phase was saponified by adding 40% methanolic KOH (5 ml). Saponification was conducted in the dark for 16 h at 22 °C. The extract was washed of acetone with five 100-ml portions of $H_2O$. The upper layer was transferred to a 100-ml flask and diluted to volume with hexane.

Samples from dried carrots were prepared according to method 970.64, AOAC (1996) with modifications. Analyses were conducted using a Waters HPLC System (Waters, Milford, Mass., U.S.A.). It consisted of a Waters 2690 separation module and a Waters 996 photodiode array detector. The samples were eluted through a 3 μm particle size reverse phase column (100 × 4.6 mm i.d.) (Microsorb-MV™, Varian, Walnut Creek, Calif., U.S.A.). The mobile phase consisted of a mixture of acetonitrite-dichloromethane-methanol (85:10:5 v/v/v) plus 0.05 % ammonium acetate. The flowrate was 1 ml/min. Carotene analyses were conducted on randomly selected samples from each drying method in triplicate.

**Table 2—Comparison of vitamin C content of Refractance Window™ and freeze dried strawberry purees without carrier.**

| Treatment | AA[1]mg/g solid | AA loss(%) | M.C[2] wb (%) |
|---|---|---|---|
| Fresh puree | 1.80 ± 0.01[a] | | 93.6 ± 0.2 |
| RW* dried | 1.69 ± 0.03[b] | 6.0 ± 1.3[b] | 9.90 ± 0.6 |
| Freeze dried | 1.68 ± 0.04[b] | 6.4 ± 1.6[b] | 12.1 ± 0.5 |

*Refractance WindowTM. [1]Ascorbic acid. [2]moisture content on a wet basis, average of 4 replicates.
[ab]Different letters in the same column indicate a significant difference (p 0.05).

### Ascorbic acid analysis

The method used for extraction of raw samples was adapted from National Canners Association Research Laboratories (NCARL 1968). In titration, the volume used to reach a permanent pink color was determined from a standard curve. Analysis of ascorbic acid was repeated four times for randomly selected samples from each drying method.

### Flavor volatile analysis (SPME Analysis)

Dehydrated strawberry purees were rehydrated at room temperature with deionized water. The amount of water used to reconstitute the strawberries was calculated based on the moisture content of the dried strawberries to reach a solid content of 21.2 % (g solid/g $H_2O$) in the mixture. The rehydrated strawberries were then macerated with a blender and centrifuged for 10 min at 13,139 *g* and 4 °C to obtain a clear juice. For thawed strawberry purees, samples (5 g) were macerated and then diluted in 100 ml distilled deionized water. The mixture was centrifuged to collect the clear juice.

A mixture of 0.65 g NaCl and 2 ml strawberry homogenate were placed in a 4 ml sample vial and mixed on a stirring plate. A SPME device (Supelco, Co., Bellefonte, Pa., U.S.A.) with a fused silica fiber coated with 65 μm poly(dimethylsiloxane)/divinlybezene was exposed to the headspace of the sample for approximately 1 h before being injected into a GC. SPME injection was achieved by splitless injection for 2 min at 200 °C into a Hewlett-Packard 5890II/5970 GC/MSD equipped with a DB-1 column (J & W Scientific, 60 m × 0.32 mm i.d., 0.25-μm film thickness). Chromatographic conditions were as described by Mattheis and others (1991) except the transfer line temperature and ion source was held at 250 °C. The GC inlet contained a 0.75 mm SPME injection sleeve that assures peak sharpness, especially for the early eluting peaks (Yang and Peppard 1994). The compounds were identified by comparing the spectra of the sample compounds with those contained in the Wiley-NBS library and by comparing retention indices of sample compounds and standards.

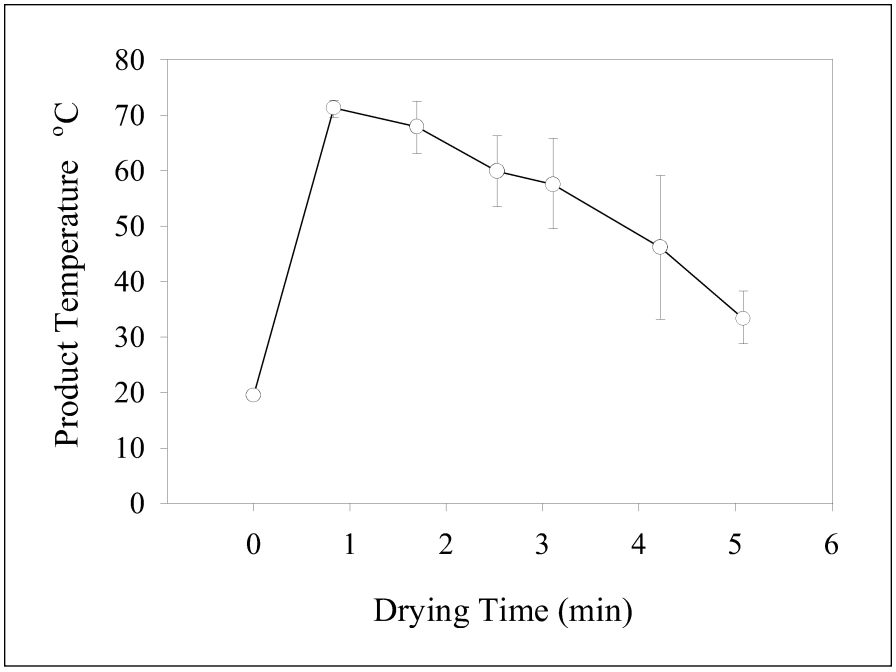


**Figure 2—Product temperature of carrot puree dried with the Refractance Window drying system at application thickness of 1 mm.**

## Results and Discussion

### Carotene retention

The total, α-, and β- carotene losses in carrot samples dried by different methods are shown in Table 1. Carotene losses in Refractance Window (RW) dried carrot samples were slightly higher but not significantly different from that of freeze-dried samples. The carotene losses for RW drying were 8.7% (total carotene), 7.4% (α-

**Table 3—Color measurement results in L*a*b*, darkness factor b*/a*, chroma and hue values for carrot puree.**

| Treatment | L* | a* | b* | b*/a* | H* | C* |
|---|---|---|---|---|---|---|
| Fresh puree | 54.3 ± 0.8$^{d}$ | 28.7 ± 0.2$^{b}$ | 44.0 ± 1.0$^{a}$ | 1.53$^{c}$ | 56.8$^{b}$ | 52.5$^{c}$ |
| Drum dried | 67.5 ± 0.6$^{c}$ | 20.8 ± 0.4$^{d}$ | 39.4 ± 1.7$^{b}$ | 1.89$^{a}$ | 62.1$^{c}$ | 44.6$^{a}$ |
| RW dried | 72.0 ± 0.3$^{b}$ | 34.1 ± 0.5$^{a}$ | 45.1 ± 0.8$^{a}$ | 1.32$^{d}$ | 52.8$^{a}$ | 56.5$^{d}$ |
| Freeze dried | 77.6 ± 0.4$^{a}$ | 27.1 ± 1.2$^{c}$ | 44.1 ± 0.4$^{a}$ | 1.63$^{b}$ | 58.5$^{b}$ | 51.8$^{b}$ |

L*: lightness, a*: redness, b*: blueness, C*: chroma = $(a^{*2} + b^{*2})^{1/2}$, H*: Hue angle = $\tan^{-1}(b^*/a^*)$.
$^{abcd}$Different letters in the same column indicate a significant difference in descending order ($p \leq 0.05$)

**Table 4—Color measurement results in L*a*b*, darkness factor b*/a*, chroma and hue values for strawberry puree + maltodextrin.**

| Treatment | L* | a* | b* | b*/a* | H* | C* |
|---|---|---|---|---|---|---|
| Fresh puree | 45.3 ± 1.6$^{d}$ | 27.0 ± 1.7$^{b}$ | 22.0 ± 1.9$^{a}$ | 0.81$^{a}$ | 39.2$^{a}$ | 34.8$^{a}$ |
| Spray dried | 77.8 ± 0.7$^{a}$ | 23.9 ± 0.6$^{c}$ | 16.8 ± 0.5$^{c}$ | 0.70$^{b}$ | 35.1$^{b}$ | 29.2$^{b}$ |
| RW dried | 63.2 ± 0.5$^{c}$ | 29.3 ± 0.6$^{a}$ | 20.2 ± 0.5$^{b}$ | 0.70$^{b}$ | 34.6$^{b}$ | 35.6$^{a}$ |
| Freeze dried | 71.5 ± 0.5$^{b}$ | 25.6 ± 0.8$^{b}$ | 16.6 ± 0.6$^{c}$ | 0.65$^{c}$ | 33.0$^{c}$ | 30.5$^{b}$ |

$^{abcd}$Different letters in the same column indicate a significant difference in descending order ($p \leq 0.05$)

**Table 5—Color measurement results in L*a*b*, darkness factor b*/a*, chroma and hue values for strawberry puree without carrier.**

| Treatment | L* | a* | b* | b*/a* | H* | C |
|---|---|---|---|---|---|---|
| Fresh puree | 36.1 ± 1.0$^{b}$ | 25.6 ± 0.6$^{c}$ | 19.8 ± 0.9$^{a}$ | 0.77$^{a}$ | 37.8$^{a}$ | 32.4$^{b}$ |
| RW dried | 53.8 ± 0.3$^{a}$ | 27.9 ± 0.3$^{b}$ | 16.9 ± 0.3$^{c}$ | 0.60$^{c}$ | 31.2$^{c}$ | 32.6$^{b}$ |
| Freeze dried | 53.8 ± 0.5$^{a}$ | 30.0 ± 0.4$^{a}$ | 18.8 ± 0.4$^{b}$ | 0.63$^{b}$ | 32.1$^{b}$ | 35.4$^{a}$ |

$^{abcd}$Different letters in the same column indicate a significant difference in descending order ($p \leq 0.05$)



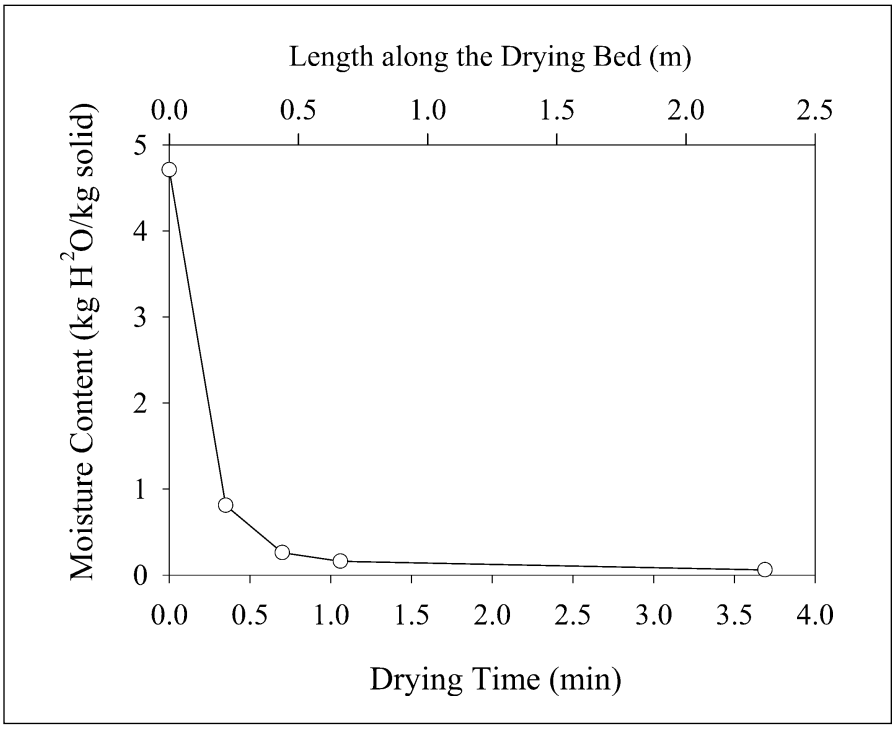


**Figure 3—Moisture content as compared with drying time for strawberry puree with carrier dried with the Refractance Window™ drying system at application thickness of ~1 mm.**

carotene), and 9.9% (β-carotene), while corresponding losses for freeze-dried carrot puree were 4.0%, 2.4%, and 5.4%. Drum dried products suffered a severe nutrient loss as indicated by carotene reduction of 56.1% (total carotene), 55.0% (α-carotene), and 57.1% (β-carotene). The amount of β-carotene degradation (5.4%) in freeze-dried carrot samples was comparable to the 8% loss reported by Desobry and others (1997). The β-carotene content in freeze-dried puree on a dry solid basis (1.7 mg/g solid) was close to 1.2 mg/g solid for carrot roots documented by Durance (1999). The drum-dried carrot purees in this study had a higher β-carotene loss (57.1%) compared to the 8% loss reported by Desobry and others (1997). This may be caused by the differences in the type of drum dryer used, operating variables selected, and cultivar and growing conditions.

Carotene degradation during drying has been attributed to its high sensitivity to oxidation (Desobry and others 1997). In a drying process, the cumulative effect of time-temperature determines the total carotene loss. In the absence of oxygen, formation of *cis*-isomers can also cause degradation of carotene (Howard and others 1999). In drum drying, the product experienced severe heating after it was applied on the drum wall that was heated to 138 °C. When most of the water was removed at the falling rate period, the product temperature could reach the wall temperature (138 °C). As a result, drum-dried product had the highest carotene loss among the methods used. In the case of freeze drying, however, sample temperature was much lower. At the initial drying period, when sublimation was dominant, the temperature was below 0 °C. Towards the end of the drying, however, product temperature would approach the heating plate temperature (20 °C). The near absence of oxygen and low temperatures effectively hindered the oxidative reactions. The slight reduction in carotene content in freeze drying might have been caused by the formation of the *cis*-isomer when exposed to a temperature close to that of the heating plate (20 °C) for a long time (about 8 h), when drying in the secondary drying stage (Desrosier and others 1985). RW drying of the carrot puree experienced relatively low temperatures (< 72 °C) (Figure 2) and a short drying time (3.75 min in Figure 3). The good carotene retention in RW-dried products may be attributed to a more moderate time-temperature combination compared to other drying methods, usually characterized by either high dry-

**Table 6—Aroma volatiles detected in control and strawberry samples (with carrier) dried with three drying methods. Threshold values are from Latrasse (1991), Larsen and Poll (1992), and Ulrich and others. (1997).**

| | Concentration (ng/ml) | | | | Threshold | Aroma value | | | |
|---|---|---|---|---|---|---|---|---|---|
| Compounds | Control | Freeze | RW[c] | Spray | ppm | Control | Freeze | RW | Spray |
| ***Fruity and green*** | | | | | | | | | |
| ethyl butanoate | 109.1 | 161.3 | 6.6 | 15.1 | 0.001 | $1.0 \times 10^5$ | $1.6 \times 10^5$ | 6600 | 15100 |
| ethyl hexanoate | 5.5 | 3.8 | 0.8 | 0.7 | 0.003 | 1833.3 | 1266.7 | 266.7 | 233.3 |
| methyl butanoate | 283.7 | 344.3 | 9.8 | 31.4 | 0.077 | 3684.4 | 4471.4 | 127.3 | 407.8 |
| methyl hexanoate | 28.8 | 32.5 | 1 | 2.6 | 0.087 | 331.0 | 3734.6 | 11.494 | 29.930 |
| hexyl acetate | 3.1 | 3.5 | 0.5 | 0.4 | 0.05 | 62 | 70 | 10 | 8 |
| trans-2-hexenola | 60.3 | 65.4 | 1.9 | 11.4 | 0.5 | 120.61 | 130.81 | 3.84 | 223.8 |
| hexanola | 134.5 | 146.8 | 5.5 | 20.7 | 0.05 | 2690 | 2936 | 110 | 414 |
| ***Lemon-like*** | | | | | | | | | |
| linalool | 47.4 | 45.5 | 5.6 | 10.1 | 0.006 | 7900 | 7583.33 | 933.33 | 1683.3 |
| ***Fir/Pine-like*** | | | | | | | | | |
| nerolidol[b] | 916.1 | 596.2 | 552 | 348.6 | 0.00004 | $2.3 \times 10^7$ | $1.5 \times 10^7$ | $10^7$ | $9 \times 10^6$ |
| ***Off-Flavor*** | | | | | | | | | |
| Ethyl acetate | 926.7 | 1003.2 | 217 | 82.6 | 0.5 | 1853.4 | 2006.4 | 433.48 | 165.2 |
| ***Heat-induced*** | | | | | | | | | |
| carvone** | 2.7 | 0 | 125.8 | 0.4 | NA | NA | NA | NA | NA |

[a]green. [b]Refractance Window™.
**(R)-2-methyl-5-(1-nethylethenyl)-2-cyclohexen-1-one

**Table 7- Flavor notes detected in strawberry samples classified according to compound group.**

| | Ester | Alcohol | Aldehyde | Ketone | Hydrocarbon |
|---|---|---|---|---|---|
| Treatment | (ng/ml) | (ng/ml) | (ng/ml) | (ng/ml) | (ng/ml) |
| Control | 1366.7 | 1183.9 | 33.7 | 3.8 | 16.2 |
| Freeze | 1560 | 887.3 | 48.1 | 1.9 | 24.2 |
| RW | 236.6 | 571.6 | 161.5 | 126.3 | 2 |
| Spray | 132.9 | 400 | 360.3 | 2.8 | 3.1 |

ing temperatures or prolonged drying times.

## Ascorbic acid retention

Ascorbic acid (AA) analysis of single strength strawberry puree is presented in Table 2. The loss of AA during freeze drying and RW drying was 6.4% and 6.0%, respectively. There was no significant difference in AA loss between the 2 drying methods. AA loss may result from reactions under both aerobic and anaerobic conditions (Lin and Agalloco 1979). It has been reported that the rate of anaerobic degradation is usually 2 to 3 magnitudes lower than that of aerobic reaction (Gregory 1996). Depletion of oxygen and low temperature, hence a depression to the dominant aerobic reactions, might be a major factor contributing to the low AA loss in freeze-dried strawberries. With the RW system, the moisture loss was significant during the 1st minute of drying as indicated by measured moisture contents after different drying times (Figure 3). During this period, partial pressure of oxygen near the product surface was low due to the high local vapor pressure resulting from intensive moisture loss. This may help to reduce AA degradation. The low AA loss may be related to the unique moisture loss characteristics associated with RW-drying technology.

## Color comparison

The color changes in carrot samples as affected by different drying methods are shown in Table 3. The freeze-dried carrot purees had a brighter color (highest L*) than the drum and RW-dried samples. No significant difference was found in b* values among the freeze-dried, RW-dried, and fresh samples. Drum drying darkened the product as indicated by high b*/a* and hue angle values. RW-dried puree was characterized by higher L*, a*, b*, and chroma values, indicating more vivid and more saturated red and yellow colors. The color of carrots is due to the presence of carotenes (Lin and others 1998). The degradation of carotenes during drying will inevitably alter the color perception of dried products. Lin and others (1998) demonstrated that high temperature processing of carrot led to darker color, which was attributed to degradation of carotenes. In this study, the darkness b*/a* values are positively related to drying temperatures except in RW-dried product, which has the lowest b*/a* value.

Tables 4 and 5 illustrate the results of color measurements for strawberry purees with and without maltodextrin. Because maltodextrin has a white color, purees with addition of maltodextrin had higher L* values. Among the strawberry purees with additive, spray-dried samples had the lowest chroma, indicating a less saturation and hence a pale appearance that is in contrary to the vivid fresh strawberry color. Overall, RW- and freeze-dried samples were more red but slightly brighter than fresh puree as evidenced by a higher hue and L* values for samples both with and without additive.

## Aroma retention

Comparisons of flavor volatiles detected in strawberry samples among 4 treatments (control, freeze-drying, RW drying, and spray drying) are presented in Tables 6 and 7. In Table 6, 11 flavor compounds detected via SPME are presented. All compounds except carvone have been reported as odor-active strawberry aroma (Hirvi 1983; Latrasse 1991; Larsen and Poll 1992; Song and others 1998; Gomez da Silva and Chaves das Neves 1999). Among the 11 compounds, ethyl butanoate, ethyl hexanoate, methyl butanoate, methyl hexanoate, hexyl acetate, trans-2-hexenol, and hexanol were classified as fruity and green flavor notes (Lawsen and Poll 1992). Gomez da Silva and Chaves das Neves (1999) described the fruity esters but did not detect the given flavor notes. Linoool was categorized as a lemon-like aroma note, and nerolidol was calssified as fir/

pine-like by Larsen and Poll (1992). The ethyl acetate was identified as an off-flavor note in strawberries (Ke and others 1991). We used aroma value, defined as the ratio of concentration to threshold value, to characterize odor-active strawberry aroma compounds (Latrasse 1991). In the strawberry puree (the control), nerolidol, ethyl butanoate, linalool, methyl butanoate, hexanol, ethyl hexanoate, and ethyl acetate are among the most important flavor notes in terms of the aroma values. Both RW- and spray-dried strawberries had a significant reduction in fruity and green ester notes compared with the control. In contrast, the fruity and green compounds are well retained in the freeze-dried strawberry product. A high nerolidol content was maintained in the control but with a decrease in concentration following the sequence of freeze, RW, and spray-dried products.

Heating of strawberry juice normally leads to a significant change in overall flavor pattern which was characterized by a loss in fruity and green notes and an enhancement in caramel-like notes (Schieberle 1994). Results in Table 6 confirmed previous findings. Considering the loss in fruity and green aroma notes, the relative impact of nerolidol in RW- and spray-dried samples on the overall aroma impression are actually more pronounced. It can be noticed that the ethyl acetate content was decreased in RW- and spray-dried samples compared to control and freeze dried samples.

One heat-enriched compound (carvone) was detected with high concentration in the RW-dried samples. It has not been previously reported in strawberry flavor studies but was found in caraway seed and mandarin peel oil (Budavari and others 1996). The concentration of this compound was low in control/spray-dried samples and was undetectable in freeze-dried samples. The interaction between heating and aroma generation is very complicated. Sugawara and others (1982) reported the presence of ketones and furans in heat-processed strawberry jam. Barron and Etiévant (1990) identified a number of heat-generated alcohols in strawberry jam. The mechanism for the enrichment of carvone concentration in RW-dried samples remains unknown. In this study, we observed an increase in aldehyde content during dehydration at elevated temperatures (RW- and spray drying) (Table 7). For RW-dried samples, a significant increase in ketone content was also observed. This demonstrated that dehydration at elevated temperatures (RW- and spray drying) altered the overall flavor impression in dried samples by enriching ketone- and aldehyde- flavor notes.

## Conclusion

ASCORBIC ACID RETENTION IN STRAWBERRY purees dried with the Refractance Window (RW) system was comparable to freeze-dried products. Total, α- and β-carotene retention in carrot purees after RW drying were comparable with freeze-dried samples and much higher than seen in drum-dried products. The color alterations in dried samples depended on both the drying method and the product. RW-dried carrot purees were comparable to fresh puree while RW-dried strawberries had color values close to that measured in freeze-dried samples. RW-dried strawberry purees had less esters and alcohols and more heat-induced ketones and aldehydes. This pattern was similar for linalool.

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*Author Abonyi and Tang are with the Dept. of Biological Systems Engineering, Washington State Univ., Pullman, WA 99164-6120; Author Feng is with the Dept. of Food Science and Human Nutrition, Univ. of Illinois at Urbana-Champaign, Urbana, IL 61801. Author Edwards is with the Dept. of Food Science and Human Nutrition, Washington State Univ., Pullman, WA 99164-6376; Author Chew is with the Dept. of Animal Sciences, Washington State Univ., Pullman, WA 99164-6310; Authors Mattinson and Fellman are with the Dept. of Horticulture and Landscape Architecture, Washington State Univ., Pullman, WA 99164-6414. Address inquiries to author Tang (E-mail: jtang@mail.wsu.edu).*