Effect of compressed propane extraction on storage stability of dried cilantro (*Coriandrum sativum* L.)

Abbreviated Title: Effect of propane extraction on storage stability of dried cilantro

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Abstract

Compressed solvents have been used to extract oils from food materials for use in the food industry. Raffinate, residue left after solvent extraction, may be utilized as a food adjunct. We investigated the effect of compressed propane extraction on the stability of color and volatile composition in cilantro during prolonged storage. Dried cilantro was extracted with compressed propane (21 - 27°C) and stored (freezer, refrigerator, room temperature and elevated temperature) for up to 12 months. At 30-day intervals, the samples were tested for change in color (L^* , a^* , b^* , chroma, hue angle and browning index BI) and volatile composition. Green color and volatile compounds were best preserved when cilantro samples were dried at 60°C, extracted with propane, and stored in refrigerator or in freezer. It was concluded that preprocessing conditions and storage conditions govern the degree of loss in color and volatile composition of cilantro during prolonged storage.

Keywords: solvent extraction with compressed propane, dehydration, storage, cilantro, color, volatile composition

1. Introduction

Herbs and spices such as cilantro are food adjuncts that enhance sensory quality and provide nutritional and medicinal value to food products (Srinivasan, 2005). Quality characteristics of fresh cilantro are appearance, leaf size, form, color, aroma and flavor. Color and aroma are important sensory attributes that govern acceptance of a product by the consumer. Volatile compounds in fresh cilantro have been reported in literature (Fan and Sokorai, 2002, Mookherjee *et al.*, 1989, Potter and Fagerson, 1990, Potter, 1996). Major volatile compounds in cilantro are aldehydes (82.6%) followed by alcohols (16.6%) (Potter & Fagerson, 1990). Higher temperature drying (60°C) has been reported to retain better color quality and higher concentration of volatile compounds in cilantro compared to lower temperature (40°C) drying (Sekhon *et al.*, 2015). However, no study till date has reported the effect of prolonged storage on color and volatile composition of dried cilantro.

Alternative extraction solvents such as supercritical carbon dioxide and compressed gases (propane and butane) have been studied extensively for oil extraction (Sparks, 2006). Several commercial processes have successfully used compressed propane as a solvent for extraction of oil from soybean, rice bran, cardamom, coriander seeds, grape seed, etc. (Hamdana *et al.*, 2008, Sparks, 2006, Freitas *et al.*, 2008, Illes *et al.*, 2000). The extract (or oil) from natural herbs is rich in antioxidants and is used in the food industry (Babovic *et al.*, 2010). Raffinate, the residue left after solvent extraction, may also be utilized as a food adjunct or as a condiment in the food industry. However, to the best of our knowledge no work has reported such utilization of raffinates from solvent extraction of herbs. Therefore, present work investigated the effect of propane extraction on the storage quality (color and volatile composition) of dried cilantro samples. Propane is a gas under ambient

conditions and liquid at $\leq -43^{\circ}\text{C}$ and atmospheric pressure. It is GRAS (generally recognized as safe) and leaves no residue, but is flammable and requires extraction to be performed in explosion-proof facility. Sekhon et al. (2015) reported no negative effect of compressed propane extraction on the quality of dried cilantro.

Dehydrated herbs such as cilantro have retail shelf life of 1 - 2 years. Previous studies have reported change in characteristic color of dehydrated herbs during storage (amaranth leaves, Negi and Roy, 2001; French tarragon, Arabhosseini et al., 2007; basil, Paakkonen et al., 1990; curry leaves, Singh and Sagar, 2010). Stability of volatiles in dried herbs can be affected by type of the plant material, drying process (method and temperature), packaging material and/or storage conditions (tarragon, Arabhosseini et al., 2007; cumin powder, Bera et al., 2001; basil, Baritiaux et al., 2006; rosemary leaves, Diaz-Maroto et al., 2009; rosemary and thyme, Usai et al., 2011; thyme, Rowshana et al., 2013).

No study till date has evaluated the effect of compressed propane extraction and prolonged storage on the stability of color and volatile composition in cilantro.

Therefore, objectives of the study were (1) to determine the effect of storage temperature and storage time on color and volatile composition of pre-processed (dried and size reduced) cilantro and (2) to determine the effect of propane extraction on storage quality (color and volatile composition) of dried cilantro.

2. Materials and methods

2.1. Chemicals

Solvent n-hexane was purchased from Fisher Scientific (Fair Lawn, New Jersey, US). β -pinene, decanal, decanol, diallyl fumerate, E-2-dodecenal, tridecanal, E-2-tridecenal, undecanal, dodecanal, E-2-undecenal, linalool, nonane, nonanal, E-2-decenol, E-9-decenol, octanal and E-2-nonenal were purchased from Sigma-Aldrich

(Sigma-Aldrich Co. LLC., St. Louis, Missouri). E-9-decenal was purchased from Bedoukian (Bedoukian Research, Inc., Danbury, Connecticut). β -myrcene, dodecanol and E-2-dodecenol were purchased from Fluka (Sigma-Aldrich GmbH, Seelze, Germany). Tetradecanal and E-2-tetradecenal were purchased from Penta (Penta manufacturing company LLC, Livingston, New Jersey).

2.2. Preparation of cilantro for storage

Cilantro was harvested from field plots at the Oklahoma Vegetable Research Station at Bixby, Oklahoma and transported on ice to laboratory facilities at Oklahoma State University, Stillwater, OK. Samples were dried at 40°C or 60°C, size reduced and fractionated into large flakes (LF), small flakes (SF) and coarse powder (CP) using a kitchen strainer (sieve size 3.3 mm x 3.03 mm, pore density 0.3/mm²) and a round splatter screen (sieve size 1.78 mm x 1.53 mm, pore density 0.57/mm²) according to Sekhon *et al.* (2015). The particle sizes of each fraction were estimated using RO-TAP sieve shaker to be LF: 0.85 - 1.18 mm, SF: 0.71 - 1.0 mm and CP: 0.25 - 0.5 mm. Dried and size reduced cilantro samples were then extracted using a 5L propane extractor (Hy-Look RV-2 Series; Eden labs, Columbus, OH) according to Sekhon *et al.* (2015). The extractor consisted of a propane storage tank, an extraction vessel, two separation vessels (I & II), and a compressor. Compressed propane (AirGas, Radnor, PA) was used as an extraction solvent at flow rate of 0.64 lpm, with extractor temperature and pressure maintained at 21 - 27°C and 1.1 - 1.9 MPa, respectively and separation vessel I temperature at $\leq 38^\circ\text{C}$. Propane dissolved non polar compounds from dried cilantro and carried them into the separation vessel I. Once extraction was complete, propane was vaporized and recondensed by the compressor into the propane storage tank. The extract and raffinate were then recovered.

2.3. Storage

Samples were stored in refrigerator ($4.9^{\circ}\text{C} \pm 0.56$), at room temperature ($23.3^{\circ}\text{C} \pm 2.91$; RH $46.84\% \pm 10.86$), at elevated temperature ($37.83^{\circ}\text{C} \pm 4.12$; RH $70.45\% \pm 18.87$), and in freezer (-20°C). Samples stored in refrigerator, at room temperature or at elevated temperature (in an environment chamber-Parameter Generation & Control Inc., Black Mountain, NC) were packaged in Al foil bags. Samples stored in freezer were packaged in brown glass bottles (with plastic caps); this treatment was used as a control to compare other storage conditions against it.

Each $0.1397\text{ m} \times 0.1778\text{ m}$ (5.5 in $\times$ 7 in; O.D) Al foil laminate bag (4.3 mil; Impak Corporation, Los Angeles, CA) was heat sealable with an open zipper end. Bags were made of four layers: polyethylene terephthalate (PET), polyethylene (PE), Al foil and linear low density polyethylene (LLDPE). PET provides strength to the package and is printable, Al foil acts as a barrier to water vapors and gases and is non-corrosive, and LLDPE and PE facilitate heat sealing of the package. Water vapor transmission rate and oxygen transmission rate of the package as provided by the manufacturer were $< 5 \times 10^{-6}\text{ kg}/0.0645\text{ m}^2 \cdot 24\text{ h}$ and $1 \times 10^3\text{ m}^3/\text{m}^2/24\text{ h}$, respectively.

For each storage temperature, twelve sets (one for each month) of twenty four samples ($2\text{ drying temperatures} \times 3\text{ particle sizes} \times 4\text{ extraction durations} = 24$ samples) were packaged in at least duplicates. Filled bags were evacuated from ambient pressure to $< 0.3\text{ kPa}$, back flushed with a standard air mixture of 21% oxygen in nitrogen (Airgas, Stillwater, OK) for 15 sec and heat sealed in a Multivac-A316 vacuum packaging machine (Multivac, Inc., Kansas City, MO). The packages were then placed in storage. On day 0 and at 30-day intervals thereafter, samples were taken out and analyzed for moisture content, color values and volatile composition.

2.4. Sample analyses

Moisture content of samples was measured in a forced air oven at 70°C to constant weight. Color and volatile composition of samples were evaluated according to Sekhon et al. (2015). Briefly, color (CIE L*, a*, b*) of dried cilantro samples was measured using a Minolta chroma meter CR-300 (Minolta Inc., Osaka, Japan). L*, a*, b* values were measured by taking 15 random samples (approximately 1 g) from the package. Chroma, hue angle, and BI were then calculated using equations 1 - 4.

$$\text{Chroma} = \sqrt{a^{*2} + b^{*2}} \quad 1 \quad \text{Hue angle} = 180 + \tan^{-1} \left(\frac{b^*}{a^*} \right) \quad 2$$

$$x = \frac{(a^* + 1.75L^*)}{(5.645L^* + a - 3.012b^*)} \quad 3 \quad \text{BI} = \frac{100(x - 0.31)}{0.17} \quad 4$$

Volatile compounds in samples were quantified by extracting representative sample (5 - 6 g) with n-hexane (4 mL). The extract obtained after extraction was concentrated under a stream of nitrogen to 1 mL. β -pinene (100 nmol) and β -myrcene (50 nmol) were used as internal and analytical standard respectively. One μ l of the concentrated extract (containing analytical standard β -myrcene; 50 nmol) was injected on to DB-5 fused silica capillary column (30 m x 0.25 mm x 0.25 μ m film thickness; J and W Scientific Inc., Rancho Cardova, CA) in a gas chromatograph (GC; Varian Star 3400 Cx, Varian Inc., 2700 Mitchell Drive, Walnut Creek, CA 94598). GC used helium as carrier gas with a linear flow rate of 20 cm/sec and FID detector. Peaks were identified by co-elution with authentic standards and quantified relative to the analytical internal standard, β -myrcene using equation 5.

$$\text{Concentration, } \frac{\text{nmol}}{\text{mL}} = \left\{ \frac{\left[\frac{(\text{sample peak area})}{(\text{sample } \beta\text{-myrcene peak area})} \right]}{\left[\frac{(\text{standard peak area})}{(\text{standard } \beta\text{-myrcene peak area})} \right]} \right\} \times \text{std concentration } \left(\frac{\text{nmol}}{\text{mL}} \right)$$

5

2.5. Statistical analysis

Analysis of Variance (ANOVA) with Proc GLM (Procedure General Linear Model) was performed in SAS (SAS Inc., Cary, NC, ver. 9.3). Least square means of response variables and multi-comparison tests for the effect stemp $\times$ stime were performed. The response variables were color values and concentration ($\mu\text{g/g}$) of volatile compounds in the cilantro samples.

3. Results

Dehydrated herbs such as cilantro are sold as shelf-stable commodities in the form of powder or flakes with a shelf life of 1 - 2 years. The results from this study provide insights into the optimum preprocessing and storage conditions that can be used to prolong shelf life of dried cilantro. In addition, this study has shown a possibility for utilization of raffinates after extraction of herbs using compressed solvents such as propane.

3.1. Moisture content

Moisture contents of cilantro samples at the start and the end of storage are listed in Table S1 (Supporting document). A considerable change in moisture content of stored samples was not observed. This was expected because of low water vapor transmission rate of Al foil laminate packages ($< 5 \times 10^{-6} \text{ kg/0.0645 m}^2 \cdot 24 \text{ h}$).

3.2. Color

3.2.1. Effect of storage temperature

Prolonged storage of cilantro samples (dried and/or propane extracted) resulted in a significant decrease in $-a^*$ values (greenness) and increase in BI values (brown color). This change in color was prominent in samples stored at room temperature or at elevated temperature. In addition, a significant decrease in L^* values (Lightness)

was also observed in samples stored at elevated temperature (Table S2 - Table S7, supporting information). Figure 1a shows the change in $-a^*$ values of CP when stored in freezer, in refrigerator, at room temperature or at elevated temperature for 12 months. Irrespective of the preprocessing conditions (dehydration temperature) a gradual decrease in $-a^*$ values of samples stored at room temperature and a drastic decrease in $-a^*$ values of samples stored at elevated temperature was observed with increase in storage time. Further, storage at elevated temperature resulted in a significant increase in BI values of all cilantro samples (Figure 1b). Storage in the freezer or in the refrigerator were found to be the best storage treatments to maximize retention of green color (highest $-a^*$ value) and minimize browning (lowest BI values) in cilantro samples. This indicated that during prolonged storage (~12 months) freezer and refrigerator storage temperature preserve better color quality of dried cilantro compared to current room temperature storage of packaged dried herbs in the retail market.

The decrease in $-a^*$ values (greenness) during storage could be due to the loss of chlorophyll to pheophytin (Steet and Tong, 1996). This decrease was greater in samples preprocessed at 40°C (lower $-a^*$ values and higher BI) compared to samples dried at 60°C (higher $-a^*$ values and lower BI values). The loss of chlorophyll in dehydrated products is also accompanied by non-enzymatic browning (Negi and Roy, 2001). Therefore, an increase in BI values during storage can be correlated with a decrease in $-a^*$ values and non-enzymatic browning. Accelerated aging of cilantro samples stored at elevated temperature (40°C, RH 70 ± 18%) was evident by loss of $-a^*$ values and increase in BI values. An increase in BI values in samples stored at elevated temperature could also be due to higher storage temperature and higher moisture contents, which are favorable conditions for non-enzymatic browning such

as Maillard reaction (Ramanujam, 2014; Sa and Sereno, 1999). Hence, it was concluded that stability of color values in cilantro samples during storage was dependent on drying temperature and storage temperature.

3.2.2. Effect of propane extraction

Compressed propane extraction did not negatively affect the color of cilantro samples during storage. At any given time during storage, $-a^*$ values of extracted samples (10 min) were greater than $-a^*$ values of unextracted samples (Figure 2a). Effect of different storage temperatures on color of extracted and unextracted samples was comparable: decrease in $-a^*$ values with increase in storage temperature.

Figure 2b shows the effect of storage on BI values of extracted (10 min) and unextracted CP samples. At any given time during storage, BI values of unextracted samples were higher than extracted samples indicating greater brown pigment in unextracted samples than in extracted samples. Further, the BI values of cilantro samples were dependent on drying temperature and storage temperature. Extracted samples stored at elevated temperature (40°C) exhibited a linear increase in BI values in the first five months, after which it became almost constant. On the other hand, no significant change in BI values of extracted samples stored in the freezer was observed. As observed for unextracted samples, BI values of extracted samples (LF, SF and CP; Table S2 - Table S7, supporting information) derived from cilantro dried at lower temperature were higher compared to samples derived from cilantro dried at higher temperature. This difference in BI values, of samples dried at two temperatures, was more pronounced in accelerated storage (elevated temperature) compared to other storage conditions (freezer, refrigerator or room temperature). This difference in BI values could be attributed to loss of chlorophyll and non-enzymatic browning at lower temperature drying compared to higher temperature drying. These

results indicate that change in color values in extracted samples followed the same trend as the unextracted samples, however compressed propane extraction resulted in improving color stability of dried cilantro during prolonged storage.

Volatile Composition

Though color quality of stored samples can be preserved by lower temperature storage (in refrigerator or in freezer), the concentration of all volatile compounds in all samples decreased with increase in storage time. This was expected because evaporation of volatile compounds is a continuous process. The rate of evaporation can be reduced but volatile loss cannot be prevented. Baritiaux *et al.* (2006) found similar results for drying and storage of basil. Volatile compounds evaluated in this study were: Major volatile compounds (concentration >40 µg/g dried cilantro): E-2-tetradecenal, dodecanal, E-2-dodecenal, and tetradecanal; Intermediate compounds (4 µg/g to 40 µg/g): decanal, nonane, octanal, decanol, tridecanal, E-2-tridecenal, E-2-dodecenol, dodecanol, and undecanal; and Minor compounds (concentration < 4 µg/g dried cilantro): linalool, nonanal, E-2-undecenal, 9-decenal, E-2-nonenal, phenyl-acetaldehyde, and E-2-decenal (Table 1).

3.3.1. Effect of storage temperature on volatile composition

The concentration of all volatile compounds, except nonane, in cilantro samples (dried and/or propane extracted) decreased with increase in storage time (Table 1 and Table 2). Regardless of drying temperature and sample particle size, the decrease in the concentration of major volatile compounds was least in samples stored in the freezer (68 - 97%) followed by those stored in the refrigerator (77 - 98%), at room temperature (94 - 99%) and at elevated temperature ($\geq 99\%$). Among all volatile compounds, maximum decrease in concentration was observed in tetradecanal, undecanal, E-2-tridecenal, dodecanal and decanal. This decrease was least in samples

287 stored in the freezer or in the refrigerator compared to samples stored at room
288 temperature or at elevated temperature. Overall, the four storage conditions may be
289 divided into two storage temperature groups, one group that preserved aromatic
290 volatile compounds (storage in freezer or in refrigerator) and second group that led to
291 least retention of aromatic volatile compounds (storage at room temperature or at
292 elevated temperature).

293 The rate of volatile loss was maximum in the first two months of storage, the loss
294 being greater in samples dried at higher temperature compared to samples dried at
295 lower temperature (Table 3). However, the concentration of volatiles at any given
296 time during the storage period was greater in samples dried at higher temperature
297 (60°C) compared to samples dried at lower temperature (40°C; Table 1 and Table 2).
298 These results are in agreement with the findings for storage of dried (45°C and 90°C)
299 tarragon leaves (Arabhosseini *et al.*, 2007). It can be concluded that higher
300 temperature drying should be a desirable processing condition for prolonged storage
301 of cilantro. At the end of the storage period, while the concentration of majority of the
302 compounds decreased, an increase in concentration of nonane was observed. The
303 concentration of nonane was greater in samples derived from cilantro dried at 60°C
304 compared to those derived from cilantro dried at 40°C (Table 1).

305 Further, smaller particle size (CP) resulted in lowest concentration of volatiles in
306 the beginning and the end of the storage as compared to larger particle size (LF and
307 SF). Grinding of dried material results in increase in surface area and increase in
308 available sites for volatile loss and oxidation (Indiramma, 2005). Volatiles can be
309 retained for a longer time when dried herbs are not ground and sold whole, because
310 whole herbs deteriorate slower than ground spices (King, 2006). But, due to small

bulk density of the whole dried cilantro (0.2 kg/m^3), packaging whole dried herb, storage, and transportation will add to the cost.

The amount of volatile loss in dried cilantro samples was dependent on the initial concentration of the volatile compound and the storage temperature. Further, initial concentration of a compound at the start of the storage period was governed by pre-processing conditions such as drying temperature and size reduction; higher concentration in samples dried at 60°C and size reduced to LF or SF (Sekhon *et al.*, 2015). This may be due to inactivation of aldehydes reductases when cilantro was dried at 60°C compared to when dried at 40°C (Quynh *et al.*, 2010). In addition, lower temperature drying resulted in longer drying time, which may have accelerated volatile loss.

As opposed to the commercial retail of dried cilantro, one method of preserving aroma of dried herbs is low temperature storage (Negi and Roy, 2001; Paakkonen *et al.*, 1990, Singh and Sagar, 2010). Losses in volatile compounds in an herb or a spice can be attributed to evaporation and oxidative reactions (Bera *et al.*, 2001, Díaz-Maroto *et al.*, 2009) which are accelerated by elevated temperatures. In the present study, storage of samples at higher temperatures (elevated temperature and room temperature) led to a higher rate of volatile loss compared to storage at lower temperatures (freezer and refrigerator).

3.3.2. Effect of propane extraction

Extraction of dried cilantro with compressed propane did not negatively affect the volatile composition during storage. The effect of propane extraction on concentration of major volatile compounds in extracted and unextracted samples is shown in Figure 3a and Figure 3b. To compare extracted and unextracted samples, one extraction time was selected. The selection of extraction time was based on the result that maximum

extraction of volatile compounds was achieved when large flake and small flake samples were extracted for 40 min and CP samples were extracted for 20 min.

The concentration of all volatile compounds in extracted samples, except nonane, decreased with increase in storage time similar to the trend observed in unextracted samples (Table 4). However, lower rate of volatile loss was observed in the extracted samples than in the unextracted samples (Table 3). This was true for all samples. Lower rate of volatile loss in extracted samples suggests solvent extraction with compressed propane may have stabilized volatile composition of dried cilantro. However, the results need to be further investigated because in the present study the initial concentration of extracted sample at the beginning of storage was lower than the unextracted samples. Lower initial concentration can result in lower rate of volatile loss.

At the end of the storage period, the loss of major volatile compounds was least in the extracted samples stored in the freezer (36 - 94%) followed by the samples stored in the refrigerator (38 - 94%), at room temperature (87 - 98%), and at elevated temperature (94 - 99%).

Regardless of the storage temperature, the concentration of nonane in extracted samples was greater in stored samples (15.96 - 143.20 $\mu\text{g/g}$) than in the control samples (4.95 - 23.79 $\mu\text{g/g}$). At the end of storage, the concentration of nonane was greater in samples derived from cilantro dried at 60°C than in those derived from cilantro dried at 40°C. In addition, the concentration of nonane in CP was lower than in LF and SF. Increase in the concentration of nonane in dried cilantro samples during storage indicates breakdown of other compounds via chemical or enzymatic reactions into alkanes such as nonane. However, further investigation is required for the development of breakdown products other than nonane. Oxidation of fatty acids

produces a number of compounds: alkanes, alkenes, ketones, aldehydes, alcohols, acids, esters, etc. (Frankel, 1984, Grosch, 1982). Nonane can be a break down product of such oxidation reaction. Decarboxylation of fatty acid produces alkanes with one or two carbon atoms less than the precursor fatty acid (Khan and Kolattukudy, 1974). Bogнар *et al.* (1984) investigated conversion of higher carbon fatty acids (C-31) to shorter alkanes (by incubating pea leaf microsomes) in the presence of ascorbic acid (acts as fatty acid breakdown catalyst). Fresh pea leaves were homogenized and prepared as an enzyme source to convert fatty acid into alkane. The enzyme from pea leaves used C-32 acids as substrates producing C-31 as the major alkane (one carbon less than the corresponding fatty acid). But, fatty acid groups present in cilantro are in the range of C-16 (palmitic acid, palmitoleic acid) to C-18 (linoleic acid, α -linolenic acid). It can be postulated that nonane was produced by decarboxylation of fatty acids in the presence of enzyme, but further investigation is required.

4. Conclusions

The present study demonstrated that propane extraction did not negatively affect the color and volatile composition of cilantro samples during prolonged storage. This study provided important insights in the storage of commercially available dried cilantro and showed a possibility for utilization of raffinates after extraction of herbs using compressed solvents such as propane. Preprocessing (drying temperature and size reduction) of cilantro plays a significant role in preserving color quality and volatile composition of propane extracted and unextracted cilantro samples during storage. Freezer and refrigerator storage temperature preserved better color quality (higher $-a^*$ values, lower BI values) and volatile composition of dried cilantro. The rate volatile loss was greater in unextracted samples compared to extracted samples. Furthermore, the final concentration of a volatile compound after prolonged storage

386 depends on the initial concentration of a volatile compound at the beginning of the
387 storage period, which depends on the preprocessing conditions.

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Figure 1

Figure 1. Effect of storage temperature and storage time on (a) $-a^*$ values and (b) browning index (BI) values of CP samples. CP: coarse powder (particle size 0.25 - 0.5 mm), Legend Dt_40_Freezer means drying temperature was 40°C and CP was stored in Freezer; Storage temperature: Freezer (-20°C), Refrigerator (4.9°C $\pm$ 0.56), at Room temperature (23.3°C $\pm$ 2.91; RH 46.84% $\pm$ 10.86) and Elevated temperature (37.83°C $\pm$ 4.12; RH 70.45% $\pm$ 18.87). Dt: drying temperature; temp: temperature.

Figure 2

Figure 2. Effect of storage temperature and storage time on (a) $-a^*$ values and (b) browning index (BI) values of unextracted (0 min) and extracted (10 min) CP (coarse powder; particle size 0.25 - 0.5 mm) samples.

Legend Dt_40C Et_0 Freezer means drying temperature was 40°C, extraction time was 0 min and CP samples were stored in Freezer. Storage temperature: Freezer (-20°C), Refrigerator (4.9°C ± 0.56), at Room temperature (23.3°C ± 2.91; RH 46.84% ± 10.86) and Elevated temperature (37.83°C ± 4.12; RH 70.45% ± 18.87).

Dt: drying temperature, Et: extraction time, temp: temperature.

Figure 3

Figure 3. Effect of storage temperature on total concentration of major compounds ($\mu\text{g/g}$ dried cilantro) in (a) unextracted and (b) propane extracted (40 min) SF samples. Storage temperature: Freezer (-20°C), Refrigerator ($4.9^{\circ}\text{C} \pm 0.56$), at Room temperature ($23.3^{\circ}\text{C} \pm 2.91$; RH $46.84\% \pm 10.86$) and Elevated temperature ($37.83^{\circ}\text{C} \pm 4.12$; RH $70.45\% \pm 18.87$). SF: small flakes (particle size 0.71 - 1.0 mm; derived from cilantro dried 60°C).

Table1

Table 1. Effect of storage (12 month) on volatile concentration (µg/g dried cilantro) in unextracted large flakes (LF), small flakes (SF) and coarse powder (CP) derived from cilantro dried at 40°C.

Particle size*	LF					SF					CP				
Storage temperature (°C)	Control	Freezer ^a	Refrigerator ^b	Room ^b	Elevated ^b (40°C)	Control	Freezer ^a	Refrigerator ^b	Room ^b	Elevated ^b (40°C)	Control	Freezer ^a	Refrigerator ^b	Room ^b	Elevated ^b (40°C)
Storage time (months)	0	12	12	12	12	0	12	12	12	12	0	12	12	12	12
Major	798.4a	179.6b	140.9c	34.7d	4.3e	637.3a	109.6b	94.6b	33.5c	4.7d	259.5a	42.7b	57.0b	12.5c	1.8c
Dodecanal	156.5a	16.5c	23.2b	4.2d	0.6d	109.8a	9.6b	8.7b	3.0bc	0.6c	56.1a	5.1b	4.4b	1.2b	0.3b
E-2-Dodecenal	59.8a	20.1c	29.0b	5.4d	0.3e	74.1a	10.3bc	15.5b	6.1cd	0.3d	27.7a	2.4c	5.6b	1.3c	0.2c
Tetradecanal	360.4a	36.7b	23.8b	6.3c	1.0c	185.5a	25.5b	15.7bc	3.5cd	1.5	67.1a	14.2b	12.1b	1.9b	0.7b
E-2-Tetradecenal	221.8a	106.4b	64.8c	18.8d	2.4e	267.9a	64.2b	54.7b	20.9c	2.3d	108.6a	20.9c	35.0b	8.1d	0.6d
Intermediate	129.5	109.9	136.6	104.4	99.6b	107.8b	98.4a	83.8a	84.7a	87.2a	54.7bc	40.7bc	52.5a	34.2c	42.5b
Nonane	26.9d	90.5b	118.6a	96.1bc	93.9bc	6.6b	86.2a	71.6a	78.2a	82.8a	4.9c	34.1b	45.5a	31.3b	40.0a
Octanal	11.1a	4.9ab	3.4b	2.3b	2.6b	6.1a	2.6b	1.7c	1.6c	1.9c	5.5a	1.3b	0.9c	0.7d	0.9c
Decanal	24.1a	4.3b	2.9c	1.0d	0.3d	18.6a	3.6b	1.9b	0.7b	0.1b	11.8a	2.2b	0.9c	0.4d	0.1d
Decanol	9.1a	1.5b	0.7c	0.6cd	0.6d	1.5a	0.4ab	0.3b	0.4ab	0.5ab	0.6a	0.2b	0.2b	.	0.1b
Undecanal	16.7a	1.2b	1.3b	0.5c	0.2c	12.6a	1.1b	0.9b	0.3b	0.3b	6.5a	0.9b	0.6b	0.2b	0.1b
E-2-Dodecenol	.	0.9a	0.8a	0.8a	0.8a	2.7a	0.31b	2.5a	0.5b	0.5b	.	0.1b	1.0a	0.2b	0.2b
Dodecanol	4.9a	1.9b	3.3ab	1.1b	0.9b	2.0a	0.6b	0.6b	0.6b	0.3b	1.7a	0.2b	0.4b	0.3b	0.2b
Tridecanal	13.1a	1.8b	2.6b	1.4b	0.3b	24.6a	1.5b	1.6b	1.5b	0.6c	7.0a	0.9b	1.2b	0.7b	0.3b
E-2-Tridecenal	23.5a	2.9b	3.1b	0.7c	0.1c	33.1a	2.1b	2.6b	0.9b	0.4b	16.7a	0.8c	1.7b	0.4c	0.6c
Minor	33.2a	20.5b	20.3b	9.2c	5.4c	35.8a	15.3ab	13.0ab	5.2b	6.8b	11.5a	13.9a	13.3a	5.1a	3.3a
Phenylacetaldehyde	1.76	.	.	.	.	3.3	.	.	.	.	.	.	.	.	.
Linalool	.	6.6a	4.1b	2.4c	2.1c	1.1c	3.9a	2.4b	1.8bc	2.2b	0.5c	2.5a	1.1b	0.8ab	0.8ab
Nonanal	27.6a	13.1bc	15.7b	6.8cd	3.2d	28.5a	9.5b	10.6b	3.4b	4.6b	10.0ab	13.4a	12.2a	4.0b	2.5b
E-2-Nonenal	0.8	0.2	.	.	.	0.5	0.2	.	.	.	.	.	.	.	.
9-Decenal	1.1	.	.	.	.	0.7	1.3	.	.	.	0.9	.	.	.	.
2-Decenal	0.6	.	.	.	.	0.6	.	.	.	.	.	.	.	.	.
E-2-Undecenal	1.3a	0.5b	0.6b	.	0.1c	1.1	0.3	.	.	.	.	.	.	0.3	.

a, b, c, d, e denote significantly different volatile concentration (µg/g dried cilantro) (at 0.05 probability level) between control samples, samples stored in freezer, refrigerator, room temperature and elevated temperature. ^a Samples stored in freezer were packaged in glass bottles with plastic screw caps. ^b samples stored in refrigerator, at room temperature, and at elevated temperature were packaged in Al foil laminate packages. *Particle size: LF: 0.85 - 1.18 mm, SF: 0.71 - 1.0 mm, CP: 0.25 - 0.5 mm. Base on the concentration, volatile compounds were designated as major (concentration >40 µg/g dried cilantro; intermediate (4 µg/g to 40 µg/g) or minor (concentration < 4 µg/g dried cilantro).

Table 2

Particle size*	LF					SF					CP				
Storage temperature (°C)	Control	Freezer ^a	Refrigerator ^b	Room ^b	Elevated ^b (40°C)	Control	Freezer ^a	Refrigerator ^b	Room ^b	Elevated ^b (40°C)	Control	Freezer ^a	Refrigerator ^b	Room ^b	Elevated ^b (40°C)
Storage time (months)	0	12	12	12	12	0	12	12	12	12	0	12	12	12	12
Major	1359.0a	432.2b	316.1c	77.4d	11.4e	1356.6a	181.8b	279.0b	82.0bc	12.4c	875.7a	127.5b	118.4bc	42.9c	3.2c
Dodecanal	189.0a	24.8b	30.3b	5.7c	2.3c	169.9a	13.7b	22.6b	7.0b	2.2b	142.4a	13.4b	11.0c	3.7d	0.6e
E-2-Dodecenal	145.5a	46.0c	60.6b	14.8d	2.3e	182.8a	17.9b	41.9b	16.3b	1.9b	90.1a	9.5b	14.8b	6.2b	0.1b
Tetradecanal	361.4a	47.7b	34.5c	8.6d	1.3d	235.3a	32.8b	39.2b	8.2b	1.7b	258.3a	36.2b	26.5b	6.0b	0.8b
E-2-Tetradecenal	663.2a	313.6b	190.7c	48.3d	5.6e	768.6a	117.3bc	175.3b	50.5cd	6.5d	384.9a	68.3b	66.1b	26.9c	1.7c
Intermediate	204.2c	226.8a	157.8c	145.5c	166.3b	198.6a	131.8a	207.6a	143.8a	147.5a	142.1a	66.7bc	76.4b	68.7bc	60.7c
Nonane	22.4d	180.7a	123.0c	128.9c	153.6b	20.4bc	111.4ab	175.5a	128.6ab	129.6ab	8.7c	45.8b	62.9a	61.3a	56.9a
Octanal	7.2a	6.7a	4.3b	3.7c	4.0bc	8.8a	3.3ab	5.1ab	3.2b	4.3b	8.3a	2.1b	1.6b	1.6b	1.3b
Decanal	26.8a	5.8b	3.2c	1.5d	0.6e	34.7a	4.8b	3.3b	1.4b	0.7b	25.3a	4.9b	2.0c	1.1c	0.2c
Decanol	19.8a	4.6b	1.6c	1.3c	1.7c	17.9a	1.5b	1.3b	1.2b	3.1b	12.5a	2.2b	0.6c	0.5c	1.1bc
Undecanal	20.7a	4.5b	1.2c	0.6d	0.3d	21.8a	2.4b	1.5b	0.6b	0.7b	15.6a	2.7b	0.9c	0.5c	0.2c
E-2-Dodecenol	.	8.8a	7.3a	2.5b	2.9b	30.6a	1.3b	4.1b	1.3b	4.5b	.	3.8a	1.4b	0.6b	0.2b
Dodecanol	17.6a	5.2bc	7.9b	3.2c	2.4c	9.9a	1.6c	6.1b	3.1c	3.5c	13.5a	2.0b	2.2b	1.4b	0.03c
Tridecanal	17.0a	2.4b	3.3b	1.4b	0.4c	3.4ab	1.7bc	3.7a	1.4bc	0.7c	15.9a	1.5b	2.2b	0.8c	0.3c
E-2-Tridecenal	72.8a	8.2b	5.9b	2.3b	0.3b	51.0a	3.9b	6.9b	2.3b	0.5b	42.3	1.7b	2.6b	1.1c	0.4c
Minor	29.4a	17.8ab	22.4a	11.9b	7.7b	45.3a	15.1b	25.7b	12.5b	9.2b	21.7a	17.5b	14.4b	10.4b	3.4c
Phenylacetaldehyde	0.9	.	.	.	.	2.1	.	.	.	.	.	.	.	.	.
Linalool	.	6.8a	4.5b	3.2c	2.6c	2.8a	4.2a	5.5a	2.8a	3.6a	0.8c	3.9a	1.9b	1.1c	1.2c
Nonanal	22.4a	9.7b	16.6ab	8.7b	5.1b	33.9a	10.2a	20.1a	9.7a	5.3a	17.1a	13.3a	12.2ab	9.3b	1.7c
E-2-Nonenal	0.8	0.1	.	.	.	0.8	0.2	.	.	0.3	0.8	.	.	.	.
9-Decenal	0.6	.	.	.	.	1.1	.	.	.	.	0.9	.	.	.	0.5
2-Decenal	1.4	0.2	.	.	.	1.2	0.1	.	.	.	0.9	.	.	.	.
E-2-Undecenal	3.4a	0.9b	1.3b	.	.	3.4	0.5	.	.	.	1.2	0.3	0.2	.	.

a, b, c, d, e denote significantly different volatile concentration (µg/g dried cilantro) (at 0.05 probability level) between control samples, samples stored in freezer, refrigerator, room temperature and elevated temperature. ^a Samples stored in freezer were packaged in glass bottles with plastic screw caps. ^b samples stored in refrigerator, at room temperature, and at elevated temperature were packaged in Al foil laminate packages. *Particle size: LF: 0.85 - 1.18 mm, SF: 0.71 - 1.0 mm, CP: 0.25 - 0.5 mm. Based on the concentration, volatile compounds were designated as major (concentration >40 µg/g dried cilantro; intermediate (4 µg/g to 40 µg/g) or minor (concentration < 4 µg/g dried cilantro).

Table 3. Rate of volatile loss in extracted and unextracted large flakes (LF), small flakes (SF) and coarse powder (CP) after 2-months of storage in freezer, in refrigerator, at room temperature and at elevated temperature.

Particle size*	Drying temperature (°C)	Storage temperature	Unextracted	Extracted ^a	Unextracted	Extracted ^a
			Storage time (months)			
			1	1	2	2
Large Flakes	40	Freezer ^b	11.5	7.7	2.4	1.4
		Refrigerator ^c	0	0	19.8	10.6
		Room temperature ^c	17.5	8.1	5.2	3.8
		Elevated temperature ^c	20.4	11.3	3.7	2.6
	60	Freezer ^b	13.8	15.9	4.5	1.4
		Refrigerator ^c	0.8	0	24.2	18.2
		Room temperature ^c	21.1	14.7	15.7	9.2
		Elevated temperature ^c	30.8	20.7	9.7	6.2
Small Flakes	40	Freezer ^b	9.1	7.7	5.2	1.5
		Refrigerator ^c	12.9	7.0	1.7	2.0
		Room temperature ^c	18.0	10.1	1.8	1.5
		Elevated temperature ^c	16.9	10.9	3.4	1.3
	60	Freezer ^b	26.0	23.7	3.9	3.0
		Refrigerator ^c	14.7	22.2	16.1	3.7
		Room temperature ^c	36.3	25.8	4.4	7.0
		Elevated temperature ^c	35.0	28.1	6.7	4.6
Coarse Powder	40	Freezer ^b	3.2	2.3	1.7	1.0
		Refrigerator ^c	5.0	2.5	0.1	0.7
		Room temperature ^c	4.3	2.1	2.4	2.0
		Elevated temperature ^c	7.2	4.2	1.0	0.7
	60	Freezer ^b	16.7	8.6	2.3	1.9
		Refrigerator ^c	16.3	6.6	3.7	2.6
		Room temperature ^c	20.3	6.7	5.4	4.1
		Elevated temperature ^c	23.5	9.0	3.6	3.4

^a Large flakes and small flakes extracted for 40 minutes and coarse powder extracted for 20 minutes. ^b Samples stored in freezer were packaged in glass bottles with plastic screw caps. ^c samples stored in refrigerator, at room temperature, and at elevated temperature were packaged in Al foil laminate packages. Rate of volatile loss (µg/day) was calculated as (C_i-C_j)/30, C = concentration of volatile compound, µg/g dried cilantro; i = month, j = i+1. *Particle size: LF: 0.85 - 1.18 mm, SF: 0.71 - 1.0 mm, CP: 0.25 - 0.5 mm.

Table 4

Table 4. Effect of 12 month storage on volatile concentration (µg/g dried cilantro) in extracted large flakes (LF), small flakes (SF) and coarse powder (CP) derived from cilantro dried at 60°C.

Particle size*	LF					SF					CP				
Extraction time (min)	40					40					20				
Storage	Control	Freezer ^a	Refrigerator ^b	Room ^b	Elevated ^b (40°C)	Control	Freezer ^a	Refrigerator ^b	Room ^b	Elevated ^b (40°C)	Control	Freezer ^a	Refrigerator ^b	Room ^b	Elevated ^b (40°C)
Storage time (months)	0	12	12	12	12	0	12	12	12	12	0	12	12	12	12
Major	907.9a	204.0b	192.5b	55.9c	6.6d	1065.2a	136.7b	130.5b	49.8c	6.5d	415.9a	56.9b	12.5c	1.8d	1.8d
Dodecanal	133.9a	11.7c	21.4b	4.4d	1.2d	153.1a	9.3b	8.5b	3.6c	1.2d	63.4a	4.4b	1.2b	0.3b	0.3b
E-2-Dodecenal	102.4a	23.2c	39.1b	10.0d	0.9e	145.4a	15.4b	23.6c	9.9d	0.5e	48.8a	5.6b	1.3c	0.2c	0.2c
Tetradecanal	248.8qa	23.6b	22.1b	6.1c	1.3d	192.7a	17.6b	12.6b	3.3bc	1.2c	77.9a	12.1b	1.9c	0.7c	0.6c
E-2-Tetradecenal	422.8a	145.5b	109.9c	35.4d	3.2e	574.0a	94.4b	85.7c	33.0d	3.6e	225.8a	35.0b	8.1c	0.6d	0.7d
Intermediate	145.2a	168.5b	142.4c	129.1c	125.8c	193.5b	125.2b	100.0b	118.5b	206.6a	91.1a	52.5a	34.2c	42.5b	45.3b
Nonane	23.8a	143.2b	118.6c	118.1c	117.1c	23.7b	109.7b	87.3b	110.7b	194.9a	9.4c	45.5a	31.3b	40.0a	42.1a
Octanal	6.9a	4.5b	3.5c	3.2c	3.1c	6.7a	2.5b	1.9c	1.9c	3.8b	8.6a	0.9b	0.7b	0.9b	0.8b
Decanal	18.2a	3.4b	1.9c	1.1d	0.3e	30.9a	3.3b	1.4bc	0.9bc	0.4c	10.3a	0.9b	0.4b	0.1b	0.1b
Decanol	12.9a	2.4b	0.9c	1.0c	1.1c	9.11a	1.3b	0.5c	0.6c	1.9b	1.6a	0.2b	.	0.1b	0.5b
Undecanal	14.2a	2.4b	0.9c	0.5d	0.2e	18.9a	1.6b	0.6b	0.3b	0.5b	6.0a	0.6b	0.2b	0.1b	0.2b
E-2-Dodecenol	.	3.7b	4.4a	0.8d	1.6c	8.7a	0.6b	0.9b	0.3c	2.8b	.	1.0a	0.2b	0.2b	0.7a
Dodecanol	10.2a	3.3ab	5.0ab	1.9b	1.9b	3.2a	1.5bc	1.9b	1.1c	1.4bc	13.1a	0.4b	0.3b	0.2b	0.2b
Tridecanal	14.8a	1.5c	2.2b	0.9c	0.2d	18.3a	1.0b	1.4b	1.0b	0.5b	7.9a	1.2b	0.7b	0.3c	0.2c
E-2-Tridecenal	44.3a	4.1b	4.8b	1.6c	0.2c	74.0a	3.6b	4.1b	1.6b	0.5c	34.2a	1.7b	0.4c	0.6c	0.5c
Minor	14.6a	16.4a	17.1a	8.7b	4.5b	52.0a	10.7a	10.2a	6.4a	8.8a	10.1a	13.3a	4.8b	3.3b	3.9b
Phenylacetaldehyde	0.9	.	.	.	.	3.6	.	.	.	.	.	.	.	.	.
Linalool	.	4.1a	3.4b	2.4c	2.1c	1.4c	2.6a	1.9b	1.5c	2.6a	0.5b	1.1a	0.8a	0.8a	0.6b
Nonanal	9.4ab	11.5ab	12.8a	6.3bc	2.4c	41.9a	7.5a	8.2a	4.9a	5.8a	8.0a	12.2a	4.0b	2.5b	1.8b
E-2-Nonenal	0.7	0.1	.	.	.	0.8	0.1	.	.	0.5	0.8	.	.	.	0.2
9-Decenal	0.5	.	.	.	.	0.9	.	.	.	.	0.8	.	.	.	0.9
2-Decenal	0.8	0.1	.	.	.	1.2	0.1	.	.	.	.	.	.	.	0.2
E-2-Undecenal	2.3a	0.5c	0.9b	.	.	2.1	0.4	.	.	.	.	.	.	.	0.2

a, b, c, d, e denote significantly different volatile concentration (µg/g dried cilantro) (at 0.05 probability level) between control samples, samples stored in freezer, refrigerator, room temperature and elevated temperature. ^a Samples stored in freezer were packaged in glass bottles with plastic screw caps. ^b samples stored in refrigerator, at room temperature, and at elevated temperature were packaged in Al foil laminate packages. *Particle size: LF: 0.85 - 1.18 mm, SF: 0.71 - 1.0 mm, CP: 0.25 - 0.5 mm. Based on the concentration, volatile compounds were designated as major (concentration >40 µg/g dried cilantro; intermediate (4 µg/g to 40 µg/g) or minor (concentration < 4 µg/g dried cilantro).

Table S1. Moisture content (% wb) in dried cilantro samples at the beginning and the end of storage period.

Particle size*	Drying temperature (°C)	40				60			
	Extraction time (min)	0	10	20	40	0	10	20	40
Large Flakes	Control ^a	4.8±0.5	4.9±0.3	5.0±0.6	5.4±0.7	2.6±0.4	3.9±0.2	4.0±0.6	2.7±0.4
	Freezer ^b (-20°C)	3.4±0.2	4.7±0.4	4.2±0.5	4.8±0.4	2.1±0.2	2.7±0.7	3.3±0.2	3.8±0.3
	Refrigerator ^b (4°C)	3.1±0.5	3.1±0.2	3.2±0.4	3.8±1.2	2.1±0.2	2.1±0.6	2.4±0.5	2.6±0.4
	Room temperature ^b	3.4±0.6	4.2±0.5	4.3±1.0	4.4±0.5	4.7±2.1	2.9±0.6	3.7±0.7	3.5±0.4
	Elevated temp ^b (40°C)	5.7±0.2	6.8±1.3	5.9±0.8	6.7±1.9	3.0±0.7	3.8±0.7	4.9±0.6	5.0±0.5
Small Flakes	Control ^a	4.6±0.2	4.8±0.4	4.8±0.2	4.7±0.4	2.8±0.8	3.6±0.6	3.9±0.5	3.1±0.7
	Freezer ^b (-20°C)	3.0±0.3	8.5±0.6	3.8±0.1	4.7±0.4	2.2±0.3	1.9±0.1	2.8±0.8	2.9±0.3
	Refrigerator ^b (4°C)	2.7±0.3	3.5±0.3	2.6±0.4	4.5±0.6	2.5±0.5	2.0±0.2	2.2±0.2	1.7±0.3
	Room temperature ^b	4.2±0.4	4.4±0.3	3.6±0.4	5.0±0.8	2.7±1.2	3.3±1.5	2.5±0.6	4.1±0.5
	Elevated temp ^b (40°C)	5.1±0.3	6.6±0.7	5.6±0.5	7.3±0.5	4.0±0.4	6.8±1.2	3.9±0.5	4.1±1.3
Coarse Powder	Control ^a	4.1±0.4	4.3±0.7	4.3±0.8	3.8±0.3	3.0±0.5	3.4±0.3	4.0±0.6	3.2±0.3
	Freezer ^b (-20°C)	4.2±0.6	6.7±2.5	5.6±0.7	3.6±0.1	1.9±0.1	1.9±0.2	2.3±0.5	1.7±0.4
	Refrigerator ^b (4°C)	3.4±0.6	2.6±0.3	3.2±0.3	1.7±0.8	1.6±0.95	2.1±0.6	2.4±0.3	1.9±0.6
	Room temperature ^b	2.6±0.5	2.5±0.7	3.2±0.5	1.96±0.4	2.4±1.3	2.5±0.7	4.2±1.8	2.3±0.6
	Elevated temp ^b (40°C)	4.1±0.8	3.6±0.9	4.9±0.8	3.9±0.6	4.1±2.6	2.7±0.4	2.9±0.5	2.9±1.0

^a moisture content of samples before storage; ^b moisture content of samples after 12 months of storage. Samples stored in freezer were packaged in glass bottles with plastic screw caps, and samples stored in refrigerator, at room temperature, and at elevated temperature were packaged in aluminum foil laminate packages.
*Particle size: Large flakes (LF): 0.85 - 1.18 mm, Small flakes (SF): 0.71 - 1.0 mm, Coarse Powder (CP): 0.25 - 0.5 mm.

Table S2. Effect of storage conditions on the color values of large flakes (dried at 40°C and/or liquid propane extracted).

Extraction time (min)	0					10					20					40				
Storage temperature* (°C)	C	FR ^a	RF ^b	R ^b	ET ^b	C	FR ^a	RF ^b	R ^b	ET ^b	C	FR ^a	RF ^b	R ^b	ET ^b	C	FR ^a	RF ^b	R ^b	ET ^b
Storage time (months)	0	12	12	12	12	0	12	12	12	12	0	12	12	12	12	0	12	12	12	12
L* (Lightness)	46.9a	46.0a	45.7a	46.1a	42.7b	47.6a	47.9a	46.4a	46.7a	43.5b	48.3a	48.3a	46.4a	46.3a	43.3b	47.7a	49.4a	47.4a	44.9b	42.9b
a* (greenness)	-12.4	-12.4a	-12.2a	-9.2b	-0.9c	-12.3a	-12.2ab	-11.5b	-10.6c	-0.6d	-12.3a	-12.4a	-12.1a	-9.7b	-0.7c	-12.4a	-11.7ab	-10.8b	-8.6c	-1.0d
b* (yellowness)	25.0a	23.5ab	24.1ab	23.5b	24.7ab	23.6a	22.7ab	22.1b	22.1b	22.8ab	23.3a	22.4ab	21.9bc	21.4c	24.0a	23.6a	23.8ab	22.3b	22.3b	24.4a
Chroma	27.9a	26.6ab	27.0a	25.3b	25.1b	26.6a	25.7ab	24.9b	24.5b	22.8c	26.3a	25.6ab	25.1b	23.5c	24.0c	26.6a	26.5ab	24.8bc	23.9c	24.4c
Hue Angle	178.9	178.9b	178.9bc	178.8bc	180.3a	178.9b	178.2b	178.9b	178.9b	180.3a	178.9b	178.9ab	178.9b	178.9b	179.6a	178.9a	178.9a	178.9a	178.8a	180.9b
Browning Index (BI)	49.4	44.8b	48.1b	50.9b	81.4a	43.1b	39.7b	40.7b	41.9b	69.9a	41.2b	37.7b	38.9b	41.9b	75.5a	42.8b	42.6b	41.8b	48.3a	77.5a

*C: Control; FR: Freezer, RF: Refrigerator, R: Room temperature, ET: Elevated temperature. a, b, c, d, e denote significantly different color values (at 0.05 probability level) between control samples, samples stored in freezer, in refrigerator, at room temperature and at elevated temperature. ^a Samples stored in freezer were packaged in glass bottles with plastic screw caps. ^b samples stored in refrigerator, at room temperature, and at elevated temperature were packaged in aluminum foil laminate packages.

Table S3. Effect of storage conditions on the color values of large flakes (dried at 60°C and/or liquid propane extracted).

Extraction time (min)	0					10					20					40				
Storage temperature*(°C)	C	FR ^a	RF ^b	R ^b	ET ^b	C	FR ^a	RF ^b	R ^b	ET ^b	C	FR ^a	RF ^b	R ^b	ET ^b	C	FR ^a	RF ^b	R ^b	ET ^b
Storage time (months)	0	12	12	12	12	0	12	12	12	12	0	12	12	12	12	0	12	12	12	12
L* (Lightness)	46.4a	45.9a	43.9a	44.2a	44.6a	47.6ab	48.3ab	45.5c	44.5c	45.9bc	47.6a	45.8abc	43.8c	45.1bc	45.9ab	48.3ab	44.1c	45.9bc	43.5c	44.3c
a* (greenness)	-13.1a	-13.0a	-11.8b	-10.5c	-3.7d	-13.4a	-11.9bc	-12.5bc	-10.9c	-3.4d	-12.8a	-12.3ab	-11.9b	-10.8c	-2.1d	-12.7a	-10.0b	-11.5c	-10.3b	-1.9d
b* (yellowness)	24.9a	23.4ab	22.6b	21.9b	22.4b	23.7a	22.2b	21.9b	19.9c	22.4b	23.3a	22.0abc	21.3bc	20.7c	21.9b	22.9a	20.7bc	21.4b	19.8c	20.9b
Chroma	28.2a	26.8ab	25.5b	24.3bc	22.7c	27.2a	25.2b	25.3b	22.7c	22.7c	26.6a	24.8ab	24.4b	23.4b	21.9c	26.3a	23.0bc	24.3b	22.3c	21.1d
Hue Angle	178.9ab	178.9ab	178.9ab	179.3a	178.6b	178.9a	178.9a	178.9a	178.9a	178.6b	178.9ab	178.9ab	178.9a	178.9b	178.5c	178.9a	178.9b	178.9a	178.9ab	178.5c
Browning Index (BI)	48.5b	43.4c	45.4bc	46.2bc	59.9a	41.2b	38.0bc	39.5b	35.9c	57.4a	40.9b	38.2b	40.2b	38.5b	56.9a	39.2b	41.9b	38.7b	38.3b	58.1a

*C: Control; FR: Freezer, RF: Refrigerator, R: Room temperature, ET: Elevated temperature. a, b, c, d, e denote significantly different color values (at 0.05 probability level) between control samples, samples stored in freezer, in refrigerator, at room temperature and at elevated temperature. ^a Samples stored in freezer were packaged in glass bottles with plastic screw caps. ^b samples stored in refrigerator, at room temperature, and at elevated temperature were packaged in aluminum foil laminate packages.

Table S4. Effect of storage conditions on the color values of small flakes (dried at 40°C and/or liquid propane extracted).

Extraction time (min)	0					10					20					40				
Storage temperature* (°C)	C	FR ^a	RF ^b	R ^b	ET ^b	C	FR ^a	RF ^b	R ^b	ET ^b	C	FR ^a	RF ^b	R ^b	ET ^b	C	FR ^a	RF ^b	R ^b	ET ^b
Storage time (months)	0	12	12	12	12	0	12	12	12	12	0	12	12	12	12	0	12	12	12	12
L* (Lightness)	47.6b	50.7a	44.8c	46.7b	44.9c	48.7a	49.8a	45.8b	46.2b	44.9b	48.9b	52.9a	45.5d	47.4c	45.4d	48.0b	51.9a	45.0c	47.1b	45.1c
a* (greenness)	-12.7a	-13.3a	-12.6a	-10.2b	-1.1c	-12.9a	-12.9a	-12.3b	-9.6c	-0.8d	-12.2b	-13.9a	-12.4b	-9.7c	-0.8d	-13.3a	-13.5a	-11.8b	-9.4c	-0.5d
b* (yellowness)	25.1b	26.4ab	22.5c	23.2c	26.1a	24.7a	24.9a	23.2b	22.5b	25.5a	24.6b	23.4c	23.3c	23.6c	27.6a	23.9b	23.1bc	21.5d	22.5c	26.0a
Chroma	28.1a	29.5a	25.8b	25.3b	26.2b	27.9a	28.1a	26.3b	24.5d	25.5b	27.5a	27.2a	26.4b	25.6c	27.6a	27.4a	26.8ab	24.5c	24.4c	26.0b
Hue Angle	178.9a	178.9a	178.9a	178.8a	178.8a	178.9b	178.7ab	178.9b	178.8b	179.5a	178.9c	178.9a	178.9b	178.8d	178.5e	178.9a	178.9ab	178.9ab	178.8a	179.5b
Browning Index (BI)	47.8b	47.0b	42.3b	46.8b	79.9a	44.2b	43.8b	44.0b	46.1b	77.7a	45.1c	33.7d	44.6c	48.4b	85.9a	41.9b	34.5d	39.6c	45.4b	80.2a

*C: Control; FR: Freezer, RF: Refrigerator, R: Room temperature, ET: Elevated temperature. a, b, c, d, e denote significantly different color values (at 0.05 probability level) between control samples, samples stored in freezer, in refrigerator, at room temperature and at elevated temperature. ^a Samples stored in freezer were packaged in glass bottles with plastic screw caps. ^b samples stored in refrigerator, at room temperature, and at elevated temperature were packaged in aluminum foil laminate packages.

Table S5. Effect of storage conditions on the color values of small flakes (dried at 60°C and/or liquid propane extracted).

Extraction time (min)	0					10					20					40				
Storage temperature*(°C)	C	FR ^a	RF ^b	R ^b	ET ^b	C	FR ^a	RF ^b	R ^b	ET ^b	C	FR ^a	RF ^b	R ^b	ET ^b	C	FR ^a	RF ^b	R ^b	ET ^b
Storage time (months)	0	12	12	12	12	0	12	12	12	12	0	12	12	12	12	0	12	12	12	12
L* (Lightness)	46.9a	47.7a	44.2c	45.5b	42.7d	45.8a	47.7a	44.2a	44.9a	40.9b	45.6b	48.1a	44.4bc	43.2c	43.7c	47.3a	47.6a	44.8b	45.6ab	45.1b
a* (greenness)	-13.0a	-13.5a	-11.9b	-10.6c	-2.5d	-13.6a	-13.4a	-12.3b	-10.9c	-1.7d	-13.3a	-13.8a	-12.9b	-11.1c	-3.4d	-12.9a	-13.1a	-12.7a	-9.7b	-2.4c
b* (yellowness)	25.3a	24.5a	22.6b	21.2c	22.3b	23.4a	23.3a	21.5b	20.6d	20.3d	22.7b	22.5abc	21.7c	19.8d	23.5d	23.2a	22.1a	21.8b	20.6c	23.3a
Chroma	28.5a	28.0a	25.6b	23.7c	22.5d	27.0a	26.8a	24.7b	23.3c	20.4d	26.3a	26.3ab	25.3b	22.7d	23.8c	26.4a	25.7ab	25.2b	22.8c	23.4c
Hue Angle	178.9ab	178.9a	178.9ab	178.9b	178.5c	178.9b	178.9ab	178.9b	178.9b	179.5a	178.9a	178.9a	178.9a	178.9b	178.6c	178.9a	178.9a	178.9a	178.9b	178.5c
Browning Index (BI)	49.2b	43.8c	44.8c	40.1d	65.9a	42.1b	39.6b	39.6b	37.9b	63.8a	40.6b	35.5c	38.9b	37.0c	67.1a	40.5b	36.3b	38.9b	39.9b	65.9a

*C: Control; FR: Freezer, RF: Refrigerator, R: Room temperature, ET: Elevated temperature. a, b, c, d, e denote significantly different color values (at 0.05 probability level) between control samples, samples stored in freezer, in refrigerator, at room temperature and at elevated temperature. ^a Samples stored in freezer were packaged in glass bottles with plastic screw caps. ^b samples stored in refrigerator, at room temperature, and at elevated temperature were packaged in aluminum foil laminate packages.

Table S6. Effect of storage conditions on the color values of coarse powder (dried at 40°C and/or liquid propane extracted).

Extraction time (min)	0					10					20					40				
Storage temperature* (°C)	C	FR ^a	RF ^b	R ^b	ET ^b	C	FR ^a	RF ^b	R ^b	ET ^b	C	FR ^a	RF ^b	R ^b	ET ^b	C	FR ^a	RF ^b	R ^b	ET ^b
Storage time (months)	0	12	12	12	12	0	12	12	12	12	0	12	12	12	12	0	12	12	12	12
L* (Lightness)	46.5b	48.6a	46.4b	47.4ab	44.8c	47.5a	47.9a	47.5a	46.9a	45.3b	47.8a	47.4a	48.2a	46.1b	45.2bc	50.0a	49.5b	49.8b	49.2b	47.4c
a* (greenness)	-12.8b	-13.7a	-12.4b	-11.1c	-2.1d	-13.1b	-13.5a	-12.8b	-11.6c	-2.1d	-13.5a	-13.3ab	-12.8b	-10.8c	-0.7d	-12.6a	-12.6a	-12.4a	-10.5ab	-1.4c
b* (yellowness)	25.1ab	25.5b	24.3a	23.3d	25.0ab	23.9b	23.9b	23.1c	22.1d	24.9a	24.1b	22.9d	23.1c	22.1d	24.6a	25.1a	23.9b	24.0b	22.9c	25.6a
Chroma	28.2b	28.9a	27.3b	25.8d	25.1d	27.3a	27.4a	26.4b	24.9c	24.9c	27.6a	26.5b	26.4b	24.6c	24.6c	28.2a	27.2ab	27.1b	25.3c	25.6c
Hue Angle	178.9b	178.9a	178.9b	178.9c	178.5d	178.9a	178.9a	178.9a	178.9b	178.5c	178.9a	178.9a	178.9a	178.9b	178.5c	178.9b	178.9a	178.9ab	178.9c	178.5d
Browning Index (BI)	49.5b	46.2bc	47.0bc	44.6c	73.8a	43.0b	41.2bc	40.3cd	39.7d	71.7a	42.2b	38.8c	39.4c	42.5b	73.1a	44.8b	41.1c	41.7c	42.1c	71.5a

*C: Control; FR: Freezer, RF: Refrigerator, R: Room temperature, ET: Elevated temperature. a, b, c, d, e denote significantly different color values (at 0.05 probability level) between control samples, samples stored in freezer, in refrigerator, at room temperature and at elevated temperature. ^a Samples stored in freezer were packaged in glass bottles with plastic screw caps. ^b samples stored in refrigerator, at room temperature, and at elevated temperature were packaged in aluminum foil laminate packages.

Table S7. Effect of storage conditions on the color values of coarse powder (dried at 60°C and/or liquid propane extracted).

Extraction time (min)	0					10					20					40				
Storage temperature *(°C)	C	FR ^a	RF ^b	R ^b	ET ^b	C	FR ^a	RF ^b	R ^b	ET ^b	C	FR ^a	RF ^b	R ^b	ET ^b	C	FR ^a	RF ^b	R ^b	ET ^b
Storage time (months)	0	12	12	12	12	0	12	12	12	12	0	12	12	12	12	0	12	12	12	12
L* (Lightness)	50.2ab	52.2ab	47.3c	48.5bc	47.4c	46.4b	48.5a	46.7b	45.9b	45.8b	46.9a	47.1a	45.9a	46.1a	44.3b	46.4ab	47.9a	46.6ab	46.4ab	45.6b
a* (greenness)	-14.1a	-15.1b	-13.5c	-11.7d	-3.4e	-13.7a	-13.9a	-13.2b	-11.8c	-4.1d	-12.7a	-13.0a	-12.4a	-9.4b	-2.6c	-13.7a	-14.1b	-13.1c	-11.9d	-3.8e
b* (yellowness)	26.9b	27.6a	25.2c	23.4d	25.5c	23.5b	23.4b	22.4c	20.8d	24.5a	23.7a	22.9b	22.1c	22.2c	23.5ab	23.3a	22.9a	22.2b	21.2c	23.2a
Chroma	30.4b	31.5a	28.6c	26.2d	25.7d	27.2a	27.2a	26.0b	23.9d	24.8c	26.9a	26.4a	25.4b	24.2c	23.6c	27.0a	26.9a	25.8b	24.3c	23.6d
Hue Angle	178.9a	178.9a	179.1a	178.9a	178.6b	178.9b	178.9a	178.9b	178.9b	178.6d	178.9a	178.9a	178.9a	178.8b	178.5c	178.9b	178.9a	178.9ab	178.9c	178.6d
Browning Index (BI)	48.2bc	46.1b	49.2b	42.4c	67.2a	41.7b	37.9d	38.2c	35.8d	65.3a	43.7b	39.8c	39.4c	45.9b	67.1a	40.7a	36.6ab	37.7b	36.5b	61.4a

*C: Control; FR: Freezer, RF: Refrigerator, R: Room temperature, ET: Elevated temperature. a, b, c, d, e denote significantly different color values (at 0.05 probability level) between control samples, samples stored in freezer, in refrigerator, at room temperature and at elevated temperature. ^a Samples stored in freezer were packaged in glass bottles with plastic screw caps. ^b samples stored in refrigerator, at room temperature, and at elevated temperature were packaged in aluminum foil laminate packages.