EFFECT OF DRYING TEMPERATURE, SIZE REDUCTION, PROPANE EXTRACTION, AND STORAGE TEMPERATURE ON THE QUALITY AND SHELF LIFE OF CILANTRO (*CORIANDRUM SATIVUM* L.)

By

JASREEN KAUR SEKHON

Bachelor of Engineering in Food Technology
Sant Longowal Institute of Engineering & Technology
Longowal, Punjab, India
2004

Master of Technology in Processing and Food Engineering
Punjab Agricultural University
Ludhiana, Punjab, India
2006

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EFFECT OF DRYING TEMPERATURE, SIZE REDUCTION, PROPANE EXTRACTION, AND STORAGE TEMPERATURE ON THE QUALITY AND SHELF LIFE OF CILANTRO (*CORIANDRUM SATIVUM* L.)

Dissertation Approved:

Dr. Carol L. Jones

Dissertation Adviser

Dr. Danielle Bellmer

Dr. Tim Bowser

Dr. Niels O. Maness

*--.

Name: JASREEN KAUR SEKHON

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ABSTRACT: Cilantro dried at 40°C and 60°C was ground and separated into large flakes (LF), small flakes (SF), and coarse powder (CP) and subjected to continuous flow liquid propane extraction at 21-25°C. Extracted and unextracted samples were packaged in aluminum foil laminate packages and stored in a freezer (-20°C), a refrigerator (4°C), at room temperature (18-30°C) and at elevated temperature (40°C) for a period of twelve months. The effect of drying temperature, particle size, propane extraction, and storage conditions on color (L*, a*, b*, chroma, hue angle, and browning index), volatile composition, and fatty acid composition was evaluated. Major volatiles present in dried cilantro were E-2-tetradecenal, dodecanal, E-2-dodecenal, and tetradecanal. Linoleic acid and α-linolenic acid were the major fatty acids found in cilantro. While percent oil (%) in samples dried at 60°C was lower than those dried at 40°C, bulk density, volatile concentration, and color values were higher. No significant effect ($p > 0.05$) of drying temperature was observed on fatty acid composition. Volatile composition was greater in SF or LF as compared to CP. However, fatty acid concentration was higher in CP followed by LF and SF. Solvent extraction with propane lead to a positive change in color values and a decrease in volatile composition, oil content (%), and fatty acid composition. There was a significant ($p < 0.05$) decrease in all volatile compounds, except nonane, with increase in storage time. During storage, color quality and retention of volatile compounds in dried samples was dependent on the particle size of the sample and the storage temperature. During storage the concentration of linoleic acid and α-linolenic acid decreased in the first three to four months and then became stable. The stability of fatty acids in storage was dependent on particle size, solvent extraction, and storage temperature.

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CHAPTER I

INTRODUCTION AND LITERATURE REVIEW

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1.0. INTRODUCTION

Cilantro (*Coriandrum sativum* L.) is an annual herb in the family Apiaceae. The word cilantro comes from a Greek word, "koris", meaning bedbug because of the unripe fruit that smells like an insect of the same name. Cilantro is native to southwestern Asia and Mediterranean regions. The plant yields two primary products that are used for flavoring purposes, fresh green herb and dried seeds (coriander) (Kaur et al., 2006). They are essential ingredients in many South Asian and Mexican foods. Cilantro is very low in saturated fat and cholesterol. It is a good source of thiamine and zinc. It is a very good source of dietary fiber, vitamin A, vitamin C, vitamin E (α- Tocopherol), vitamin K, riboflavin, niacin, vitamin B6, folate, pantothenic acid, calcium, iron, magnesium, phosphorous, potassium, copper, and manganese (USDA, 2008). Cilantro has been recognized from the ancient times as a medicinal herb and as a flavoring agent (Ahmed et al., 2001). It is widely used in the food and pharmaceutical industries. Cilantro is considered an aid to the digestive system and has antibacterial, anticancerous and antimutagenic, antioxidant, and antidiabetic properties (Chen et al., 2009). Culinary uses of the plant are found in pickles, curries, and chutneys in the Middle East. In Mexico and Southwestern USA, it is used in salsas, salads, burritos, and meat dishes.

The market potential of cilantro is expanding because of the popularity of Asian and Mexican cuisines in the USA (Walters, 2007). California is a major producer of cilantro in the US with a total of 1,638 hectare of land under cultivation in 2009, producing 19,054 kg/hectare and a gross value of $12,617/hectare (Smith et al, 2011). Canada exported 9300 tons of coriander in 2007 with a total value of $7,631,000. Out of this, 49% was imported by the US (AAFC, 2007). Owing to cilantro being a high value, less water intensive and a low

maintenance crop, farmers in Oklahoma and Texas are adopting the cultivation of and earning profits from this herb. In Texas in 1997-2003, a 230% increase in herbs and spices production occurred, with cilantro accounting for $1.8 million of the business (Smith and Anicso, 2005).

Fresh cilantro is perishable in nature. After harvesting, it tends to degrade due to stress and moisture loss. To retain fresh quality it is important to maintain a low temperature and high humidity environment. Dehydration is the most common method for food preservation. However, dehydration of cilantro leads to many quality defects such as structure and texture loss, color degradation, loss of aroma and flavor, and development of off-flavors. Solvent extraction has been used for various commodities (coriander seeds, Illes et al., 2000; Grosso et al., 2008; rice bran, Sparks et al., 2006; grape seed, Freitas et al., 2008) for extracting variable amounts of non-polar and polar compounds.

This research evaluated the effect of drying temperature, particle size, and liquid propane extraction at ambient conditions on the quality of cilantro. Further, the effect of storage conditions on the stability of unextracted and extracted (with liquid propane) dried cilantro was investigated.

1.1. LITERATURE REVIEW

1.1.1. Growing and harvesting

Cilantro is a soft hairless plant with green, feathery, and flat leaves. Cilantro can be grown under wide climatic conditions, but it grows well in full sun at temperatures of 10-30˚C (Laemmlen and Smith, 1998). The dried fruit (coriander) is planted as seed, which germinates in 7-10 days. Each seed has two embryos, which can produce two plants. For early harvest, cilantro is usually first germinated in the greenhouse and then transplanted to

the field. At high temperature conditions the plant tends to bolt and fruit rapidly. Slow bolt varieties such as Santo, Slo bolt, Leisure, and Caribe are used in the lower Midwest climate (Walters, 2007). Cilantro can withstand a light frost but a hard frost kills the plant. Hand weeding, mechanical cultivation, and straw mulching can control weeds in the field.

Crop can be harvested manually or mechanically when the plant is 4-6 inch tall, which takes 40-60 days after planting. Although plants can re-grow after harvesting for a second harvest in mild climates, growers prefer one crop per season because of low growing efficiency of the second crop. Cilantro should be harvested at the coolest times of the day to minimize field heat going into post-harvest storage.

1.1.2. Quality Characteristics

1.1.2.1. Fresh appearance: One of the most important quality attributes for fresh market is the fresh appearance of cilantro. Cilantro has a large surface to volume ratio, which makes it susceptible to water loss and wilting. Therefore, it is necessary to maintain a low temperature and high humidity environment after harvesting. Low temperature will reduce the respiration rate and hence, retard senescence of the non-chilling sensitive green leafy tissues (Loaiza and Cantwell, 1997). Stress can be induced by high temperature storage or bulk storage without aeration. Low temperature storage, humidification, aeration, and partially permeable polymer packages can be employed to prevent or delay wilting.

1.1.2.2. Uniformity of leaf size, form, and color: It is desired that the leaves of cilantro should have uniform size, form, and color. Dark lesions are formed after harvesting by inappropriate post-harvest handling (cuts and abrasions) of the crop. Color of leaves should be bright green without yellow tips or brown spots. Chlorophyll content of freshly harvested cilantro is approximately 1.9 mg/g fresh mass (Loaiza and Cantwell, 1997). Warm temperature usually

increases degradation of chlorophyll, hence reducing green color. Color can be maintained by storing cilantro at a low temperature and/or modified atmosphere with 5-10% carbon dioxide and 3% oxygen in air (Loaiza and Cantwell, 1997).

1.1.2.3. Characteristic aroma and flavor: Characteristic aroma and flavor of cilantro are important for culinary value. Flavor is a complex mixture of many sensorial active components. These can be volatile (odorous or aromatic substances) or non-volatile (flavoring substances). Volatile aroma substances are individual sensorial active components with vapor pressure ≥ 0.025 Pa at 25 ˚C. These aroma substances can be any organic compound, such as aldehydes, alcohols, ketones or alkanes. It is not the absolute amount of individual sensorial active components that is important but their combined sensory contribution.

1.1.2.3.1. Secretory structures: Volatiles or volatile oil or essential oil are produced in various secretory structures and their nature depends on genetic and ecological factors and mode of extraction (Svoboda and Svoboda, 2000). The secretory structures contain chemicals such as salts, latex, waxes, fats, flavonoids, sugars, gums, nucliage, essential oils, and resins. Type of secretory structure depends on the plant tissue. There are three types of secretory structures depending upon the plant family:

1. Secretory cavities: Citrus family - orange, grape fruit, etc.
2. Secretory ducts: Umbelliferae family - cilantro, fennel, dill, cumin, etc.
3. Glandular trichomes: Labiatae family - basil, lavender, mint, thyme, etc.

Secretory ducts in the Umbelliferae family are elongated cavities (Svoboda and Svoboda, 2000), which can branch from the stems to the leaves, flowers, and fruits. Cavity is created by expansion of the space formed by the asynchronous division of the parenchyma

cells. Oil is produced in the leucoplast and transferred to the cavity by endoplasmic reticulum. The cavities join together to form ducts.

Major volatile compounds in fresh cilantro are aldehydes (about 82%) and alcohols (about 16%) (Potter and Fagerson, 1990). Carblom (1936) reported that decanal, 2-decenal, and 8-methyl-2-nonenal were the major constituents of cilantro leaf oil, whereas MacLeod and Islam (1976) have reported series of saturated and unsaturated aldehydes in C_8- C_{15} range. They did not report 2-alkenals. In contrast, Mookherjee et al. (1989) have reported the detection of 2-alkenals in the C_{10}-C_{14} range. Potter and Fagerson (1990) reported alkanals and 2-alkenals in the C_9-C_{16} range, C_{10}-C_{14} 2-alkenols, aliphatic aldehydes and alcohols, and nonane. Fan and Sokorai (1996) reported decanal (51% of total detected), E-2-decenal (32% of total detected), E-2-dodecenal (5% of total detected), nonane (4.25% of total detected), linalool (2.13% of total detected), and tetradecanal (1.65% of total detected) among other volatile compounds. Quynh (2010) reported E-2-tetradecenal (52.6%), E-2-pentedecenal (10.04%), E-2-hexadecenal (3.64%), E-2-tridecenal (4.21%), E-2-dodecenal (13.47%), E-2-decenal (3.64%), and decanal (3.73%) as the major compounds.

1.1.2.4. Essential fatty acids: Cilantro is a good source of essential fatty acids. Fatty acids present in cilantro leaves are palmitic acid (16:0), palmitoleic acid (16:1), Cis-10-heptadecenoic acid (17:1), stearic acid (18:0), oleic acid (18:1), linoleic acid (18:2 (n-6)), α-linolenic acid (18:3 (n-3)) and stearidonic acid (18:4(n-3)) (Neffati and Marzouk, 2008). Linoleic acid and α-linolenic are present in high concentration, are essential fatty acids and are precursors of omega-6 fatty acids and omega-3 fatty acids, respectively.

Fatty acid is a carboxylic acid with a long unbranched aliphatic chain, which is either saturated or unsaturated. They are mostly present in plant tissues as triglycerides or

phospholipids. In the leaf cell, fatty acids are an integral part of the chloroplast membrane. Chloroplast, in addition to its role in carbon dioxide fixation, ATP generation and oxygen formation, plays an important role in the synthesis of palmitic and oleic acids. Free oleic acid can move through the chloroplast to the cytoplasm by getting converted to oleoyl-CoA by a long chain acyl-CoA synthetase. Here, either it can be a part of the membrane lipids or be further modified by an extrachloroplast organelle to linoleic acid and α-linolenic acid, which are transported back to chloroplast and become part of the lamellar membranes. Apart from providing nutrition, fatty acids are used as indicators of crop growing conditions and in the post-harvest environment as indicators of quality of the product.

1.1.2.5. Lack of defects, such as decay or yellowing: Cilantro is rarely attacked by insects or pests, because of linalool being insecticidal, 2-dodecenal being an antifungal, E-2-decenal being an antibacterial. Bacterial leaf spot *Pseudomonas syringae*, a seed borne pathogen, causes leaf lesions, coalesce, and blighting effect. Bulk storage, stress, lack of oxygen, and high temperatures in the storage environment will cause decay. Yellow leaves are undesirable for fresh market.

1.1.3. Shelf life of fresh cilantro

Very good visual quality of cilantro can be maintained for 18 to 22 days at 0˚C, 12 to 14 days at 5˚C, 7 to 8 days at 7.5˚C, and 4 to 5 days at 10˚C (Loaiza and Cantwell, 1997). Aroma quality decreases before the decrease in visual quality. Controlled atmospheres with 5-10% carbon dioxide will retain color and visual quality at intermediate temperatures of 7.5˚C. When stored in air under low temperature and high humidity conditions, the best aroma quality is maintained up to 14 days and visual quality up to 22 days (Loaiza and Cantwell, 1997). Storage life can be extended by using modified atmosphere packages with

regulated oxygen transmission rates (OTR) in combination with low temperatures (Luo et al., 2004). Ethylene enhances senescence of cilantro by loss of chlorophyll and protein degradation (Jiang et al., 2002). Ethylene binding inhibitors such as 1-methylcyclopropene can be used, which compete with ethylene for receptor sites. Investigations are currently being undertaken to evaluate the use of solid carbon dioxide pellets, ozone, antioxidants, and anti-browning agents to extend shelf life of cilantro and selected vegetables during shipping (Zhang et al., 2004).

1.1.4. Dehydration

Fresh cilantro is perishable in nature. To retain fresh quality, best postharvest conditions for the crop are a low temperature and high humidity environment. This will retain the quality of cilantro for a maximum of 14-22 days. Dehydration is the most common method for food preservation and long term storage (Kaur et al., 2006). The main purpose of drying is to remove free water (lowering water activity below 0.7) from the food. Simultaneously, total solids such as sugars, organic acids, etc. are concentrated exerting osmotic pressure. Three important methods of dehydrating cilantro are,

- Solar drying: economically less expensive, but causes loss in structure of the plant tissue, and is weather dependent
- Hot air dehydration: moderately expensive, causes loss in structure of the plant tissue
- Freeze drying: expensive, causes minimum damage to structure of plant tissue

Solar drying and hot air tray drying are the most economical processes that produce acceptable quality of cilantro (Pande et al., 2000; Ahmed et al., 2001; Kaur et al., 2006). Ahmed et al. (2001) suggested a drying temperature of 45˚C or lower for cilantro to retain color in the dried product. Diaz-Maroto et al. (2002) investigated dehydration of parsley and

found that oven drying at 45˚C and freeze drying lead to significant reduction in the volatile compounds that contribute to characteristic odor.

1.1.5. Effect of dehydration on the quality of cilantro

1.1.5.1. Structure and texture loss: Change in structure of a plant tissue is quantified by change in bulk density and porosity. Drying method directly affects the bulk density and porosity of the food. Air dried samples have lower porosity than other methods. Air drying leads to rapid loss of surface moisture and shrinkage of the tissue (Askari et al, 2004). Prolonged exposure to high temperature leads to a high degree of shrinkage and low values of bulk density and porosity. This can be minimized by pretreatments, blanching, and optimum dehydration conditions.

1.1.5.2. Color: The color of cilantro after dehydration changes from bright green to olive green. This change in color is quantified by continuous decrease in "L" (progressing from light to darker) and "a" (becoming less green) values with increase in drying temperature or drying time (Nisha et al, 2004). During dehydration, chlorophyll degrades to pheophytins and pyripheophytin resulting in loss of green color. This change can also be due to degradation/reaction of other compounds in the matrix. Therefore, adding salts such as sodium chloride, can retard degradation of chlorophyll or magnesium chloride and stabilize chlorophyll under alkaline conditions. Treating the product with 2% NaCl solution before drying will stabilize chlorophyll (pH ~ 6) (Nisha et al, 2004). This will prevent conversion of chlorophyll into pheophytin and pyripheophytin, thereby stabilizing the green color of the leaves. However, this results in salts within the final product, which might not be desired by the consumer.

1.1.5.3. Loss of volatiles and aroma: Volatiles are low molecular weight compounds, which may evaporate from the food matrix even at room temperature. Change in the volatile composition after dehydration has been studied for other leafy vegetables such as, marjoram (Raghavan et al., 1997), thyme (Venskutonis, 1997), spinach (Masanetz et al., 1998), parsley (Diaz-Maroto et al., 2002), and dehydrated basil (Barbieri et al., 2004). High temperature treatment and low temperature drying for a prolonged time increases the rate of volatile loss.

1.1.5.4. Off flavor development: During dehydration some off flavors are formed. One known cause is peroxidation of fatty acids. One off flavor compound produced in parsley by peroxidation of two furan fatty acids (F20 and F22) is 3-methyl-2, 4-nonanedione, (MND) (Masanetz and Grosch, 1998). It gives hay-like odor to dried parsley. Hexanal and E-2-hexenal, breakdown products of oxidation of linoleic acid and α-linolenic acid, are often used as indicators of off-flavor in frozen storage and dehydrated products stored for a prolonged time.

1.1.6. Fluid extraction

Hydro distillation and steam distillation are traditional methods for extraction of desired components from aromatic plants (Grosso et al., 2008). However, limitations of hydrolysis and insolubility of the fatty acids by water in hydro distillation and thermal degradation of the plant matrix by exposure to steam during steam distillation exist. Supercritical fluids have higher solubility than hydro and steam distillation with reduced thermal degradation. Two popular supercritical fluids are carbon dioxide and propane. Carbon dioxide, because of its low critical temperature, and propane, because of its mild critical temperature and low critical pressure, have been used for extracting nonpolar compounds from coriander seeds (Illes et al., 2000; Grosso et al., 2008), rice bran (Sparks et

al., 2006), and grape seed (Freitas et al., 2008). Typical supercritical conditions for carbon dioxide are 35˚C/100-300 bar and sub critical at 25˚C/100 bar. For propane, super critical conditions are 25˚C/80 bar and sub critical conditions are 25˚C/50 bar. These conditions were used by Illes et al (2000) for coriander seed oil extraction. High pressure treatment by carbon dioxide can alter the food matrix and hence, render it useless after extraction. Also, modifiers (methanol, ethanol, acetonitrile, acetone, water or dichloromethane) are used to extract polar components (Lang, 2001). This adds to the cost of extraction.

1.1.6.1. Propane as a solvent: Propane is a gas under ambient conditions and liquid at or below -43˚C. Its boiling point increases with an increase in pressure. It has strong dissolving power for non-polar and weak polar compounds at lower pressures than carbon dioxide and hence reduces operation costs (Suoqi et al., 2001; Sparks et al., 2006).

Propane as a solvent has advantages over liquid solvents and supercritical fluids such as carbon dioxide. Some of its advantages compared to liquid solvents are that it is nontoxic and leaves no residue. It is being preferred over carbon dioxide because it requires low operating pressure (100s of psi as compared to 1000s of psi for carbon dioxide). Propane has low solvent/sample ratio, high extraction yields for hydrophobic compounds, and faster extraction time. One main disadvantage is that propane is flammable, which makes it necessary to operate the extractor in a facility designed for explosion hazards.

The parameters affecting extraction yield in solvent extraction are pressure, temperature, flow rate of the solvent, extraction time, sample particle size, and moisture content. Particle size impacts exposure of the sample to the extraction solvent. With a decrease in particle size, surface area of the solid matrix increases, which leads to an increase in extraction yield (Pourmortazavi and Hajimirsadeghi, 2007). Moisture in the sample can

have a positive or a negative effect on extraction depending on the moisture content, the solute to be extracted, and the food matrix (Lehotay, 1997).

In the present research an attempt was made to investigate continuous liquid propane extraction as a value added technique, which will improve the quality of dry cilantro, in addition to producing an extract rich in volatile compounds.

1.1.7. Packaging and Storage

The main objective of dehydration is to prolong the shelf life of food beyond that of fresh food. This is accomplished by reducing water activity (a_w) to a value that will inhibit the growth and development of pathogenic and spoilage microorganisms, significantly reducing enzyme activity and the rate at which undesirable chemical reactions occur. Currently dehydrated herbs such as cilantro, basil, curry leaves, mint, oregano, thyme, sage, etc. are sold as shelf-stable commodities. Herbs find their culinary use because of their characteristic aroma and flavor. Therefore, before commercializing dried products it is necessary to evaluate their stability under different storage conditions over prolong storage. Though various studies have evaluated the effect of storage on dehydrated vegetables and herbs, no literature was found for cilantro.

Prolonged storage of a dried product, while maintaining its quality, is possible by selecting the optimum drying method, package, and storage conditions. Ranganath and Dubash (1981) reported 50-58% reduction in ascorbic acid of oven dried spinach at 55-90°C for short time period and further losses during storage at 24°C.

Adom et al (1996) studied the effect of package material, physical form, and storage time on color and moisture content of solar dried okra during storage using two packaging materials (polyethylene and cotton) for two physical forms of solar dried okra (unmilled and

milled), at weekly intervals over a 6 week storage period. The combined effect of packaging material and storage time significantly affected color and moisture content. Overall analysis showed that powdered dried okra kept in a polyethylene package showed acceptable color quality at the end of the storage period. Sagar and Roy (1997) studied the effect of packaging and storage of potato powder (4.18% initial moisture, 335 ppm SO_2). The powder was packed in 200 gauge and 400 gauge LDPE bags (10.16 × 15.24 cm) and stored at ambient conditions (18-30°C and RH 45-80%), cool chamber (26-28.5°C and RH 90-95%), and cold storage (6-7°C, RH 70-85%). Moisture content and non-enzymatic browning was evaluated. In order to increase shelf life of the product, 400 gauge LDPE film was found to be suitable for storage of potato powder samples for 6 months at ambient conditions and 9 months at low temperature conditions. Misra and Kulshrestha (2002) prepared potato flours from three potato varieties and stored them for 6 months at room temperature and refrigerated temperature. Flours were subjected to microbial analysis at 0, 3, and 6 months storage to evaluate their microbial safety. An increase in total bacterial count with increased storage time was observed. Marwaha and Sandhu (2003) used six low dry matter containing Indian potato varieties for evaluation of flour yield, sensory characteristics, nutritional composition, and storability of flours. Flours prepared from different varieties were sealed in polythene bags and stored at ambient temperature (15-29°C) and at -18°C. The flour was found to be organoleptically acceptable for up to 6 months of storage at ambient temperature while quality remained unchanged for more than one year at -18°C.

Various studies on storage of dehydrated leafy plant material have indicated a loss of volatile composition with storage time (mint species, Singh et al., 1990; marjoram, Misharina et al., 2003). Chen et al. (2009) and Arabhosseini et al. (2007) suggested that drying

conditions affect the rate of volatile loss during storage. Arabhosseini et al. (2007) dried tarragon at 45, 60, and 90°C and stored samples at 5°C in glass bottles for 15, 30, 60, and 120 days. They concluded that while drying at 45°C and storage led to a small change in essential oil, drying at 90°C did not affect the essential oil content, but subsequent storage resulted in its loss. Storage conditions are crucial for retention of volatiles in products under storage. Paakkonen et al. (1990) found that storage of dried basil and marjoram at 23°C retained better sensory quality (odor and taste) than samples stored at 35°C and the taste of samples stored at 23°C was maintained for two years. Another study found that with an increase in storage time volatile concentration in dried basil (packaged in aluminum polyethylene polyamide bags at 4°C) decreased (Baritaux et al., 2006). Díaz-Maroto et al. (2009) tested two packaging materials, polystyrene (PS) bottles and glass bottles to store dried (45°C) rosemary leaves at room temperature (21°C) for 21 months. They found that samples packaged in PS bottles retained more volatiles than glass bottles. Low temperature storage (7-8.5°C) and HDPE (High Density Polyethylene) packaging was suggested for prolonged shelf life (in terms of retention of b-carotene, ascorbic acid, chlorophyll content, rehydration ratio, and sensory quality) of savoy beet and amaranth (Negi and Roy, 2001), and curry leaves and drumstick leaves (Singh and Sagar, 2010).

1.2. GOAL AND OBJECTIVES

Literature review section discussed in detail the requirement for processing of fresh cilantro in order to increase its shelf life and undesirable effects of the most economic method of preservation, dehydration. These include changes in color, aroma, flavor, and texture. Due to negative impacts of dehydration on the long term storage of cilantro, methods to improve dry cilantro quality need to be developed.

Goal of this research was to evaluate continuous flow liquid propane extraction as a method to improve or at least stabilize the quality of dried cilantro and extend its shelf life. Objectives devised for evaluation were:

Objective 1: To study the effect of dehydration temperature (40°C and 60°C) and particle size classification on the quality of cilantro.

Objective 2: To study the effect of continuous flow liquid propane extraction duration (0 min, 10 min, 20 min, and 40 min) on the quality of dehydrated cilantro.

Objective 3: To evaluate the shelf life of partially extracted dehydrated cilantro, with propane, stored at four temperature conditions (in freezer, in refrigerator, at room temperature, and at elevated temperature) for a period of twelve months.

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CHAPTER II

SOLVENT EXTRACTION WITH LIQUID PROPANE- A VALUE ADDED PROCESSING TECHNIQUE FOR CILANTRO (*Coriandrum sativum* L.)

Abstract

Cilantro was dehydrated at 40˚C and 60˚C and size reduced and separated into particle size ranges of large flakes (0.85-1.18 mm), small flakes (0.71-1.0 mm), and coarse powder (0.25-0.5 mm). The samples were then subjected to continuous flow liquid propane extraction at 21-25˚C. The effect of drying temperature, particle size classification, and propane extraction on color (L*, a*, b*, chroma, hue angle, and browning index), volatile composition, and fatty acid composition was evaluated. Major volatile compounds found in dried cilantro were E-2-tetradecenal, dodecanal, E-2-dodecenal, and tetradecanal. Linoleic acid and α-linolenic acid were the major fatty acids found in cilantro. While oil content (%) in samples dried at 60˚C was lower than those dried at 40˚C, bulk density, volatile concentration and color values were higher in samples dried at 60˚C. No significant ($p > 0.05$) effect of drying temperature was observed on fatty acid concentration. Volatile concentration was greater in small flakes (SF) and large flakes (LF) compared to coarse powder (CP). However, fatty acid concentration was higher in CP than LF and SF. Propane extraction led to a positive change (increase in –a* and hue angle values, and decrease in browning index) in color values and a decrease in volatile composition, oil content (%), and fatty acid composition.

2.0. INTRODUCTION

Cilantro (*Coriandrum sativum* L.) is an annual herb in the family Apiaceae and native to southwestern Asia and Mediterranean regions. It has been recognized from ancient times as a medicinal herb and as a flavoring agent (Ahmed et al., 2001). The plant yields two primary products that are used for flavoring purposes, the immature fresh green herb and mature seed as the spice coriander (Kaur et al., 2006). These products are

essential ingredients in many South Asian and Mexican foods. Cilantro is very low in saturated fat and cholesterol and a good source of thiamine and zinc. It is a very good source of dietary fiber, vitamins, and minerals (USDA, 2008) and considered to be an aid to the digestive system. It has antibacterial, anticancenogenic, antimutagenic, antioxidant, and antidiabetic properties (Chen et al., 2009). Cilantro is used as a culinary ingredient in pickles, curries, and chutneys in the Middle East and salsas, salads, burritos, and meat dishes in Mexico and the Southwestern United States.

The market potential of cilantro is expanding because of the popularity of Asian and Mexican cuisines in the USA (Walters, 2007). California is a major producer of cilantro in the US with a total of 1,638 hectare of land under cultivation in 2009, producing 19,054 kg/hectare and a gross value of $12,617/hectare (Smith et al, 2011). Owing to cilantro being a high value, less water intensive, and low maintenance crop, farmers in Oklahoma and Texas are adopting the cultivation of, and earning profits from, this herb. In Texas in 1997-2003, a 230% increase in herbs and spices production occurred, with cilantro accounting for $1.8 million of the business (Smith and Anicso, 2005).

Volatile compounds that contribute to cilantro's characteristic aroma have been studied in detail (Carblom, 1936; Potter and Fagerrson, 1990; Potter, 1996; Mookherjee, 1989; Fan and Sokorai, 2002; Marsili, 2002). Table 2.1 briefly lists the volatile impact compounds for fresh cilantro. Major compounds in cilantro are aldehydes (82.6%) followed by alcohols (16.6%) (Potter and Fagerson, 1990). Cilantro is a good source of essential fatty acids.

Fatty acids present in cilantro leaves are palmitic acid (16:0), palmitoleic acid (16:1), Cis-10-heptadecenoic acid (17:1), stearic acid (18:0), oleic acid (18:1), linoleic acid (18:2 (*n*-6)), α-linolenic acid (18:3 (*n*-3)), and stearidonic acid (18:4(n-3)) (Neffati and Marzouk, 2008). Linoleic acid and α-linolenic are present in high concentration, are essential fatty acids and are precursors of omega-6 fatty acids and omega-3 fatty acids, respectively.

Fresh cilantro is perishable in nature. After harvesting, it tends to rapidly deteriorate due to stress and loss of moisture. Very good visual quality can be maintained for about 18 to 22 days at 0°C; substantial loss of aroma occurs within 8-10 days of storage even at low temperature (0°C) (Loaiza and Cantwell, 1997; Wang et al., 2004; Fan et al., 2003). Dehydration is the most common method for food preservation. Solar drying and tray drying are the most economical processes that produce acceptable quality of cilantro (Pande et al., 2000; Ahmed et al., 2001; Kaur et al., 2006). Ahmed et al. (2001) suggested a drying temperature of 45˚C, or lower, for cilantro to retain color and maximum rehydration capacity. While dehydration preserves cilantro for a long period of time, it reduces its aesthetic and flavor quality. It causes quality defects such as structure and texture loss, color degradation, loss of aroma and flavor, and development of off-flavors. Drying method and drying temperature directly affect bulk density and porosity of the food by rapid loss of surface moisture and shrinkage of tissue (Askari et al, 2004). Change in color with increase in drying temperature and drying time is quantified by a decrease in ‘L’ and ‘a’ values (lightness and greenness) (Nisha et al, 2004). Change in the volatile composition after dehydration has been studied for leafy vegetables such as marjoram (Raghavan et al., 1997), thyme (Venskutonis, 1997), spinach (Masanetz et al.,

1998), parsley (Diaz-Maroto et al., 2002), and basil (Barbieri et al., 2004). High temperature treatment has been found to increase the rate of volatile loss. However, no study till date has reported the effect of drying on volatile and fatty acid composition in cilantro.

Partial lipid extraction with propane was evaluated in the present study as a technique that may increase the quality of dried cilantro, and in addition produce two products, extract and raffinate. Propane is a gas under ambient conditions and liquid at or below -43˚C and atmospheric pressure. Some of its advantages compared to liquid solvents are that it is nontoxic and leaves no residue. Compared to carbon dioxide, it requires lower operating pressure: hundreds of psi as compared to thousands of psi for carbon dioxide, hence reduces operation costs (Sparks et al., 2006). Propane has low solvent/sample ratio, high extraction yields, and faster extraction time. The main disadvantage is that it is flammable, which makes it necessary to operate the extractor in an explosion-proof facility.

Some of the parameters affecting extraction yield in solvent extraction include pressure, temperature, flow rate of the solvent, extraction time, sample particle size, and moisture content. Particle size impacts exposure of the sample to extraction solvent. With a decrease in particle size, surface area of the solid matrix increases, which leads to an increase in solvent contact and extraction yield (Pourmortazavi and Hajimirsadeghi, 2007). However, very small particle size can cause fluid channeling and compaction under flow during extraction, decreasing yield (Sabio et al, 2003; Louli et al, 2004; Grosso et al, 2008). Moisture in the sample can have a positive or a negative effect on extraction depending on the moisture content, the solute to be extracted, and the food

matrix (Lehotay, 1997). The effect of drying temperature, particle size, and liquid propane extraction on the quality of cilantro has not yet been studied.

The specific objectives of the present study were:

1. To evaluate the effect of drying temperature and particle size classification on the quality of cilantro; and
2. To evaluate the effect of continuous flow propane extraction under ambient conditions on the quality of dried cilantro.

2.1. MATERIALS AND METHODS

Flowchart in Figure 2.1 briefly outlines the processing steps i.e. sample preparation, propane extraction, and sample analysis.

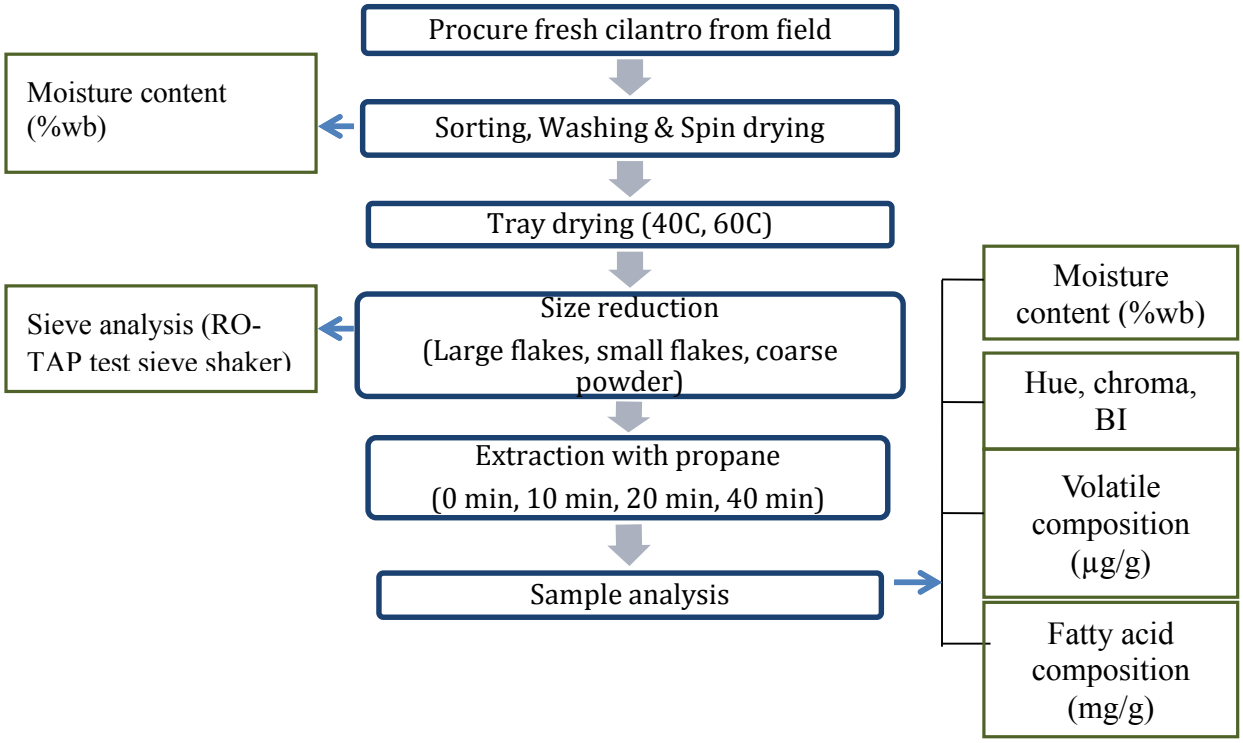

Figure 2.1. Flowchart outlining sample preparation, propane extraction, and sample analysis.

2.1.1. Chemicals

For volatile analysis: Solvent n-hexane was purchased from Fisher Scientific (Fair Lawn, New Jersey, US). Standard compounds β-pinene, decanal, decanol, diallyfumerate, 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 (≥95%) were purchased from Fluka (Sigma-Aldrich GmbH, Seelze, Germany). Tetradecanal and E-2-tetradecenal were purchased from Penta (Penta manufacturing company LLC, Livingsten, New Jersey).

For fatty acid analysis: Solvent diethyl ether and standard compounds, palmitc acid, palmitoleic acid, heptadecanoic acid, cis-10-heptadecenoic acid, stearic acid, oleic acid, linoleic acid, α-linolenic acid, and acetyl chloride were purchased from Sigma-Aldrich (Sigma-Aldrich Co. LLC., St. Louis, Missouri). For methanolysis, methyl acetate was purchased from EM Science (Gibbstown, New Jersey) and tert-butanol from Fisher Scientific (Fair Lawn, New Jersey). All solvents and standards used for the analysis were GC grade.

2.1.2. Dehydration

Cilantro (*Coriandrum sativum* L.) was harvested using a mechanical harvester from field plots at the Oklahoma Vegetable Research Station in Bixby, in November 2009. Immediately after harvest, samples were stored in a cold room (4-5˚C) at the facility to remove field heat and transported on ice to laboratory facilities at Oklahoma State University, Stillwater, Oklahoma. Samples were stored overnight at 4˚C and then hand

sorted to remove foreign material or degraded product, washed, and spin dried in a manual salad spinner (SD92SC; Dynamic International, Champlain, NY) to remove excess water. Plant material (1 kg fresh weight) was packaged in cheesecloth and dried at 40˚C or 60˚C in a forced air tray drier (062; Proctor and Schwartz, Inc. Horsham, PA).

Dehydration was considered complete when stems became brittle and were easy to break, which occurred after about 48 hours at 40˚C and 24 hours at 60˚C. Dried samples were packaged in pre-weighed and labeled freezer bags, flushed with nitrogen, and stored in a freezer (-20˚C approx.) until further processing. Moisture content of samples was measured before and after dehydration by drying at 70˚C to constant weight.

2.1.3. Size reduction and particle size analysis

Dry cilantro was taken out of the freezer and thawed to room temperature. The samples were then coarsely ground in a food processor (DLC-2011RN; Cousinart Inc., East Windsor, NJ) (5-7 times for 10 seconds). The ground samples were passed through two sieves, first through a kitchen strainer (sieve size: 3.3 mm x 3.03 mm, pore density: $0.3/mm^2$) and then through a round splatter screen (sieve size: 1.78 mm x 1.53 mm, pore density: $0.57/mm^2$). This segregated the sample into three size classes:

1. Large flakes (LF): retained on the first sieve
2. Small flakes (SF): retained on the second sieve
3. Coarse powder (CP): passed through the second sieve

To determine the particle size distribution in each size class, a RO-TAP test sieve shaker (R-30050; W.S.Tyler, OH) was used. The RO-TAP uses a tapping motion and a horizontal circular motion, which simulates a typical hand shaking movement while sieving. The test was performed by stacking six sieves (Table 2.2) in descending order of

sieve openings with the largest opening (2.36 mm for large flakes, 1.18 mm for small flakes and 0.85 mm for coarse powder) on the top and the smallest opening (0.5 mm for large flakes, 0.25 mm for small flakes and 0.125 mm for coarse powder) at the bottom. A bottom pan, called a receiver, collected fine material that passed through the last sieve. Weighed amounts of sample (100 g for LF and SF, and 150 g for CP) were allowed to run in the RO-TAP for 10 min. Weight of aggregate retained on each sieve (W_{sieve}) and total weight (W_{total}) were recorded. Percentage retained on each sieve was calculated (equation 1).

$$\% \text{ Retained} = \frac{W_{sieve}}{W_{total}} * 100 \qquad -1$$

2.1.4. Bulk density

Bulk density of particle size classes derived from cilantro dried at 40˚C and 60˚C was measured as a ratio of mass of untapped sample and volume. A straight sided plastic container was used and its volume measured by recording the amount of water displaced from a measuring cylinder. To measure the mass of sample, the empty container was placed on a weighing balance and tared. Then using a funnel, sample was poured into the container from a fixed height (1 inch above the container edge), extra sample particles were scraped from the surface and final weight of the container and contents was noted. Bulk density was calculated as g/ml, which was then converted to g/m^3. This was repeated five times and average of five readings calculated.

2.1.5. Continuous flow propane extraction

The samples dried at two drying temperatures and reduced into three particle sizes were subjected to propane extraction using a continuous flow propane extractor. The extractor (Hy-Look RV-2 Series; Eden labs, Columbus, OH) consisted of a propane storage tank,

an extraction vessel, two separation vessels (I & II), and a compressor. The temperature and pressure of each tank was monitored using temperature and pressure gauges. Instrument grade liquid propane (AirGas, Radnor, PA) was used as an extraction solvent.

Dried cilantro samples (600 g approx.) were accurately weighed into pre-weighed unbleached cotton bags and placed in the extraction vessel (5 L capacity). The system was placed under -68 kPa (-20 in Hg) vacuum to remove air, before releasing propane into the extraction vessel at a continuous liquid flow of 0.64 lpm (0.17 gpm) When liquid propane came in contact with the solid matrix, it dissolved non polar compounds and carried them into the separation vessel I. Propane was vaporized and recondensed by the compressor into the propane storage tank. Extractor temperature was maintained between 21 and 27°C (70 and 80°F), and vessel I temperature never exceeded 38°C (100°F). Extractor pressure was approximately 1.103 MPa (160 psi) and never exceeded 1.241 MPa (180 psi). At the end of the extraction time, liquid propane flow was stopped, propane was vaporized and pumped back into the propane storage tank. Extract was collected in the receiver at the bottom of the separation vessel I. The system was placed under at least 0.1 MPa vacuum to return the solvent back into the propane storage tank. The pump was then turned off, and extract and raffinate (extracted cilantro) were recovered.

2.1.6. Sample analysis

Extracted (raffinates) and unextracted (controls) samples of dried cilantro were analyzed for color, volatile composition, and fatty acid composition. Extracts were analyzed only for volatile composition.

2.1.6.1. ***Color analysis:*** Color (CIE L*, a*, b*) of dried cilantro samples was measured using a Minolta chroma meter CR-300 (Minolta Inc., Osaka, Japan). It consisted of a xenon lamp as light source and six silicon photocells as receptors (3 to measure light illumination and 3 to measure reflected light) to detect tristimulus values of red, green, and blue light. The CIE (Commission Internationale de l'Eclairage) color scale is based on the opponent colors theory, which assumes that receptors in the human eye perceive color as pairs of opposites, L*: Lightness = 100 or dark = 0; a*: redness = + or greenness = -; b*: yellowness = + or blueness = -.

To measure L*, a*, and b* values, about 1 g of a random sample was taken from each package containing cilantro sample and placed in the granular materials attachment (CR-A560; Minolta Inc., Osaka, Japan). Reading was recorded and the sample was put back into the same package and contents mixed before taking the next random sample. This was repeated for the next fourteen measurements.

L*, a*, and b* values were used to calculate chroma, hue angle, and browning index of the samples. Chroma is the degree of saturation of the perceived color and was calculated (equation 2) according to Cantwell's method (1993). Hue angle (equation 3) is the color of a commodity such that an angle of 0 to 360˚ represents red hue, and angles 90˚, 180˚, and 270˚ indicate yellow, green, and blue hues, respectively (Nunes and Edmond, 1998). Browning index (BI) is the purity of brown color and was calculated (equation 4, 5) according to Maskan's method (2001).

$$\text{Chroma} = \sqrt[2]{(a^{*2} + b^{*2}} \qquad -2$$

$$\text{Hue angle} = 180 + tan^{-1}\left(\frac{b^*}{a^*}\right) \qquad -3$$

$$x = \frac{(a^{*}+1.75L^{*})}{(5.645L^{*}+a-3.012b^{*})} \quad -4$$

$$BI = \frac{100(x-0.31)}{0.17} \quad -5$$

2.1.6.2. ***Volatile analysis:*** Evaluation of volatile compounds in unextracted samples (control), the raffinate (extracted) samples, and the extract (obtained by propane extraction) was performed in three steps: solvent extraction; concentration; and gas chromatography. For extraction, a representative sample of control/raffinate (5-6 g from a total of 11-12 g) was ground in a UDY cyclone sample mill (3383N90; UD Corporation, Boulder, CO), with 1 mm screen size, and three replicates (0.5 g) were accurately weighed into tared 2-dram vials. Extraction standard (β-pinene; 100 nmol) was added to each vial to account for extraction recovery. A micro stirring bar and 4 ml of hexane were added to each vial and stirred for 20 min at 25˚C (room temperature) followed by centrifugation at 3,000 gn. Supernatant was transferred to a new vial and re-centrifuged until an extract free of solid particles was obtained.

Density (g/ml) of the extract from each vial (replicate) was measured by weighing 1 ml in a pre-weighed 2-dram vial. The calculated density (0.657 g/ml to 0.666 g/ml) was used to gravimetrically predict the volume of the extract in the concentration step, in which the vial containing the extract was subjected to a gentle stream of nitrogen at 25˚C (room temperature) to concentrate the extract to a final volume of approximately 1 ml. During the concentration step, the weight of the vial was measured intermittently until the required weight was attained.

Extract obtained from propane extraction was diluted for volatile analysis by dissolving 50 mg in 1 ml of n-hexane and centrifuged to remove any insoluble residue.

2.1.6.2.1 Preparation of sample for gas chromatograph (GC): 950 µl of the 1 ml concentrate/propane extract was taken in a GC vial and to it 50 µl of analytical standard (β-myrcene; 50 nmol) was added. One µl of this mixture and one µl of n-hexane were injected on to DB-5 fused silica capillary column (30 m x 0.25 mm x 0.25 µm film thickness; J and W Scientific Inc., Rancho Cardova, CA). Two different Gas Chromatographs were used to analyze samples from control/ raffinate samples and extracts. For controls and raffinates, gas chromatograph (6890N, Agilent Technologies Inc., Agilent Technologies, Inc., 2850 Centerville Road, Wilmington, DE) used hydrogen as the carrier gas with a linear flow rate of 50 cm/sec. It was equipped with a FID detector, which was maintained at 290°C to analyze sample chemical components. A spilt injector was used at a temperature of 270°C, with split ratio of 10:1. The initial column temperature was at 75°C with a hold of 2 min. It was raised to 300°C at a rate of 6°C/min with a hold of 10 min.

For extracts, a gas chromatograph (Varian Star 3400 Cx, Varian Inc., 2700 Mitchell Drive, Walnut Creek, CA) used helium as a carrier gas with a linear flow rate of 20 cm/sec. The GC was equipped with a FID detector, which was maintained at 300°C. Initial injector temperature was 55°C, which was raised immediately after injection to 290°C at a rate of 100°C/min with a hold of 5 min at 290°C. The initial column temperature was at 55°C with a hold of 2 min. It was raised to 120°C at a rate of 2°C/min, and then to 160°C at a rate of 1°C/min and finally to 280°C at a rate of 20°C/min with a hold of 10 min.

2.1.6.2.2. Quantification: Peaks were identified by co-elution with authentic standards and quantified relative to the analytical internal standard, β-myrcene. Concentration

(nmol/ml) of each compound in the injection vial was calculated for each GC (equation

6). $$\text{Concentration, nmol/ml} = \frac{\frac{\text{sample peak area}}{\text{sample } \beta\text{−myrcene peak area}}}{\frac{\text{standard peak area}}{\text{standard } \beta\text{−myrcene peak area}}} * \text{concentration of standard} \quad -6$$

Chemical recoveries (65-81%) were adjusted according to recovery of the extraction internal standard (β-pinene). The concentration was then converted into µg/g dried cilantro.

2.1.6.3. ***Fatty acid analysis:*** The fatty acid composition in control and raffinate samples was performed in three steps: oil extraction; methanolysis; and gas chromatography. Oil was extracted by solvent extraction, using diethyl ether as a solvent. Triplicate aliquots (0.5 g) of the same sample used for volatile analysis were weighed into 2-dram vials. To check extraction recovery, a fourth vial was spiked with 0.015 g of canola oil. Then a micro magnetic stir bar and 4 ml of diethyl ether were added to each vial and the vials were stirred for 20 min at 25˚C (room temperature) followed by centrifugation at 3,000 gn for 20 min. Supernatant was transferred into a tared vial and the pellet was re-extracted (as above) three more times for a total of four extractions. Supernatants from the extractions were combined and evaporated in the Speed Vac concentrator (Savant SVC-100H, Farmingdale, NY) for 15 min. Lipid content was determined gravimetrically and extraction recovery was calculated (equation 7) and varied between 90-106%.

$$\%\ \text{Recovery} = \frac{(\text{oil in spiked sample} - \text{average oil in non spiked sample}) * 100}{\text{spike}} \quad -7$$

2.1.6.3.1. Methanolysis: Methanolysis, essentially as described by Kanamangala et al. (1999) was carried out by taking 1 mg of oil in a vial containing 600 nmoles of heptadecanoic acid (HDA, added as an internal standard). To this, 200 µl methanolic HCl (3% HCl in methanol) and 50 µl methyl acetate (water scavenger) were added. The vials

containing the samples were securely capped, mixed, and incubated over night at 90˚C. Vials were cooled to room temperature and tert-butanol (4-6 drops) was added to co-evaporate with HCl under a stream of nitrogen gas. After complete evaporation, n-hexane (700 µl) was added.

2.1.6.3.2. Preparation of sample for GC: One µl of the mixture from the vials was injected onto a DB 23 fused silica capillary column (30 m x 0.25 mm x 0.25 µm film thickness; J and W Scientific Inc., Rancho Cardova, CA). A Tracor model 540 gas chromatograph (Tracor Instruments, Austin, TX) equipped with a split injection port (split ratio of 50:1) and a FID was used. Helium was used as carrier gas at a linear flow rate of 20 cm/sec. The injector temperature was 275˚C and the detector temperature was 300˚C. Initial column temperature was 50˚C for 2 min. The temperature was then raised from 50˚C to 180˚C at a rate of 10˚C/min, and a hold at 180˚C for 5 min, and a second temperature raise from 180˚C to 240˚C at 5˚C/min and a hold at 240˚C for a final 5 min period.

2.1.6.3.3. Quantification: Peaks were identified by co-elution with authentic standards and quantified relative to the analytical internal standard, heptadecanoic acid (HDA). Concentration (nmol/ml) of each FAME in the injection vial was calculated (equation 8)

$$\text{Concentration, nmol/ml} = \frac{\frac{\text{sample peak area}}{\text{sample HDA peak area}}}{\frac{\text{standard peak area}}{\text{standard HDA peak area}}} * \text{concentration of standard} \quad \text{-8}$$

The concentration of each fatty acid was converted to mg/g dried cilantro.

2.1.7. Statistical analysis

Analysis of Variance (ANOVA) with Proc GLM was performed in SAS (SAS Inc., Cary, NC, ver. 9.3). MEANS statement was used to compute means of the response variables and multi comparison tests for the main effects were performed using LSD option.

Factors were drying temperature, particle size, and extraction time. Response variables were L*, a*, b*, hue, chroma, browning index, concentration (µg/g) of volatile compounds in raffinates and extracts, oil content (%), and concentration (mg/g) of fatty acids in raffinates.

2.2. RESULTS AND DISCUSSION

Moisture content of fresh cilantro was 89% (wb) and of dried cilantro was 3.63% (wb) and 4.43% (wb) when dried at 60˚C for 24 hours and at 40˚C for 48 hours, respectively. After drying, cilantro was coarsely ground and separated into three size classes of large flakes (LF), small flakes (SF), and coarse powder (CP).

Particle size distribution in each size class was determined by sieve analysis using a RO-TAP machine and the results were recorded as percent sample retained on each sieve (Table 2.2). Particles in large flakes, small flakes, and coarse powder were found in the range of 0.85-1.18 mm, 0.71-1.0 mm, and 0.25-0.5 mm, respectively. Particle size distribution (PSD) was further analyzed by plotting percent particles retained on the sieve and percent cumulative of particles passing through the sieve against logarithmic sieve size (Figure 2.2-2.4). While large flakes showed normal distribution with >50% of particles retained on one sieve, small flakes, and coarse powder showed distribution with two peaks. The plot for large flakes (Figure 2.2) shows that 51.35% (>50%) of the particles were retained on 1.18 mm sieve size and only 12% passed through 0.85 mm sieve size. In small flakes (Figure 2.3) 34.98, 21.7, and 29.77% of the particles were retained on sieve size 1, 0.85, and 0.71 mm, respectively and only 10% passed through sieve size 0.71 mm. Same trend was observed in coarse powder (Figure 2.4) with 39.5, 17.9, and 28.1% of particles retained on 0.5, 0.425, and 0.25 mm sieve size and only 6%

of the particles passed through sieve size 0.25 mm sieve size. Sieve analysis is best suited for spherical particles and not irregular shaped particles such as ground dried cilantro. Whole dried cilantro (stems and leaves) was ground in a food processor resulting in variable shape and size particles. While large flakes constituted of larger leaf and stem particles, small flakes and coarse powder constituted of smaller leaf and stem particles. The leave particles are flat and the stem particles are round in shape. Due to the shaking and rotating motion of the RO-TAP, stems can orient themselves so as to pass through the sieve openings. Hence, an irregular shape and size particles may have contributed to the present results for small flakes and coarse powder. Also, because the shape of leaves and stems is different, it is possible that the two were separated at different sieve sizes resulting in two peaks.

2.2.1. Bulk density

Bulk density of cilantro was found to be dependent on particle size and drying temperature (Table 2.3). Bulk density (kg/m^3) of cilantro dried at higher temperature (60˚C) was greater and moisture content lower than those dried at lower temperature (40˚C) (Table 2.3). There was a significant affect (< 0.001) of drying temperature and particle size on the bulk density. At any drying temperature, the bulk density of large flakes, small flakes, and coarse powder were significantly different. Bulk density of a commodity is dependent on its moisture content (Lozano et al., 1983; Madamba et al., 1994; Karanathos et al., 1993; Boukouvalas et al., 2006). Bulk density of high moisture foods depends on the density of water and that of low moisture foods on the density of dry matter. Hence, density of some fruits and vegetables increases with decrease in moisture content such as carrot and potato (Lozano et al., 1983; Zogzas et al. 1994) and

yet decreases in others such as apple (Korokida and Maroulis, 2000; Lozano et al., 1983), mint leaves (Park et al., 2002), and garlic (Madamba et al, 1994). Greater bulk density of coarse powder can be attributed to the fact that smaller particles tend to pack more tightly.

2.2.2. Volatile compounds

Based on literature on fresh cilantro (Carblom, 1936; MacLeod and Islam, 1976; Mookherjee et al., 1989; Potter and Fagergson, 1990; Smallfield et al., 1994; Potter, 1996; Fan and Sokorai, 2002; Eyres, 2005) twenty volatile compounds were evaluated. These were classified as major, intermediate, and minor volatile compounds.

In decreasing order of concentration, volatile compounds present in dried cilantro were: Major 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; Minor compounds (concentration < 4 μg/g dried cilantro): linalool, nonanal, E-2-undecenal, 9-decenal, E-2-nonenal, phenylacetaldehyde, and E-2-decenal. The concentration of major, intermediate, and minor compounds is presented in Table 2.4.

Many studies (Carlbom, 1936; Mookherjee et al., 1989; Potter and Fagergson, 1990; Smallfield et al., 1994; Fan and Sokorai, 2002; Eyres, 2005) have reported decanal and E-2-decenal as the most abundant compounds in fresh cilantro. In the present study, it was observed that decanal and E-2-decenal were present in intermediate and minor concentrations, respectively in dried cilantro. We suspect our differences in the concentrations from that reported by literature were primarily due to our use of dried vs

fresh product, in addition to inherent differences in genetics, climate and growth conditions, geographical location, and different post-harvest processing and separation methods used (Fan and Sokari 2002; Eyres et al, 2005; Qunyh et al, 2010).

2.2.3. Oil content (%) and Fatty acids

Oil in dried cilantro samples was extracted using diethyl ether, a universal lipid solvent. The amount of oil (%) present in the samples derived from dried cilantro was present in the range 2.95-5.32% (Table 2.5). USDA (2008) reported 4.2% of fat in dried cilantro leaves. An aliquot of the extracted oil was used to prepare fatty acid methyl esters.

Seven fatty acids were found in dehydrated cilantro: palmitic acid (16:0), palmitoleic acid (16:1), Cis-10-heptadecenoic acid (17:1; HDE), stearic acid (18:0), oleic acid (18:1), linoleic acid (18:2 (*n*−6)), and α-linolenic acid (18:3 (*n*−3)). Among these, linoleic acid, α-linolenic acid, palmitic acid, and HDE were the major fatty acids (Table 2.6). Linoleic acid and α-linolenic acid are essential fatty acids and precursors of omega-6 fatty acids, and omega-3 fatty acids, respectively. Oleic acid, linoleic acid, and α-linolenic acid are most abundant unsaturated fatty acids found in plant tissues (Murphy, 1993). In the present study, linoleic acid was the main compound in large flakes and small flakes contributing 40-44% and 31-41% of the total fatty acids, respectively. α-linolenic acid was the main fatty acid in coarse powder contributing 39-44% of the total fatty acids. Neffati and Marzouk, (2008) studied the effect of salinity on the fatty acid composition of fresh cilantro leaves. They found that α-linolenic acid (C18: 3n3) was the main compound, 24.14 mg/g, followed by linoleic acid (C18: 2n6), 9.85 mg/g, heptadecenoic acid (C17: 1n7), 9.77 mg/g, and palmitic acid (C16:0), 7.8 mg/g.

2.2.4. Effect of drying temperature

2.2.4.1. Color*:* The effect of drying temperature on color values of large flakes, small flakes, and coarse powder was analyzed (Table 2.7). The L*, b*, and browning index values of cilantro samples dried at higher temperature (60˚C) were lower compared to cilantro samples dried at lower temperature (40˚C). Among all color values, L*, a*, b*, a*-value is of highest significance because it indicates greenness of cilantro. The –a* and hue angle values were higher for cilantro samples dried at higher temperature compared to cilantro samples dried at lower temperature. The difference in color values between samples derived from cilantro dried at two drying temperatures could be attributed to difference in moisture content. High –a* values and lower browning index values being related to less moisture (3.63% wb) in the samples (dried at higher temperature, 60˚C). Opposed to the present findings, Maharaj and Sankat (1996) found a decline in hue angle of dasheen leaves with an increase in drying temperature (40˚C to 70˚C). On the other hand, Negi and Roy (2001) reported better retention of green color when savoy beet leaves were dried in a cabinet drier (65±5˚C) compared to when dried in a solar drier (30-40˚C). Ahmed et al. (2001) found the retention of green color in blanched cilantro leaves (hot water at 80˚C for 3 minutes) decreased with increase in drying temperature (45˚C to 65˚C). Kaur et al (2006) reported pre-treatment (0.1% sodium bicarbonate and 2.0% potassium metabisulphite [KMS] in water at room temperature) and cabinet drying (55˚C) as the best method (compared to solar drying) for maximum retention of green color (a* value) in dehydrated cilantro. Shaw et al (2007) found that microwave drying produced a dehydrated product with smaller color change index as compared to convective drying (50˚C), which produced a product with higher color change index.

2.2.4.2. Volatile compounds: There was a significant effect of drying temperature on the concentration of volatile compounds in cilantro. Concentrations of major, intermediate, and minor compounds in large flakes, small flakes, and coarse powder is presented in Table 2.4. The retention of volatile compounds in samples dried at 60°C was greater than those dried at 40°C. However, the degree of retention of individual volatiles varied. In large flakes and small flakes, among the four major compounds, the retention of E-2-dodecanal and E-2-tetradecanal in samples dried at 60°C was two and three times greater than samples dried at 40°C. Similar greater retention of volatile compounds at higher drying temperature compared to lower drying temperature was observed in intermediate compounds: dodecanol, E-2-dodecanol, and E-2-tridecenal; and minor compounds: linalool, phenylacetaldehyde, and E-2-decenal.

Effect of dehydration on volatile composition has been previously studied for leafy vegetables such as marjoram (Raghavan et al., 1997), thyme and sage (Venskutonis, 1997), spinach (Masanetz et al., 1998), parsley (Diaz-Maroto et al., 2002), and basil (Barbieri et al., 2004). Generally, it is considered that an increase in drying temperature leads to an increase in volatile loss. However, the loss of volatiles also depends on the drying method, drying temperature, and drying time, and properties of the herb. All plant materials do not respond to drying in the same way because various physiochemical changes such as oxidation and evaporation of aromatic volatiles take place. Some work has been reported in drying of herbs where the retention of volatiles was greater at higher drying temperature (Gregory et al., 2005; Barbosa et al, 2006) and yet others reported loss of volatiles with an increase in drying temperature. Barbieri et al. (2004) used convective drier to dry basil leaves at 40, 50, and 60˚C. They found that with an increase

in drying temperature, the concentration of volatiles in basil samples decreased, except for methyl chavicol. On the other hand, Gregory et al. (2005) studied the effect of drying temperature on the production and retention of volatiles in saffron. They found that initial high temperature air-drying (80-92˚C) followed by low temperature drying (43˚C) led to an increase in safranal (25 times) and crocin pigments. This increase was attributed to direct thermal conversion of picrocrocin to safranal as opposed to enzymatic conversion, which may have been inhibited due to denaturation of enzymes at higher temperatures, which prevented degradation of crocin compared to when dried at lower temperature. The process is comparable to blanching, which is a high temperature treatment (80-100˚C) followed by a low temperature treatment. This results in denaturation of enzymes, which are responsible for browning and loss of volatile compounds (Smallfield, 1994; Fan and Sokari, 2002; Quynh et al., 2010)

Figiel (2010) suggested that loss of volatiles was related to moisture loss. The highest rate of volatile loss (at 60˚C) during drying of fresh oregano occurred in the initial stage (60 min), which accounted for 80% of water removal. With further drying, the loss of volatiles occurred at a slower rate. They suggested that water vapors acted as a carrier to diffuse volatile compounds out of the plant tissue and the volatile loss was greater in convective drying compared to vacuum microwave drying. This loss further increased at high temperature because of the increase in volatile evaporation rate. But, oregano has glandular secretary structures as compared to cilantro, which has internal ducts as secretory structures. Therefore, the loss of volatile compounds during drying is not necessarily related to water loss. Figueiredo (2008) suggested that the concentration of volatile compounds in a plant depends, among other factors (light, humidity,

temperature, age of material, contaminations, oxidation, etc.), on the type of the secretory structures. During handling and transportation the loss of volatiles will be more in plants with external structures (by cuticle disruption) than in those with internal structures. This will also be true in the case of dehydration.

Another explanation is greater enzyme activity at lower temperature drying than at higher temperature drying. Smallfield (1994) and Fan and Sokari (2002) have reported the loss of high impact aldehydes (E-2-decenal) to low impact alcohols (E-2-decenol) and acids in fresh cilantro. Quynh et al. (2010) found strong activity of aldehydes reductases (at pH 5-9) and weak activity of aliphatic aldehyde dehydrogenase (at neutral pH) in cilantro leaves. It is possible that drying at 60°C lead to quicker inactivation of aldehyde reductases. Prolonged enzyme activity during slow drying at 40°C may have resulted in greater loss of cilantro volatiles from internal secretory ducts.

2.2.4.3. Oil content (%) and Fatty acids: Effect of drying temperature on oil content (%) is shown in Table 2.5. With increase in drying temperature, % oil decreased from 3.12-5.10% at 40°C to 2.87-3.99% at 60°C. The amount of fatty acids present in the oil (by weight) varied from 34-45% (in samples dried at 40°C) to 51-52% (in samples dried at 60°C).

The fatty acid concentrations of cilantro samples dried at two temperatures are presented in Table 2.6. Comparable concentrations of fatty acids were found at both drying temperatures. The concentration of linoleic acid and α-linolenic acid in coarse powder was 5.21 mg/g and 8.89 mg/g, respectively when dried at 40°C; and 7.12 mg/g and 8.10 mg/g, respectively when dried at 60°C. The values have been corrected for moisture content. Perez-Galvez et al. (1999) reported that major fatty acids in pericarp of

pepper were linoleic acid and α-linolenic acid, and with dehydration while concentration of palmitic acid did not change, the linoleic acid increased (from 27.15% to 28.11%) and α-linolenic acid decreased (from 29.93% to 23.38%). Stewart et al (2003) reported a significant decrease in unsaturated fatty acids with drying in soybean. They found drying time to be a more significant factor than drying temperature. Decrease in moisture content also led to an increase in degradation of linoleic acid and α-linolenic acid (from 13% to 10%, when soybean is dried at 40°C: linoleic acid decreased from 0.61mg/g to 0.31mg/g; α-linolenic acid decreased from 0.12 mg/g to 0.11mg/g).

2.2.5. Effect of particle size

2.2.5.1. Color: The changes in color values with particle size for each drying temperature are presented in Table 2.7. There was a significant difference between L*, -a*, b*, and chroma values of coarse powder versus large flakes and small flakes derived from cilantro dried at 60˚C. The values of L*, -a*, b*, and chroma of coarse powder was higher than large flakes or small flakes. This indicates coarse powder samples derived from cilantro dried at 60˚C were lighter, greener, and yellower than large flakes and small flakes. There was no significant difference between color values of large flakes, small flakes, and coarse powder derived from cilantro dried at 40˚C.

One reason for difference in L*, -a*, b* values among coarse powder versus large flakes and small flakes could be the less uniformity in particle size of large flakes and small flakes compared to coarse powder as indicated by the particle size distribution analysis (Table 2.2).

2.2.5.2. Volatile composition: The total volatile concentration of major, intermediate, and minor compounds is presented in Table 2.4. The concentrations of individual compounds

in large flakes, small flakes, and coarse powder are presented in Tables 2.9-2.11. The concentration of volatiles in large flakes and small flakes was comparable and greater than in coarse powder. Lower concentration of volatiles in coarse powder could be due to small particle size (0.25-0.5 mm) and large surface area. Depending on the drying temperature and the particle size, the contribution of major, intermediate, and minor compounds to the total volatile concentration in dried cilantro was 71-82%, 16-26%, and 1-3%, respectively. Even though small flakes had maximum total concentration of major compounds, the concentration of individual compounds varied. For samples dried at 40°C, the concentration of dodecanal (109.80 μg/g) and tetradecanal (185.49 μg/g) in small flakes was lower than in large flakes (156.50 μg/g dodecanal and 360.42 μg/g tetradecanal) (Table 2.9, Table 2.10). In addition, concentration of intermediate compounds, except decanal, in small flakes derived from cilantro dried at 40°C was lower than in large flakes. However, the concentration of intermediate compounds in small flakes and large flakes derived from cilantro dried at 60°C was comparable. Lower concentration of intermediate compounds for samples dried at 40°C compared to samples dried at 60°C was also observed for coarse powder.

In solvent extraction, particle size of a sample is an important parameter. It influences the yield of the volatile compounds in the extract, their retention in the raffinate and protection against oxidation during storage of the raffinates. Particle size impacts exposure of the sample to an extraction solvent. With a decrease in particle size, surface area of the solid matrix increases, which leads to an increase in extraction yield (Pourmortazavi and Hajimirsadeghi, 2007). However, very small particle size can cause fluid channeling and compaction under flow during extraction, decreasing yield (Sabio et

al, 2003; Louli et al, 2004; Grosso et al, 2008). Two factors contributing to the rate of volatile loss from a matrix are volatility of the aroma compound in the product and resistance to mass transfer from food matrix to air (De Roos, 2000). Volatility is a function of composition of the matrix and the temperature, but not of texture and structure. However, resistance to mass transfer is affected by texture and structure (De Roos, 2003). Therefore, volatile loss would be expected to be greater in coarse powder than in large flakes and small flakes.

2.2.5.3. Oil content (%) and Fatty acids: Amount of oil present in the three particle sizes was evaluated (Table 2.5). With decrease in particle size from large flakes or small flakes to coarse powder, the oil content (%) present in the plant tissue increased. For samples dried at 40°C, oil content (%)was 5.32% (38% fatty acids) in coarse powder, 3.28% (46% fatty acids) in large flakes, and 3.33% in small flakes (34% fatty acids). For samples dried at 60°C, oil content (%) was 4.11% (51% fatty acids) in coarse powder, 2.95% (52% fatty acids) in large flakes, and 2.81% in small flakes (51% fatty acids). Goodrun and Kilgo (1987) reported an increase in oil recovery from 36% to 82% with decrease in particle size of peanuts from 3.35-4.75 mm to 0.86-1.19 mm. Nwabanne (2010) separated ground pumpkin seeds by using five different test sieves into particle sizes 2.0, 2.36, 3.35, 4.75, and 7.0 mm and found that with decrease in particle size, oil yield increased from 20% to 41%. The same method was used to separate ground dried cilantro. Decrease in particle size leads to an increase in surface area and ruptured cells. However, in the present study, prior to oil extraction large flakes, small flakes, and coarse powder were ground into particle size ≤ 1 mm. Omara Alwala (1991) investigated concentration of saturated and unsaturated fatty acids in different parts of purslane (*Portulaca*

oleracea). Highest concentration of fatty acids (palmitic acid, linoleic acid, and α-linolenic acid) was present in leaves than in stems or in the whole plant. In the present study, maximum concentration of α-linolenic acid was found in coarse powder and of linoleic acid in coarse powder derived from cilantro dried at 60˚C.

A significant difference between the total fatty acid concentrations of large flakes, small flakes, and coarse powder was observed (Table 2.6). The concentration was highest in coarse powder (20.34-20.95 mg/g) followed by large flakes (14.92-5.18 mg/g) and small flakes (11.47-14.37 mg/g). α-Linolenic acid, linoleic acid, palmitic acid, HDE, and stearic acid showed a significant difference among the three particle sizes. For cilantro dried at 40°C, concentrations of palmitic acid and stearic acid in large flakes were significantly higher than in small flakes and coarse powder; concentrations of HDE and α-linolenic acid in coarse powder were significantly higher than in large flakes or small flakes; and concentrations of linoleic acid were significantly different in all particle sizes. For cilantro dried at 60°C, the concentrations of HDE and α-linolenic acid in coarse powder were significantly higher than large flakes or small flakes.

2.2.6. Effect of extraction time

2.2.6.1. Color: Effect of liquid propane extraction under ambient conditions on color values of dried cilantro was assessed (Table 2.8). Propane extraction led to a positive change in the color of dried samples. This was evident with a significant ($p < 0.05$) increase in L*, -a*, and hue angle values and a decrease in browning index (BI). The increase in greenness (–a* values) was significant for small flakes (derived from cilantro dried at 40˚C) and coarse powder (derived from cilantro dried at 40°C or 60°C). The decrease in chroma was significant for samples derived from cilantro dried at 60˚C (large

flakes, small flakes and coarse powder). Hue angle and browning index were correlated such that with extraction, decrease in browning index (purity of brown color) led to an increase in hue angle (green color of cilantro). This was expected because preliminary studies showed a decrease in darkness in dried samples with propane extraction. Lowest values of BI resulted for large flakes extracted for 20 min, for small flakes extracted for 40 min, and for coarse powder extracted for 20 min (for samples dried at 40°C) and 40 min (for samples dried at 60°C), respectively. These results suggest that though solvent extraction with propane leads to positive change in the color quality of dried cilantro by removal of brown pigment, the degree of this change is dependent on the drying temperature and the particle size and.

2.2.6.2. Volatile compounds in raffinate: Extraction time is a vital processing parameter in solvent extraction. Its effect depends on the plant type, extractant, and extraction conditions. Propane extractions led to a decrease in all chemical compounds in large flakes (Table 2.9), small flakes (Table 2.10), and coarse powder (Table 2.11). Maximum extraction of volatile compounds was achieved when large flakes and small flakes were extracted for 40 min and coarse powder was extracted for 20 min. This difference in the extraction time could be due to the difference in the particle sizes (0.85-1.180 mm of large flakes and 0.71-1.0 mm of small flakes versus 0.25-0.50 mm of coarse powder).

The concentration of major compounds, E-2-tetradecenal and E-2-dodecenal, decreased to about half when extracted for 40 min. In small flakes (extracted for 40 min) and coarse powder (extracted for 20 min), maximum decrease in concentration was observed for tetradecanal followed by dodecanal, E-2-tetradecenal, and E-2-dodecenal.

The concentration of intermediate compounds, decanal and decanol, showed noticeable decrease in large flakes derived from cilantro dried at 40°C. In addition to decanal and decanol, in large flakes derived from cilantro dried at 60°C, other compounds that showed prominent decrease were E-2-dodecenol, dodecanol, and E-2-tridecenal. Compounds that showed noticeable decrease in small flakes derived from cilantro dried at 60°C were decanol, undecanal, E-2-dodecenal, dodecanal, and E-2-tridecenal.

The volatile composition of extracts obtained from the corresponding particle sizes is presented in Table 2.12. Particle size and moisture content are important parameters that govern solvent extraction. Large particle size may require more extraction time (basil 5 hours when particle size was 0.55 mm and 2 hours when particle size was 0.17 mm) because of diffusion-controlled extraction (Modey et al, 1996). Pulverizing can cause channeling. Louli (2004) found an increase in extraction rate with a decrease in particle size (diffusion controlled 0.495 mm to 0.293 mm). However, very small particle size (0.345 mm to 0.08 mm) led to a decrease in extract yield (Sabio et al, 2003) of dried tomato peel and seed mixture because of inhomogeneous extraction. The results showed an increase in the yield from large flakes to small flakes and then a decrease from small flakes to coarse powder. The results are similar to those found by Goodrun (1996). They reported that with decrease in particle size of ground peanuts from 3.35-4.75 mm to 0.86-1.19 mm the oil recovery increased 32-82%, but with further decrease in particle size at 0.08 mm, the yield decreased because of uneven extraction. Hence, to optimize an extraction process, one must consider pretreatment as an important factor.

2.2.6.3. Volatile compounds of Extract: Irrespective of drying temperature and particle size, the volatile compounds present in highest concentration were E-2-tetradecenal, tetradecanal, dodecanal, and E-2-dodecenal. These were also the major compounds found in control samples of dried cilantro. Nonanal, which was a minor compound in dried cilantro, was present in intermediate concentration in extracts. Octanal, which was an intermediate compound in dried cilantro, was present as a minor compound in extracts. Overall, the total volatile concentration in extracts from cilantro dried at 60°C was more than those dried at 40°C. Similar to dried cilantro, the concentration of volatile compounds was more in extracts from small flakes followed by large flakes and coarse powder (Table 2.12).

2.2.6.4 Oil content (%) and Fatty acids in raffinates: Raffinates from liquid propane extraction were evaluated for oil content. The samples were extracted with diethyl ether to study the effect of continuous liquid propane extraction on the oil content of dried cilantro samples (Table 2.5). With an increase in extraction time, from 0 to 40 min, oil content in the raffinate samples decreased. There was a significant difference between unextracted samples (control) and extracted samples, except for large flakes derived from cilantro dried at 60˚C. The fraction of oil extracted by liquid propane varied from 12% in large flakes (dried at 60˚C) to 41% in small flakes (dried at 40˚C) and 38% (dried at 40˚C) in coarse powder.

Extraction with propane had a significant effect on the total fatty acids (Table 2.13, 2.14) present in the samples. However, the difference between three extraction times, 10, 20, and 40 min, was not significant for all samples. This is similar to the effect of propane extraction on the volatile concentration. Extraction times for which maximum

decrease in total fatty acids occurred were 10 min and 20 min for large flakes derived from cilantro dried at 40˚C and 60˚C, respectively, and 40 min for coarse powder derived from cilantro dried at 40˚C. The extraction of coarse powder (derived from cilantro dried at 60°C) did not have significant effect on the total fatty acids. Illes et al. (1997) extracted hiprose fruits with propane under sub-critical conditions (28°C temperature and 100 bar pressure; 25°C temperature and 50 bar pressure). They reported linoleic acid (52-55%) and α-linolenic acid (23-24%) as the most abundant fatty acids, but found no significant effect of extraction on change in fatty acid composition with extraction.

2.3. CONCLUSION

Propane extraction had a significant effect on color, volatile composition and fatty acid composition of dried cilantro. Among three test factors, drying temperature, particle size, and extraction time, the first two govern the extraction efficiency. Bulk density of cilantro increased with increase in drying temperature, which resulted in higher moisture content in samples. There was a significant effect of drying temperature and particle size on the color values of cilantro. While, with increase in drying temperature, L*, -a*, b* values increased, browning index decreased. Propane extractions lead to a significant increase in L* and –a* values and a decrease in browning index values, which indicates increase in lightness and greenness, and decrease in brownness of raffinates. Major compounds found in dried cilantro were E-2-tetradecenal, dodecanal, E-2-dodecenal, and tetradecanal. Drying temperature and particle size had a significant effect on the concentration of volatile compounds. Overall, aromatic compounds were best preserved in large flakes and small flakes dried at higher temperature (60˚C) compared to lower temperature (40˚C). Propane extraction lead to a decrease in concentration of all

compounds in varying amounts. Oil content in dried cilantro is dependent on the drying temperature and the particle size. Maximum oil content (%) was found in samples dried at lower temperature (40˚C) compared to higher temperature (60˚C) and smallest particle size (coarse powder) compared to large flakes and small flakes. α-linolenic acid was the main compound in coarse powder contributing 39-44% of the total fatty acids. Linoleic acid was the main compound in small flakes and large flakes contributing 40-44% and 31-41% of the total fatty acids, respectively. Extraction with propane led to a significant decrease in the total fatty acids. However, the difference between three extraction times, 10, 20, and 40 min, was not significant for all samples.

2.4 TABLES AND FIGURES

Table 2.1: Characteristic impact volatile compounds in fresh cilantro.

Reference	Characteristic compounds
Carlbom, (1936)	decanal, 2-decenal, and 8-methyl-2-nonenal
MacLeod and Islam (1976)	7-dodecenal (21.37%), dodecanal (16.27%), decanal (10.05%)
Fischetti (1985)	D-linalool, E-2-decenal, octanal, and decanal
Mookherjee et al. (1989)	E-2-decenal (35.5% leaf on the plant; 39.2% harvested leaf), nonane (15.2 % in living; 4.7% in picked), decanal (11.4% in living; 4.7% in picked), E-2-dodecenal (9.7% in living; 4.3% in picked)
Potter and Fagergson (1990)	E-2-decenal (46.1%TIC[a]), E-2-dodecenal (10.3%TIC[a]), 2-decenol (9.2%TIC[a]), decanal (4.4%TIC[a])
Smallfield et al. (1994)	E-2-decenal (48.2% in unchopped; 32.6% in chopped), E-2-decenol (1.6% in unchopped to 8.5% in chopped)
Potter (1996)	E-2-dodecenal (15.6% TIC[a]), E-2-tetradecenal (12.7% TIC[a]), E-2-decenal (12.1% TIC[a])
Rowe et al. (2000)	E-2-dodecenal
Fan and Sokorai (2002)	decanal (51%), (E) 2-decenal (32%), E-2-dodecenal (5%), nonane (4.25%), linalool (2.13%) and tetradecanal (1.65%) of total detected
Marsili, 2002	D-linalool, E-2-dodecenal, octanal and decanal
Eyres, (2005)	E-2-decenol (26.0% TIC[a]), (26.0% TIC[a]), E-2-decenal (9.1%), E-2-tetradecenal (7.0%), E-2-dodecenal (5.4%)
Quynh (2010)	E-2-tetradecenal (52.6%), E-2-pentedecenal (10.04%), E-2-hexadecenal (3.64%), E-2-tridecenal (4.21%), E-2-dodecenal (13.47%), E-2-decenal (3.64%), decanal (3.73%)

[a] TIC: Total ion current

Table 2.2: Sieve analysis: particle size distribution in cilantro samples presented as mean percent retained on each sieve.

Large flakes				Small flakes				Coarse powder			
Sieve no.	Sieve[a] size (mm)	Mean % retained	STDEV % retained	Sieve No.	Sieve[a] size (mm)	Mean % retained	STDEV % retained	Sieve no.	Sieve[a] size (mm)	Mean % retained	STDEV % retained
8	2.36	1.3	0.6	16	1.2	2.7	1.4	20	0.9	0.2	0.2
10	2	3.6	1.3	18	1	34.8	5.4	25	0.7	8.2	2.9
16	1.2	51.4	8.7	20	0.9	21.5	0.8	35	0.5	39.5	4.4
20	0.8	31.4	5.0	25	0.7	31.1	4.5	40	0.4	17.9	1.0
25	0.7	8.3	3.4	35	0.5	8.7	2.4	70	0.3	28.1	4.0
35	0.5	3.2	1.8	70	0.3	1.0	0.5	120	0.1	3.6	1.3
Receiver		0.7	0.4	Receiver		0.1	0.03	Receiver		2.5	2.6

[a] Sieve size corresponds to the value for test sieve openings recommended by the International Standards Organization, Geneva, Switzerland. RO-TAP test sieve shaker (R-30050, W.S.Tyler, OH) with six sieves (arranged in descending order of sieve opening) was used to determine particle size distribution in large flakes (LF), small flakes (SF) and coarse powder (CP). Weighed amounts of sample (100 g for LF and SF, and 150 g for CP) were allowed to run in the RO-TAP for 10 min and weight of aggregate retained on each sieve (W_{sieve}) and total weight (W_{total}) were recorded to calculate % retained on each sieve.

Table 2.3: Effect of drying temperature and particle size on bulk density of cilantro.

Drying temperature (℃)	Particle[a] size	Moisture content (% db)	Bulk density (g/m^3)
40	LF	5.00	148.24b
	SF	4.81	135.03c
	CP	4.30	164.12a
60	LF	2.69	184.12b
	SF	2.84	149.32c
	CP	3.07	269.65a

[a]LF: large flakes (0.85–1.18 mm); SF: small flakes (0.71-1.0 mm); CP: coarse powder (0.25-0.5 mm)

Table 2.4: Effect of drying temperature and particle size on volatile concentration (µg/g) in dried cilantro.

Drying temperature (℃)	Particle[a] size	Major compounds (µg/g)	Intermediate compounds (µg/g)	Minor compounds (µg/g)
40	LF	275.56a	85.56a	11.63a
	SF	277.53a	54.68b	8.54ab
	CP	103.95b	31.28c	2.76b
60	LF	549.44b	121.90a	13.78a
	SF	733.67a	129.90a	13.23ab
	CP	345.29c	87.92b	7.35b

[a]LF: large flakes (0.85-1.18 mm); SF: small flakes (0.71-1.0 mm); CP: coarse powder (0.25-0.5 mm); a, b, c Denote different letters denote significantly different (at 0.05 probability level) volatile concentrations between three particle sizes at a drying temperature.

Table 2.5: Effect of drying temperature, particle size, and extraction time on oil content (%) in cilantro.

Drying temperature (℃)	Extraction time (min)	% Oil*		
		LF[a]	SF[a]	CP[a]
40	0	3.24a	3.33a	5.32a
	10	2.62b	1.95b	3.89b
	20	2.81b	2.82a	3.84b
	40	2.54b	3.38a	3.31c
60	0	2.87a	2.73b	3.99a
	10	2.70a	3.22a	3.53b
	20	2.49a	3.13a	3.89a
	40	2.53a	2.96ab	3.52b

[a]LF: large flakes (0.85–1.18 mm); SF: small flakes (0.71-1.0 mm); CP: coarse powder (0.25-0.5 mm) for moisture (% db); a, b, c Different letters denote significantly different % oil value (at 0.05 probability level) between different extraction times.

Table 2.6: Effect of drying temperature and particle size on fatty acid composition (mg/g dried cilantro) of cilantro.

Drying temperature (˚C)	Particle size[a]	C16:0	C16:In9	C17:1	C18:0	C18:In9	C18:2n6	C18:3n3	**Total**
40	LF	2.56a	0.15a	1.43b	0.29a	0.39a	6.04a	4.06b	**14.92b**
	SF	1.16b	0.10a	1.66b	0.22b	0.41a	3.59c	4.32b	**11.47c**
	CP	1.83b	0.14a	3.75a	0.20b	0.32a	5.21b	8.89a	**20.34a**
60	LF	2.16a	0.33a	1.31b	0.23a	0.52ab	6.60a	4.02b	**15.18b**
	SF	1.73a	0.17a	1.18b	0.26a	0.54a	5.87a	4.60b	**14.37b**
	CP	2.19a	0.13a	2.79a	0.20a	0.42b	7.12a	8.10a	**20.95a**

[a]LF: large flakes (0.85–1.18 mm); SF: small flakes (0.71-1.0 mm); CP: coarse powder (0.25-0.5 mm); C16:0: Palmitic acid, C16:In9: Palmitoleic acid, C17:1: Cis-10-heptadecenoic acid, C18:0: Stearic acid, C18:In9: Oleic acid, C18:2n6: Linoleic acid, and C18:3n3: α-Linolenic acid; a, b, c Different letters denote significantly different (at 0.05 probability level) fatty acid concentration between three particle sizes derived from cilantro dried at 40˚C or 60˚C.

Table 2.7: Effect of drying temperature on color values of dried cilantro.

Drying temperature (˚C)	Particle[a] size	L*	-a*	b*	Chroma	Hue angle	BI[b]
40	LF	47.22a	-12.35a	25.03a	27.93a	178.89a	49.38a
	SF	47.60a	-12.66a	25.06a	28.09a	178.89a	47.81a
	CP	46.46a	-12.80a	25.11a	28.18a	178.90a	49.47a
60	LF	46.02b	-13.06a	24.95b	28.17b	178.91a	48.46a
	SF	46.91b	-13.02a	25.33b	28.48b	178.90a	49.17a
	CP	50.22a	-14.12b	26.95a	30.43a	178.91a	48.22a

[a]LF: large flakes (0.85–1.18 mm); SF: small flakes (0.71-1.0 mm); CP: coarse powder (0.25-0.5 mm); [b]BI: Browning Index; a, b, c Different letter denote significantly different (at 0.05 probability level) color values between three particle sizes at any drying temperature.

Table 2.8: Effect of propane extraction on color values of dried cilantro.

Drying temperature (℃)	Particle[a] size	Extraction time (min)	L*	a*	b*	Chroma	Hue Angle	Browning Index
40	LF	0	47.23a	-12.35a	25.04a	27.94a	178.89b	48.97a
		10	47.63a	-12.29a	23.59b	26.61b	178.91ab	43.05b
		20	48.27a	-12.28a	23.26b	26.32b	178.92a	41.18b
		40	47.72a	-12.35a	23.56b	26.61b	178.91a	42.75b
	SF	0	47.60b	-12.66ab	25.06a	28.09a	178.90bc	47.81a
		10	48.74ab	-12.97bc	24.69ab	27.90a	178.91b	44.23bc
		20	48.99a	-12.23a	24.63ab	27.51a	178.89c	45.10b
		40	48.07a	-13.28c	23.97b	27.41a	178.94a	41.96c
	CP	0	46.46c	-12.80bc	25.11a	28.18a	178.90c	49.47a
		10	47.49b	-13.06b	23.96b	27.29b	178.93b	43.02c
		20	47.81b	-13.51a	24.07b	27.61b	178.94a	42.16c
		40	50.00a	-12.64c	25.14a	28.15a	178.90c	44.78b
60	LF	0	46.02b	-13.06a	24.95a	28.17a	178.91b	48.47a
		10	47.63a	-13.39a	23.67b	27.20ab	178.94a	41.15b
		20	47.60a	-12.83a	23.26b	26.57b	178.93a	40.96b
		40	47.47a	-12.70a	22.97b	26.27b	178.93a	39.21b
	SF	0	46.91a	-13.02a	25.33a	28.48a	178.90c	49.17a
		10	45.76b	-13.56a	23.37b	27.02b	178.95ab	42.09b
		20	45.55b	-13.26a	22.74b	26.33b	178.96a	40.62b
		40	47.02a	-12.93a	23.05b	26.44b	178.94b	40.54b
	CP	0	50.22a	-14.12a	26.95a	30.43a	178.91c	48.22a
		10	46.37b	-13.65b	23.53bc	27.20b	178.95a	41.70c
		20	46.90b	-13.38c	23.74b	26.93b	178.92b	43.68b
		40	46.37b	-13.67b	23.29c	27.01b	178.96a	40.73d

[a]LF: large flakes (0.85–1.18 mm); SF: small flakes (0.71-1.0 mm); CP: coarse powder (0.25-0.5 mm); a, b, c Different letters denote significantly different (at 0.05 probability level) color values between four extraction times of a particle size and drying temperature.

Table 2.9: Change in volatile concentration (µg/g) in large flakes (derived from cilantro dried at two temperatures) with propane extraction duration.

Drying Temperature (˚C)	40				60			
Extraction time (min)	0	10	20	40	0	10	20	40
Major compounds	**798.43**	**595.59**	**578.48**	**456.41**	**1359.02**	**1051.06**	**1021.31**	**907.92**
Dodecanal	156.50	122.47	117.43	109.64	189.04	156.69	155.12	133.94
E-2-Dodecenal	59.76	50.90	49.04	33.03	145.46	116.99	110.35	102.43
Tetradecanal	360.42	254.50	245.51	207.96	361.37	277.46	280.00	248.78
E-2-Tetradecenal	221.75	167.73	166.50	105.77	663.16	499.92	475.84	422.78
Intermediate compounds	**129.49**	**102.94**	**90.21**	**91.84**	**204.23**	**156.08**	**152.29**	**145.18**
Nonane	26.95	21.84	16.69	20.23	22.35	22.12	25.16	23.79
Octanal	11.07	7.60	6.76	6.53	7.18	6.96	6.56	6.89
Decanal	24.12	16.26	13.76	13.84	26.79	17.46	17.81	18.16
Decanol	9.10	7.94	5.90	6.35	19.79	13.25	12.98	12.91
Undecanal	16.70	13.59	12.07	12.53	20.72	16.10	14.85	14.16
E-2-Dodecenol	.	.	.	.	.	.	.	.
Dodecanol	4.97	4.61	5.07	5.10	17.60	15.04	15.33	10.15
Tridecanal	13.09	11.72	12.08	11.96	17.01	12.84	11.89	14.80
E-2-Tridecenal	23.50	19.39	17.88	15.30	72.78	52.31	47.72	44.34
Minor compounds	**33.23**	**27.41**	**24.76**	**30.96**	**29.35**	**23.65**	**17.54**	**14.58**
Phenylacetaldehyde	1.76	1.36	1.71	1.09	0.92	1.25	0.94	0.88
Linalool	.	.	.	.	.	.	.	.
Nonanal	27.63	22.71	20.52	27.59	22.36	17.46	12.09	9.44
E-2-Nonenal	0.78	0.86	0.78	0.92	0.76	0.80	0.72	0.74
E-9-Decenal	1.14	0.72	0.86	0.54	0.59	1.08	0.90	0.50
E-2-Decenal	0.62	0.85	.	.	1.37	0.62	0.81	0.76
E-2-Undecenal	.	.	.	.	.	.	.	.

Table 2.10: Change in volatile concentration (µg/g) in small flakes (derived from cilantro dried at two temperatures) with propane extraction duration.

Drying Temperature (˚C)	40				60			
Extraction time (min)	0	10	20	40	0	10	20	40
Major compounds	**637.29**	**521.62**	**560.91**	**381.67**	**1356.58**	**1080.16**	**1119.55**	**1065.18**
Dodecanal	109.80	112.02	102.24	68.85	169.88	166.83	163.06	153.09
E-2-Dodecenal	74.13	60.30	75.96	55.58	182.81	139.52	160.41	145.40
Tetradecanal	185.49	133.95	157.44	87.82	235.25	212.38	192.31	192.66
E-2-Tetradecenal	267.87	215.34	225.27	169.42	768.64	561.43	603.78	574.04
Intermediate compounds	**107.78**	**97.61**	**117.04**	**97.80**	**198.55**	**188.95**	**209.46**	**193.54**
Nonane	6.61	9.62	16.28	10.65	20.35	18.24	20.05	23.66
Octanal	6.10	7.04	7.28	7.31	8.80	6.42	6.85	6.70
Decanal	18.57	17.61	24.58	22.02	34.74	37.30	38.90	30.97
Decanol	1.46	0.61	0.57	0.58	17.88	9.13	12.59	9.11
Undecanal	12.63	12.06	16.17	13.26	21.81	19.15	18.06	18.87
E-2-Dodecenol	2.67	3.11	2.98	2.79	30.61	8.05	9.21	8.71
Dodecanol	2.04	1.62	1.69	1.57	9.96	4.60	5.69	3.16
Tridecanal	24.61	18.64	16.32	12.66	3.38	9.02	17.50	18.33
E-2-Tridecenal	33.07	27.31	31.17	26.97	51.01	77.06	80.61	74.03
Minor compounds	**45.70**	**39.16**	**38.14**	**38.62**	**90.05**	**53.06**	**61.06**	**65.25**
Phenylacetaldehyde	3.29	2.34	2.73	3.63	2.09	3.31	3.56	3.57
Linalool	1.11	1.03	1.42	0.79	2.79	1.08	1.21	1.43
Nonanal	28.48	21.57	15.84	15.35	33.92	17.79	31.35	41.98
E-2-Nonenal	0.48	0.63	0.70	0.66	0.81	0.72	0.73	0.78
E-9-Decenal	0.68	0.72	0.98	1.67	1.13	0.93	0.88	0.96
E-2-Decenal	0.62	0.79	0.72	0.76	1.17	1.64	2.24	1.15
E-2-Undecenal	2.68	3.27	3.71	2.81	1.42	0.72	1.35	.

Table 2.11: Change in volatile concentration (µg/g) in coarse powder (derived from cilantro dried at two temperatures) with propane extraction duration.

Drying Temperature (˚C)	40				60			
Extraction time (min)	0	10	20	40	0	10	20	40
Major compounds	**259.48**	**167.77**	**157.85**	**249.99**	**875.66**	**460.54**	**415.93**	**483.15**
Dodecanal	56.11	31.66	29.67	47.95	142.40	80.57	63.36	78.92
E-2-Dodecenal	27.67	20.64	20.93	26.04	90.05	53.48	48.78	65.75
Tetradecanal	67.09	32.14	23.05	60.25	258.31	110.44	77.95	94.11
E-2-Tetradecenal	108.61	83.33	84.20	115.75	384.89	216.05	225.84	244.36
Intermediate compounds	**54.69**	**42.15**	**40.16**	**45.09**	**142.08**	**88.48**	**91.07**	**138.71**
Nonane	4.85	4.83	4.95	7.01	8.73	9.43	9.44	38.77
Octanal	5.53	6.25	5.53	6.00	8.28	5.92	8.55	6.43
Decanal	11.82	7.34	6.34	7.21	25.25	13.12	10.27	19.05
Decanol	0.64	0.75	0.56	.	12.52	2.72	1.58	4.89
Undecanal	6.52	3.97	3.99	4.98	15.57	7.72	6.01	10.46
E-2-Dodecenol	.	.	.	.	.	.	.	14.83
Dodecanol	1.66	0.85	0.57	.	13.46	4.27	13.09	5.01
Tridecanal	7.03	4.86	4.27	5.87	15.97	9.98	7.92	8.39
E-2-Tridecenal	16.65	13.31	13.94	14.01	42.30	35.32	34.21	30.89
Minor compounds	**11.45**	**19.67**	**20.29**	**15.90**	**21.70**	**15.41**	**10.07**	**17.83**
Phenylacetaldehyde	.	.	.	.	.	.	.	0.54
Linalool	0.49	1.06	1.12	0.42	0.84	0.65	0.52	3.09
Nonanal	10.04	16.89	17.63	13.60	17.13	13.56	8.01	10.82
E-2-Nonenal	.	0.62	0.57	0.65	0.83	0.68	0.78	0.68
E-9-Decenal	0.93	0.74	0.62	0.66	0.88	0.53	0.76	0.65
E-2-Decenal	.	.	.	.	0.85	.	.	0.79
E-2-Undecenal	.	.	.	.	.	.	.	.

Table 2.12: Change in volatile concentration (µg/g) in extracts with drying temperature and particle size at extraction duration of 40 min for large flakes and small flakes and 20 min for coarse powder.

Drying Temperature (˚C)	40	60	40	60	40	60
Particle size[a]	LF	LF	SF	SF	CP	CP
Extraction time[b] (min)	40	40	40	40	20	20
Major compounds	**6959**	**64883**	**51498**	**38077**	**7016**	**8478**
Dodecanal	2755	6493	9735	4351	1718	3085
E-2-Dodecenal	180	3875	3803	1897	26	509
Tetradecanal	2336	12093	20272	13955	5146	1395
E-2-Tetradecenal	1687	42423	17688	17875	126	3490
Intermediate compounds	**5607**	**9784**	**16571**	**6475**	**7452**	**5368**
Nonane	48	25	72	1375	3799	1931
Linalool	1635	1686	4977	786	729	724
Nonanal	.	.	.	.	.	.
Decanal	597	1301	1880	757	470	544
Decanol	162	456	652	165	67	159
Undecanal	352	658	1257	343	199	274
E-2-Dodecenol	56	1120	778	716	85	239
Dodecanol	220	789	134	294	61	101
Tridecanal	359	2057	1202	583	254	554
E-2-Tridecenal	2177	1691	5619	1455	1786	841
Minor compounds	**273**	**206**	**460**	**123**	**167**	**134**
Octanal	8	11	19	8	7	10
Phenylacetaldehyde	115	28	104	25	68	65
E-2-Nonenal	36	22	63	15	28	20
9-Decenal	17	17	66	9	28	11
2-Decenal	19	19	75	23	27	.
E-2-Undecenal	78	109	133	43	9	28

[a]LF: large flakes (0.85–1.18 mm); SF: small flakes (0.71-1.0 mm); CP: coarse powder (0.25-0.5 mm);
[b]Extraction duration corresponds to extraction completion for each size class (LF, SF and CP)

Table 2.13: Effect of extraction time on fatty acid concentration (mg/g dried cilantro) of cilantro dried at 40˚C.

Particle size[a]	Extraction time (min)	C16:0	C16:In9	C17:1	C18:0	C18:In9	C18:2n6	C18:3n3	**Total**
LF	0	2.56a	0.15a	1.43a	0.29ab	0.39a	6.04a	4.06a	**14.92a**
	10	1.59b	0.10a	0.80b	0.20b	0.34a	5.37ab	2.78b	**11.18b**
	20	1.80b	0.11a	1.26a	0.24ab	0.46a	5.29ab	3.40ab	**12.56b**
	40	1.53b	0.14a	0.90b	0.41a	0.35a	5.05b	3.09b	**11.47b**
SF	0	1.16ab	0.10b	1.66a	0.22a	0.41ab	3.59a	4.32a	**11.47ab**
	10	1.03b	0.13ab	0.85c	0.13a	0.16b	2.70b	2.28b	**7.29c**
	20	1.27ab	0.19ab	1.63a	0.21a	0.23b	3.49a	3.91a	**10.94b**
	40	1.47a	0.23a	1.96b	0.28a	0.51a	3.86a	4.62a	**12.93a**
CP	0	1.83a	0.14a	3.75a	0.20ab	0.32b	5.21a	8.89a	**20.34a**
	10	1.51a	0.10b	2.90bc	0.15c	0.33b	4.04b	7.09ab	**16.12ab**
	20	1.89a	0.12ab	3.53ab	0.23a	0.48A	4.85ab	8.43ab	**19.53ab**
	40	1.65a	0.10ab	2.70c	0.17bc	0.30b	4.20ab	6.58b	**15.70b**

[a]LF: large flakes (0.85–1.18 mm); SF: small flakes (0.71-1.0 mm); CP: coarse powder (0.25-0.5 mm); C16:0: Palmitic acid, C16:In9: Palmitoleic acid, C17:1: Cis-10-heptadecenoic acid, C18:0: Stearic acid, C18:In9: Oleic acid, C18:2n6: Linoleic acid, and C18:3n3: α-Linolenic acid; a, b, c Different letters denote significantly different (at 0.05 probability level) fatty acid concentration between three particle sizes derived from cilantro dried at 40˚C or 60˚C.

Table 2.14: Effect of extraction time on fatty acid concentration (mg/g dried cilantro) of cilantro dried at 60˚C.

Particle size[a]	Extraction time (min)	C16:0	C16:In9	C17:1	C18:0	C18:In9	C18:2n6	C18:3n3	**Total**
LF	0	2.16a	0.33a	1.31a	0.23a	0.52a	6.60a	4.02a	**15.18a**
	10	2.04a	0.17ab	0.95b	0.19a	0.36a	6.14ab	3.32a	**13.17ab**
	20	1.55a	0.09b	0.81b	0.15a	0.46a	5.35b	3.48a	**11.90b**
	40	1.72a	0.07b	1.29a	0.24a	0.37a	5.89ab	3.44a	**13.03ab**
SF	0	1.73ab	0.17a	1.18b	0.26a	0.54a	5.87a	4.60b	**14.37ab**
	10	1.56ab	0.17a	1.97a	0.20a	0.37b	4.84b	6.05a	**15.16a**
	20	1.50b	0.24a	1.80a	0.32a	0.54a	4.31c	4.96b	**13.67b**
	40	1.79a	0.40a	1.98a	0.20a	0.42ab	4.57bc	5.09b	**14.45ab**
CP	0	2.19a	0.13a	2.79a	0.20a	0.42a	7.12a	8.10a	**20.95a**
	10	1.56b	0.22a	2.75a	0.15b	0.31b	4.58b	7.76a	**17.34a**
	20	1.75ab	0.15a	3.20a	0.14bc	0.30b	4.55b	8.01a	**18.10a**
	40	1.57b	0.14a	2.79a	0.13c	0.29b	4.20b	7.50a	**16.61a**

[a]LF: large flakes (0.85–1.18 mm); SF: small flakes (0.71-1.0 mm); CP: coarse powder (0.25-0.5 mm); C16:0: Palmitic acid, C16:In9: Palmitoleic acid, C17:1: Cis-10-heptadecenoic acid, C18:0: Stearic acid, C18:In9: Oleic acid, C18:2n6: Linoleic acid, and C18:3n3: α-Linolenic acid; a, b, c Different letters denote significantly different (at 0.05 probability level) fatty acid concentration between three particle sizes derived from cilantro dried at 40˚C or 60˚C.

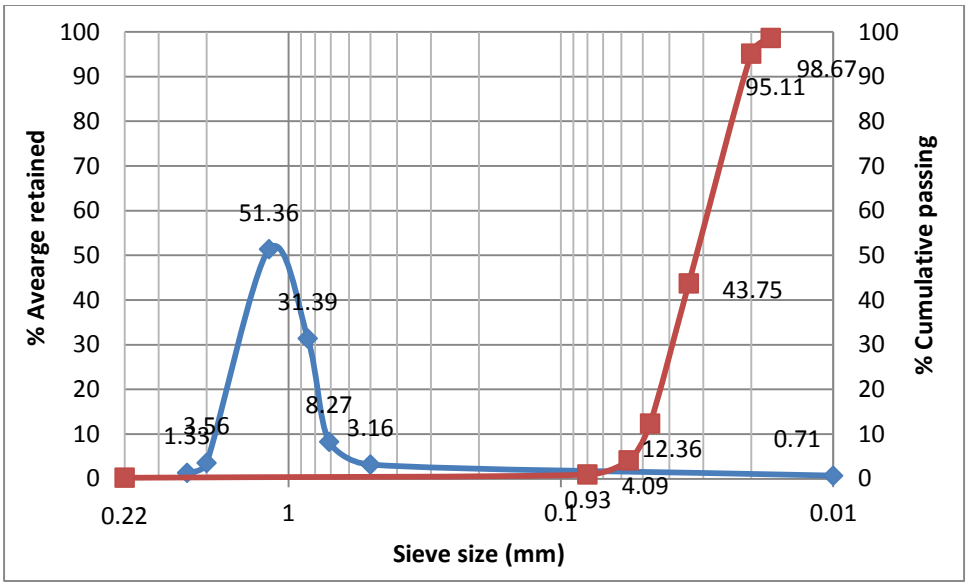

Figure 2.1. Logarithmic curve of percent average large flake particles retained and percent cumulative particles passing through a sieve against sieve size.

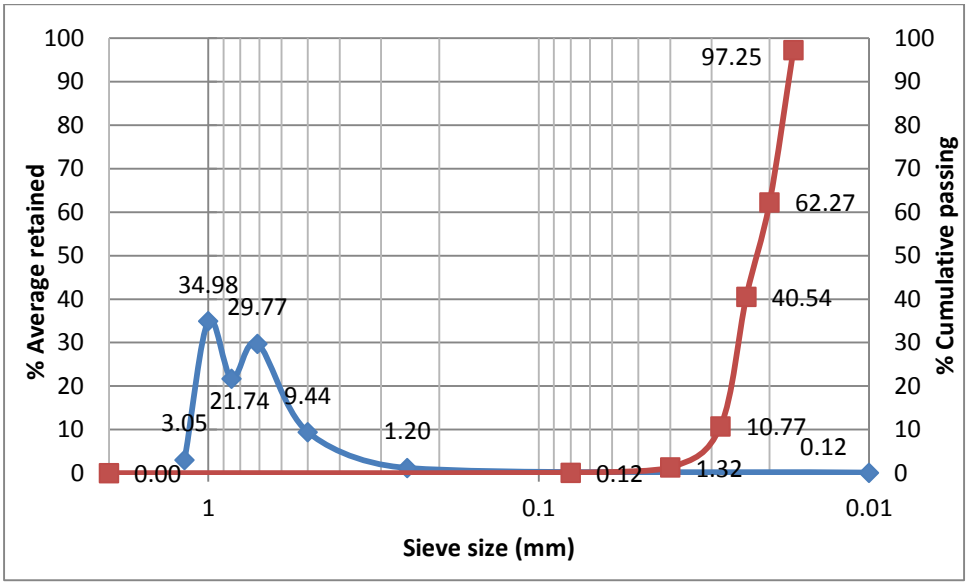

Figure 2.2. Logarithmic curve of percent average small flake particles retained and percent cumulative particles passing through a sieve against sieve size.

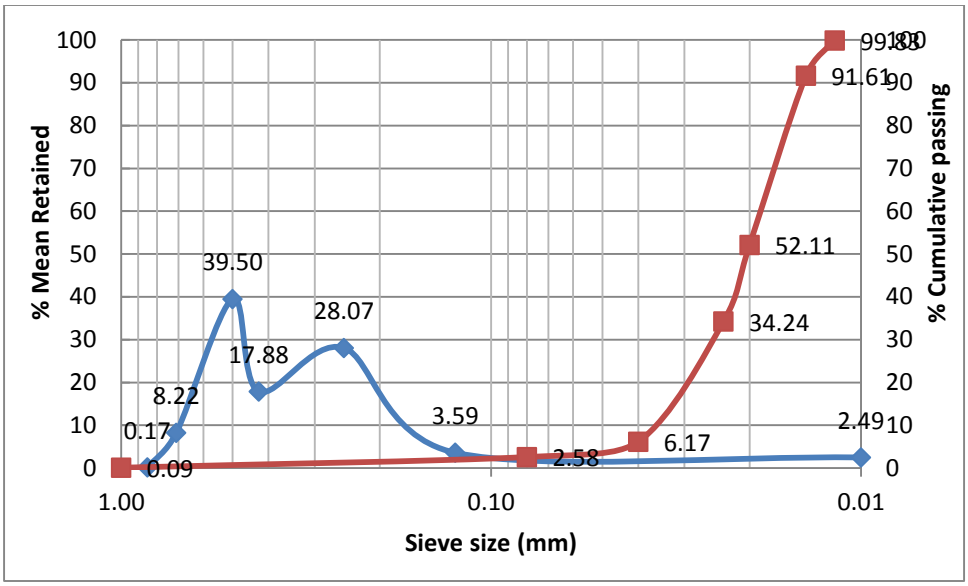

Figure 2.2. Logarithmic curve of percent average small flake particles retained and percent cumulative particles passing through a sieve against sieve size.

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CHAPTER III

EFFECT OF STORAGE CONDITIONS ON VOLATILE COMPOSITION OF PRE-PROCESSED CILANTO (*Coriandrum sativum* L.)

Abstract

Cilantro was dried at 40°C and 60°C, size reduced into large flakes, small flakes, and coarse powder and extracted with liquid propane for 0, 10, 20, and 40 min. The extracted and unextracted samples were packaged in aluminum foil bags (4.3 mil) or glass bottles and stored in freezer (-20°C), in refrigerator (4.9°C), at room temperature (18-30°C) and at elevated temperature (40°C) for a period of twelve months. At intervals of 30 days and over one year duration, samples were taken out of storage and evaluated for concentration of volatile compounds. There was a significant ($p < 0.05$) decrease in all volatile compounds, except nonane, with increase in storage time. The retention of volatile compounds in dried samples was dependent on particle size and storage temperature. The loss in volatile concentration was greater in coarse powder than in large flakes or small flakes. This loss was greatest in samples stored at elevated temperature (40°C), followed by room temperature, refrigerator, and freezer with maximum loss occurring in the first 2-3 months. Compounds that showed maximum loss during storage were tetradecanal, dodecanal, undecanal, E-2-tridecenal, and decanal. At the start and the end of the storage period, the volatile concentration of samples extracted with liquid propane was less than that of the corresponding unextracted samples, but the rate of loss of volatiles in extracted samples was less than in unextracted samples.

3.0. INTRODUCTION

Dehydration and storage are critical to the quality of cilantro such as aroma, flavor, and color. The objective of dehydration is to reduce water activity (a_w) of the product to a value which inhibits the growth of pathogenic and spoilage microorganisms, reduces enzyme activity, and limits chemical reactions. After dehydration the herbs and spices are generally size reduced by grinding, packaged, and stored for further marketing

or processing. Storage conditions such as temperature, humidity, oxygen lead to loss of aroma and flavor, deterioration of color, increase in moisture content, and microbial spoilage (Indiramma, 2005).

Selecting an appropriate packaging material prevents deterioration in storage by checking humidity, light, oxygen, and infestation. In addition, it provides easy handling and transportation of the product. Properties of various packaging materials are presented in Table 3.1 (Marsh and Bugusu, 2007). Selection of a packaging material depends on the type of a product, its intended use and its expected shelf life. For example, green or red color peppers are sensitive to color bleaching by oxidative changes. Therefore, aluminum foil laminate is a suitable packaging material to package green or red peppers due to its efficient blockage of light and oxygen transmission into the package. Also, its water barrier properties are ideal to prevent microbial growth (Kumar and Anandaswamy, 1974; Bera et al., 2001). As opposed to Aluminum foil laminates, LDPE (Low Density Polyethylene) and HDPE (High Density Polyethylene) are semi permeable polymer films that allow migration of oxygen, carbon dioxide, and water vapor to and from the package. Negi and Roy (2001) and Singh and Sagar (2010) found HDPE to be suitable packaging material to prolong shelf life of savoy beet, amaranth, curry leaves, and drumstick leaves. Polyethylene terephthalate (PET) and polystyrene (PS) jars are also used for packaging dried herbs. PS jars have been found to retain more volatiles in dried basil than glass bottles (Diaz-Maroto et al., 2009). Shelf life and percent loss in volatile oil of different spice powders packaged in various flexible packages and stored at room temperature (65% RH and 27°C) and accelerated storage (92% RH and 38°C) is presented in Table 3.2 and 3.3 (Indiramma, 2005).

There are various studies that report influence of storage temperature on the sensory quality of dried food material. Marwaha and Sandhu (2003) used six low dry matter containing Indian potato varieties for evaluation of flour yield, sensory characteristics, nutritional composition, and storability of flours. Flours prepared from different varieties were sealed in polyethylene bags and stored in refrigerator (3-4°C, RH 95%) and at ambient temperature (15-29°C, RH 80-94%). The flour was found to be organoleptically acceptable for up to 6 months of storage at ambient temperature compared to unacceptable quality of samples stored in refrigerator. Lambou (1956) dehydrated sweet potato (cubes, slices) and stored dried samples under nitrogen in cans at 10, 75, and 100°C. Stored samples were tested by a sensory panel at 9, 18, and 27 week intervals after reconstitution (adding water 3.5 times the weight of dried product at 60°C/2 hours). The hot samples were evaluated by 19 judges for odor, flavor, texture, and color. Stored cubes dehydrated at 15.5°C and 21-24°C produced palatable results. Dansby and Benjamin (2003) processed dried hydroponic sweet potato roots into flour and evaluated the nutritive composition and the color of flour during storage for 5 months at room and refrigerated temperatures. The sweet potato flour contained 3, 4.5, 1, 1, 90.6% moisture, ash, fat, protein, and carbohydrate, respectively with no significant changes during storage. The sweet potato flour can be stored at 4°C or 21°C for 5 months without deterioration in quality.

Various studies have reported loss in volatile compounds in herbs with storage time. The stability of carotenoids in paprika (Malchev et al., 1982) and volatiles in tarragon (Arabhosseini et al., 2007) was dependent on drying conditions and the degradation increased with an increase in drying temperature. Arabhosseini et al. (2007)

packaged dried tarragon (dried at 45, 60, and 90°C) in glass bottles and stored dried samples at 5°C for 15, 30, 60, and 120 days. They found that storage of samples dried at 45°C lead to a small change in essential oil, as compared to samples dried at 90°C. Bera et al. (2001) investigated the effect of grinding temperature, packaging material and storage temperature on the volatile oil of cumin powder. They found that with increase in temperature (20.4°C to 69°C) during grinding, the percent volatile oil decreased (3% to 2.5%). The samples were packaged in LDPE, cellophane, and aluminum foil polyethylene at 25°C/90% RH and 37°C/70% RH. Aluminum/polyethylene package and storage temperature of 37°C resulted in maximum volatile oil retention for 119 days.

Storage conditions are crucial for retention of volatiles in products. Storage of dried basil and marjoram at 23°C retained better sensory quality (odor and taste) than storage at 35°C. In addition, the taste of samples stored at 23°C was maintained for two years (Paakkonen et al., 1990). Another study found that with increase in storage time (dried basil packaged in aluminum polyethylene polyamide bags at 4°C) volatile concentration decreased (Baritaux et al., 2006). Díaz-Maroto et al. (2009) tested two packaging materials, polystyrene (PS) bottles and glass bottles (glass bottles commonly used for storing spices) to store dried (at 45°C) rosemary leaves at room temperature (21°C) for 21 months. They found that the samples packaged in PS bottles retained more volatiles than glass bottles. Negi and Roy (2001) and Singh (2010) suggested low temperature storage (7-8.5°C) and HDPE (High Density Polyethylene) to prolong shelf life (in terms of retention of b-carotene, ascorbic acid, chlorophyll content, rehydration ratio and sensory quality) of dried savory beet and amaranth, and curry leaves and drumstick leaves, respectively. Orav et al. (2004) ground (<0.2 mm) air-dried black,

green and white pepper and stored them in glass bottles for twelve months in a dark place at room temperature. They found that the amount of essential oil and terpenes decreased due to evaporation of volatile compounds, but the amount of oxygenated terpenoids increased due to oxidation process. The affect was more pronounced in air-dried green pepper than sublimation-dried green pepper.

Though various studies have evaluated the effect of storage on dehydrated vegetables and herbs, no literature was found for cilantro. Furthermore, dehydrated herbs such as cilantro, basil, curry leaves, mint, oregano, thyme, and sage are sold as shelf-stable commodities in the form of powder or flakes with a shelf life of up to two years. Many such commercially available dried herbs lose their characteristic aroma and flavor over time. This is especially true for dried cilantro. Therefore, it is important to study the effect of dehydration, size reduction, and storage conditions on the volatile composition of dried cilantro.

Therefore, the aim of the present work was to evaluate the effect of storage temperature and storage time on the volatile composition of dehydrated, size reduced, and liquid propane extracted cilantro.

3.1. MATERIALS AND METHODS

Figure 3.1 outlines the process flow from procurement of fresh cilantro to analyze the effect of storage on volatile composition of dried cilantro samples.

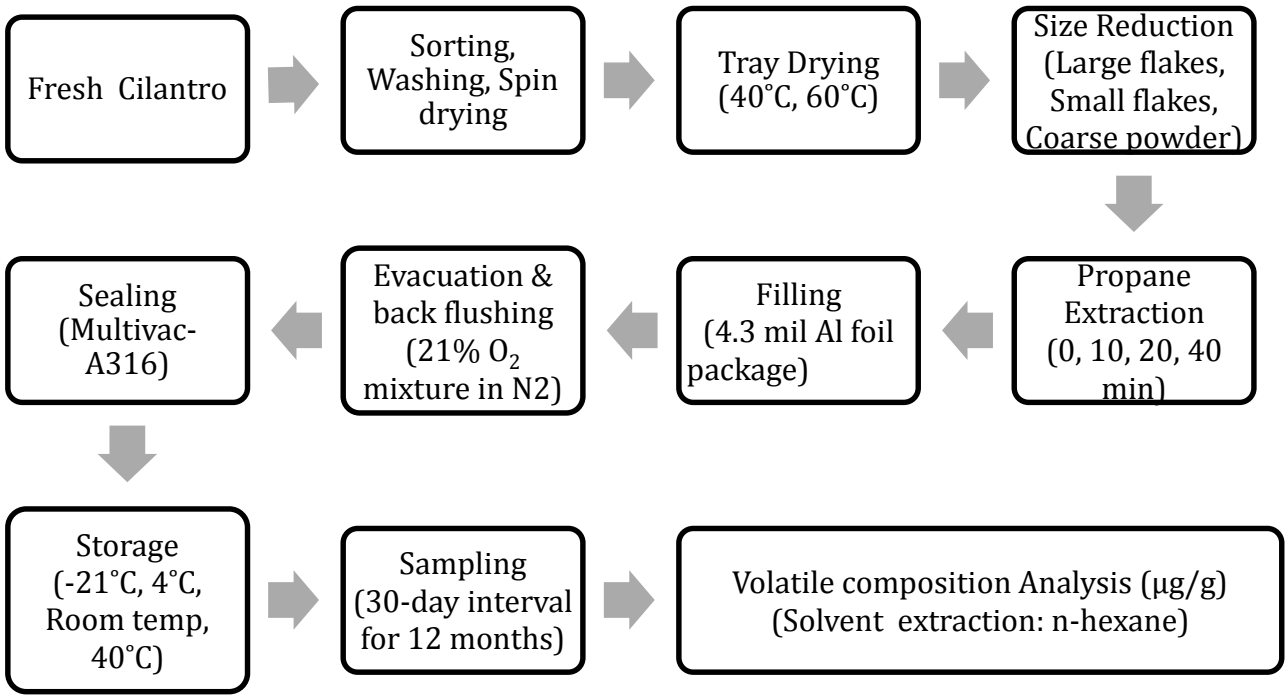

Figure 3.1: Schematic process flow depicting each step undertaken in the experiment to analyze the effect of storage on the volatile composition of cilantro.

Cilantro (*Coriandrum sativum* L.) harvested from field plots, at the Oklahoma Vegetable Research Station in Bixby, in November 2009 was brought back to laboratory facilities at Oklahoma State University, Stillwater, Oklahoma. It was stored overnight at 4˚C and then hand sorted to remove foreign material or degraded product, washed, and spin dried in a manual salad drier (SD92SC; Dynamic International, Champlain, NY) to remove excess water. Plant material was packaged in cheesecloth and dried at 40˚C and 60˚C in a tray drier (062; Proctor and Schwartz, Inc. Horsham, PA). Dehydration was considered complete when stems became brittle and were easy to break. Dried samples were packaged in freezer bags, flushed with nitrogen, and stored in the freezer (-20˚C approx.) for four months until further processing.

Dehydrated cilantro was ground in a food processor (DLC-2011RN Cousinart Inc., East Windsor, NJ) and size reduced into three particle size classes: large flakes, small flakes, and coarse powder. Particle size distribution in each size class was determined by sieve analysis using a RO-TAP test sieve shaker (R-30050, W.S.Tyler, OH). Largest fraction of particles present in each size class was in the range 0.85-1.18 mm, 0.71-1.0 mm, and 0.25-0.5 mm for large flakes, small flakes, and coarse powder, respectively.

The samples dried at two drying temperatures and reduced into three particle sizes were then subjected to propane extraction using a continuous flow propane extractor. The extractor (Hy-Look RV-2, Series Eden labs, Columbus, OH) consisted of a propane storage tank, an extraction vessel, two separation vessels (I & II), and a compressor. The temperature and pressure of each tank was monitored using temperature and pressure gauges. Instrument grade liquid propane (Airgas, Radnor, PA) was used as an extraction solvent.

Dried cilantro samples (600 g approx.) were placed in pre-weighed bags, placed in the extraction vessel (5L capacity) and extracted following the same procedure as mentioned in section 2.1.5.

3.1.1. Storage

Cilantro was dried at two temperatures, size reduced by grinding into large flakes (0.85-1.18 mm), small flakes (0.71-1.0 mm), and coarse powder (0.25-0.5 mm), and extracted with liquid propane for 0, 10, 20, and 40 min. The extracted and unextracted samples (control) were then packaged in aluminum foil bags or glass bottles and stored for up to twelve months. Four storage conditions were evaluated: freezer (-20°C approx.),

refrigerator (4.9°C ± 0.56), room temperature (23.3°C ± 2.91), and elevated temperature (37.83°C ± 4.12). Samples packaged in aluminum foil laminate packages were stored in a refrigerator, at room temperature, and at elevated temperature (in an environment chamber-Parameter Generation & Control Inc., Black Mountain, NC). Samples packaged in glass bottles with plastic screw caps were stored in a freezer. At 30 day intervals, samples were taken out and investigated for volatile composition.

Aluminum foil laminate (Impak Corporation, Los Angeles, CA), which acts as light and moisture barrier, was used as a packaging material. The 5.5 in x 7 in (O.D) bag was heat sealable with open zipper end. It constituted of four layers: polyethylene terephthalate (PET), polyethylene (PE), aluminum foil, and linear low density polyethylene (LLDPE). PET provides strength to the package and is printable, aluminum foil acts as a barrier to water vapor and gases and is non-corrosive, and LLDPE and PE facilitate heat sealing of the package. Properties of the aluminum foil laminate bag are listed in Table 3.4.

For each storage temperature, twelve sets (one for each month) of twenty four samples (2 drying temperatures x 3 particle sizes x 4 extraction durations = 24 samples) were packaged in at least duplicates. Filled bags were evacuated from ambient pressure to < 0.3 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 (Table 3.5) were placed into storage. Freezer samples were packaged in brown bottles with plastic screw caps. Average temperature and relative humidity values for the four storage conditions over a period of twelve months are presented in Table 3.6. On day 0 and at 30-day intervals

thereafter, samples were taken out and analyzed for moisture content and volatile composition. Sampling was carried out a total of 13 times (including day zero) over one year duration.

3.1.2. Sample analysis

After a 30-day interval, samples were taken out of the storage and tested for moisture content and volatile composition.

3.1.2.1. *Moisture content*: Empty tins were placed in hot air oven in order to evaporate any moisture present. After 15 minutes tins were removed from the oven and placed in a desiccator until they reached room temperature. Three replicates of 0.5 g were weighed in pre-weighed tins and placed in the oven for 24 hours. At the end of 24 hours, tins were removed from the oven and placed in the desiccator until they reached room temperature. The final weight of the tin was noted and moisture content (%wb) calculated.

3.1.2.2. *Volatile analysis:* Evaluation of volatile compounds in the control samples (not extracted), the raffinate (extracted) samples, and the extract (substances obtained by propane extraction) was performed in three steps: solvent extraction, concentration and gas chromatography. For extraction, a representative sample of control/raffinate (5-6 g from a total of 11-12 g) was ground in a UDY cyclone sample mill (UD Corporation, Boulder, CO), with 1 mm screen size, and three replicates (0.5 g) were accurately weighed into tared 2-dram vials. Extraction standard (β-pinene; 100 nmol) was added to each vial to account for extraction recovery. A micro stirring bar and 4 ml of hexane were added to each vial and stirred for 20 min at 25˚C (room temperature) followed by centrifugation at 3,000 gn. Supernatant was transferred to a new vial and re-centrifuged until an extract free of solid particles was obtained.

Density (g/ml) of the extract was measured by weighing 1ml in a pre-weighed 2-dram vial. The calculated density (0.657 g/ml to 0.666 g/ml) was used to gravimetrically predict the volume of the extract in the concentration step, in which the vial containing the extract was subjected to a gentle stream of nitrogen at 25˚C (room temperature) to concentrate the extract to a final volume of approximately 1 ml. During the concentration step, the weight of the vial was measured intermittently until the required weight was attained.

Extract obtained from propane extraction was diluted for volatile analysis by dissolving 50 mg in 1 ml of n-hexane and centrifuged to remove any insoluble residue.

3.1.2.2.1. Preparation of sample for Gas Chromatograph*:* 950 µl of the 1 ml concentrate/propane extract was taken in a GC vial and to it 50 µl of analytical standard (β-myrcene; 50 nmol) was added. One µl of this mixture and one µl of n-hexane were injected on to DB-5 fused silica capillary column (30 m x 0.25 mm x 0.25 µm film thickness; J and W Scientific Inc., Rancho Cardova, CA). Two different Gas Chromatographs were used to analyze samples from control/raffinate samples and extracts. For controls and raffinates, gas chromatograph (6890N, Agilent Technologies Inc., Agilent Technologies, Inc., 2850 Centerville Road, Wilmington, DE) used hydrogen as the carrier gas with a linear flow rate of 50 cm/sec. It was equipped with a FID detector, which was maintained at 290°C to analyze sample chemical components. A spilt injector was used at a temperature of 270°C, with split ratio of 10:1. The initial column temperature was at 75°C with a hold of 2 min. It was raised to 300°C at a rate of 6°C/min with a hold of 10 min.

For extracts, gas chromatograph (Varian Star 3400 Cx, Varian Inc., 2700 Mitchell Drive, Walnut Creek, CA 94598) used helium as a carrier gas with a linear flow rate of 20 cm/sec. The GC was equipped with a FID detector, which was maintained at 300°C. Initial injector temperature was 55°C, which was raised immediately after injection to 290°C at a rate of 100°C/min with a hold of 5 min at 290°C. The initial column temperature was at 55°C with a hold of 2 min. It was raised to 120°C at a rate of 2°C/min, and then to 160°C at a rate of 1°C/min and finally to 280°C at a rate of 20°C/min with a hold of 10 min.

3.1.2.2.2. Quantification: Peaks were identified by co-elution with authentic standards and quantified relative to the analytical internal standard, β-myrcene. Concentration (nmol/ml) of each compound in the injection vial was calculated for each GC as in equation 6.

$$\text{Concentration, nmol/ml} = \frac{\frac{\text{sample peak area}}{\text{sample } \beta\text{−myrcene peak area}}}{\frac{\text{standard peak area}}{\text{standard } \beta\text{−myrcene peak area}}} * \text{concentration of standard -6}$$

Chemical recoveries (65-81%) were adjusted according to recovery of the extraction internal standard (β-pinene). The concentration was then converted into µg/g dried cilantro.

3.1.3. Statistical Analysis

Analysis of Variance (ANOVA) with Proc GLM (Procedure General Linear Model) was performed in SAS (SAS Inc., Cary, NC, ver. 9.3). LSMEANS statement was used to compute least square means of the response variables and multi comparison tests for the effect stemp*stime were performed using PDIFF option. Response variable was concentration (µg/g) of volatile compounds in the cilantro samples.

3.2. RESULTS AND DISCUSSION

Dried cilantro was investigated for the effect of storage on twenty volatile compounds, the majority of them being C9-C14 aldehydes and alcohols. Commercially, dried cilantro is sold in the form of flakes or powder and as a shelf-stable product with a shelf life of 2-3 years. But, no study till date has reported the change in the volatile profile of the dried herb during prolonged storage. In this section, the evolution of volatile compounds in dried cilantro when stored at room temperature for a period of twelve months is presented. In addition, the effect of other storage temperatures on the retention of volatile compounds is discussed. Finally, the stability of volatile compounds in extracted and unextracted dried cilantro samples with storage is described.

As mentioned in Chapter II, major volatile compounds found in dried cilantro were E-2-tetradecenal, dodecanal, E-2-dodecenal, and tetradecanal. Drying temperature and particle size had a significant effect on the concentration of volatile compounds in dried samples i.e. aromatic compounds were best preserved in large flakes and small flakes compared to coarse powder, and when dried at higher temperature (60˚C) compared to lower temperature (40˚C). Extraction of dried samples with liquid propane, under ambient conditions, lead to a decrease in concentration of all compounds in varying amounts. Extracted and unextracted samples were then subjected to storage under different conditions to study the effect of storage temperature and time on the volatile concentration.

3.2.1. Moisture content

Moisture contents of large flakes, small flakes, and coarse powder, derived from cilantro dried at two temperatures, at the start and the end of the storage study are listed in Table

3.7. The samples were extracted with liquid propane for 0, 10, 20, and 40 minutes and stored in freezer, in refrigerator, at room temperature, and at elevated temperature for up to 12 months. A considerable change in moisture content with storage period was not observed except in a few samples. This would be expected due to low water vapor transmission rate (<0.005 g/100 in^2 in 24 hours) of aluminum foil laminate packages.

3.2.2. Storage at room temperature

Table 3.8 lists the concentration of volatile compounds in large flakes, small flakes, and coarse powder at the beginning (0 months) and at the end of the storage period (12 months at room temperature). Also, listed are the results of pairwise comparisons ($p < 0.05$) between lsmeans of concentration of each volatile compound at the beginning and the end of storage.

Irrespective of the particle size and the drying temperature, the concentration of all volatile compounds, except nonane, significantly ($p < 0.05$) decreased with increase in storage time. This is similar to the findings of Baritaux et al. (2006). The decrease in the volatiles after twelve months of storage varied from 58% to 99% with maximum loss occurring in the first two months of storage (Figure 3.2). After two months, the concentration of major compounds became relatively stable until ten months, after which the concentrations decreased further with increase in storage time. The rate of volatile loss in major compounds in large flakes, small flakes, and coarse powder in the first two months of storage is presented in Table 3.9. The rate of volatile loss was maximum in the first month of storage than in the second month. Further, the rate of loss was greater in the samples dried at higher temperature compared to the samples dried at lower temperature. This is in agreement with the findings of Arabhosseini et al. (2007) for

storage of dried (45°C and 90°C) tarragon leaves. Despite this, the concentration of samples at any point during the storage period was greater in samples dried at higher temperature compared to samples dried at lower temperature because the initial concentrations of the latter were lower (Figure 3.2). This suggests that in storage the initial concentration of volatile compounds is an important factor that governs the aroma quality of the product.

At the end of the storage period, majority of the compounds showed a loss of >90%. This loss was highest in tetradecanal (97-99%), undecanal (97-99%), E-2-tridecenal (95-99%), dodecanal (96-97%), and decanal (94-97%). Three compounds that showed loss in concentration < 90% were octanal (48-87%), dodecanol (69-84%), and nonanal (60-79%).

While in small flakes the loss was greater in the samples dried at 40°C (69-98%) compared to the samples dried at 60°C (58-97%), in coarse powder the loss was greater in the samples dried at 60°C (67-99%) compared to the samples dried at 40°C (60-98%). The loss in volatile compounds in all samples can be attributed to evaporation of volatile compounds or oxidative reactions, and a greater loss of volatiles in coarse powder could be due to small particle size and increased surface area.

The degree of volatile loss was dependent on particle size of the stored samples, the loss being greater in coarse powder (67-99%) than in large flakes (48-98%) and small flakes (58-98%). While, the concentration of major volatile compounds in large flakes decreased from 798.43-1359.02 µg/g to 34.73-77.41 µg/g; the concentration of nonane increased from 26.95-22.35 µg/g to 90.50-180.68 µg/g. Similar decrease in the

concentration of major volatile compounds was observed in small flakes (637-1356.58 µg/g to 33.54-82.01 µg/g) and coarse powder (259.48-875.66 µg/g to 12.53-42.85 µg/g).

Regardless of the drying temperature and particle size, initial concentration of a volatile compound seemed to govern its final concentration at the end of storage. It was observed that the concentration of major volatile compounds in the beginning and the end of storage in coarse powder was least as compared to large flakes and small flakes. Grinding of dried material results in smaller particle size and an increase in surface area, as a consequence, more sites are available for volatile loss by evaporation or oxidative reaction (Indiramma, 2005). Volatile loss can be prevented by packaging whole dried herb. But, owing to small bulk density of the whole dried cilantro, packaging, storage, and transportation will be tedious and will add to the cost. Another approach to preserve aroma of dried herbs is storage at lower temperature (Paakkonen et al., 1990; Negi and Roy, 2001; Singh and Sagar, 2010).

3.2.3. Storage at room vs freezer, refrigerator and elevated temperature

Dried cilantro samples were packaged in aluminum foil bags and stored in refrigerator, at room temperature, and at elevated temperature. Another set of samples were packaged in glass bottles with plastic screw caps and stored in the freezer. Volatile composition at the beginning (0 months) and at the end of the storage period (12 months) in large flakes (Table 3.10, 3.11), small flakes (Table 3.12, 3.13), and coarse powder (Table 3.14, 3.15) is presented. Regardless of the storage temperature, a considerable loss of all volatile compounds (except nonane) was observed in dried cilantro samples at the end of the storage period (12 months). The loss in concentration of all compounds was maximum in the first two months. The change in the total concentration of major volatile

compounds in large flakes, small flakes, and coarse powder (derived from cilantro dried at 40°C and 60°C) with storage time is shown in Figure 3.3-Figure 3.8.

The loss in the total 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 (≥ 99%). Among all volatile compounds, tetradecanal, undecanal, E-2-tridecenal, dodecanal, and decanal showed maximum decrease in volatile concentration in samples stored at all storage temperatures. However, the degree of loss of these compounds was lower in samples stored in the freezer and in the refrigerator than in samples stored at room temperature and at elevated temperature. The loss in tetradecanal, was 87-90% and 90-93% in large flakes stored in the freezer and in the refrigerator, respectively compared to 98% and 99% loss in samples stored at room temperature and at elevated temperature, respectively. The loss in dodecanal was 87-89% and 84-85% in samples stored in the freezer and the refrigerator, respectively compared to 97% and 99% loss in samples stored at room temperature and elevated temperature, respectively. Overall, the four storage conditions can be divided into two groups, the group that preserved aromatic compounds was storage in the freezer and refrigerator, and the group that led to least retention of aromatic compounds was storage at room temperature and at elevated temperature.

Losses in volatile compounds in an herb or a spice have been attributed to evaporation and oxidative reactions (Bera et al., 2001; Diaz-Marato et al., 2009), which are promoted by oxygen, pro-oxidant conditions, light, and elevated temperatures (Diaz-Marato et al. 2009). This explains lower concentration of all volatile compounds when

stored at room and at elevated temperature. In addition, poor retention of some compounds in samples stored in the freezer than in samples stored in the refrigerator may be attributed to the difference in packaging. Samples stored in the freezer were packaged in glass bottles with plastic screw caps and the samples stored in the refrigerator were packaged in aluminum foil bags, back flushed with oxygen in nitrogen and heat sealed. While plastic material can hermetically seal a plastic container, the seal on a glass bottle is not total (Diaz-Maroto et al., 2009). This lack of hermetic seal may have increased volatile loss by evaporation. This may explain variation in total major volatile concentration in samples stored in the freezer over time.

There were some exceptions where major compounds in small flakes and large flakes (derived from cilantro dried at 60°C) showed higher concentration in samples stored in the refrigerator than in the freezer. In addition, the concentration of two intermediate compounds, dodecanol and tridecanal was greater in all samples stored in the refrigerator than those stored in the freezer. Some samples also showed a greater retention of E-2-dodecenol (in small flakes derived from 40°C dried cilantro and coarse powder), E-2-tridecenal (in small flakes, and large flakes and coarse powder derived from 40°C dried cilantro), and nonanal (large flakes and small flakes) when stored in the refrigerator than when stored in the freezer.

Regardless of the storage temperature, the concentration of nonane was greater in the stored samples (34.13-180.68 µg/g) than in the control samples (4.85 -26.95 µg/g). At the end of storage, the concentration of nonane was greater in samples derived from cilantro dried at 60°C (45.75-180.68 µg/g) than in those derived from cilantro dried at 40°C (34.13-118.58 µg/g). In addition, the concentration of nonane in coarse powder

(34.13-62.96 μg/g) was lower than in large flakes (90.50-180.68 μg/g) or small flakes (71.64-175.46 μg/g).

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. It is possible that nonane is a breakdown product of oxidation of fatty acids, which produces a large number of compounds: alkanes, alkene, ketones, aldehydes, alcohols, acids, esters, etc. (Grosch, 1982; Frankel, 1984). Ahn et al. (2001) have reported an increase in the concentration of volatiles (alkanes, aldehydes, and alcohols) as products of lipid oxidation in irradiated normal, pale soft exudates and dark firm dry pork after refrigerator storage for 10 days. However, Khan and Koattukudy (1974) found that decarboxylation of fatty acid into an alkane take place to one or two carbon atoms less than the precursor fatty acid. Bognar et al. (1984) homogenized fresh pea leaves and prepared it as an enzyme source to convert fatty acid into alkane. They investigated if higher carbon fatty acids (C-31) can generate shorter alkanes by incubating pea leaf microsomes in the presence of ascorbic acid (acts as fatty acid breakdown catalyst). The enzyme from pea leaves can use C-18, C-22, C-24, and C-32 acids as substrates for alkane generation, producing C-31 as the major alkane. Fatty acid groups present in cilantro are in the range C16 (palmitic acid, palmitoleic acid) to C18 (linoleic acid, α-linolenic acid). Therefore, the origin of nonane is not clear.

3.2.3. Extracted versus Unextracted

Concentrations of volatile compounds in extracted and unextracted large flakes (Table 3.10, 3.11), small flakes (Table 3.12, 3.13), and coarse powder (Table 3.14, 3.15) at the beginning (0 months) and the end of storage period (12 months) are presented. To

compare the extracted and unextracted samples, one extraction duration 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 coarse powder samples were extracted for 20 min. Also, listed in the tables are the results of pairwise comparisons between averages of volatile concentrations in control and samples stored at different temperatures for both extracted and unextracted samples.

As observed for unextracted samples, in extracted samples the concentration of all volatile compounds, except nonane, decreased with increase in storage time. The change in volatile concentration of major volatile compounds is shown in Figure 3.9-Figure 3.14. As seen in the unextracted samples, maximum loss occurred during the first two months of storage. At the end of the storage period (12 months), the volatile concentration of samples extracted with propane was less than that of the corresponding unextracted samples. The final total concentration of major compounds in extracted samples stored in the freezer for twelve months was: 106.87 μg/g-204.02 μg/g in large flakes, 55.48 μg/g-136.69 μg/g in small flakes and 22.11 μg/g-59.43 μg/g in coarse powder. On the other hand, the final volatile concentration of unextracted samples stored in the freezer for 12 months was: 179.62 μg/g-432.18 μg/g in large flakes, 109.57 μg/g-181.76 μg/g in small flakes and 23.83-42.65 μg/g-μg/g in coarse powder.

However, the rate of volatile loss in extracted samples was less than unextracted samples (Table 3.9). This was true for all samples. Hence, the degree of volatile loss in extracted samples was smaller compared to the loss in unextracted samples. This suggests that the final concentration of a volatile compound in storage depends on its initial

concentration at the beginning of the storage period and that the evaporation of volatile compounds from a food matrix is a continuous process. Low initial concentration of volatile compounds in extracted samples compared to unextracted samples (798.43-1359.02 μg/g in unextracted large flakes to 456.14-907.92 μg/g in large flakes extracted for 40 minutes) could be one reason of lower rate of volatile loss in extracted samples. This is comparable to lower rate of volatile loss in coarse powder samples (3.2-16.7 μg/g) compared to large flake samples (11.5-13.8 μg/g) and small flake samples (9.1-26 μg/g) in unextracted freezer samples. Both extracted samples and smaller particle size samples had lower initial volatile composition before subjecting them to storage compared to unextracted and larger particle size samples. Hence, even though the degree of volatile loss is smaller in extracted samples, in prolonged storage the final concentration of volatile compounds will depend on the initial concentration and the storage temperature.

At the end of the storage period, the loss in the major volatile compounds was least in the extracted samples stored in the freezer (41-94%) followed by the samples stored in the refrigerator (38-94%), at room temperature (87-98%), and at an elevated temperature (94-99%). The compounds that showed maximum loss (>90%) in all the extracted samples stored in the freezer were dodecanal (91-94%), tetradecanal (86-91%), tridecanal (90-95%), and E-2-tridecenal (88-96%). Other compounds that showed a considerable loss when stored in the freezer were undecanal (in large flakes and small flakes derived from 40°C dried cilantro), E-2-dodecenol (in small flakes), and E-2-dodecenal (in coarse powder). The total loss of these compounds in the samples stored in the freezer was greater in the extracted samples than in the unextracted samples. This

total loss includes loss due to propane extraction of dried samples and subsequent storage.

However, the percent loss of volatile compounds in the extracted and the unextracted samples stored in the refrigerator was comparable. The compounds that showed maximum (>90%) loss in all the extracted samples stored in the refrigerator were dodecanal, decanal, undecanal, and E-2-tridecenal. Other compounds that showed considerable loss were tetradecanal (in large flakes and small flakes derived from 60°C dried cilantro), decanol (in large flakes, small flakes derived from 60°C cilantro), and tridecanal (small flakes).

At the end of the storage period, the loss in the concentration of all volatile compounds in the extracted samples stored at room temperature and elevated temperature was greater than 90%, except octanal, dodecanol, nonanal, and nonane. The concentration of nonane in all samples increased with the increase in storage time.

As observed in unextracted samples, regardless of the storage temperature, the concentration of nonane in extracted samples was greater in stored samples (15.96 μg/g-143.20 μg/g) than in the control samples (4.95 μg/g-23.79 μg/g). At the end of the storage, the concentration of nonane was greater in samples derived from cilantro dried at 60°C (34.13 μg/g-143.20 μg/g) than in those derived from cilantro dried at 40°C (15.96 μg/g-136.00 μg/g). In addition, the concentration of nonane in coarse powder (30.50 μg/g-45.54 μg/g) was lower than in large flakes (76.0 μg/g-143.20 μg/g) or small flakes (45.58 μg/g-121.67 μg/g).

3.3.CONCLUSION

Cilantro dried at two temperatures was reduced into three particle size classes and subjected to continuous flow liquid propane extraction. Stability of volatile compounds in extracted and unextracted cilantro samples under different storage conditions over a period of twelve months was evaluated. Irrespective of the type of the processing (drying temperature and particle size classification) and the storage conditions, concentration of all volatile compounds, except nonane, decreased with increase in storage time. The degree of volatile loss in dried cilantro samples was dependent on the initial concentration of the volatile compound and the storage temperature. Furthermore, initial concentration of a sample depends on the type of pre-processing such as drying temperature and size reduction. In contradiction to previous studies, drying cilantro at higher temperature resulted in better retention of volatile compounds compared to drying at lower temperature. Grinding contributes to the loss of volatiles (large surface area) by exposing the constituents to the environment. The loss being greater in smaller particle size (coarse powder) than larger particle size (large flakes and small flakes). Loss of volatiles in a plant matrix occurs either by evaporation or by oxidative reactions, hence storage at higher temperature (elevated temperature and room temperature) led to a higher rate of volatile loss than storage at lower temperatures (freezer and refrigerator). In all samples, maximum rate of volatile loss was observed in the first two months of storage and this was true at all storage conditions. Even though the initial and final concentration of extracted samples was less than unextracted samples, the degree of volatile loss in extracted samples was smaller compared to the loss in unextracted samples. This suggests that the final concentration of a volatile compound in storage

depends on its initial concentration at the beginning of the storage period and that the evaporation of volatile compounds from a food matrix is a continuous process.

3.4 TABLES AND FIGURES

Table 3.1: Advantages and disadvantages of packaging materials.

Material	Advantages	Disadvantages	Cost
Glass	•Impermeable to moisture and gases •Nonreactive(inert) •Withstands heat processing	•Brittle and breakable •Needs a separate dosure	•Low cost material but somewhat costly to transport
Aluminum	•Impermeable to moisture and gases •Resistant to corrosion •Withstands heat processing	•Cannot be welded •Limited structural strength	•Relatively expensive but value encourages recycling
Tinplate	•Impermeable •Strong and formable •Resistant to corrosion •Withstands heat processing	•Can react with foods; coating required	•Cheaper than aluminum
Tin-free steel	•Strong •Good resistance to corrosion •Withstands heat processing	•Difficult to weld, requires removal of coating •Less resistant to corrosion	•Cheaper than tinplate
Polyolefins	•Good moisture barrier •Strong •Resistant to chemicals	•Poor gas barrier	•Low cost
Polyesters	•Strong •Withstands hot filling •Good barrier properties		•Inexpensive but higher cost among plastics
Polyvinyl chloride	•Moldable •Resistant to chemicals		•Inexpensive
Polyvinylidene chloride	•High barrier to moisture and gases •Heat sealable •Withstands hot filling		•Inexpensive but higher cost among plastics
Polystyrene	•Available in rigid, film, and foam form	•Poor barrier properties	•Inexpensive
Polyamide	•Strong •Good barrier properties		•Inexpensive but higher cost among plastics
Ethylene vinyl alcohol	•High barrier to gases and oils/fats	•Low moisture barrier/ moisture sensitive	•Inexpensive when used as thin film
PLA	•Biodegradable hydrolysable		•Relatively expensive
Paper & paperboard	•Very good strength to weight characteristics	•Poor barrier to light •Recyded content makes it unsuitable for food contact material	•Low cost
Laminates/ co-extrusions	•Properties can be tailored for product needs		•Relatively expensive but cost effective for purpose

Table reproduced from Marsh and Bugusu (2007).

Table 3.2: Shelf life of ground spices in different flexible pouches stored at 92% relative humidity and 27°C (room storage).

Sl. No.	Packaging material	Pepper		Turmeric***		Cumin		Coriander	Chilli	Remarks on packaging material
		SL*	% Loss** of V.O.	SL*	% Loss** of V.O.	SL*	% Loss** of V.O.	SL*	SL*	
	Maximum moisture content (% by wt. of the product in an atmosphere at 65% RH & 27°C	10.0		11.0		9.0		11.0	-	
1	50 µm LDPE	60	80	30	50	60	75	80	90	1,2,3,4 & 5: good
2	85 µm LDPE	60	75	30	50	60	-	60	90	moisture barriers but
3	50 µm LDPE	90	75	60	-	90	-	90	120	poor volatile barriers;
4	50 µm PP	90	65	60-90	40	90	45	120	150	6: fairly moisture
5	85 µm PP	120	50	120	15	120	-	150	-	proof, good v.o barrier.
6	75 µm MXXT Cellophane	200	10	200	10	200	-	200	200	7: moisture proof,
7	Double Pouch of glassine gusset inside + 62 µm LDPE	120	50	120	15	120	-	150	-	fair barrier to v.o. 8: good barrier to both
8	Double Pouch of 75 µm MSAT cellophane inside + 62 µm LDPE	200	10	200	10	200	20	200	200	moisture and v.o. 9, 10: fairly moisture
9	Glassine / 37 µm PE laminate	120	-	120	15	120	-	200	200	proof, good barrier to
10	Saran coated cello/PE laminate	200	-	200	10	-	-	-	-	v.o. 11: good moisture
11	Metallised polyester 12 µm / 37 µm PE laminate***	1 yr	10-20	1 yr	20-30	1 yr	10	1 yr	1 yr	proof, good barrier to v.o. 12: very
12	Paper /0.009 mm Al foil / 37 µm PE	1 yr	5	1 yr	10	1 yr	-	1 yr	1 yr	good moisture proof & barrier to v.o.

* Shelf-life with respect to caking, lumping; ** % loss of volatile oil at the end of shelf-life period;
*** Delamination will occur in turmeric and chilli if bond strength is not satisfactory.

Table reproduced from Indiramma (2005)

Table 3.3: Shelf life of ground spices in different flexible pouches stored at 92% relative humidity and 38°C (accelerated storage).

Packaging material	Pepper		Turmeric***		Cumin		Coriander	Chilli
	SL*	% Loss** of V.O.	SL*	% Loss** of V.O.	SL*	% Loss** of V.O.	SL*	SL*
Initial moisture content (% by w.t.)	9.5		9.5		6.0		6.0	6.0
Critical moisture content (% wt.) w.r.t. caking & lumping	11-12		11-12		9-10		10-11	10-11
50 µm LDPE	30	80	25	35	70	75	80	-
75 µm LDPE	50	75	45	30	-	-	-	60
50 µm LDPE	60	75	-	-	-	-	-	70
50 µm PP	40	50	35	30	70	50	-	-
85 µm PP	60	60	50	20	-	-	-	-
75 µm MXXT Cellophane	25	10	35	5	-	-	-	-
Double Pouch of glassine gusset inside + 62 µm LDPE	35	50	45	20	-	-	80	-
Double Pouch of 75 µm MSAT cello-phane inside + 62 µm LDPE	40	10	45	15	80	10	80	-
Glassine / 37 µm PE laminate	-	-	20	5	-	-	-	-
Saran coated cello/PE laminate	-	-	40	5	-	-	75	50
Metallised polyester 12 µm / 37 µm LDPE laminate***	120	20	120	10	120-150	30	150-180	150-180
Paper /0.009 mm Al foil / 37 µm PE	expected 1 year	20% @ 180 days	expected 1 year	5% @ 180 days	expected 1 year	-	expected 1 year	expected 1 year

* Shelf-life with respect to caking, lumping; ** % loss of volatile oil at the end of shelf-life period;
*** Delamination will occur in turmeric and chilli if bond strength is not satisfactory.

Table reproduced from Indiramma (2005)

Table 3.4: Properties of aluminum foil laminate (as provided by the manufacturer) used to package dried cilantro samples for the storage study.

Layers	48Ga PET/PE/0.00035 mm foil/LLDPE
Total thickness (mil)	4.3
Water vapor transmission rate	< 0.005 g/100in.^{2} 24 hrs.
Oxygen Transmission Rate	0.001/cc/m^2 /24 hrs.
Tensile strength	22 lb/in
Breaking strength	58 lb
Mullen bursting strength	57 lb/in2
Puncture strength	15.2 lb
Foil thickness	0.00035 minimum

Table 3.5: Cilantro sample treatments subjected to storage (24 samples).

Drying temperature (˚C)	40			60		
Particle size	LF	SF	CP	LF	SF	CP
Extraction time (min)	0	0	0	0	0	0
	10	10	10	10	10	10
	20	20	20	20	20	20
	40	40	40	40	40	40

*LF: large flakes (0.85-1.18 mm), SF: small flakes (0.71-1.0 mm), CP: coarse powder (0.25-0.5 mm)

Table 3.6: Average temperature and relative humidity for storage conditions over a period of twelve months.

Storage Condition	Temperature (°C)	Relative Humidity* (%)
Freezer	-20	.
Refrigerator	4.90 ± 0.56	.
Room	23.30 ± 3.20	46.85 ± 10.86
Elevated temperature	37.83 ± 4.12	70.45 ± 18.87

*Relative humidty of freezer and refrigerator was not measured

Table 3.7: Moisture content (% wb) in dried cilantro samples at the beginning and the end of storage period.

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	1.98±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	4.95±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.

Table 3.8: Concentration of volatile compounds in large flakes, small flakes, and coarse powder at the beginning (0 months) and the end of storage period (12 months) at room temperature.

Psize	LF				SF				CP			
Dtemp	40		60		40		60		40		60	
Stemp	C	3	C	3	C	3	C	3	C	3	C	3
Stime	0	12	0	12	0	12	0	12	0	12	0	12
Major	**798.43**	**34.73**	**1359.02**	**77.41**	**637.29**	**33.54**	**1356.58**	**82.01**	**259.48**	**12.53**	**875.66**	**42.85**
Dodecanal	156.50	4.18	189.04	5.73	109.80	3.03	169.88	7.01	56.11	1.22	142.40	3.67
E-2-Dodecenal	59.76	5.40	145.46	14.82	74.13	6.09	182.81	16.25	27.67	1.28	90.05	6.18
Tetradecanal	360.42	6.31	361.37	8.57	185.49	3.50	235.25	8.23	67.09	1.95	258.31	6.03
E-2-Tetradecenal	221.75	18.84	663.16	48.29	267.87	20.92	768.64	50.51	108.61	8.08	384.89	26.97
Intermediate	**129.49**	**104.43**	**204.23**	**145.50**	**107.78**	**84.66**	**198.55**	**143.40**	**54.69**	**34.21**	**142.08**	**68.74**
Nonane	26.95	96.09	22.35	128.96	6.61	78.16	20.35	128.63	4.85	31.27	8.73	61.27
Octanal	11.07	2.33	7.18	3.71	6.10	1.58	8.80	3.15	5.53	0.72	8.28	1.55
Decanal	24.12	1.02	26.79	1.52	18.57	0.71	34.74	1.39	11.82	0.39	25.25	1.05
Decanol	9.10	0.63	19.79	1.29	1.46	0.38	17.88	1.20	0.64	.	12.52	0.52
Undecanal	16.70	0.48	20.72	0.63	12.63	0.34	21.81	0.64	6.52	0.24	15.57	0.45
E-2-Dodecenol	.	0.77	.	2.51	2.67	0.46	30.61	1.34	.	0.22	.	0.56
Dodecanol	4.97	1.09	17.60	3.23	2.04	0.64	9.96	3.06	1.66	0.26	13.46	1.43
Tridecanal	13.09	1.38	17.01	1.39	24.61	1.53	3.38	1.44	7.03	0.73	15.97	0.84
E-2-Tridecenal	23.50	0.65	72.78	2.27	33.07	0.88	51.01	2.55	16.65	0.37	42.30	1.09
Minor	**33.23**	**9.17**	**29.35**	**11.91**	**45.70**	**5.21**	**90.05**	**12.51**	**11.45**	**5.11**	**21.70**	**10.39**
Phenylacetaldehyde	1.76	.	0.92	.	3.29	.	2.09	.	.	.	.	.
Linalool	.	2.38	.	3.24	1.11	1.84	2.79	2.79	0.49	0.80	0.84	1.12
Nonanal	27.63	6.79	22.36	8.67	28.48	3.37	33.92	9.72	10.04	4.03	17.13	9.27
E-2-Nonenal	0.78	.	0.76	.	0.48	.	0.81	.	.	.	0.83	.
9-Decenal	1.14	.	0.59	.	0.68	.	1.13	.	0.93	.	0.88	.
2-Decenal	0.62	.	1.37	.	0.62	.	1.17	.	.	.	0.85	.
9-Decenol	.	.	.	.	2.68	.	1.42	.	.	.	.	.
2-Decenol	.	.	.	.	.	.	31.36	.	.	.	.	.
Diallylfumerate	.	.	.	.	7.22	.	12.00	.	.	.	.	.
E-2-Undecenal	1.30	.	3.36	.	1.14	.	3.36	.	.	0.29	1.18	.

Table 3.9: Rate of volatile loss in extracted and unextracted large flakes, small flakes, and coarse powder at 30-day storage interval in two months (stored at four storage conditions).

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]	-2.9	-1.8	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	-1.2	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 aluminum foil laminate packages. Rate of volatile loss was calculated as $(C_i-C_j)/30$, C = concentration of volatile compound, i = month, j = i+1

Table 3.10: Effect of twelve month storage on volatile concentration (µg/g dried cilantro) in large flakes, derived from cilantro dried at 40°C.

Extraction time (min)	0					40				
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)
Storage time (months)	0	12	12	12	12	0	12	12	12	12
Major	**798.43a**	**179.62b**	**140.87c**	**34.73d**	**4.27e**	**456.14a**	**106.87b**	**109.01b**	**23.62c**	**4.69d**
Dodecanal	156.50a	16.45c	23.19b	4.18d	0.62d	113.22a	10.72c	18.15b	2.74d	0.50d
E-2-Dodecenal	59.76a	20.05c	29.03b	5.40d	0.26e	33.84a	15.39c	20.99b	3.24d	0.29e
Tetradecanal	360.42a	36.70b	23.82b	6.31c	1.03c	207.39a	17.94b	16.57b	4.33c	1.16d
E-2-Tetradecenal	221.75a	106.42b	64.84c	18.84d	2.36e	105.70a	62.83b	53.29c	13.31d	2.73e
Intermediate	**129.49**	**109.99**	**136.63**	**104.43**	**99.58b**	**94.98a**	**151.79a**	**91.34a**	**107.43a**	**103.81a**
Nonane	26.95d	90.50b	118.58a	96.09bc	93.95bc	19.88a	136.00b	78.00c	100.89d	97.68d
Octanal	11.07a	4.93ab	3.36b	2.33b	2.55b	6.70a	4.17b	2.03c	2.24c	2.33c
Decanal	24.12a	4.29b	2.96c	1.02d	0.27d	14.55a	3.26b	1.68c	0.66d	0.12d
Decanol	9.10a	1.51b	0.72c	0.63cd	0.56d	6.65a	1.05b	0.48c	0.52c	0.45c
Undecanal	16.70a	1.17b	1.27b	0.48c	0.15c	12.80a	1.13b	1.06b	0.37c	0.18c
E-2-Dodecenol	.	0.95a	0.80a	0.77a	0.80a	.	1.03a	1.05a	0.85a	1.21a
Dodecanol	4.97a	1.95b	3.27ab	1.09b	0.87b	7.66a	2.18b	3.14c	0.93c	1.31c
Tridecanal	13.09a	1.81b	2.59b	1.38b	0.30b	12.18a	1.25b	1.84c	0.68d	0.32e
E-2-Tridecenal	23.50a	2.86b	3.08b	0.65c	0.11c	14.56a	1.71b	2.06b	0.30c	0.20c
Minor	**33.23**	**20.48b**	**20.33b**	**9.17c**	**5.42c**	**31.06a**	**14.15ab**	**17.04a**	**6.82b**	**4.00b**
Phenylacetaldehy	1.76	.	.	.	.	1.08	.	.	.	.
Linalool	.	6.64a	4.06b	2.38c	2.10c	.	5.27a	3.11a	2.14b	1.59b
Nonanal	27.63a	13.08bc	15.65b	6.79cd	3.20d	27.59a	7.34b	13.51c	4.68bd	2.33d
E-2-Nonenal	0.78	0.23	.	.	.	0.85	0.18	.	.	.
9-Decenal	1.14	.	.	.	.	0.77	1.08	.	.	.
2-Decenal	0.62	.	.	.	.	.	.	.	.	.
E-2-Undecenal	1.30a	0.54b	0.63b	.	0.12c	0.75a	0.28b	0.42ab	.	0.09b

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 aluminum foil laminate packages.

Table 3.11: Effect of twelve month storage on volatile concentration (µg/g dried cilantro) in large flakes, derived from cilantro dried at 60°C.

Extraction time (min)	0					40				
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)
Storage time (months)	0	12	12	12	12	0	12	12	12	12
Major	**1359.02a**	**432.18b**	**316.08c**	**77.41d**	**11.42e**	**907.92a**	**204.02b**	**192.49b**	**55.87c**	**6.60d**
Dodecanal	189.04a	24.79b	30.30b	5.73c	2.26c	133.94a	11.72c	21.41b	4.41d	1.18d
E-2-Dodecenal	145.46a	46.04c	60.58b	14.82d	2.30e	102.43a	23.18c	39.11b	10.03d	0.94e
Tetradecanal	361.37a	47.72b	34.46c	8.57d	1.32d	248.78qa	23.64b	22.07b	6.07c	1.31d
E-2-Tetradecenal	663.16a	313.63b	190.74c	48.29d	5.55e	422.78a	145.48b	109.90c	35.36d	3.16e
Intermediate	**204.23c**	**226.76a**	**157.80c**	**145.50c**	**166.30b**	**145.18a**	**168.45b**	**142.36c**	**129.06c**	**125.79c**
Nonane	22.35d	180.68a	123.01c	128.96c	153.62b	23.79a	143.20b	118.63c	118.07c	117.08c
Octanal	7.18a	6.68a	4.29b	3.71c	4.03bc	6.89a	4.50b	3.52c	3.19c	3.12c
Decanal	26.79a	5.81b	3.23c	1.52d	0.62e	18.16a	3.36b	1.89c	1.08d	0.34e
Decanol	19.79a	4.56b	1.60c	1.29c	1.73c	12.91a	2.38b	0.92c	1.01c	1.12c
Undecanal	20.72a	4.49b	1.24c	0.63d	0.26d	14.16a	2.44b	0.92c	0.48d	0.16e
E-2-Dodecenol	.	8.80a	7.29a	2.51b	2.90b	.	3.72b	4.41a	0.75d	1.59c
Dodecanol	17.60a	5.20bc	7.88b	3.23c	2.42c	10.15a	3.28ab	5.02ab	1.95b	1.99b
Tridecanal	17.01a	2.40b	3.33b	1.39b	0.40c	14.80a	1.50c	2.24b	0.97c	0.21d
E-2-Tridecenal	72.78a	8.15b	5.93b	2.27b	0.32b	44.34a	4.08b	4.82b	1.55c	0.18c
Minor	**29.35a**	**17.84ab**	**22.44a**	**11.91b**	**7.69b**	**14.58a**	**16.36a**	**17.08a**	**8.73b**	**4.50b**
Phenylacetaldeh	0.92	.	.	.	.	0.88	.	.	.	.
Linalool	.	6.84a	4.54b	3.24c	2.56c	.	4.05a	3.40b	2.39c	2.09c
Nonanal	22.36a	9.70b	16.57ab	8.67b	5.14b	9.44ab	11.52ab	12.84a	6.33bc	2.41c
E-2-Nonenal	0.76	0.13	.	.	.	0.74	0.10	.	.	.
9-Decenal	0.59	.	.	.	.	0.50	.	.	.	.
2-Decenal	1.37	0.20	.	.	.	0.76	0.11	.	.	.
E-2-Undecenal	3.36a	0.95b	1.33b	.	.	2.25a	0.48c	0.85b	.	.

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 aluminum foil laminate packages.

Table 3.12: Effect of twelve month storage on volatile concentration (µg/g dried cilantro) in unextracted and extracted small flakes, derived from cilantro dried at 40°C.

Extraction time (min)	0					40				
Storage temperature (°C)	Control	Freezer[a]	Refrigerator[b]	Room[b]	Elevated[b]	Control	Freezer[a]	Refrigerator[b]	Room[b]	Elevated[b] (40°C)
Storage time (months)	0	12	12	12	12	0	12	12	12	12
Major	**637.29a**	**109.57b**	**94.55b**	**33.54c**	**4.68d**	**381.67a**	**55.48b**	**57.64b**	**13.56b**	**4.29b**
Dodecanal	109.80a	9.59b	8.66b	3.03bc	0.55c	68.85a	5.18b	5.16b	1.34b	0.51b
E-2-Dodecenal	74.13a	10.29bc	15.46b	6.09cd	0.32d	55.58a	6.18bc	7.82b	1.93c	0.37c
Tetradecanal	185.49a	25.47b	15.71bc	3.50cd	1.50	87.82a	11.46b	9.56b	2.58b	1.24b
E-2-Tetradecenal	267.87a	64.22b	54.72b	20.92c	2.31d	169.42a	32.67bc	35.10b	7.71cd	2.17d
Intermediate	**107.78b**	**98.38a**	**83.80a**	**84.66a**	**87.22a**	**97.80ab**	**66.06ab**	**53.10b**	**70.90a**	**68.84ab**
Nonane	6.61b	86.23a	71.64a	78.16a	82.78a	10.65d	57.67b	45.58c	66.92a	64.54a
Octanal	6.10a	2.56b	1.70c	1.58c	1.87c	7.31a	2.16b	1.30c	1.40c	1.75c
Decanal	18.57a	3.56b	1.86b	0.71b	0.13b	22.02a	2.15b	1.07b	0.35b	0.13b
Decanol	1.46a	0.37ab	0.30b	0.38ab	0.51ab	0.58a	0.57a	0.31b	0.34b	0.39b
Undecanal	12.63a	1.07b	0.93b	0.34b	0.28b	13.26a	0.81b	0.66b	0.26b	0.22b
E-2-Dodecenol	2.67a	0.31b	2.54a	0.46b	0.45b	2.79a	0.18b	0.18b	0.17b	0.54b
Dodecanol	2.04a	0.62b	0.64b	0.64b	0.27b	1.57a	0.87ab	1.50a	0.43b	0.46b
Tridecanal	24.61a	1.53b	1.63b	1.53b	0.59c	12.66a	0.67b	1.00c	0.77b	0.48b
E-2-Tridecenal	33.07a	2.13b	2.55b	0.88b	0.35b	26.97a	1.00b	1.50b	0.25b	0.33b
Minor	**35.80a**	**15.25ab**	**13.00ab**	**5.21b**	**6.78b**	**24.40a**	**11.42ab**	**15.67ab**	**5.01b**	**6.86b**
Phenylacetaldeh	3.29	.	.	.	.	3.63	.	.	.	.
Linalool	1.11c	3.86a	2.40b	1.84bc	2.19b	0.79bc	2.66a	1.36b	1.32b	1.68b
Nonanal	28.48a	9.54b	10.60b	3.37b	4.59b	15.35a	7.74b	14.30a	3.69bc	3.59c
E-2-Nonenal	0.48	0.22	.	.	.	0.66	0.08	.	.	0.40
9-Decenal	0.68	1.29	.	.	.	1.67	0.69	.	.	1.20
2-Decenal	0.62	.	.	.	.	0.76	.	.	.	.
E-2-Undecenal	1.14	0.33	.	.	.	1.55	0.25	.	.	.

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 aluminum foil laminate packages.

Table 3.13: Effect of twelve month storage on volatile concentration (µg/g dried cilantro) in extracted and unextracted small flakes, derived from cilantro dried at 60°C.

Extraction time (min)	0					40				
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)
Storage time (months)	0	12	12	12	12	0	12	12	12	12
Major	**1356.58a**	**181.76b**	**279.02b**	**82.01bc**	**12.38c**	**1065.18a**	**136.69b**	**130.51b**	**49.78c**	**6.52d**
Dodecanal	169.88a	13.73b	22.55b	7.01b	2.24b	153.09a	9.27b	8.51b	3.55c	1.18d
E-2-Dodecenal	182.81a	17.94b	41.95b	16.25b	1.98b	145.40a	15.42b	23.62c	9.88d	0.51e
Tetradecanal	235.25a	32.78b	39.18b	8.23b	1.65b	192.66a	17.63b	12.63b	3.33bc	1.24c
E-2-Tetradecenal	768.64a	117.32bc	175.34b	50.51cd	6.50d	574.04a	94.37b	85.74c	33.03d	3.59e
Intermediate	**198.55a**	**131.83a**	**207.59a**	**143.80a**	**147.48a**	**193.54b**	**125.22b**	**100.03b**	**118.49b**	**206.57a**
Nonane	20.35bc	111.39ab	175.46a	128.6ab	129.62ab	23.66b	109.71b	87.25b	110.69b	194.89a
Octanal	8.80a	3.34ab	5.14ab	3.15b	4.26b	6.70a	2.50b	1.94c	1.93c	3.79b
Decanal	34.74a	4.79b	3.29b	1.39b	0.72b	30.97a	3.28b	1.43bc	0.93bc	0.41c
Decanol	17.88a	1.45b	1.27b	1.20b	3.05b	9.11a	1.28b	0.45c	0.61c	1.93b
Undecanal	21.81a	2.39b	1.54b	0.64b	0.70b	18.87a	1.62b	0.64b	0.31b	0.46b
E-2-Dodecenol	30.61a	1.28b	4.13b	1.34b	4.53b	8.71a	0.76b	0.93b	0.31c	2.80b
Dodecanol	9.96a	1.59c	6.12b	3.06c	3.45c	3.16a	1.51bc	1.90b	1.13c	1.36bc
Tridecanal	3.38ab	1.73bc	3.72a	1.44bc	0.65c	18.33a	1.00b	1.43b	1.01b	0.45b
E-2-Tridecenal	51.01a	3.89b	6.93b	2.55b	0.50b	74.03a	3.55b	4.06b	1.57b	0.46c
Minor	**45.27a**	**15.08b**	**25.66b**	**12.51b**	**9.20b**	**52.01a**	**10.73a**	**10.17a**	**6.38a**	**8.87a**
Phenylacetaldehy	2.09	.	.	.	.	3.57	.	.	.	.
Linalool	2.79a	4.15a	5.53a	2.79a	3.55a	1.43c	2.62a	1.98b	1.50c	2.60a
Nonanal	33.92a	10.19a	20.13a	9.72a	5.32a	41.98a	7.48a	8.19a	4.89a	5.77a
E-2-Nonenal	0.81	0.17	.	.	0.34	0.78	0.09	.	.	0.50
9-Decenal	1.13	.	.	.	.	0.96	.	.	.	.
2-Decenal	1.17	0.10	.	.	.	1.15	0.13	.	.	.
E-2-Undecenal	3.36	0.47	.	.	.	2.14	0.41	.	.	.

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 aluminum foil laminate packages.

Table 3.14: Effect of twelve month storage on volatile concentration (µg/g dried cilantro) of unextracted and extracted coarse powder, derived from cilantro dried at 40°C.

Extraction time (min)	0					20				
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)
Storage time (months)	0	12	12	12	12	0	12	12	12	12
Major	**259.48a**	**42.65b**	**56.99b**	**12.53c**	**1.79c**	**157.85a**	**22.11b**	**35.30b**	**6.78c**	**2.76d**
Dodecanal	56.11a	5.07b	4.37b	1.22b	0.27b	29.67a	3.62b	2.28b	0.76bc	0.30c
E-2-Dodecenal	27.67a	2.43c	5.55b	1.28c	0.16c	20.93a	1.98c	3.53b	0.57cd	0.24d
Tetradecanal	67.09a	14.23b	12.06b	1.95b	0.73b	23.05a	5.56b	5.57b	1.39c	1.42c
E-2-Tetradecenal	108.61a	20.93c	35.01b	8.08d	0.62d	84.20a	16.17c	23.92b	4.06d	0.80d
Intermediate	**54.69bc**	**40.65bc**	**52.52a**	**34.21c**	**42.51b**	**40.16bc**	**30.39aB**	**34.50ab**	**36.33a**	**18.67c**
Nonane	4.85c	34.13b	45.54a	31.27b	40.01a	4.95d	27.21	30.50ab	33.97a	15.96c
Octanal	5.53a	1.25b	0.94c	0.72d	0.99c	5.53a	0.74b	0.67b	0.60b	0.51b
Decanal	11.82a	2.24b	0.96c	0.39d	0.08d	6.34a	1.09b	0.48c	0.22c	0.11c
Decanol	0.64a	0.22b	0.23b	.	0.12b	0.56a	0.20c	.	.	0.27b
Undecanal	6.52a	0.87b	0.60b	0.24b	0.14b	3.99a	0.61b	0.40b	0.14b	0.21b
E-2-Dodecenol	.	0.11b	1.00a	0.22b	0.19b	.	0.09a	0.26a	0.20a	0.33a
Dodecanol	1.66a	0.17b	0.43b	0.26b	0.17b	0.57a	0.15b	0.32ab	0.15b	0.19ab
Tridecanal	7.03a	0.87b	1.17b	0.73b	0.26b	4.27a	0.56b	0.60b	0.78b	0.31b
E-2-Tridecenal	16.65a	0.79c	1.66b	0.37c	0.56c	13.94a	0.52bc	1.27b	0.28c	0.77bc
Minor	**11.45a**	**13.88a**	**13.27a**	**5.11a**	**3.28a**	**20.29a**	**8.17b**	**5.90b**	**3.09b**	**4.36b**
Phenylacetaldehy	.	.	.	.	.	.	.	.	.	.
Linalool	0.49c	2.50a	1.08b	0.80ab	0.82ab	1.12a	1.04a	0.43a	0.45a	0.74a
Nonanal	10.04ab	13.38a	12.19a	4.03b	2.46b	17.63a	6.40b	5.46b	2.64b	2.90b
E-2-Nonenal	.	.	.	.	.	0.57	0.10	.	.	.
9-Decenal	0.93	.	.	.	.	0.62a	0.63a	.	.	0.73a
2-Decenal	.	.	.	.	.	.	.	.	.	.
E-2-Undecenal	.	.	.	0.29	.	0.36	.	.	.	.

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 aluminum foil laminate packages.

Table 3.15: Effect of twelve month storage on volatile concentration (µg/g dried cilantro) of unextracted and extracted coarse powder, derived from cilantro dried at 60°C.

Extraction time (min)	0					20				
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)
Storage time (months)	0	12	12	12	12	0	12	12	12	12
Major	**875.66a**	**127.47b**	**118.36bc**	**42.85c**	**3.22c**	**415.93a**	**56.99b**	**12.53c**	**1.79d**	**1.81d**
Dodecanal	142.40a	13.43b	11.00c	3.67d	0.62e	63.36a	4.37b	1.22b	0.27b	0.29b
E-2-Dodecenal	90.05a	9.47b	14.79b	6.18b	0.13b	48.78a	5.55b	1.28c	0.16c	0.21c
Tetradecanal	258.31a	36.23b	26.45b	6.03b	0.82b	77.95a	12.06b	1.95c	0.73c	0.58c
E-2-Tetradecenal	384.89a	68.34b	66.13b	26.97c	1.65c	225.84a	35.01b	8.08c	0.62d	0.73d
Intermediate	**142.08a**	**66.65bc**	**76.39b**	**68.74bc**	**60.65c**	**91.07a**	**52.52a**	**34.21c**	**42.51b**	**45.28b**
Nonane	8.73c	45.75b	62.96a	61.27a	56.88a	9.44c	45.54a	31.27b	40.01a	42.10a
Octanal	8.28a	2.13b	1.63b	1.55b	1.32b	8.55a	0.94b	0.72b	0.99b	0.76b
Decanal	25.25a	4.90b	2.01c	1.05c	0.20c	10.27a	0.96b	0.39b	0.08b	0.12b
Decanol	12.52a	2.23b	0.58c	0.52c	1.13bc	1.58a	0.23b	.	0.12b	0.49b
Undecanal	15.57a	2.68b	0.91c	0.45c	0.23c	6.01a	0.60b	0.24b	0.14b	0.22b
E-2-Dodecenol	.	3.77a	1.41b	0.56b	0.23b	.	1.00a	0.22b	0.19b	0.73a
Dodecanol	13.46a	2.01b	2.15b	1.43b	0.03c	13.09a	0.43b	0.26b	0.17b	0.17b
Tridecanal	15.97a	1.52b	2.17b	0.84c	0.27c	7.92a	1.17b	0.73b	0.26c	0.16c
E-2-Tridecenal	42.30	1.66b	2.56b	1.09c	0.36c	34.21a	1.66b	0.37c	0.56c	0.52c
Minor	**21.70a**	**17.51b**	**14.39b**	**10.39b**	**3.37c**	**10.07a**	**13.27a**	**4.83b**	**3.28b**	**3.96b**
Phenylacetaldehy	.	.	.	.	.	.	.	.	.	.
Linalool	0.84c	3.86a	1.94b	1.12c	1.19c	0.52b	1.08a	0.80a	0.82a	0.60b
Nonanal	17.13a	13.32a	12.23ab	9.27b	1.70c	8.01a	12.19a	4.03b	2.46b	1.80b
E-2-Nonenal	0.83	.	.	.	.	0.78	.	.	.	0.20
9-Decenal	0.88	.	.	.	0.48	0.76	.	.	.	0.94
2-Decenal	0.85	.	.	.	.	.	.	.	.	0.22
E-2-Undecenal	1.18	0.33	0.22	.	.	.	.	.	.	0.21

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 aluminum foil laminate packages.

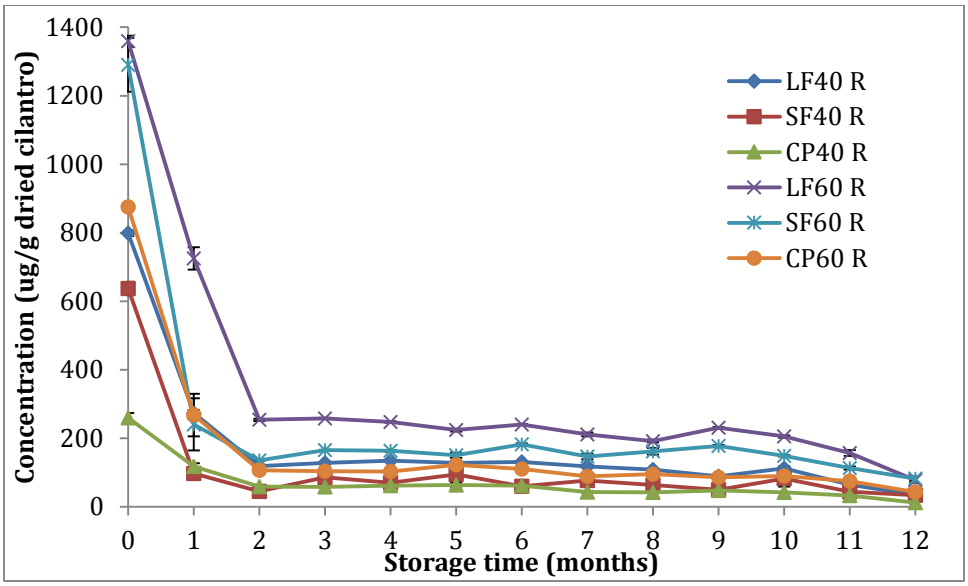

Figure 3.2: Change in concentration of major volatile compounds in unextracted large flakes (LF), small flakes (SF), and coarse powder (CP) (derived from cilantro dried at 40˚C or 60˚C) when stored at room temperature (R).

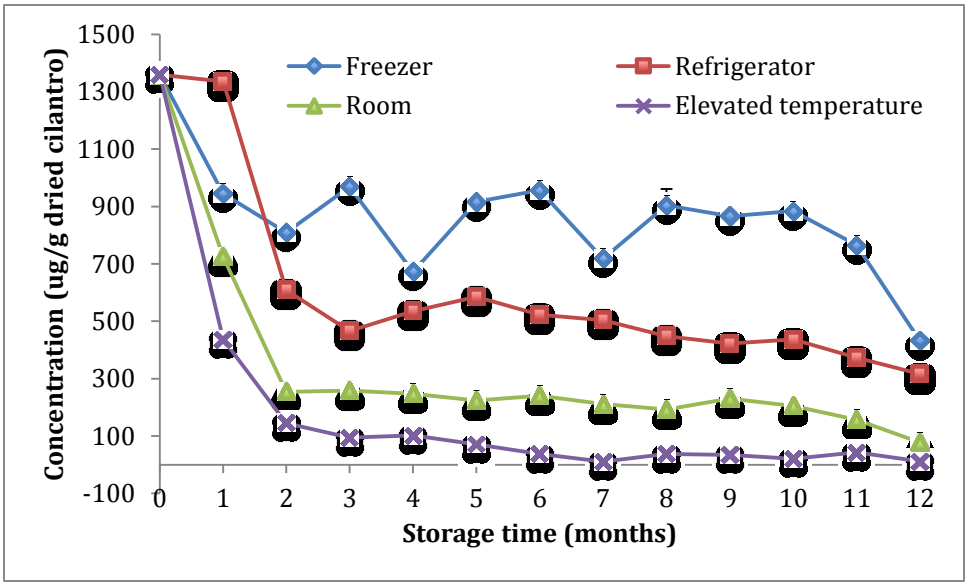

Figure 3.3: Effect of storage temperature on total concentration of major compounds (µg/g dried cilantro) in unextracted large flakes, derived from cilantro dried at 40°C.

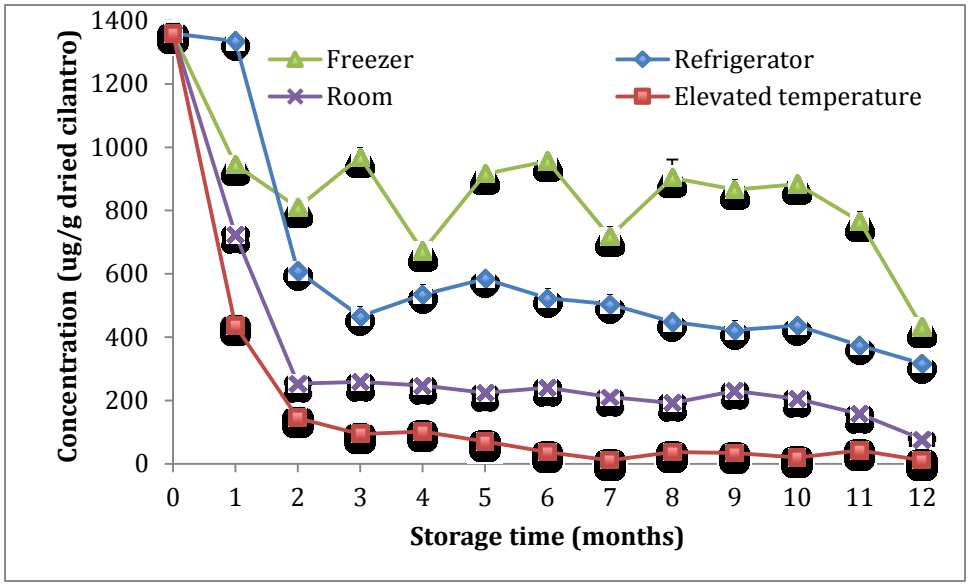

Figure 3.4: Effect of storage temperature on total concentration of major compounds (µg/g dried cilantro) in unextracted large flakes, derived from cilantro dried at 60°C.

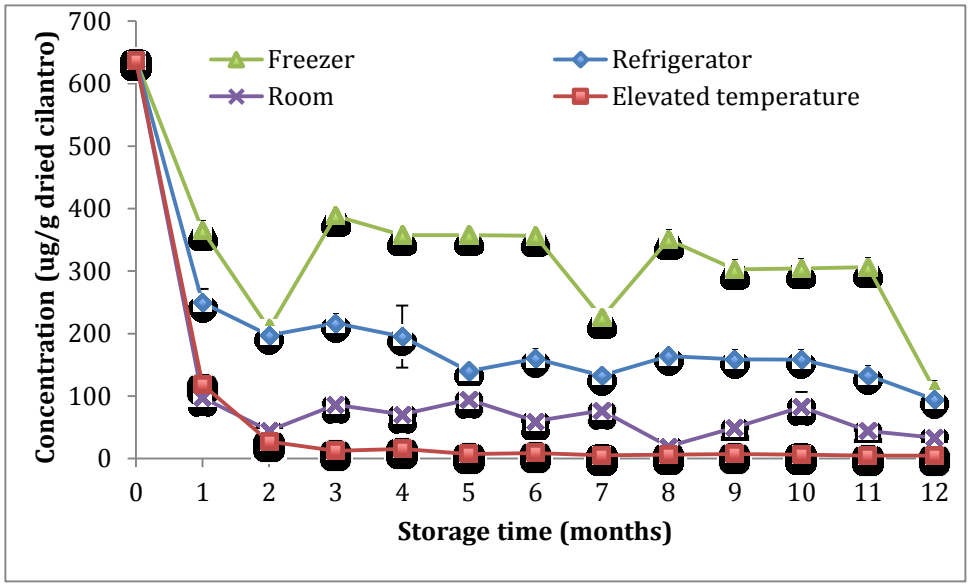

Figure 3.5: Effect of storage temperature on total concentration of major compounds (µg/g dried cilantro) in unextracted small flakes, derived from cilantro dried at 40°C.

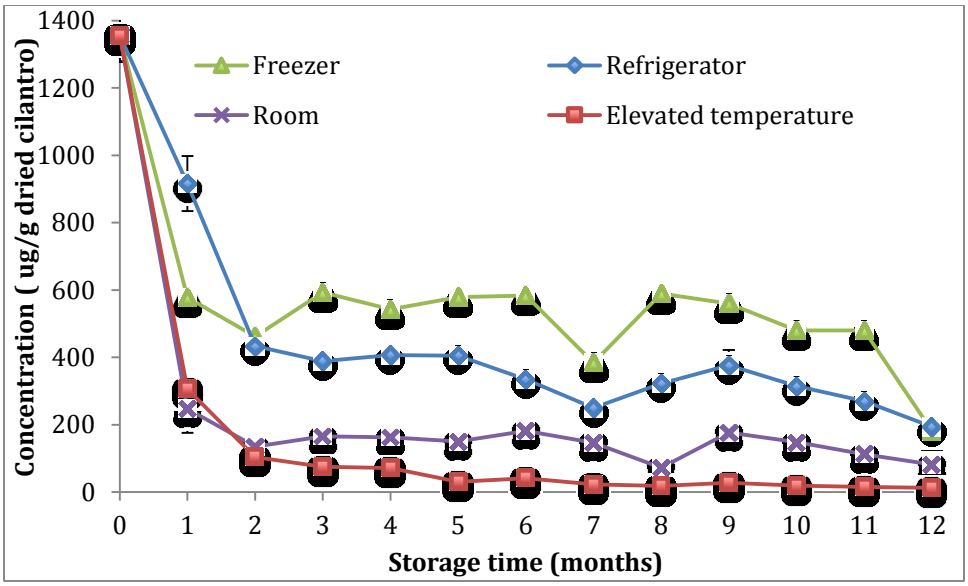

Figure 3.6: Effect of storage temperature on total concentration of major compounds (µg/g dried cilantro) in unextracted small flakes, derived from cilantro dried at 60°C

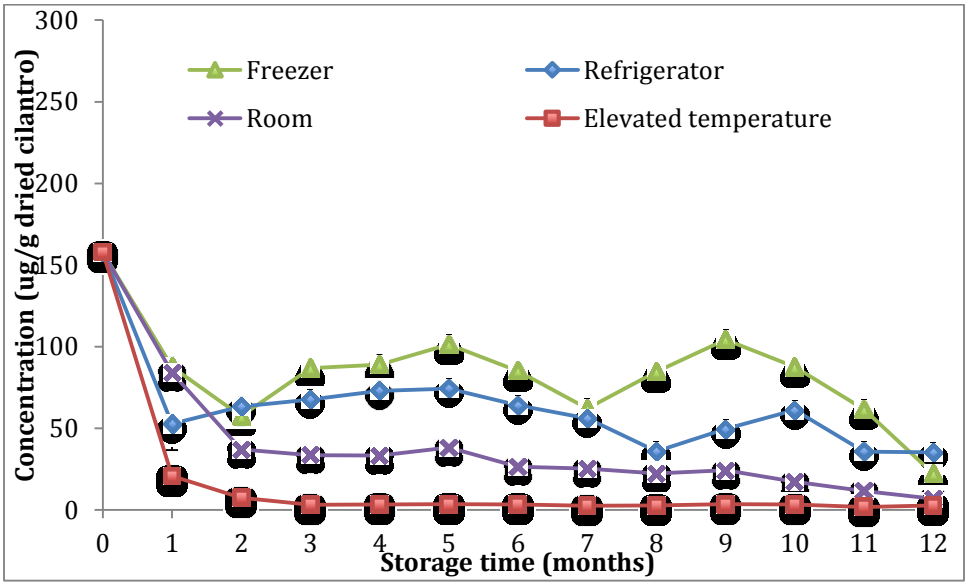

Figure 3.7: Effect of storage temperature on total concentration of major compounds (µg/g dried cilantro) in unextracted coarse powder, derived from cilantro dried at 40°C

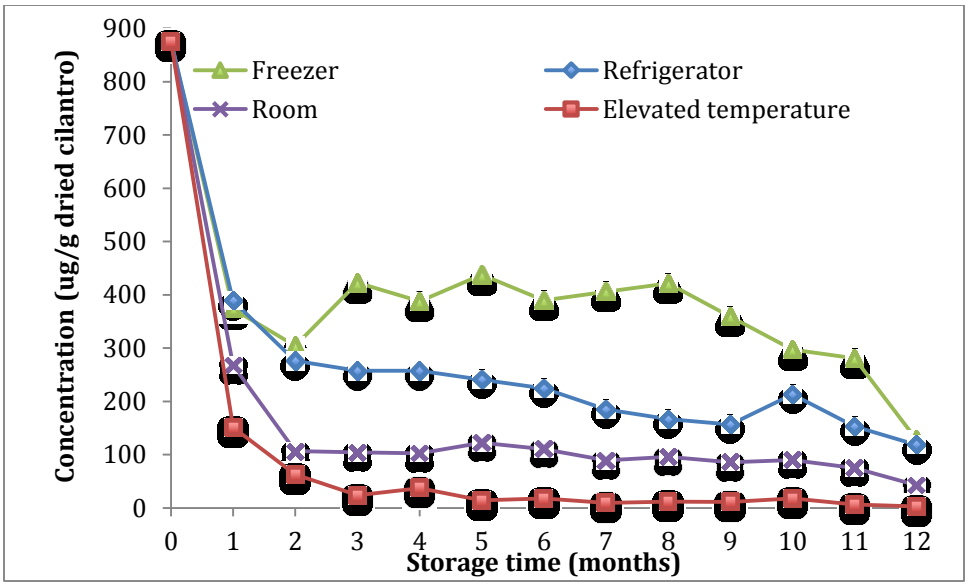

Figure 3.8: Effect of storage temperature on total concentration of major compounds (µg/g dried cilantro) in unextracted coarse powder, derived from cilantro dried at 60°C.

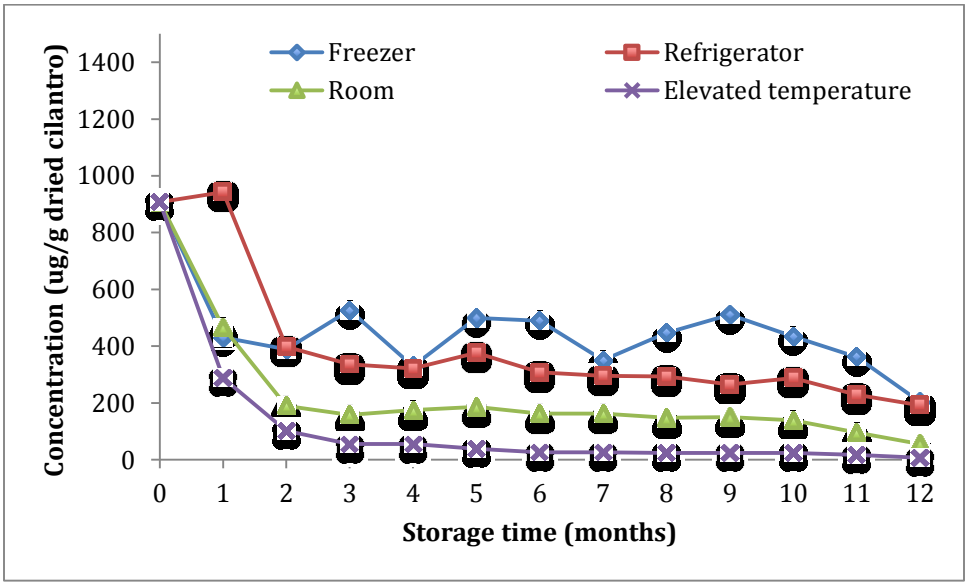

Figure 3.9: Effect of storage temperature on total concentration of major compounds (µg/g dried cilantro) in large flakes (derived from cilantro dried at 40°C) extracted with propane for 40 minutes.

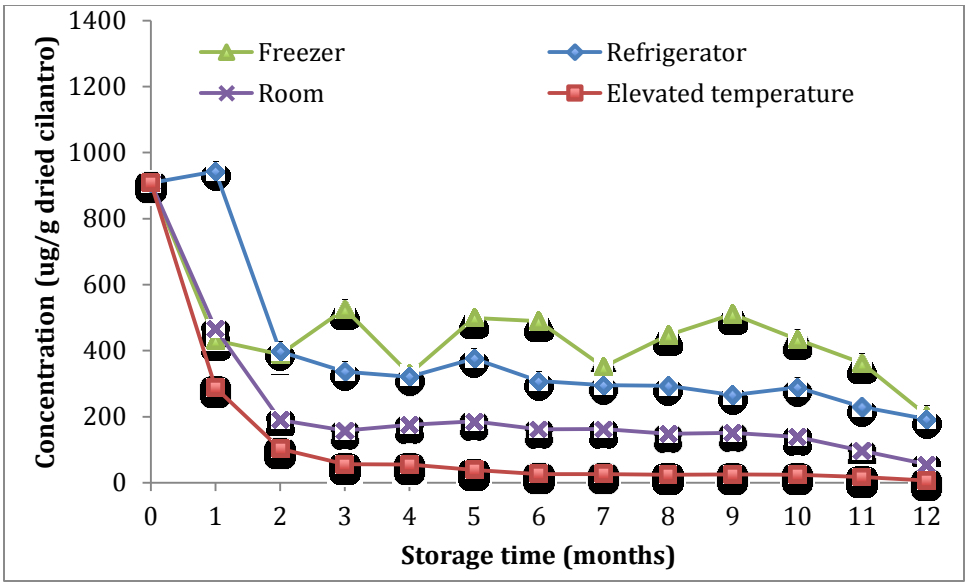

Figure 3.10: Effect of storage temperature on total concentration of major compounds (µg/g dried cilantro) in large flakes (derived from cilantro dried at 60°C) extracted with propane for 40 minutes.

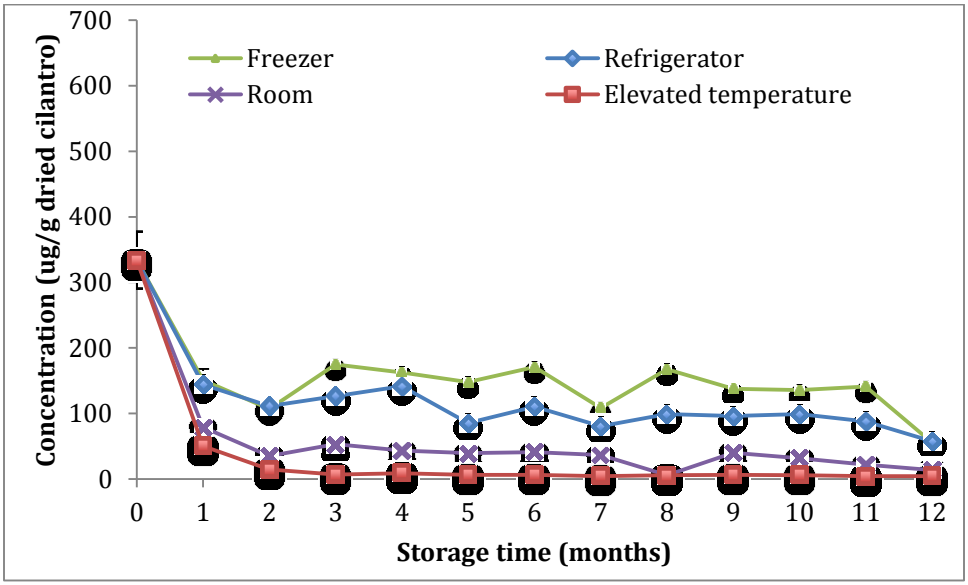

Figure 3.11: Effect of storage temperature on total concentration of major compounds (µg/g dried cilantro) in small flakes (derived from cilantro dried at 40°C) extracted with propane for 40 minutes.

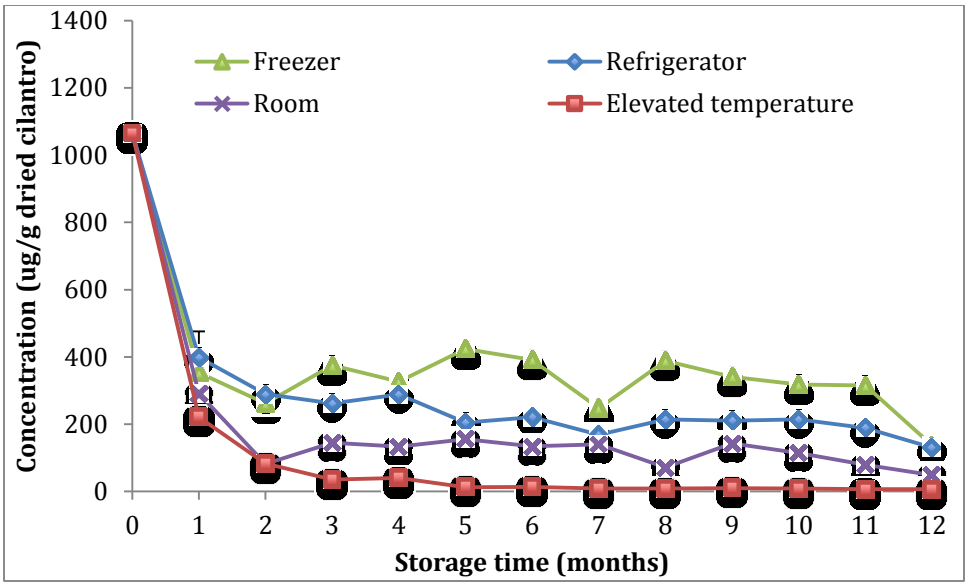

Figure 3.12: Effect of storage temperature on total concentration of major compounds (µg/g dried cilantro) in small flakes (derived from cilantro dried at 60°C) extracted with propane for 40 minutes.

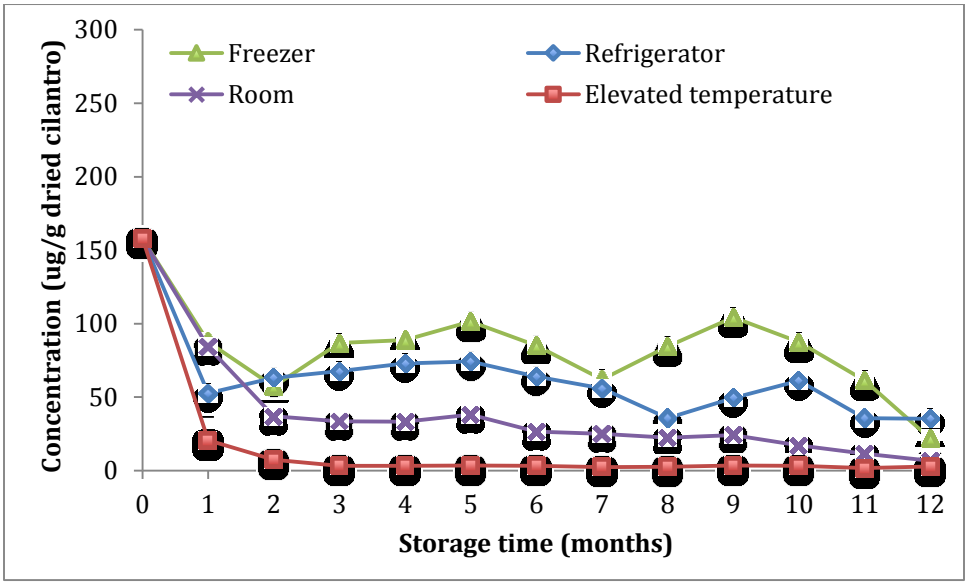

Figure 3.13: Effect of storage temperature on total concentration of major compounds (µg/g dried cilantro) in coarse powder (derived from cilantro dried at 40°C) extracted with propane for 20 minutes.

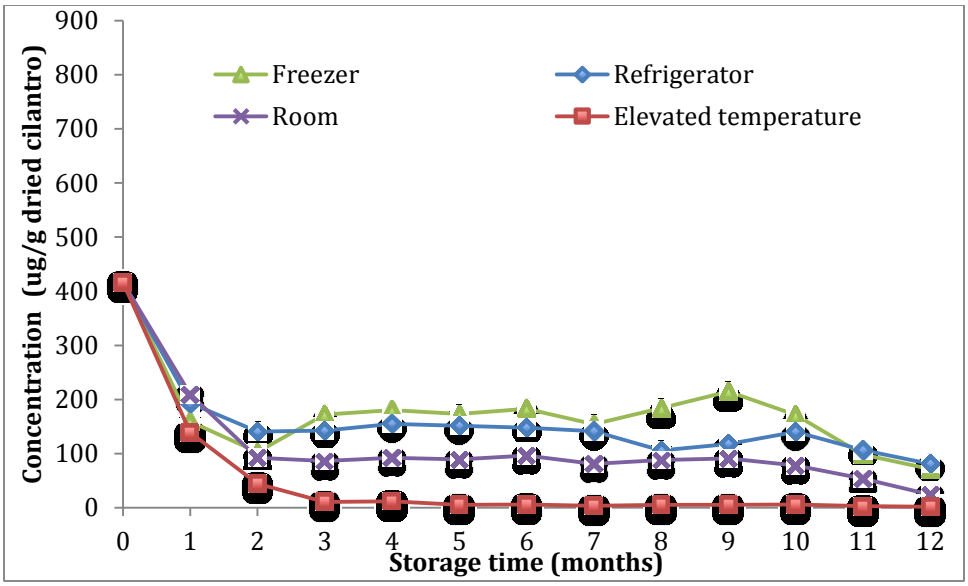

Figure 3.14: Effect of storage temperature on total concentration of major compounds (µg/g dried cilantro) in coarse powder (derived from cilantro dried at 60°C) extracted with propane for 20 minutes.

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CHAPTER IV

EFFECT OF STORAGE CONDITIONS ON COLOR AND FATTY ACID COMPOSITION OF PRE-PROCESSED CILANTRO (*Coriandrum sativum* L.)

Abstract

Cilantro dried at 40°C and 60°C and size reduced into large flakes, small flakes, and coarse powder was subjected to liquid propane extraction (ambient conditions). The extracted and unextracted samples (control samples) were analyzed for color and fatty acid composition to evaluate the effect of processing and storage conditions on the quality and shelf life of cilantro. Results indicate that color quality of the samples was dependent on the drying temperature and the storage temperature. A decrease in L*, -a*, and chroma values and an increase in browning index was observed in samples stored at elevated temperature (40°C). Room temperature storage did not result in browning of the plant tissue, but it led to a decrease in the green color. Solvent extraction with propane led to an increase in -a* values and decrease in browning index values. In storage, extracted samples retained higher -a* and chroma values than unextracted samples. Major fatty acids present in dried cilantro were linoleic acid, α-linolenic acid, and palmitic acid. During storage the concentration of major fatty acids in all particles sizes except small flalkes decreased in the first three to four months before becoming stable. In small flakes, an initial increase (3-4 months) followed by a decrease in the fatty acid concentration was observed. Fatty acids, especially linoleic acid and α-linolenic acid are more stable in larger size particles than in smaller particle size, and in extracted samples compared to unextracted samples. In unextracted samples (coarse powder and small flakes) stored at elevated temperature, an increase in α-linolenic acid (after 5 months) with an increase in storage time was observed.

4.0 INTRODUCTION

Herbs and spices such as cilantro are food adjuncts that enhance the sensory quality of foods and in addition provide nutritional and medicinal properties (Srinivasan, 2005). Post-harvest processing such as dehydration negatively affects the aesthetic quality of the herb. Cell structures collapse by evaporation of water during dehydration and result in the loss of texture, green color, and aroma and flavor by evaporation, oxidation or enzyme activity (Karathanos et al., 1996).

Color is an important parameter that contributes to the visual acceptance of a product by the consumer. Loss in color of dried herbs and spices is a serious problem for the spice industry (Schweiggert et al., 2007). After dehydration, color of cilantro changes from bright green to olive green, by conversion of chlorophyll to pheophytins (Rocha et al, 1993; Loaiza and Cantwell, 1997; Nisha et al, 2004; Schweiggert et al., 2005). As opposed to Lewis et al. (1995) the deterioration of green color (-a* value) in cilantro is greater at low temperature drying (40°C) than at high temperature drying (60°C) (Chapter II).

The rate of non-enzymatic browning of dehydrated vegetables is a function of storage temperature, moisture content, and storage environment (Legault et al., 1947). Moisture content in carrot, potato, onion, and sweet potato governed the effect of oxygen on the rate of browning. Malchev et al. (1982) reported that the stability of carotenoids in dried paprika during storage is dependent on drying conditions and the degradation rate increases with increase in drying temperature. Bolin and Steele (1987) found that packaging dried apples with oxygen-scavengers decreased product darkening during storage. Negi and Roy (2001) reported a continuous decrease in chlorophyll and an

increase in browning of dried (65°C±5°C) savoy beet and amaranth leaves during storage. However, low temperature storage (8.5°C compared to 15-36.5°C) and double layer polyethylene film packaging reduced the rate of color loss in savoy and amaranth leaves. Badifu (1991) found that pretreatment (blanching) prior to dehydration (95°C) of green leafy vegetables influenced the retention of ascorbic acid during storage (6 months). However, storage conditions (ambient temperature: 27-30°C, refrigerator: 7-10°C, freezer: -18°C) did not have a significant effect on ascorbic acid concentration. Negi and Roy (2000) packaged dried carrot slices in double layer high density polyethylene (HDPE) and stored the packages for nine months. They found a significant reduction of β-carotene in carrot slices (blanched and dehydrated) during storage. Arabhosseini et al. (2007) dried French tarragon leaves at 45, 60 and 90°C and stored the dried material in airtight glass bottles in a refrigerator (5°C) for a period of four months. During storage, L* values increased after 15 days followed by a decrease after 60 days.

Bestard et al. (2001) found a significant effect of storage temperature on the degradation of cell wall material (pectic substances: uronic acids, arabinose, galactose, and rhamnose) in dried broccoli. The degradation of uronic acid and neutral sugars was measured after rehydration of the dried samples subjected to storage and correlated with water sorption capacity. The degradation of cell wall material was maximum at higher storage temperature (40°C) and least at lower storage temperature (5°C). Degradation in cell wall was due to the degradation of pectic polysaccharides owing to enzymatic or heat induced chemical degradation (Levi et al., 1988). Decrease in glucose content was also observed, which may be due to breakdown on xyloglucans or cellulose. Sanjuan et al. (2004) stored dried (65°C) broccoli samples in glass bottles at 5, 15, 25, and 40°C over a

period of 427 days. After an interval of 30 days, samples were taken out of storage, rehydrated, and tested for chlorophyll content. A significant decrease in chlorophyll content with increase in storage time and storage temperature (40°C) was observed. The loss in chlorophyll content was attributed to the aging of vegetable tissue. Storage temperature influenced color of dehydrated apricots (Rosselló et al., 1994), raisins (Cañellas et al., 1993), and dried onions (Samaniego-Esguerra et al., 1991). They concluded that browning of the dried plant tissue during prolonged storage is dependent on the storage temperature. On the other hand, Paakkonen (1990) stored dried and chopped (air dried at 35-37°C and freezer dried) basil and marjoram samples in polyethylene-aluminum-polyethylene bags under nitrogen, in vacuum, in glass jars, and in paper bags. The packages were stored at 23°C and 35°C for a period of nine months. Dehydration resulted in browning of air-dried basil and marjoram samples, and development of intense green color of the freeze-dried samples. They concluded that drying process governed the final quality of the product during and after storage. Singh and Sagar (2010) packaged dried (58°C) curry leaves and drumstick leaves in LDPE and HDPE packages and stored them at 7°C and room temperature (15-35°C) for a period of three months. HDPE package and low storage temperature resulted in greater retention of β-carotene and chlorophyll content of the dried material.

The above literature suggests that final quality of a product subjected to storage is affected by type of the plant material, drying process (method and temperature), type of packaging material, and storage conditions (temperature and time). As discussed in Chapter II, one objective of the present research was to evaluate continuous flow solvent extraction with liquid propane as a technique to improve the color of dehydrated cilantro.

Results showed significant decrease in browning index of the dried cilantro samples after solvent extraction with propane. However, stability of color under different storage conditions remains to be tested.

Fatty acids are important constituents of the cell membrane lipids, which regulate fluidity and permeability to and from the external environment (Taarit et al., 2010). Lipids and proteins being the most abundant component of membranes play an important role in the resistance of plant cells to environmental stresses (Suss and Yordanov, 1986). Plant membranes are constituted of C-16 and C-18 fatty acids (Millar et al., 2000). Most abundant fatty acids in cilantro are linoleic acid, α-linolenic acid, and palmitic acid. α-Linolenic acid is a major constituent of leaves. Leaves from castor, lettuce, cabbage, chicory, brussels sprouts, and other higher plants have similar fatty acid composition (James, 1962). In a plant tissue, oleic acid is a precursor of linoleic acid and further linoleic acid is a precursor of linolenic acid (Yuan and Bloch, 1960). Linolenic acid is an integral part of chloroplast membrane lipids. Studies suggest that linolenic acid is involved in the photosynthetic reactions that lead to the production of oxygen or that the mechanism of linolenic acid synthesis from linoleate in chloroplasts require oxygen (Benson, 1964). These hypotheses originate from the evidence of production of oxygen and synthesis of linolenic acid occuring together in the photosynthetic system. Erickson (1993) investigated the contribution of phospholipids to the volatiles in the headspace during storage (room temperature) of pecans. They reported a decrease in phospholipid content and an increase in free fatty acid content. Loss in polyunsaturated fatty acids (PUFA) in phospholipid fraction occurred in the fifth month of storage. Their results also suggested that membrane lipids would be the first site of attack in the early stages of

oxidation. Viswanath and Ramaswamy (1934) found gradual increase in the fatty acid composition of coriander powder with prolonged storage. However, in soybean axes the concentration of linoleic and linolenic acid in phospholipids (polar fraction) decreased with an increase in storage time (Stewart and Bewley, 1980). On the other hand, Priestley and Leopold (1979) reported no change in the unsaturated fatty acids in soybean with accelerated aging. Similar results were reported by Kanamangala et al. (1999) for partial lipid extracted pecans stored at 25°C for 37 weeks.

Bera et al. (2001) evaluated the effect of conventional grinding versus cold grinding of cumin on volatile oil content, moisture content, total plate counts, and free fatty acid content (% oleic acid). Effect of different packaging materials and storage conditions were also investigated. Regardless of the storage conditions, free fatty acids in cumin powder packaged in low density polyethylene (LDPE) pouches were greater than those packaged in cellophane and aluminum-polyethylene laminate pouches. The increase in free fatty acid content was less at lower temperature storage (25°C /90% RH) than at higher temperature storage (37°C /90% RH). Neffati et al. (2008) reported that concentration of fatty acids in leaves of cilantro plant decreased with an increase in salt concentration in the soil. The ratio of unsaturated and saturated fatty acids was retained in basal leaves, under 25 and 50 mM concentration of salt. However, the ratio of unsaturated and saturated fatty acids reduced (from 6.46 to 5.52) when the concentration of unsaturated fatty acids decreased with increase in salinity in the soil. The increase in passive permeability in upper leaves was a result of an increase in saturated to unsaturated ratio at 25 mM of salt concentration. These results suggest that the change in the external environment of a cilantro plant induces a change in polyunsaturated fatty

acids (PUFA), and hence a change in the fluidity of the cell membranes. Various studies have evaluated the effect of dehydration/water deficit conditions on the plant membranes. In some studies a small increase in linolenic acid was reported with a corresponding decrease in linoleic acid. Stevanovic et al. (1992) studied the change in fatty acid composition in romanda flowering plants (R. *nathaliae* and R. *serbica*) by desiccation followed by rehydration. As found in cilantro, the major fatty acids in romanda plants were linoleic acid and linolenic acid with palmitic acid, palmitoleic acid, stearic acid, and oleic acid being minor fatty acids. They observed that in R. *nathaliae* desiccation lead to a small increase in linolenic acid, which was balanced by a decrease in linoleic acid. But, in severely stressed R. *serbica* leaves, an opposite trend was reported. The disruption in the association of membrane lipids and proteins results from strong water deficit (Caldwell and Whitman, 1987).

Hence, the purpose of this study was to evaluate the effect of storage conditions: (temperature and time), on the color and fatty acid composition of dried cilantro. While, color is an attribute of visual quality of the product, fatty acid composition maybe the measure of damages occurring in the plant tissue at the cellular level.

4.1. MATERIALS AND METHODS

Cilantro samples were dried, extracted with liquid propane and subjected to storage in a freezer (-20°C), in a refrigerator (4°C), at room temperature (18-30°C), and at elevated temperature (40°C) for a period of twelve months. Samples were taken out of storage every 30 days and analyzed for color and fatty acid composition using procedures described in section 2.1.2., 2.1.5., and 3.1.1, respectively. Once samples were taken out of storage they were analyzed for color and fatty acid composition according to section

2.1.6.1., and 2.1.6.3., respectively.

4.1.2. Statistical Analysis

Analysis of Variance (ANOVA) with Proc GLM (Procedure General Linear Model) was performed in SAS (SAS Inc., Cary, NC, ver. 9.3). LSMEANS statement was used to compute least square means of the response variables and multi comparison tests for the effect stemp*stime were performed using PDIFF option. The response variables were L*, a*, b*, chroma, hue angle, browning index and concentration (µg/g) of fatty acid in the cilantro samples.

4.2. RESULTS AND DISCUSSION

Cilantro dried at two temperatures (40°C and 60°C) and size reduced into three particle classes (large flakes, small flakes, and coarse powder) was subjected to liquid propane extraction (ambient conditions). The extracted and unextracted samples (control) were tested for the effect of processing and storage conditions on the quality and shelf life of cilantro. Cilantro samples were packaged in heat sealable 5.5 in x 7 in (O.D) aluminum foil bags (samples stored in the refrigerator, room temperature and elevated temperature) or glass bottles with plastic screw caps (samples stored in the freezer) and stored for a period of twelve months. After an interval of 30 days, samples were taken out and evaluated for the stability of color and fatty acid composition under different storage conditions over a period of twelve months.

4.2.1. Color

Once samples were taken out of storage, color was estimated by measuring CIE L*, a*, b* values (15 replicate measurements from each package) by using a Minolta chroma meter CR-300. Measured L*, a*, b* values of the test sample were then used to

calculate chroma, hue angle, and browning index (BI) of the sample. L* is a measure of lightness, a* is a measure of redness (+a*) or greenness (-a*), and b* is a measure of yellowness (+b*) or blueness (-b*). Chroma is the degree of saturation of the perceived color, hue angle is the color of a commodity and browning index (BI) is the purity of brown color.

Presented in this section are the results for the change in L*, a*, b*, chroma, hue angle and BI values when stored in the freezer, in the refrigerator, at room temperature and at elevated temperature for a period of twelve months.

4.2.1.1. Effect of room temperature on color values: Color values of dried cilantro samples (unextracted) stored at room temperature for a period of twelve months is presented in Table 4.1. Regardless of the drying temperature and the particle size, a significant ($p < 0.05$) difference between -a*, b* and chroma values of cilantro samples in the beginning and the end of the storage period was observed. -a*, b*, and chroma values decreased with an increase in storage time. Even though a decrease in L*, hue angle, and browning index was noticed, the change was not significant ($p > 0.05$).

At the end of the storage period, a significant decrease in -a* values (large flakes: 12.35-13.06 to 9.23-10.47, small flakes: 12.66-13.01 to 10.22-10.64, and coarse powder: 12.80-12.12 to 11.11-11.76), b* values (large flakes: 24.04-24.96 to 23.45-21.85, small flakes: 24.06-25.33 to 23.16-21.16, and coarse powder: 25.11-26.95 to 23.31-23.43), and chroma values (large flakes: 27.93-28.17 to 25.31-24.27, small flakes: 28.09-28.48 to 25.33-23.70, and coarse powder: 28.18-30.43 to 25.83-26.22) was observed. Chroma is a function of a* and b* values. Therefore, a decrease in both -a* values and b* values led to a decrease in chroma values.

Figure 4.1, 4.2, and 4.3 show the effect of storage time on the -a*, b*, and chroma values of large flakes, small flakes, and coarse powder when stored at room temperature. A gradual decrease in -a*, b*, and chroma values of all dried cilantro samples with an increase in storage time can be seen. During storage, highest values of –a*, b*, and chroma were observed for coarse powder (derived from cilantro dried at 60°C). Higher temperature drying led to a better retention of green color in all samples during storage. This was indicated by higher -a* values of all samples derived from cilantro dried at 60°C compared to the samples derived from cilantro dried at 40°C.

Arabhosseini et al. (2007) dried French tarragon leaves at 45, 60, and 90°C and stored the dried material in airtight glass bottles in a refrigerator (5°C) for a period of four months. During storage (120 days), hue angle values of samples dried at 45°C and 60°C was constant, but decreased for samples dried at 90°C. L* values increased after 15 days followed by a decrease after 60 days. They concluded the change in color values during storage was due to the drying temperature and the drying time. The deterioration in color of tarragon leaves dried at higher temperature (90°C) continued into storage compared to no change in color of samples dried at lower temperatures (45 and 60°C). The greater changes in color in initial stages of drying were also linked with higher moisture content in samples dried at 45 and 60°C compared to samples dried at 90°C. Malchev et al. (1982) reported the effect of drying temperature (60, 70, 80 and 90°C) and storage conditions (20±3°C for 6 months) on carotenoids in red pepper and red pepper powder. They reported a significant loss of pigments with increase in storage time, the rate of loss being higher in samples dried at higher temperature. Steet and Tong (1996) found that the loss in chlorophyll to pheophytin was solely responsible for the loss of visual green color

(-a value) in peas heated at 70, 80, and 90°C for 140 minutes. La Borde (1994) reported a linear relationship between sensory scores and -a values of thermally processed peas. Chlorophyll degradation to pheophytin and further pheophytin to pyropheophytin is a heat sensitive process, which can be controlled by high temperature and short time processing (Schwartz and Lorenzo, 1991). During thermal processing the central magnesium in central magnesium in the chlorophyll ring is replaced by two hydrogen ions, thus converting green chlorophylls (chlorophyll a: blue-green and chlorophyll b: yellow-green) into olive brown pheophytins (Schwartz and Elbe, 1983; Steet and Tong, 1996).

4.2.1.2. Extracted vs unextracted **:** Figure 4.4 and Figure 4.5 show the effect of extreme storage conditions (freezer and elevated temperature) on the L* values of extracted (10 min) and unextracted small flakes (Plots for large flakes and coarse powder are presented in Figure B1-B4 in Appendix B). Regardless of the drying temperature, extracted samples (10 min) had higher L* values than unextracted samples. As expected, the samples stored at lower temperature (freezer) retained high L* values compared to the samples stored at elevated temperature (40°C). The decrease in L* values at elevated temperature storage was observed for both extracted and unextracted samples.

Figure 4.6, 4.7, and 4.8 show the effect of storage in freezer and at elevated temperature on the -a* values of large flakes, small flakes, and coarse powder, respectively. Irrespective of the extraction time and the storage temperature, the -a* values were higher for samples derived from cilantro dried at 60°C compared to samples derived from cilantro dried at 40°C. Furthermore, -a* values of extracted samples (10 min) were higher than the unextracted samples. When samples were stored at elevated

temperature, a significant decrease in –a* values with increase in storage time was observed. On the other hand, no significant change in –a* values of samples stored in the freezer was observed. This indicates freezer storage temperature preserves green color (-a*) of dried cilantro. Figure 4.9, 4.10, and 4.11 and Figure 4.12, 4.13, and 4.14 show the effect of storage temperature with storage time on b* and chroma values of the three particle sizes, respectively. The b* values showed negligible change compared to -a* values. The b* values of samples stored at higher temperature were lower compared to samples dried at lower temperature. The chroma values of samples stored at freezer temperature were higher compared to the samples stored at other storage temperatures. For elevated storage, chroma values decreased with increase in storage time. Chroma is a function of a* and b* values, therefore, a greater decrease in –a* values must have contributed to the lower chroma values compared to the decrease in b* values of samples stored at other storage temperatures.

Figure 4.15, 4.16, and 4.17 show the effect of storage on browning index (BI) of large flakes, small flakes, and coarse powder, respectively. Browning index (BI) of dried cilantro was dependent on the drying temperature and the storage temperature. Cilantro samples (extracted and unextracted) stored at elevated temperature (40°C) exhibited an almost linear increase in browning index in the first three (large flakes) to five (coarse powder) months, after which it became almost constant. On the other hand, samples stored in the freezer did not show any change in the browning index. But, the BI values of unextracted samples stored in the freezer were greater than extracted samples, which indicate more brown color in unextracted samples than in extracted samples. This was also true for cilantro samples stored at elevated temperature (40°C).

Irrespective of the storage temperature, browning index values of samples (large flakes, small flakes and coarse powder) derived from cilantro dried at lower temperature were higher compared to samples derived from cilantro dried at higher temperature. However, this difference in browning index of samples dried at two temperatures was more pronounced in samples stored at elevated temperature storage compared to samples stored at the other three temperatures. Zhan et al. (1999) reported that browning of dehydrated products during storage is non-enzymatic. Discoloration in leaves due to loss of chlorophyll is accompanied by browning (Negi and Roy, 2001). They reported a continuous decrease in chlorophyll and an increase in browning of dried savoy beet and amaranth leaves during cold storage (7.5-8.5°C) and ambient storage (15-36.5°C). However, cabinet drying (65±5°C) (compared to solar drying at 40-50°C), low temperature storage, and double layer polyethylene film packaging reduced the rate of color loss in savoy and amaranth leaves.

Sanjuan et al. (2004) reported a significant effect of storage temperature (5, 15, 25, and 40°C) on the chlorophyll content of dried broccoli florets (65°C/4 hours). Storage time also affected the chlorophyll content, but its affect was influenced by the storage temperature. They found three groups of storage temperatures (5 and 15°C; 25°C; 40°C), which differed significantly from each other. Under same processing conditions for broccoli stems, Sanjuan et al. (2000) reported three groups of storage temperatures (5°C; 15°C; 25 and 40°C), which significantly differed from each other for broccoli stems. At 40°C they observed an accelerated ageing, which is related to greater quality losses and higher degradation. Samaniego-Esguerra et al. (1991) studied the kinetics of nonenzymic browning in dried onion flakes and chlorophyll loss in dried green beans. They predicted

nonenzymatic browning and chlorophyll loss of dried products as a function of temperature and water activity. Sa and Sereno (1999) stored freeze dried onion powder in containers conditioned at 33, 44, and 53% of relative humidity and stored at 5, 15, 25, 35, and 45°C (for 160 days) and determined the extent of browning by measurement of absorbance. They found that non-enzymatic browning increased with storage time, storage temperature, and humidity. This suggests that an increase in browning index values in samples stored at elevated temperature (40°C, 70±18%) could also be due to higher moisture contents compared to other storage temperatures. Furthermore, the initial higher browning index values of samples derived from cilantro dried at 40°C (moisture content 4.43% wb) compared to samples derived from cilantro dried at 60°C (moisture content 3.63% wb) could also be due to difference in moisture contents.

4.2.2 Oil content (%) content and Fatty acid composition

Cilantro is a good source of fatty acids, in particular the essential fatty acids, linoleic acid and α-linolenic acid. Breakdown of these two fatty acids in the plant tissue has been linked with degradation of cell membranes. Linoleic acid and α-linolenic acid are precursors of hexanal (rancid almond flavor) (Jadhav et al. 1971). This section presents the effect drying temperature, liquid propane extraction, and storage conditions on the quality of cilantro during storage over a period of twelve months.

4.2.2.1. Effect of storage temperature on oil content (%) and fatty acid composition:

The oil content and fatty acid composition of unextracted dried cilantro at the end of the storage period are presented in Table C1-Table C6 in Appendix C. Irrespective of the storage temperature, oil content in large flakes and small flakes at the end of the storage period was greater than oil content at the start of storage. The increase in oil content was

28-48% in large flakes and 22-31% in small flakes. In coarse powder, no significant change in oil content (%) at the end of the storage period was observed.

At the end of the storage period, the total concentration of fatty acids decreased in all the samples, except small flakes derived from cilantro. The decrease was maximum in large flakes (28-48%) followed by coarse powder (10-40%) and small flakes (5-31%). At the end of the storage period, the total concentration of fatty acids in large flakes stored in freezer, in refrigerator, at room temperature, and at elevated temperature was 7.93-11.13 mg/g, 8.81-9.05 mg/g, 7.97-8.97 mg/g, and 12.32-13.43 mg/g, respectively.

Small flake samples showed an initial increase in fatty acid concentration with increase in storage time (first 2-3 months), after which the concentration became almost constant. After twelve months of storage, the concentration of fatty acids was maximum in samples stored at elevated temperature compared to other storage conditions. These results are in agreement with change in polyunsaturated fatty acids (PUFA) under accelerated aging (Priestley and Leopold, 1979) and natural aging (Priestley and Leopold, 2006) of soybean seeds. When soybean seeds were stored at 4°C and low humidity for 44 months, a decrease in the proportion of PUFA was observed. However, when soybean seeds were stored at 40°C for several days, no change in PUFA was noticed. In both studies, aging did lead to loss of vigor and viability.

Regardless of the storage conditions, major fatty acids present in cilantro at the end of the storage period were: linoleic acid, α-linolenic acid, and palmitic acid. These were also the major fatty acids in control samples. Depending on the particle size, the decrease in the major fatty acids varied from 4-50% (10-50% in large flakes, 4-30% in small flakes and 10-30% in coarse powder). Figure 4.18 and Figure 4.19 show the effect

of storage temperature and storage time on the concentration of linoleic acid, α-linolenic acid, and palmitic acid in unextracted large flakes derived from cilantro dried at two temperatures. In the first 3-4 months, the concentration of all fatty acids decreased with increase in storage time, after which the concentration became stable. Small flakes and coarse powder showed the same trend of decrease in fatty acids with increase in storage time. In contradiction to the present results Galliard and Gallagher (1988) reported an increase in deterioration (measured as oxygen uptake capacity) of wheat bran with decrease in particle size (<0.5 mm, 0.5-1 mm, 1-2 mm, and >2 mm). The samples were stored at 20°C and -20°C for 16 weeks. After 16 weeks of storage, oxygen uptake and fatty acid content increased with decrease in particle size (5.3 mg/g to 32.4 mg/g for particle size <0.5 mm; 25 mg/g to 8 mg/g for particle size >2 mm). The increase in fatty acid content was directly linked with increase in oxygen uptake. The deterioration in wheat bran with storage time was more prominent in samples stored at ambient conditions than in samples stored at lower temperature.

4.2.2.2. Effect of drying temperature on fatty acid composition: Figure 4.20-Figure 4.22 show the effect of drying temperature on the major fatty acids: linoleic acid, α-linolenic acid, and palmitic acid in large flakes, small flakes, and coarse powder, respectively, when stored in the freezer over a period of twelve months. During prolonged storage, no significant effect of drying temperature on fatty acid composition in large flakes (Figure 4.20) was observed. In large flakes, linoleic acid (3.79-4.78 mg/g) was present in maximum concentration followed by α-linolenic (2.13-3.33 mg/g) acid, and palmitic acid (1.10-1.48 mg/g).

Small flakes samples derived from cilantro dried at higher temperature (60°C) had higher concentration of α-linolenic acid and linoleic d acid compared to small flake samples derived from cilantro dried at lower temperature (40°C). At both drying temperatures, the concentration of α-linolenic acid was greater than linoleic acid. However, the concentration of palmitic acid was not affected by drying temperature. I

In large flakes and small flakes the change in major fatty acids with storage time was negligible. The concentration of linolenic acid and linoleic acid in coarse powder (Figure 4.22) was almost same in the first six months of storage, after which the concentration of linolenic acid increased and the concentration of linoleic acid decreased. The affect was prominent in samples derived from cilantro dried at 40°C. No change in palmitic acid was observed with drying temperature and storage time. In a plant tissue, linoleic acid is a precursor of linolenic acid (Yuan and Bloch, 1960). Stevanovic et al. (1992) reported a change in fatty acid composition in romanda flowering plants (R. *nathaliae* and R. *serbica*) by desiccation followed by rehydration. They observed that in R. *nathaliae* desiccation lead to a small increase in linolenic acid, which was balanced by a decrease in linoleic acid. But, in severely stressed R. *serbica* leaves, an opposite trend was reported. As found in cilantro, the major fatty acids in romanda plants were linoleic acid and linolenic acid with palmitic acid, palmitoleic acid, stearic acid, and oleic acid being minor fatty acids.

4.2.2.3. Extracted vs unextracted: Irrespective of the storage temperature, the major fatty acids (linoleic acid and α-linolenic acid) in extracted samples were stable during the storage period. Effect of storage in freezer and at elevated temperature (40°C) on linolenic acid and linoleic acid in samples extracted for 0, 10, 20, and 40 min is presented

in Figure C1 to Figure C12 in Appendix C. As observed in unextracted samples with increase in storage time the concentration of all extracted samples decreased in the first 2-3 months, after which the concentrations became constant. And as noticed an opposite trend was observed in small flakes compared to large flakes and coarse powder. In extracted small flake samples an initial increase (in the first 2-3 months) followed by a decrease in concentrations was noticed.

In control samples (coarse powder and small flakes) stored at elevated temperature, an increase in α-linolenic acid (after 5 months) with increase in storage time was observed. No such change was noticed in extracted coarse powder and small flake samples. These results indicate that fatty acids, especially linoleic acid and α-linolenic acid are more stable in larger size particles than in smaller particle size, and in extracted samples compared to unextracted samples. Kanamangala et al. (1999) extracted pecan halves with supercritical CO_2 (15 g of sample extracted at 69 MPa, 40C for 20 min or 8 hours), packaged in laminated polyethylene packages, and stored for 37 weeks at 25°C and 55% relative humidity. Notable production of hexanal was retarded from 6 weeks (in control samples) to 22 weeks (in extracted samples). Another study by Crowe and White (2003) reported low hexanal concentration in extracted walnut pieces (full fat, 25% reduced fat, and 40% reduced fat) during storage (25 and 40°C for 8 weeks). They suggested hexanal is a breakdown product of linoleic acid. However, both studies investigated products rich in oil content (pecans 64%; walnut 69%) compared to cilantro (3-5%)

4.3. CONCLUSION

Dried cilantro samples stored at four storage conditions for a period of twelve months were evaluated for change in color and fatty acid composition. Color quality was dependent on storage temperature and storage time. It was also governed by the pre-processing (drying temperature, size reduction by grinding) conditions. The initial higher –a* values in samples dried at higher temperature were maintained during storage. Similarly, coarse powder with initial higher –a* values preserved the greenness of the samples in storage. However, storage at elevated temperature led to an almost linear decrease in greenness (-a* values) and an increase in brownness (browning index). Greenness of cilantro samples stored in the freezer and the refrigerator was maintained over a period of twelve months. Extracted samples (10 min) retained higher L* and -a* values than unextracted samples during the storage period. Browning index of dried cilantro was dependent on drying temperature and storage temperature. The oil content (%) in larger particle sizes (large flakes and small flakes) at the end of the storage period was greater compared to the beginning of the storage. In the first 3-4 months, the concentration of all fatty acids decreased with an increase in storage time, after which the concentration became stable. At the end of the storage period, the total concentration of fatty acids decreased in all samples, except small flakes. In small flakes, an initial increase (3-4 months) followed by a decrease in the fatty acid concentration was observed. Fatty acids, especially linoleic acid and α-linolenic acid are more stable in larger size particles than in smaller particle size, and in extracted samples compared to unextracted samples. In unextracted samples (coarse powder and small flakes) stored at elevated temperature, an increase in α-linolenic acid (after 5 months) with an increase in

storage time was observed. No such change was noticed in extracted coarse powder and small flake samples. Hence, to maintain the color quality and stabilize fatty acids over prolonged storage, dried cilantro should be stored in the freezer or the refrigerator. Though room temperature storage does not result in browning of the plant tissue, it leads to decrease in the green color. When considering pre-processing conditions, higher drying temperature should be preferred. In addition, value added techniques such as solvent extraction with liquid propane results in a better quality product in terms of color and stable fatty acid concentration during prolonged storage.

4.4 TABLES AND FIGURES

Table 4.1. Color values of unextracted cilantro samples at the beginning and the end of storage at room temperature.

Particle size	Large Flakes				Small Flakes				Coarse Powder			
Drying temperature	40		60		40		60		40		60	
Storage temperature*	C	R	C	R	C	R	C	R	C	R	C	R
Storage time (months)	0	12	0	12	0	12	0	12	0	12	0	12
L* (Lightness)	46.97a	46.01a	46.39a	44.18a	47.60b	46.72b	46.93a	45.52b	46.46b	47.35ab	50.22ab	48.45bc
a* (greeness)	-12.35a	-9.23b	-13.06a	-10.47c	-12.66a	-10.22b	-13.01a	-10.64c	-12.80b	-11.11c	-14.12a	-11.76d
b* (yellowness)	25.04a	23.45b	24.96a	21.85b	25.06b	23.16c	25.33a	21.16c	25.11ab	23.31d	26.95b	23.43d
Chroma	27.93a	25.31b	28.17a	24.27bc	28.09a	25.33b	28.48a	23.70c	28.18b	25.83d	30.43b	26.22d
Hue Angle	178.89c	178.80bc	178.91ab	179.29a	178.90a	178.84a	178.90ab	178.89b	178.90b	178.87c	178.91a	178.89a
Browning Index (BI)	49.38b	50.84b	48.46b	46.15bc	47.81b	46.75b	49.17b	40.11d	49.47b	44.61c	48.22bc	42.38c

*C: Control; R: Room temperature. a, b, c, d, e denote significantly different color values (at 0.05 probability level) between control sample and samples stored at room temperature

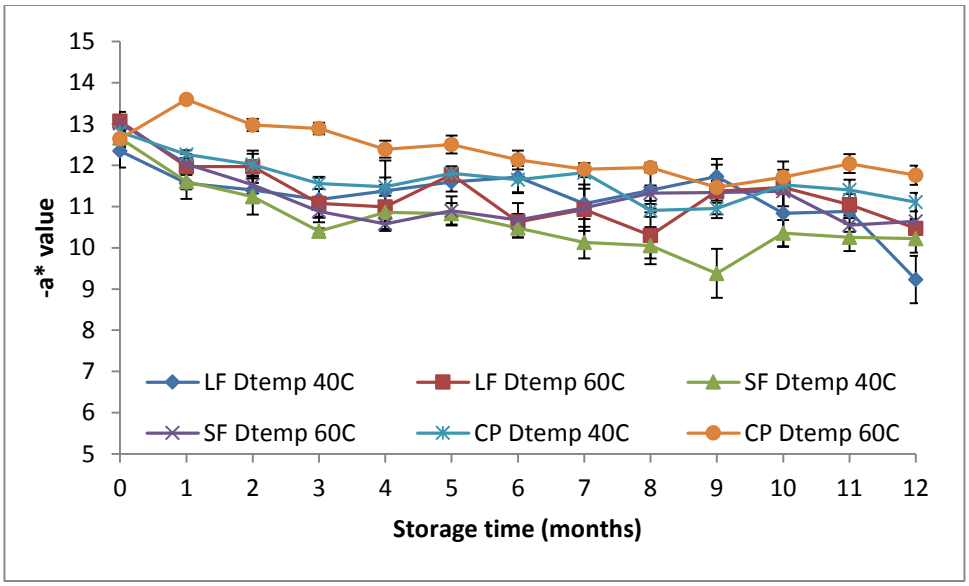

Figure 4.1. Effect of storage time on -a* values of large flakes (LF), small flakes (SF), and coarse powder (CP) stored at room temperature; Dtemp: drying temperature.

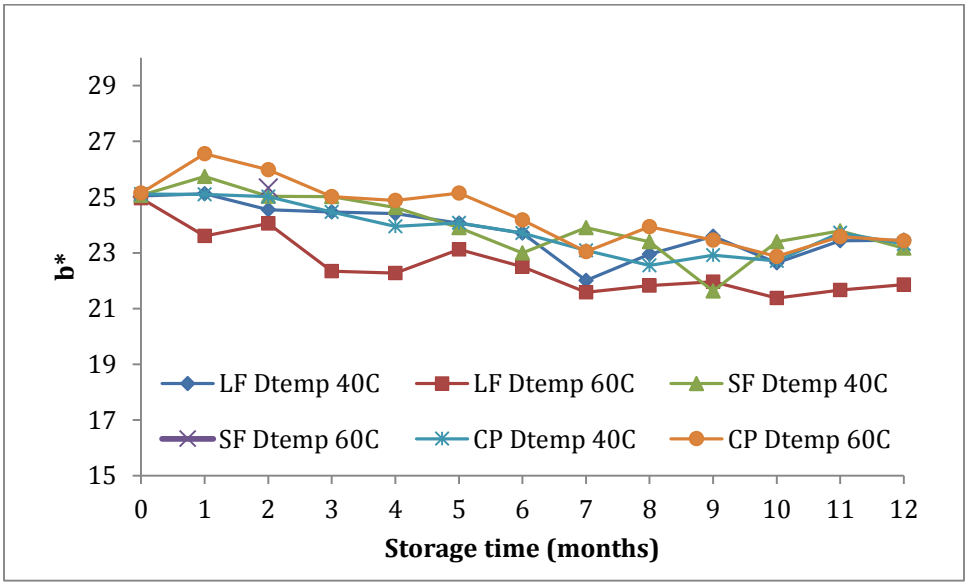

Figure 4.2. Effect of storage time on b* values of large flakes (LF), small flakes (SF), and coarse powder (CP) stored at room temperature; Dtemp: drying temperature.

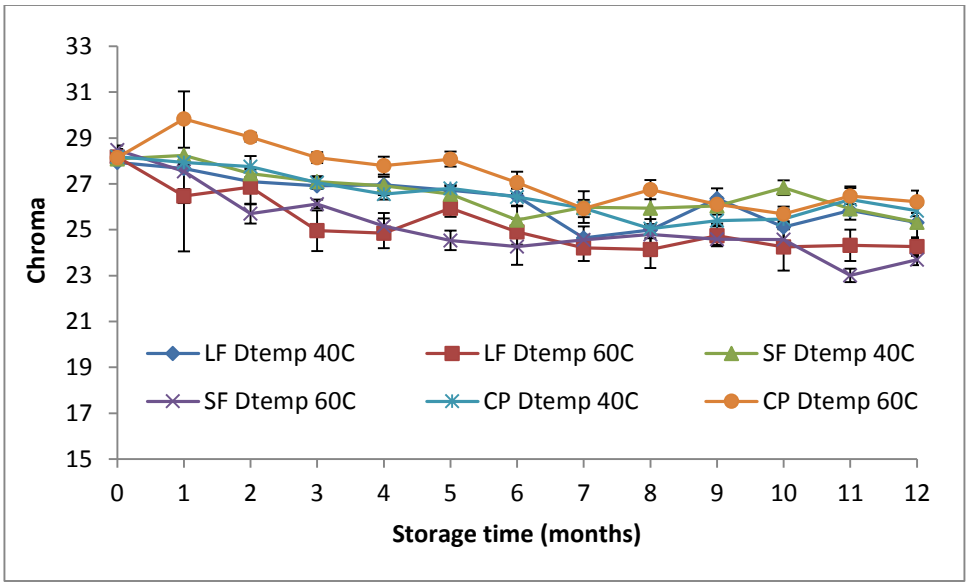

Figure 4.3. Effect of storage time on chroma values of large flakes (LF), small flakes (SF), and coarse powder (CP) stored at room temperature; Dtemp: drying temperature.

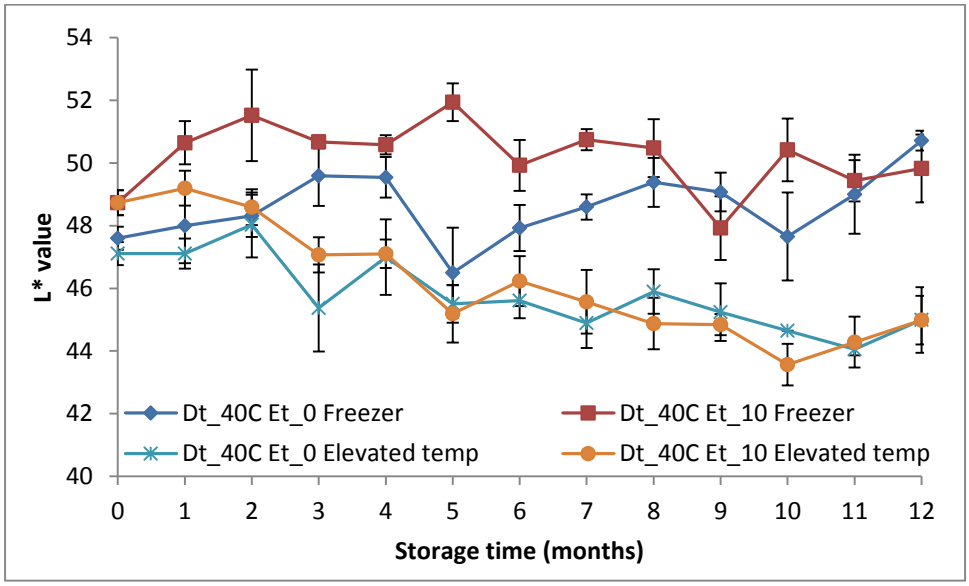

Figure 4.4. Effect of storage temperature and storage time on L* values of extracted (10 min) and unextracted (0 min) small flakes (derived from cilantro dried at 40°C); Dt: drying temperature, Et: extraction time; temp: temperature.

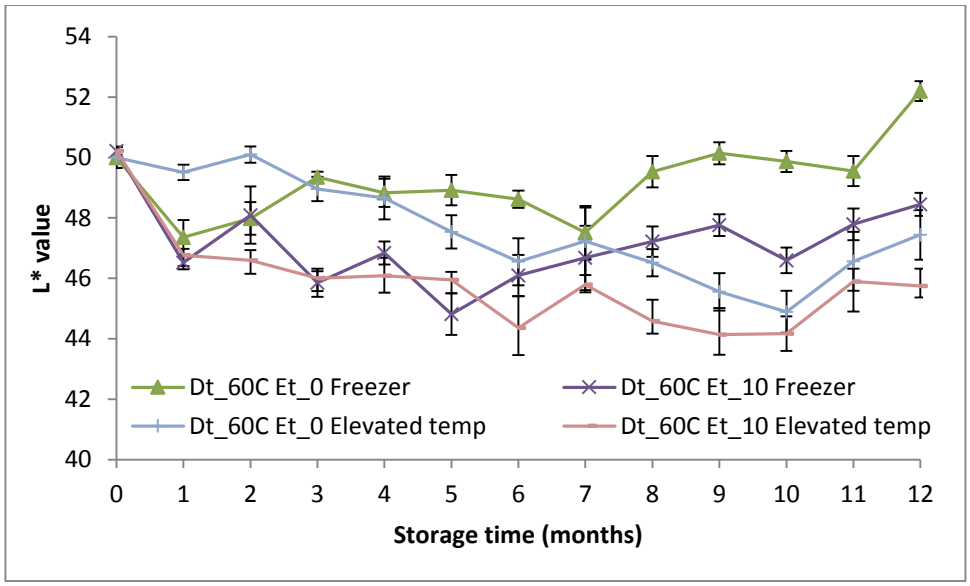

Figure 4.5 Effect of storage temperature and storage time on L* values of extracted and unextracted small flakes (derived from cilantro dried at 60°C); Dt: drying temperature, Et: extraction time; temp: temperature.

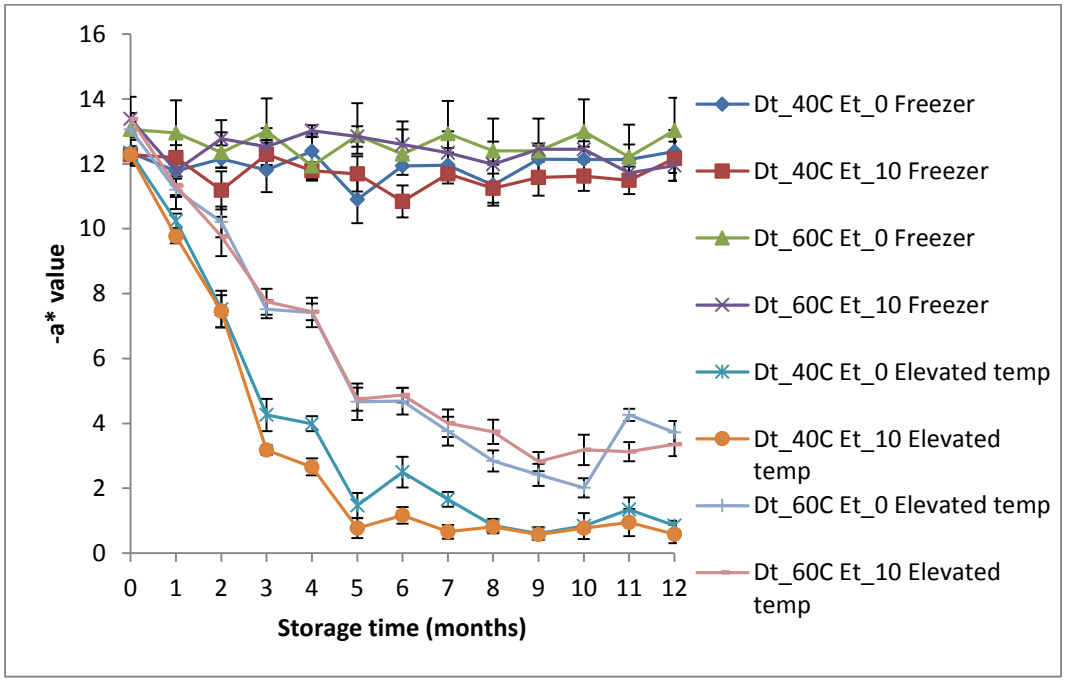

Figure 4.6. Effect of storage temperature and storage time on –a* values of extracted (10 min) and unextracted (0 min) large flakes; Dt: drying temperature, Et: extraction time; temp: temperature.

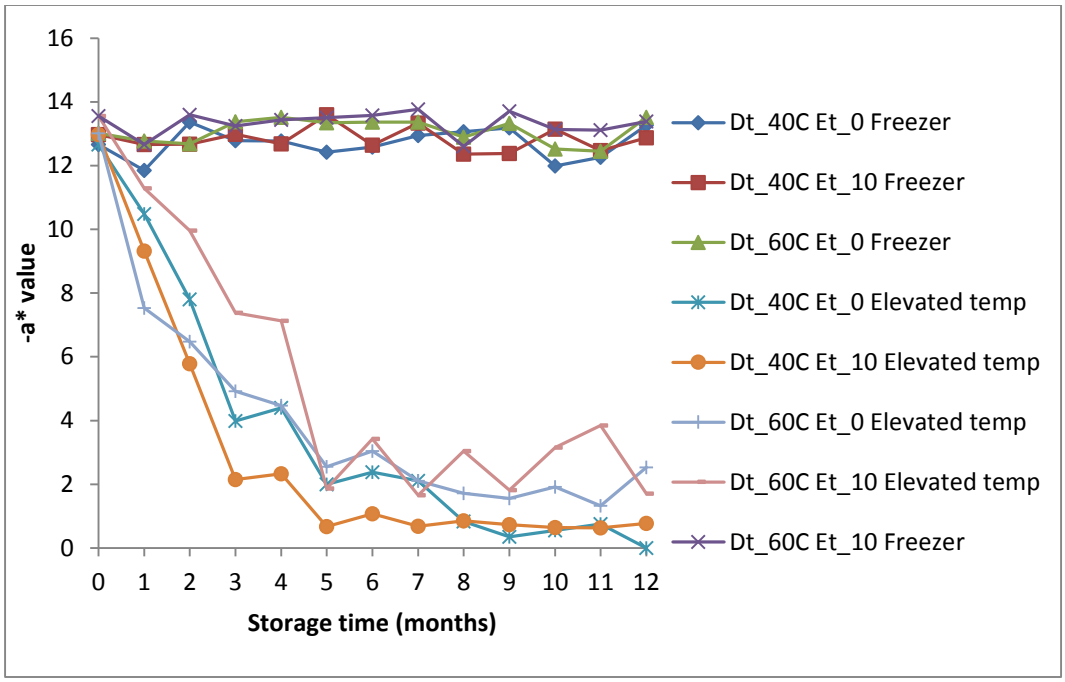

Figure 4.7. Effect of storage temperature and storage time on –a* values of extracted (10 min) and unextracted (0 min) small flakes; Dt: drying temperature, Et: extraction time; temp: temperature.

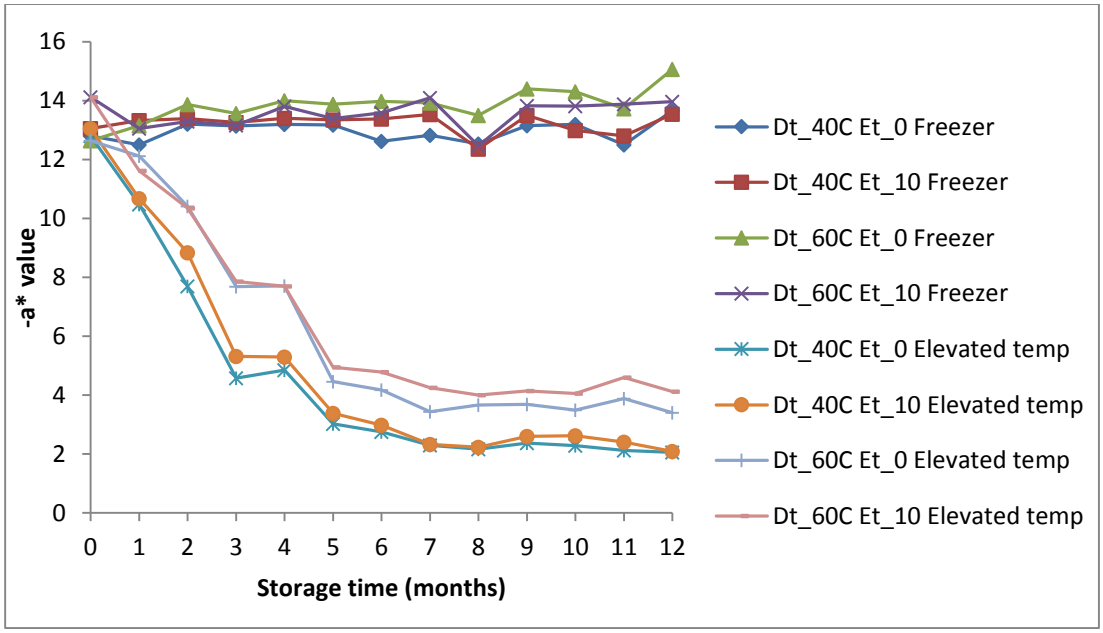

Figure 4.8. Effect of storage temperature and storage time on –a* values of extracted (10 min) and unextracted (0 min) coarse powder. Dt: drying temperature, Et: extraction time; temp: temperature.

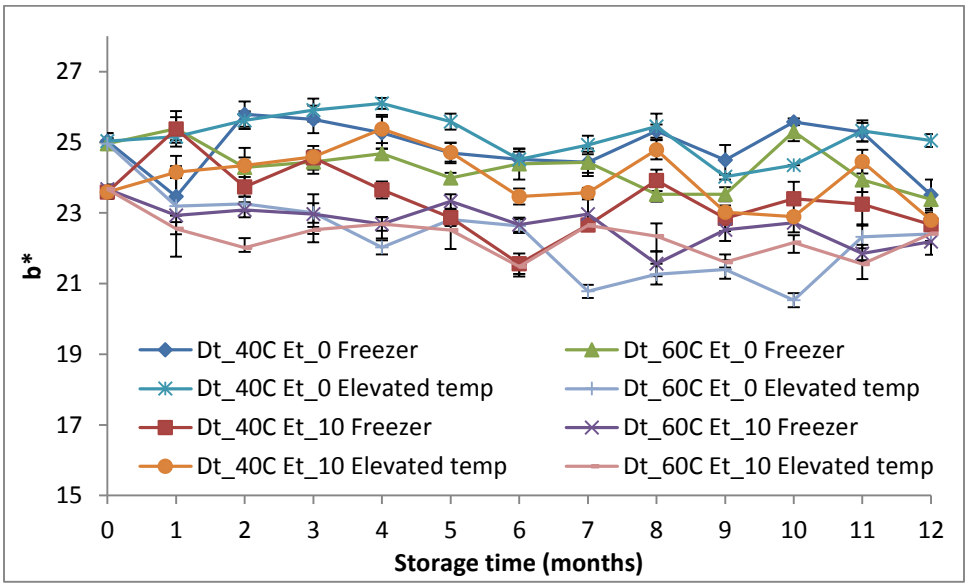

Figure 4.9. Effect of storage temperature and storage time on b* values of extracted (10 min) and unextracted (0 min) large flakes. Dt: drying temperature, Et: extraction time; temp: temperature.

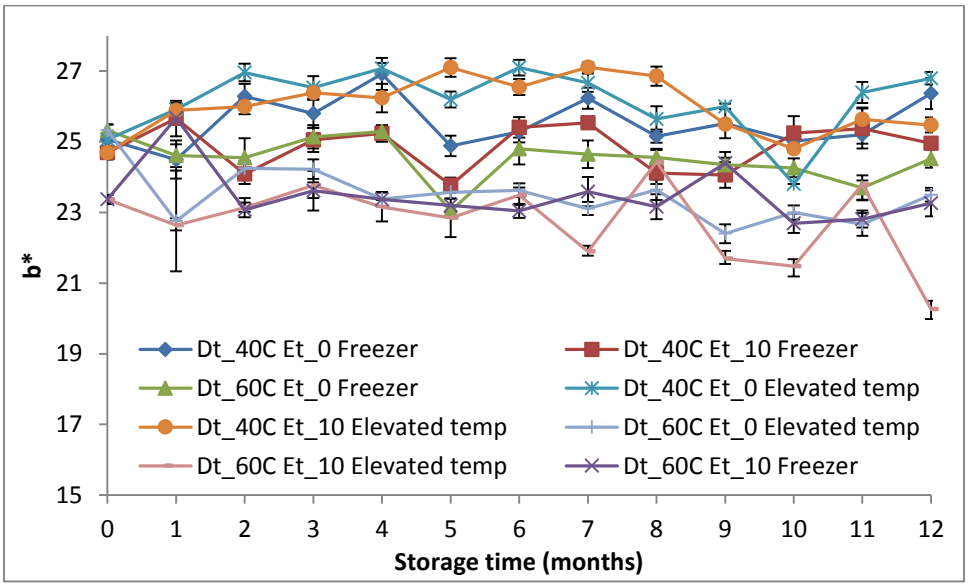

Figure 4.10. Effect of storage temperature and storage time on b* values of extracted (10 min) and unextracted (0 min) small flakes. Dt: drying temperature, Et: extraction time; temp: temperature.

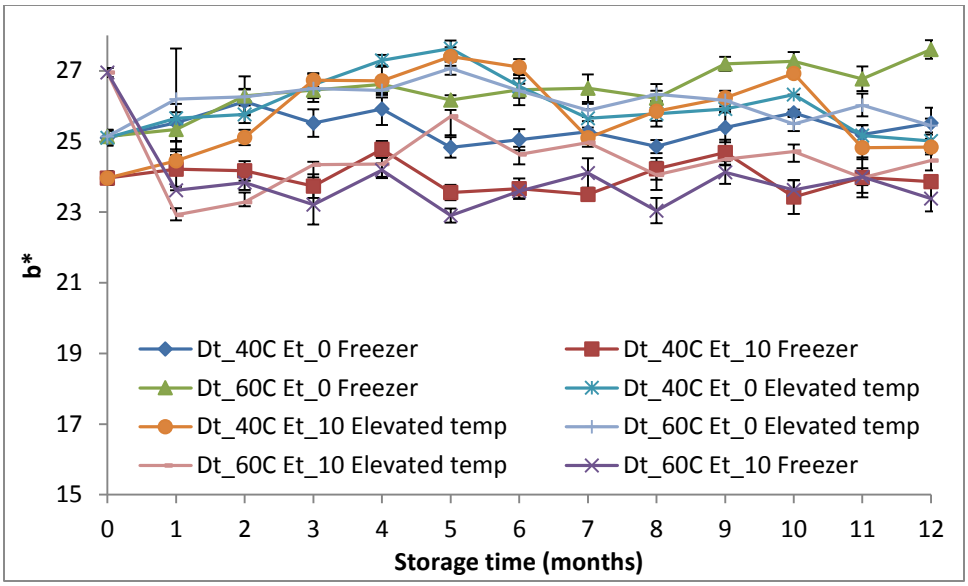

Figure 4.11. Effect of storage temperature and storage time on b* values of extracted (10 min) and unextracted (0 min) coarse powder. Dt: drying temperature, Et: extraction time; temp: temperature.

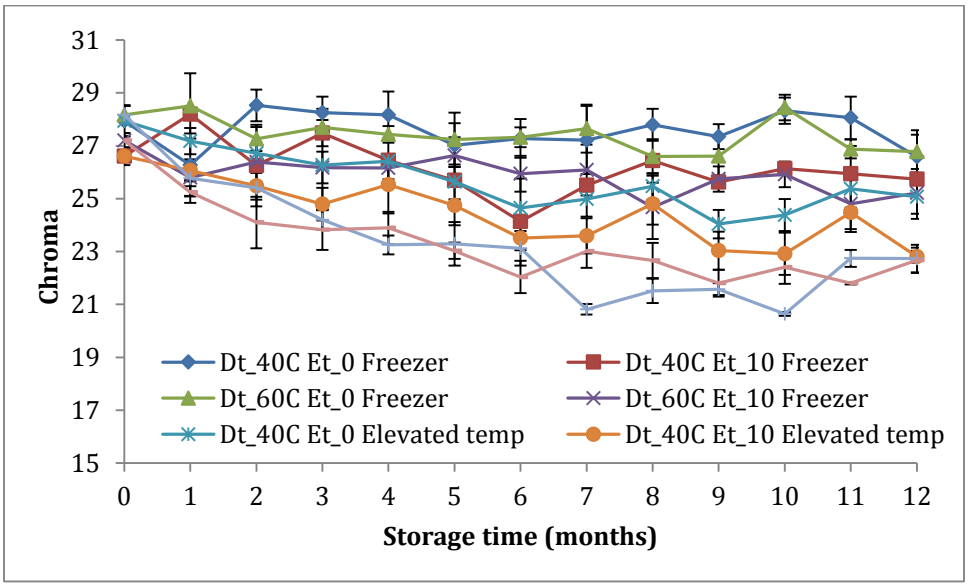

Figure 4.12. Effect of storage temperature and storage time on chroma values of extracted (10 min) and unextracted (0 min) large flakes. Dt: drying temperature, Et: extraction time; temp: temperature.

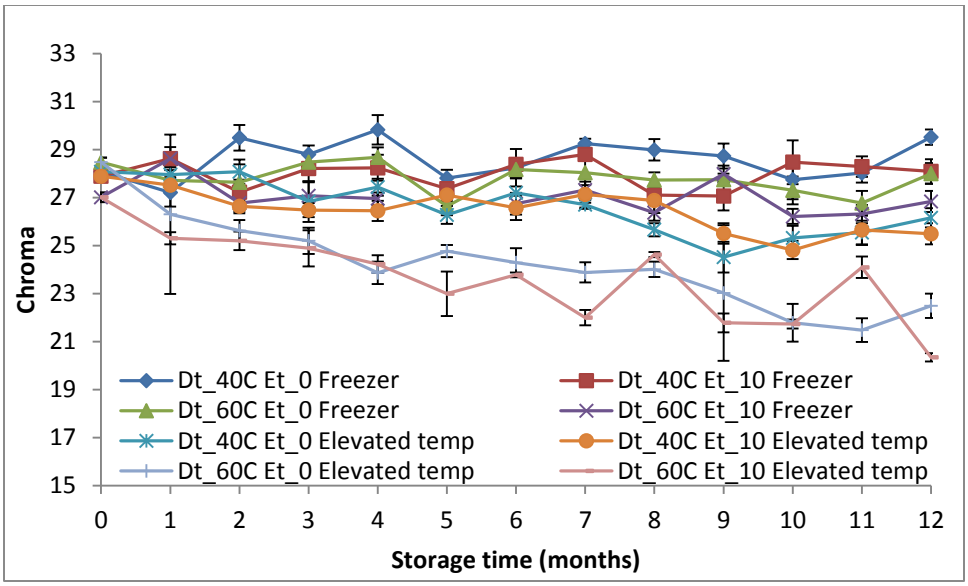

Figure 4.13. Effect of storage temperature and storage time on chroma values of extracted (10 min) and unextracted (0 min) small flakes. Dt: drying temperature, Et: extraction time; temp: temperature.

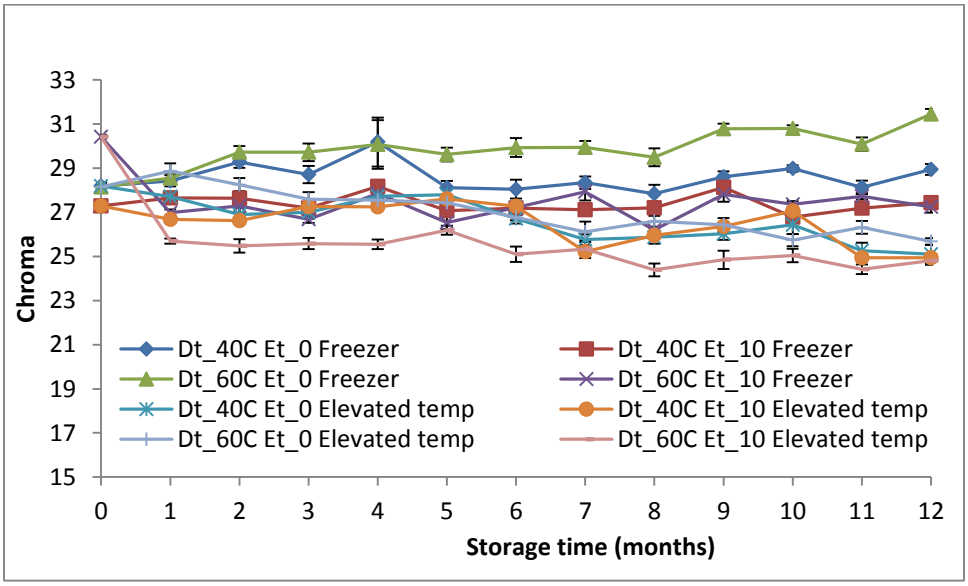

Figure 4.14. Effect of storage temperature and storage time on chroma values of extracted (10 min) and unextracted (0 min) coarse powder. Dt: drying temperature, Et: extraction time; temp: temperature.

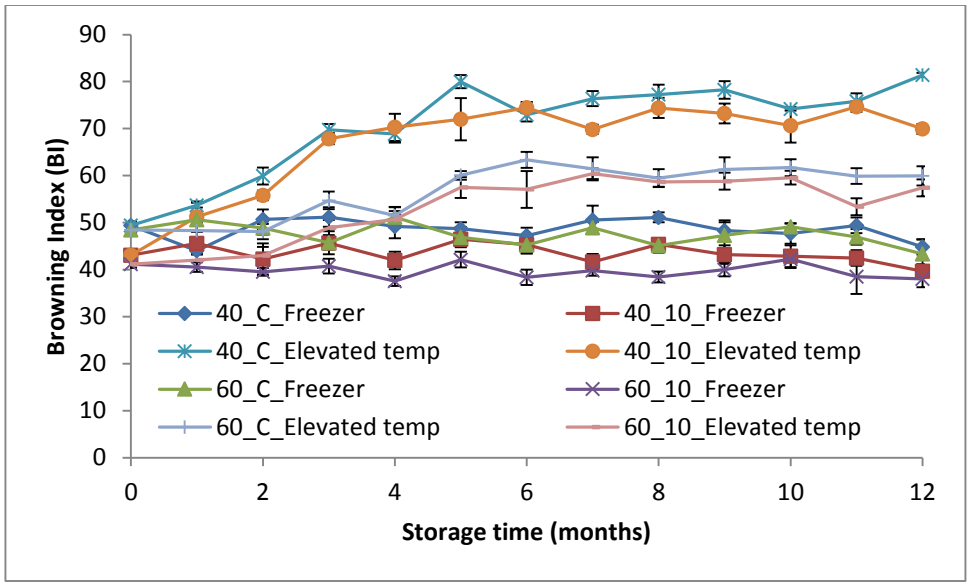

Figure 4.15. Effect of storage temperature and storage time on browning index values of extracted (10 min) and unextracted (0 min) large flakes derived from cilantro dried at 40°C and 60°C.

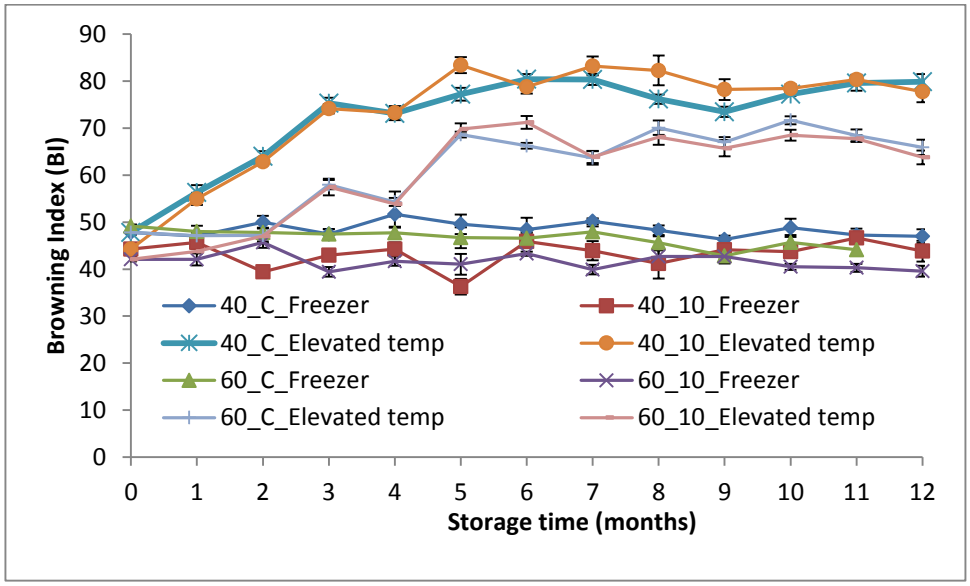

Figure 4.16. Effect of storage temperature and storage time on browning index values of extracted (10 min) and unextracted (0 min) small flakes derived from cilantro dried at 40°C and 60°C.

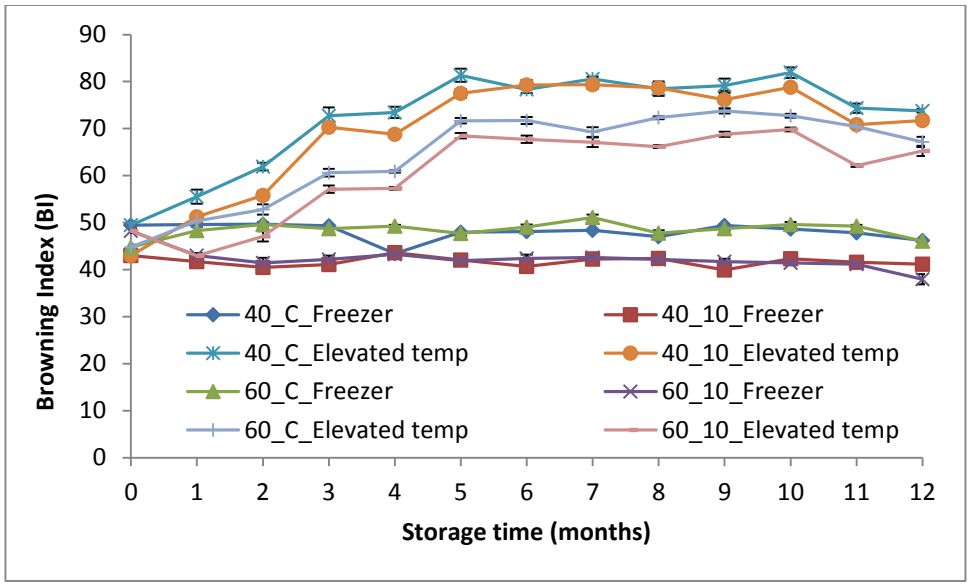

Figure 4.17. Effect of storage temperature and storage time on browning index values of extracted (10 min) and unextracted (C) coarse powder derived from cilantro dried at 40°C and 60°C.

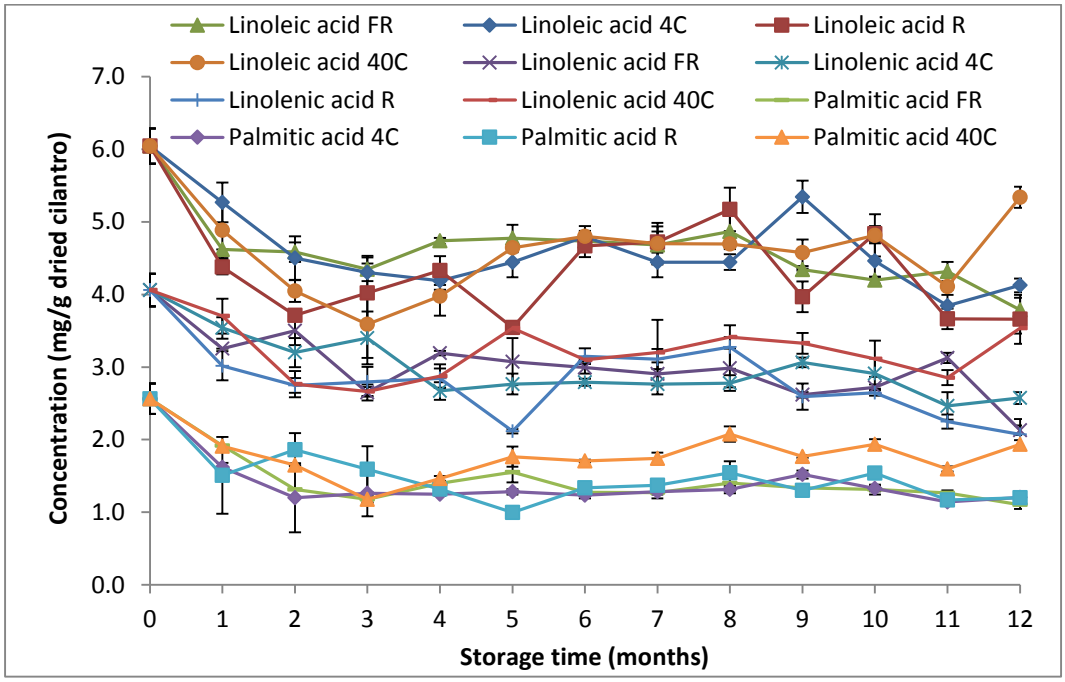

Figure 4.18. Effect of storage temperature and storage time on concentration of linoleic acid, α-linolenic acid, and palmitic acid in unextracted large flakes derived from cilantro dried at 40°C; FR: freezer, R: Room.

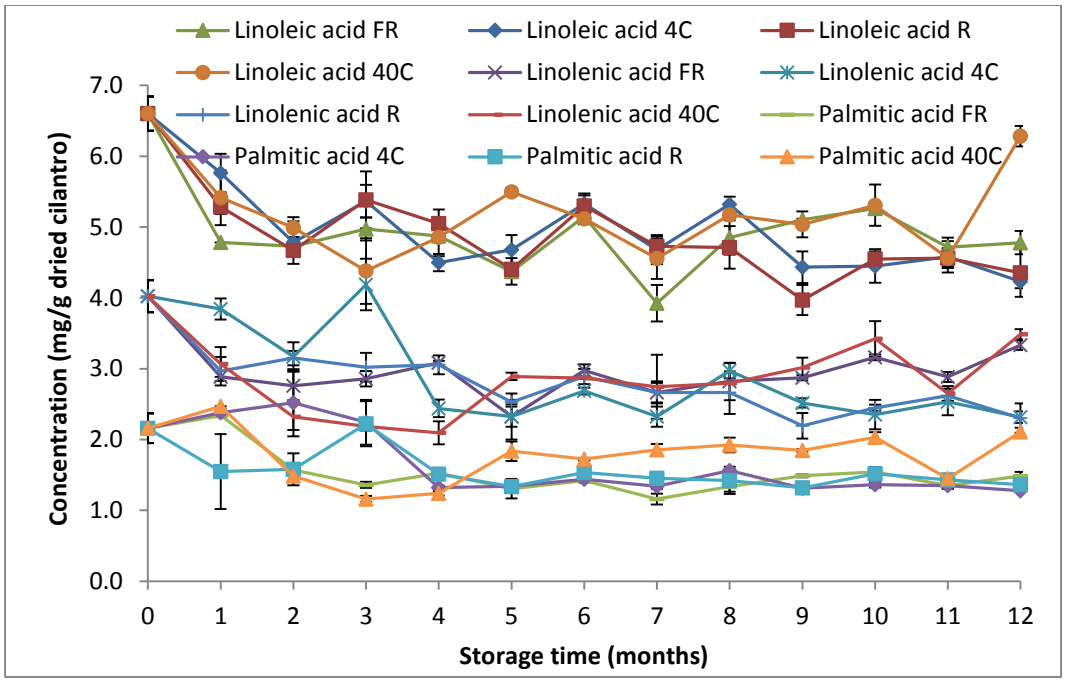

Figure 4.19. Effect of storage temperature and storage time on concentration of linoleic acid, α-linolenic acid, and palmitic acid in unextracted large flakes derived from cilantro dried at 60°C. FR: freezer, R: Room.

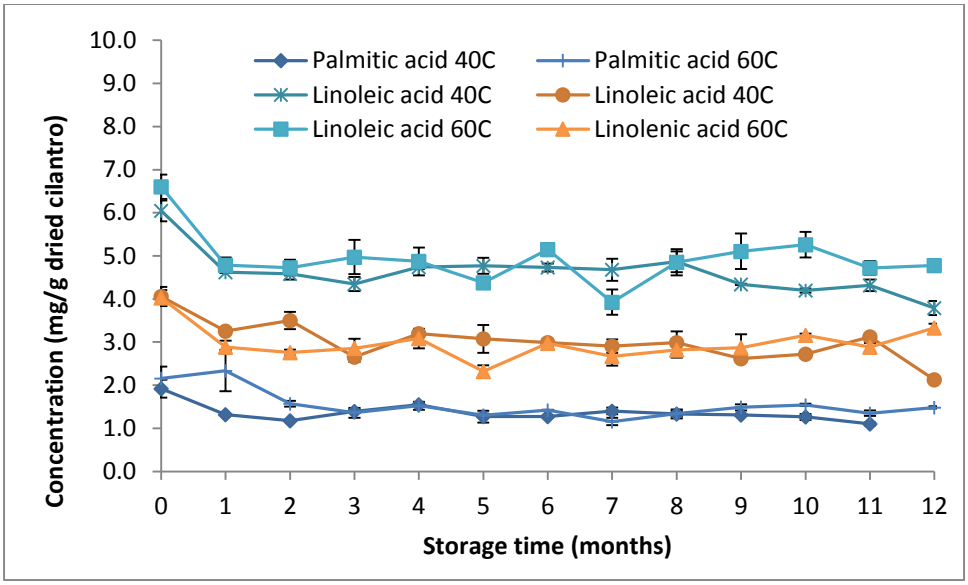

Figure 4.20. Effect of drying temperature and storage time on concentration of linoleic acid, α-linolenic acid, and palmitic acid in unextracted large flakes stored in the freezer.

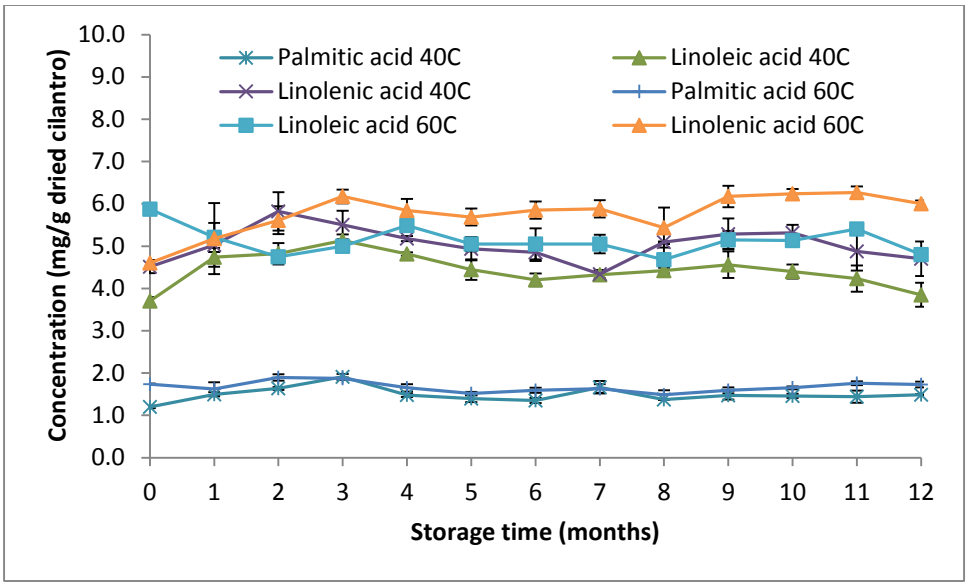

Figure 4.21. Effect of drying temperature and storage time on concentration of linoleic acid, α-linolenic acid, and palmitic acid in unextracted small flakes stored in the freezer.

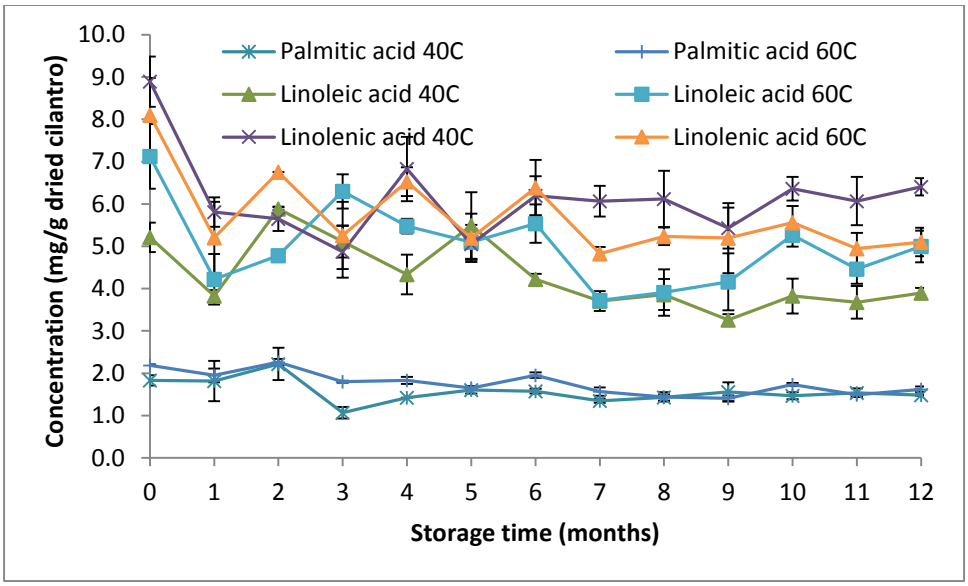

Figure 4.22. Effect of drying temperature and storage time on concentration of linoleic acid, α-linolenic acid, and palmitic acid in unextracted coarse powder stored in the freezer.

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APPENDICES

APPENDIX A

Table A. Average temperature and relative humidity of room temperature storage conditions during the storage period (June 2010-June 2011)

Month	Temperature (°C)	STDEV*	Relative Humidity (%)	STDEV*
June	30.20	3.94	49.14	10.67
July	23.98	3.30	65.70	8.59
August	22.26	1.46	66.39	7.98
September	23.41	1.29	68.86	9.11
October	22.40	1.38	56.92	9.32
November	24.80	0.80	40.39	7.95
December	19.97	2.80	33.52	12.47
January	18.17	3.05	39.56	12.83
February	21.24	7.23	33.02	14.73
March	22.54	1.5	36.11	10.73
April	24.98	6.12	44.01	10.81
May	23.7	5.61	34.78	11.9
June	25.31	3.11	40.66	14.1

***STDEV: Standard deviation**

APPENDIX B

Table B1. Effect of storage conditions on the color values of extracted and unextracted large flakes (derived from cilantro dried at 40°C).

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)	46.97a	46.03a	45.69a	46.01a	42.71b	47.63a	47.91a	46.39a	46.71a	43.45b	48.27a	48.30a	46.44	46.25a	43.29b	47.67a	49.41a	47.38a	44.95b	42.97b
a* (greenness)	-12.35a	-12.38a	-12.17a	-9.23b	-0.85c	-12.29a	-12.16ab	-11.52b	-10.56c	-0.59d	-12.28a	-12.41a	-12.07a	-9.71b	-0.69c	-12.36a	-11.66ab	-10.77b	-8.56c	-1.03d
b* (yellowness)	25.04a	23.51ab	24.13ab	23.45b	24.65ab	23.59a	22.67ab	22.06b	22.05b	22.79ab	23.26a	22.37ab	21.95bc	21.41c	24.01a	23.56a	23.77ab	22.32b	22.33b	24.41a
Chroma	27.93a	26.58ab	27.03a	25.31b	25.07b	26.60a	25.73ab	24.90b	24.46b	22.80c	26.32a	25.61ab	25.06b	23.54c	24.02c	26.61a	26.49ab	24.81bc	23.95c	24.43c
Hue Angle	178.89c	178.91b	178.90bc	178.80bc	180.32a	178.91b	178.92b	178.91b	178.88b	180.31a	178.92b	178.94ab	178.93b	178.86b	179.57a	178.91a	178.89a	178.88a	178.80a	180.92b
Browning Index (BI)	49.38b	44.82b	48.07b	50.84b	81.41a	43.05b	39.65b	40.65b	41.94b	69.94a	41.18b	37.65b	38.95b	41.90b	75.45a	42.75b	42.55b	41.78b	48.31a	77.47a

*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 B2. Effect of storage conditions on the color values of extracted and unextracted large flakes (derived from cilantro dried at 60°C).

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)	46.39a	45.97a	43.86a	44.18a	44.64a	47.63ab	48.26ab	45.46c	44.50c	45.87bc	47.55a	45.76abc	43.75c	45.10bc	45.90ab	48.34ab	44.12c	45.99bc	43.51c	44.32c
a* (greenness)	-13.06a	-13.04a	-11.80b	-10.47c	-3.72d	-13.39a	-11.95bc	-12.45bc	-10.90c	-3.36d	-12.83a	-12.28ab	-11.86b	-10.83c	-2.08d	-12.70a	-10.02b	-11.54c	-10.29b	-1.90d
b* (yellowness)	24.96a	23.38ab	22.58b	21.85b	22.40b	23.67a	22.19b	21.98b	19.92c	22.42b	23.26a	22.02abc	21.27bc	20.71c	21.85b	22.97a	20.67bc	21.39b	19.83c	20.96b
Chroma	28.17a	26.77ab	25.49b	24.27bc	22.73c	27.20a	25.21b	25.26b	22.72c	22.67c	26.57a	24.84ab	24.36b	23.38b	21.97c	26.27a	23.01bc	24.32b	22.35c	21.05d
Hue Angle	178.91ab	178.94ab	178.91ab	179.29a	178.59b	178.94a	178.92a	178.94a	178.93a	178.58b	178.93ab	178.95ab	178.94a	178.91b	178.52c	178.93a	178.88b	178.92a	178.91ab	178.51c
Browning Index (BI)	48.46b	43.35c	45.40bc	46.15bc	59.95a	41.15b	38.04bc	39.48b	35.97c	57.42a	40.96b	38.23b	40.16b	38.49b	56.95a	39.21b	41.95b	38.71b	38.31b	58.08a

*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 B3. Effect of storage conditions on the color values of extracted and unextracted small flakes (derived from cilantro dried at 40°C).

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)	47.60b	50.71a	44.84c	46.72b	44.99c	48.74a	49.83a	45.79b	46.18b	44.99b	48.97b	52.96a	45.48d	47.43c	45.41d	48.02b	51.93a	45.01c	47.07b	45.10c
a* (greenness)	-12.66a	-13.26a	-12.58a	-10.22b	-1.12c	-12.97a	-12.87a	-12.30b	-9.63c	-0.77d	-12.24b	-13.85a	-12.37b	-9.72c	-0.79d	-13.28a	-13.49a	-11.78b	-9.42c	-0.51d
b* (yellowness)	25.06b	26.37ab	22.51c	23.16c	26.13a	24.69a	24.96a	23.21b	22.47b	25.48a	24.63b	23.39c	23.28c	23.62c	27.56a	23.97b	23.13bc	21.49d	22.51c	26.01a
Chroma	28.09a	29.53a	25.80b	25.33b	26.16b	27.90a	28.09a	26.27b	24.45d	25.49b	27.51a	27.19a	26.37b	25.56c	27.57a	27.41a	26.78ab	24.51c	24.41c	26.02b
Hue Angle	178.90a	178.90a	178.94a	178.84a	178.78a	178.91b	178.7ab	178.92b	178.83b	179.49a	178.89c	178.96a	178.92b	178.82d	178.46e	178.94a	178.96ab	178.93ab	178.83a	179.48b
Browning Index (BI)	47.81b	47.00b	42.28b	46.75b	79.88a	44.23b	43.84b	44.00b	46.06b	77.73a	45.10c	33.67d	44.58c	48.37b	85.93a	41.96b	34.45d	39.61c	45.37b	80.23a

*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 B4. Effect of storage conditions on the color values of extracted and unextracted small flakes (derived from cilantro dried at 60°C).

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)	46.93a	47.76a	44.07c	45.52b	42.67d	45.76a	47.67a	44.23a	44.91a	40.92b	45.55b	48.12a	44.42bc	43.23c	43.67c	47.33a	47.58a	44.79b	45.63ab	45.13b
a* (greenness)	-13.01a	-13.51a	-11.98b	-10.64c	-2.53d	-13.56a	-13.38a	-12.27b	-10.97c	-1.70d	-13.26a	-13.77a	-12.86b	-11.09c	-3.35d	-12.87a	-13.07a	-12.70a	-9.71b	-2.37c
b* (yellowness)	25.33a	24.52a	22.59b	21.16c	22.34b	23.37a	23.26a	21.45b	20.56d	20.26d	22.74b	22.45abc	21.72c	19.84d	23.51d	23.19a	22.10a	21.76b	20.63c	23.27a
Chroma	28.48a	28.01a	25.57b	23.70c	22.49d	27.02a	26.84a	24.72b	23.32c	20.35d	26.33a	26.34ab	25.25b	22.74d	23.75c	26.44a	25.69ab	25.20b	22.83c	23.39c
Hue Angle	178.90ab	178.93a	178.92ab	178.89b	178.54c	178.95b	178.95ab	178.95b	178.92b	179.49a	178.96a	178.98a	178.96a	178.94b	178.57c	178.94a	178.96a	178.96a	178.87b	178.53 c
Browning Index (BI)	49.17b	43.83c	44.79c	40.11d	65.93a	42.09b	39.58b	39.63b	37.89b	63.77a	40.62b	35.52c	38.99b	37.00c	67.05a	40.54b	36.33b	38.98b	39.96b	65.95a

*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 B5. Effect of storage conditions on the color values of extracted and unextracted coarse powder (derived from cilantro dried at 40°C).

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)	46.46b	48.55a	46.44b	47.35ab	44.76c	47.49a	47.93a	47.46a	46.96a	45.26b	47.81a	47.38a	48.17a	46.12b	45.21bc	50.00a	49.54b	49.75b	49.24b	47.41
a* (greenness)	-12.80b	-13.66a	-12.43b	-11.11c	-2.06d	-13.06b	-13.54a	-12.79b	-11.57c	-2.09d	-13.51a	-13.26ab	-12.81b	-10.78c	-0.73d	-12.64a	-12.60a	-12.39a	-10.54b	-1.36c
b* (yellowness)	25.11ab	25.52b	24.28a	23.31d	25.02ab	23.96b	23.86b	23.07c	22.06d	24.85a	24.08b	22.89d	23.06c	22.11d	24.55a	25.14a	23.96b	24.04b	22.98c	25.59a
Chroma	28.18b	28.95a	27.28b	25.83d	25.10d	27.29a	27.44a	26.39b	24.91c	24.94c	27.61a	26.45b	26.38b	24.61c	24.57c	28.15a	27.24ab	27.05b	25.29c	25.62c
Hue Angle	178.90b	178.92a	178.90b	178.87c	178.51d	178.93a	178.95a	178.94a	178.91b	178.51c	178.94a	178.95a	178.94a	178.88b	178.46c	178.90b	178.91a	178.90ab	178.86c	178.48d
Browning Index (BI)	49.47b	46.17bc	47.00bc	44.61c	73.79a	43.02b	41.15bc	40.33cd	39.66d	71.72a	42.16b	38.80c	39.39c	42.47b	73.09a	44.78b	41.05c	41.72c	42.14c	71.47a

*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 B6. Effect of storage conditions on the color values of extracted and unextracted coarse powder (derived from cilantro dried at 60°C).

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)	50.22ab	52.20ab	47.29c	48.45bc	47.44c	46.37b	48.45a	46.71b	45.94b	45.75b	46.90a	47.12a	45.90a	46.08a	44.26b	46.37ab	47.92a	46.56ab	46.38ab	45.62b
a* (greenness)	-14.12a	-15.06b	-13.47c	-11.76d	-3.40e	-13.65a	-13.97a	-13.15b	-11.76c	-4.12d	-12.71a	-13.02a	-12.43a	-9.40b	-2.62c	-13.67a	-14.13b	-13.10c	-11.90d	-3.77e
b* (yellowness)	26.95b	27.60a	25.21c	23.43d	25.45c	23.53b	23.39b	22.44c	20.75d	24.46a	23.74a	22.94b	22.10c	22.24c	23.48ab	23.29a	22.92a	22.23b	21.16c	23.24a
Chroma	30.43b	31.45a	28.58c	26.22d	25.68d	27.20a	27.24a	26.01b	23.85d	24.81c	26.93a	26.38a	25.36b	24.18c	23.63c	27.01a	26.93a	25.81b	24.28c	23.55d
Hue Angle	178.91a	178.93a	179.14a	178.89a	178.56b	178.95b	178.97a	178.96b	178.95b	178.60d	178.92a	178.95a	178.94a	178.83b	178.54c	178.96b	178.98a	178.96ab	178.94c	178.59d
Browning Index (BI)	48.22bc	46.07b	49.19b	42.38c	67.15a	41.70b	37.95d	38.20c	35.79d	65.28a	43.68b	39.81c	39.41c	45.94b	67.08a	40.73a	36.63ab	37.72b	36.52b	61.37a

*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.

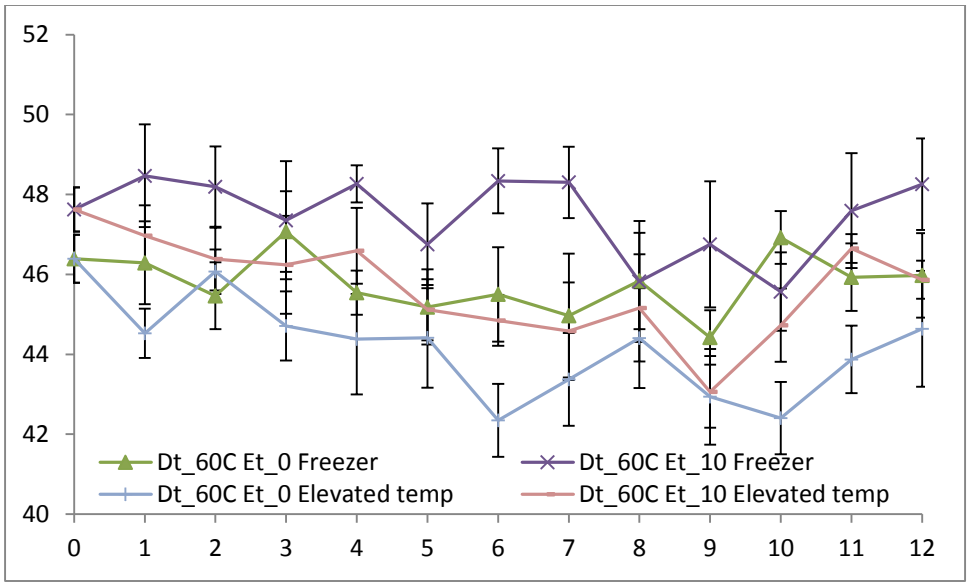

Figure B1: Effect of storage time on L* values of extracted and unextracted large flakes (derived from cilantro dried at 60°C) stored in freezer and at elevated temperature.

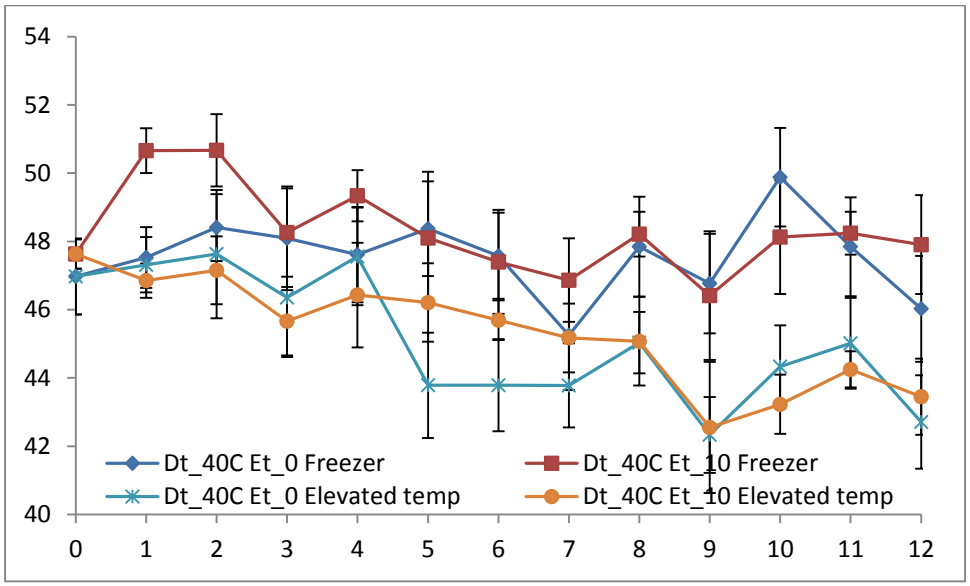

Figure B2: Effect of storage time on L* values of extracted and unextracted large flakes (derived from cilantro dried at 40°C) stored in freezer and at elevated temperature.

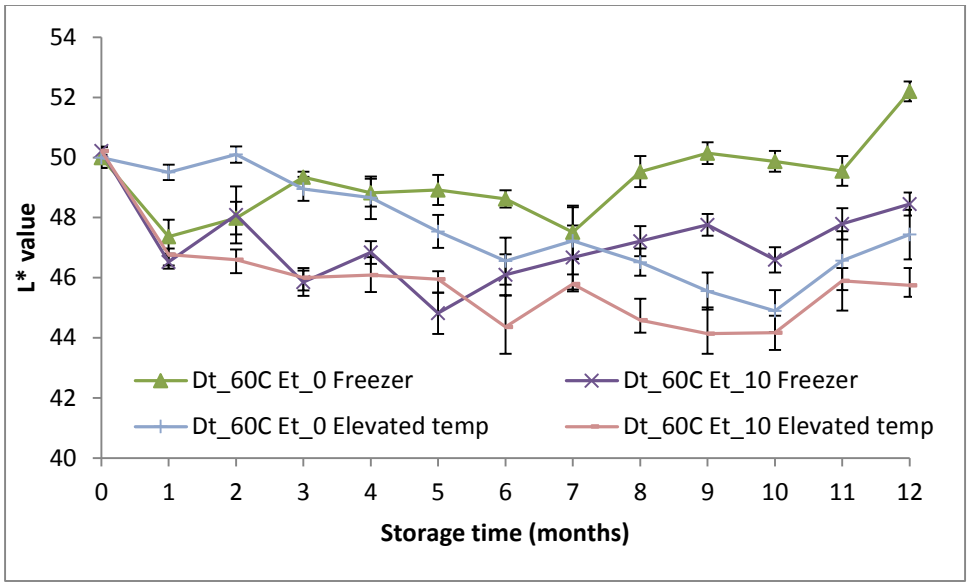

Figure B3: Effect of storage time on L* values of extracted and unextracted coarse powder (derived from cilantro dried at 60°C) stored in freezer and at elevated temperature.

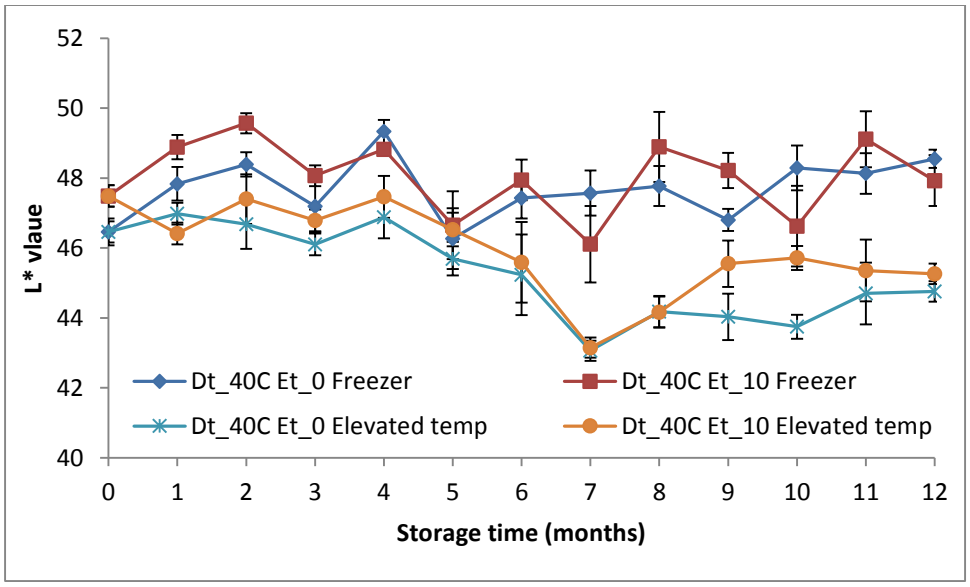

Figure B4: Effect of storage time on L* values of extracted and unextracted coarse powder (derived from cilantro dried at 40°C) stored in freezer and at elevated temperature.

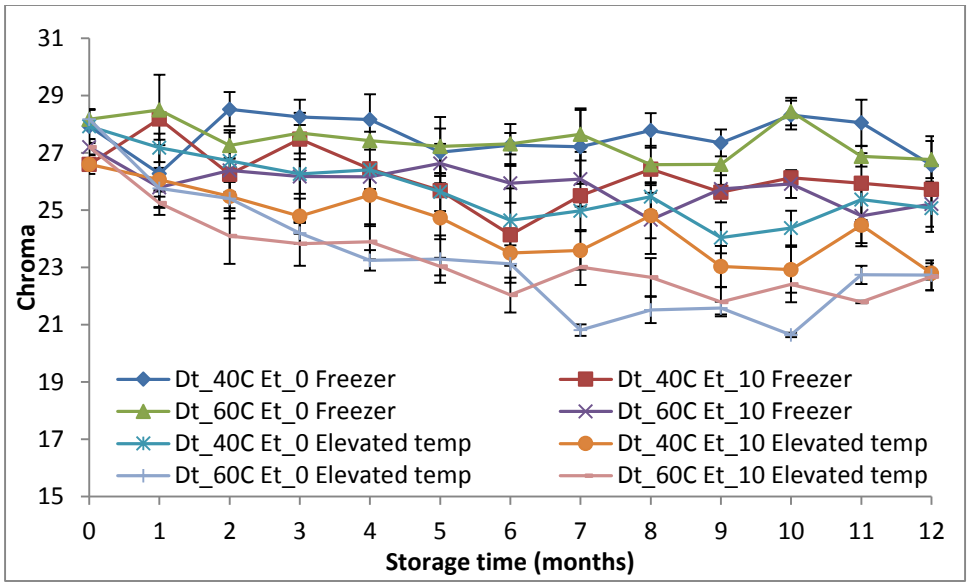

Figure B5: Effect of storage time on chroma values of extracted and unextracted large flakes stored in freezer and at elevated temperature.

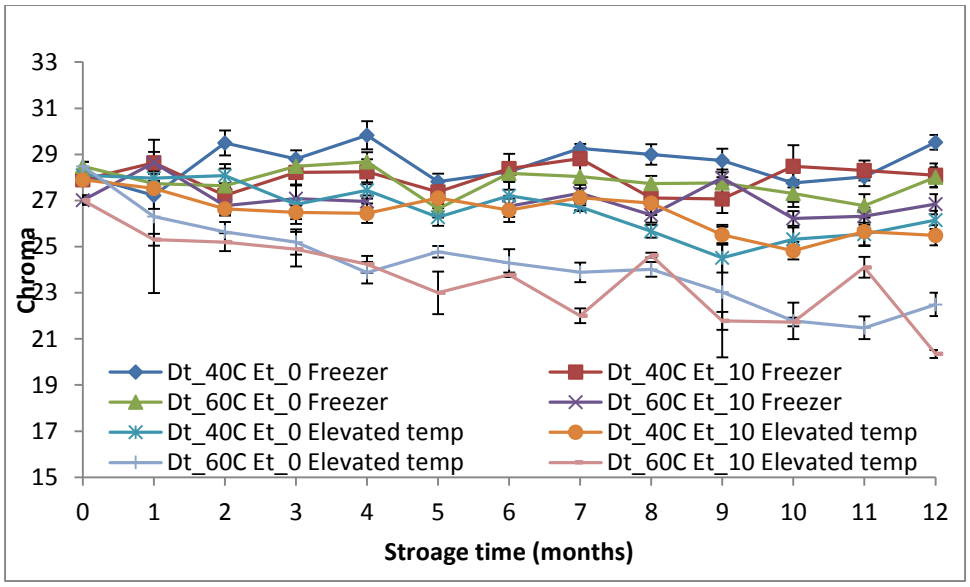

Figure B6: Effect of storage time on chroma values of extracted (10 min) and unextracted (0 min) small flakes stored in freezer and at elevated temperature.

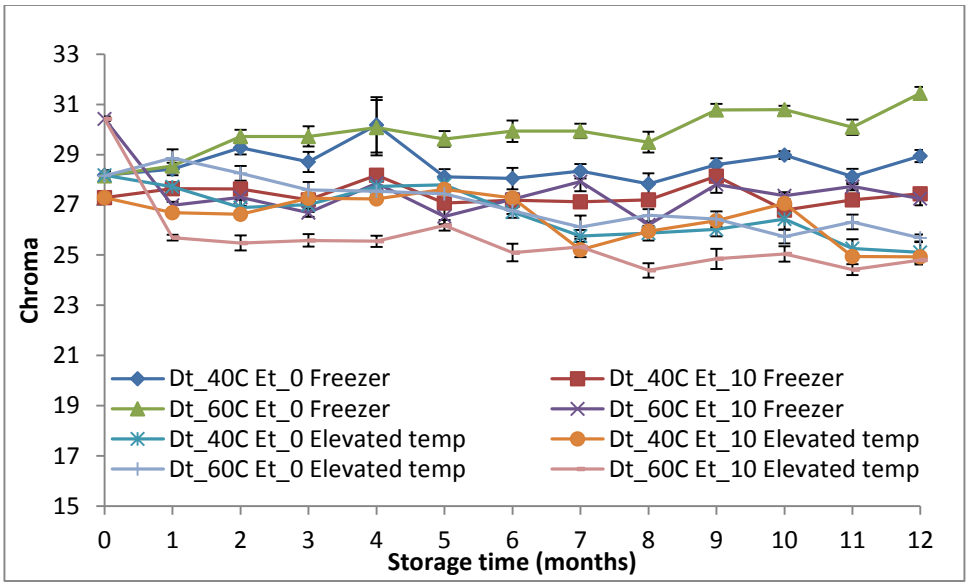

Figure B7: Effect of storage time on chroma values of extracted (10 min) and unextracted (0 min) coarse powder stored in freezer and at elevated temperature.

APPENDIX C

Table C1. Effect of storage conditions on the fatty acid composition of extracted and unextracted large flakes (derived from cilantro dried at 40°C).

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
Palmitic acid	2.56a	1.10b	1.20b	1.20b	1.94c	1.59b	1.3b0	1.1b1	1.27b	2.43a	1.80a	1.06b	1.00b	1.17b	1.95a	1.53b	1.14c	1.14c	1.33bc	1.97a
Palmitoleic acid	0.15	.	.	.	0.09	0.10	.	.	0.07	0.10	0.11	.	.	.	0.11	0.14	.	.	.	0.10
Cis-10-Heptadecenoic acid	1.43a	0.61c	0.81bc	0.58c	0.94b	0.80a	0.69a	0.49b	0.44b	0.72a	1.26a	0.72bc	0.81b	0.61c	0.90b	0.90a	0.74ab	0.58b	0.58b	0.78a
Stearic acid	0.29a	0.14b	0.14b	0.26a	0.22a	0.20ab	0.24ab	0.13b	0.14b	0.28a	0.24a	0.13b	0.10b	0.21a	0.24a	0.41a	0.17a	0.14a	0.21a	0.23a
Oleic acid	0.39a	0.16c	0.19c	0.20bc	0.26b	0.34a	0.24a	0.19a	0.21a	0.39a	0.46a	0.17b	0.14b	0.21b	0.29ab	0.35a	0.18b	0.21b	0.21b	0.28ab
Linoleic acid	6.04a	3.79b	4.12b	3.66b	5.34a	5.37ab	4.06ab	3.72ab	4.08ab	6.09a	5.29a	3.99b	3.44b	3.73b	5.07a	5.05a	3.66b	3.79b	4.21ab	4.87ab
Linolenic acid	4.06a	2.13b	2.57b	2.07b	3.53a	2.78a	2.37ab	1.86b	1.91b	3.32a	3.40a	2.35b	2.32b	2.13b	3.49a	3.09a	2.30b	2.05b	2.18b	3.16a
Total	14.92a	7.93b	9.05b	7.97b	12.32a	11.12a	8.91ab	7.50b	8.08ab	13.35a	12.56a	8.43b	7.80b	8.05b	12.05a	11.47a	8.20b	7.91b	8.73b	11.39a
%oil	3.00a	4.44b	4.22b	4.16b	3.85a	2.37c	3.45a	3.29ab	3.30ab	3.11b	2.54c	3.51a	3.22b	3.28b	3.25b	2.27b	2.79a	2.82a	3.06a	2.89a

*C: Control; FR: Freezer, RF: Refrigerator, R:Room temperature, ET: Elevated temperature. a, b, c, d, e denote significantly different concentrations of fatty acids (mg/g dried cilantro) (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 C2. Effect of storage conditions on the fatty acid composition of extracted and unextracted large flakes (derived from cilantro dried at 60°C.

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
Palmitic acid	2.16a	1.48b	1.28b	1.36b	2.11a	2.04a	1.33b	1.14b	1.27b	1.56b	1.55b	1.23bc	1.25bc	1.16c	1.99a	1.72a	1.25b	1.19b	1.25b	2.43a
Palmitoleic acid	0.33	0.06	.	.	0.09	0.17	.	.	.	0.05	0.09	.	.	.	0.07	0.07	.	.	.	0.15
Cis-10-Heptadecenoic acid	1.31a	1.00b	0.63c	0.58c	0.86b	0.95a	0.63b	0.52b	0.45c	0.49bc	0.81a	0.66a	0.67a	0.45b	0.71a	1.29a	0.74c	0.51d	0.58d	0.90b
Stearic acid	0.23a	0.18a	0.13a	0.13a	0.21a	0.19a	0.23a	0.11b	0.15b	0.18ab	0.15ab	0.12b	0.11b	0.10b	0.19a	0.24a	0.10b	0.10b	0.14b	0.25a
Oleic acid	0.52a	0.30bc	0.23c	0.25bc	0.39b	0.36a	0.27ab	0.22b	0.27ab	0.20b	0.46a	0.24a	0.24a	0.20a	0.34a	0.37ab	0.146c	0.191bc	0.25bc	0.47ab
Linoleic acid	6.60a	4.78b	4.23b	4.35b	6.28a	6.14a	4.12b	3.76b	4.11b	4.81a	5.89a	4.35b	4.36b	3.92b	5.77a	5.89a	4.34a	4.20a	4.17a	5.08a
Linolenic acid	4.02a	3.33b	2.31c	2.30c	3.49b	3.32a	2.44b	2.06c	1.98c	2.35b	3.48a	2.43ab	2.47ab	1.98b	3.10ab	3.44ab	2.45b	1.97b	2.16b	4.85a
Total	15.18a	11.13a	8.81b	8.97b	13.43a	13.11a	9.00bc	7.81c	8.23c	9.65b	13.17a	9.04b	9.10b	7.72b	12.18a	12.92a	8.61b	7.83b	8.42b	14.13a
%oil	2.76b	3.62a	3.38a	3.43a	3.46a	2.59b	3.56a	3.43a	3.43a	3.55a	2.39c	3.54ab	3.39ab	3.34b	3.71a	2.46b	3.47a	3.24a	3.42a	3.40a

*C: Control; FR: Freezer, RF: Refrigerator, R:Room temperature, ET: Elevated temperature. a, b, c, d, e denote significantly different concentrations of fatty acids (mg/g dried cilantro) (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 C3. Effect of storage conditions on the fatty acid composition of extracted and unextracted small flakes (derived from cilantro dried at 40°C).

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
Palmitic acid	1.73a	1.74a	1.49b	1.59a	1.97a	1.56b	1.19c	1.33c	1.47bc	2.27a	1.50b	2.17a	1.42b	1.61b	2.08ab	1.79ab	1.60ba	1.51c	1.32c	1.84a
Palmitoleic acid	0.17a	0.10a	0.05a	0.18a	0.10a	0.17ab	0.07b	0.07b	0.10ab	0.22a	0.24a	0.13a	0.08a	0.10a	0.86a	0.40a	0.09b	0.08b	0.09b	0.16b
Cis-10-Heptadecenoic acid	1.18a	2.00b	0.92a	0.96a	1.01a	1.97a	1.57a	1.51a	1.49a	1.76a	1.80a	1.84a	1.69a	1.68a	1.82a	1.98a	1.40b	1.70a	1.34b	1.47b
Stearic acid	0.26a	0.18a	0.18a	0.15a	0.15a	0.20a	0.16a	0.17a	0.14a	0.24a	0.32a	0.27a	0.18	0.23a	0.24a	0.20a	0.14b	0.19ab	0.13b	0.20a
Oleic acid	0.54a	0.36b	0.32b	0.35b	0.35b	0.37a	0.23a	0.31a	0.34a	0.35a	0.54a	0.40a	0.35a	0.40a	0.48a	0.42ab	0.27b	0.33ba	0.25b	0.43a
Linoleic acid	5.87a	4.80b	5.02ab	4.74b	5.82ab	4.84a	3.82b	3.93b	3.87b	4.55ab	4.31ab	5.17ab	4.17ab	4.05b	4.83a	4.57a	3.78ab	4.45a	3.46b	4.31a
Linolenic acid	4.60b	6.00a	3.27c	3.18c	4.02bc	6.05a	4.52b	4.45b	4.26b	5.73a	4.96a	5.31a	4.85b	4.63b	6.15a	5.09a	3.82b	4.70a	3.73b	5.03a
Total	14.37a	15.18a	11.22b	11.15b	13.44ab	15.16a	11.64b	11.77b	11.66b	15.13a	13.67a	15.28a	12.75b	12.71b	16.47a	14.32a	11.10b	12.95a	10.32b	13.44a
%oil	2.64b	3.38a	3.43a	3.50a	3.54a	3.10b	3.31ab	3.37ab	3.41ab	3.65a	3.00b	3.39a	3.33b	3.63a	3.61a	2.87b	3.22b	3.44a	3.50a	3.48a

*C: Control; FR: Freezer, RF: Refrigerator, R:Room temperature, ET: Elevated temperature. a, b, c, d, e denote significantly different concentrations of fatty acids (mg/g dried cilantro) (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 C4. Effect of storage conditions on the fatty acid composition of extracted and unextracted small flakes (derived from cilantro dried at 60°C).

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
Palmitic acid	1.20b	1.49b	1.40b	1.57b	2.20a	1.03b	1.80a	1.42ab	1.16b	1.79a	1.27b	1.88ab	1.24b	1.26b	1.95a	1.41a	1.44a	1.84a	1.33a	1.95a
Palmitoleic acid	0.08	0.06	0.06	0.08	0.20	0.13a	0.08b	0.06b	0.06b	0.13a	0.19a	0.08a	0.05a	0.08a	0.16a	0.23b	.	0.34a	0.05d	0.14c
Cis-10-Heptadecenoic acid	1.69a	1.90a	1.87a	1.68a	1.78a	0.85a	1.29b	1.85b	0.88a	0.98a	1.63a	1.55ab	1.35ab	1.08b	1.32ab	1.90a	0.82a	1.34a	0.72a	0.92a
Stearic acid	0.21a	0.20a	0.21a	0.21a	0.25a	0.13a	0.23a	0.20a	0.13a	0.22a	0.28a	0.23ab	0.18ab	0.14b	0.20ab	0.19a	0.18a	0.68a	0.15a	0.17a
Oleic acid	0.47a	0.25b	0.27b	0.28b	0.37ab	0.16b	0.26a	0.25a	0.20ab	0.22b	0.23a	0.22a	0.20a	0.20a	0.25a	0.55a	0.22b	0.32ab	0.27b	0.29b
Linoleic acid	3.71b	3.85b	4.25ba	3.93b	4.94a	2.70b	4.34a	4.14a	3.18b	3.91a	3.49a	4.16a	3.66ba	3.24b	4.01a	3.92a	3.88a	2.79a	3.65a	4.34a
Linolenic acid	4.51ab	4.70b	4.76ab	4.13b	5.78a	2.28b	3.46a	4.59a	2.56b	3.68a	3.91a	3.90ab	3.63ab	2.96b	4.47a	4.76a	2.56b	1.94b	2.41b	3.81ab
Total	11.87ab	12.45ab	12.82ab	10.51b	15.52a	7.29b	11.45a	12.46a	8.14b	10.93a	10.37a	12.05a	10.28a	8.97a	12.39a	12.95a	9.10b	9.03b	8.58b	11.62a
%oil	3.18b	3.26b	4.15a	3.84ab	4.20a	1.76 b	3.1a	3.30a	3.31a	3.30a	2.54b	3.37a	3.2a	3.39a	3.35a	3.07ab	2.88a	3.01ab	3.10b	2.93a

*C: Control; FR: Freezer, RF: Refrigerator, R:Room temperature, ET: Elevated temperature. a, b, c, d, e denote significantly different concentrations of fatty acids (mg/g dried cilantro) (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 C5. Effect of storage conditions on the fatty acid composition of extracted and unextracted coarse powder (derived from cilantro dried at 40°C).

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
Palmitic acid	1.83b	1.53c	1.95c	1.46c	2.53a	1.51b	1.20bc	1.10c	1.06c	2.42a	1.89a	1.15b	1.35b	1.27b	2.56a	1.56a	1.75a	1.14a	1.83a	1.48a
Palmitoleic acid	0.14b	0.09c	0.08c	0.10c	0.29a	0.10b	0.07b	0.07b	0.08b	0.31a	0.12b	0.08c	0.07c	0.10bc	0.32a	0.09a	0.06a	0.05a	0.07a	0.15a
Cis-10-Heptadecenoic acid	3.75a	2.83b	2.56b	2.12b	2.60b	2.90a	2.33ab	2.05bc	1.61c	2.20b	3.53a	1.83cb	1.91cb	1.72c	1.97b	2.57a	1.72b	1.44b	1.56b	1.17b
Stearic acid	0.20a	0.20a	0.18a	0.19a	0.22a	0.15b	0.16b	0.15b	0.13b	0.21ab	0.23a	0.11b	0.15b	0.13b	0.22a	0.17a	0.11a	0.14a	0.14a	0.14a
Oleic acid	0.32a	0.16c	0.22bc	0.21c	0.26b	0.33ab	0.17b	0.22b	0.20b	0.24b	0.48a	0.16d	0.20c	0.19c	0.25b	0.30a	0.10b	0.16b	0.18b	0.15b
Linoleic acid	5.21a	3.90bc	3.85bc	3.33c	4.54ab	4.04a	3.14ab	2.81b	2.46b	3.81a	4.85a	2.76c	2.67c	2.82c	3.73b	4.01a	2.67ab	2.54ab	2.75b	2.40b
Linolenic acid	8.89a	6.41b	5.98bc	5.05c	7.57b	7.09a	5.25ab	4.61b	3.89b	6.76a	8.43a	4.37c	4.36c	4.32c	6.61b	6.25a	4.15b	3.45b	3.86b	3.72b
Total	20.34a	15.06ba	14.27bc	12.45c	18.01ab	16.12a	12.33ab	10.99b	9.43b	15.94a	19.53a	10.47c	10.70c	10.56c	15.71b	14.95a	9.84b	8.80b	9.74b	9.21b
%oil	4.88a	4.29a	4.21a	4.50a	4.58a	3.56ab	3.37b	3.51ab	2.68c	3.78a	3.52a	3.33a	3.38a	2.91b	3.48a	3.06a	3.01a	3.03a	2.50b	3.13a

*C: Control; FR: Freezer, RF: Refrigerator, R:Room temperature, ET: Elevated temperature. a, b, c, d, e denote significantly different concentrations of fatty acids (mg/g dried cilantro) (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 C6. Effect of storage conditions on the fatty acid composition of extracted and unextracted coarse powder (derived from cilantro dried at 40°C).

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
Palmitic acid	2.19a	1.62b	1.55b	1.52b	2.05ab	1.56a	1.50a	1.46a	1.25b	1.89a	1.75a	1.31b	1.39ab	1.19b	1.78a	1.57a	1.31b	1.43ab	1.27b	1.70a
Palmitoleic acid	0.13a	0.09c	0.08c	0.09c	0.17b	0.22a	0.12a	0.11a	0.11a	0.23a	0.15b	0.09c	0.10c	0.10c	0.22a	0.14b	0.11b	0.10b	0.11b	0.21a
Cis-10-Heptadecenoic acid	2.79a	1.79b	1.71b	1.56b	1.60b	2.75a	2.45ab	2.14ab	1.68c	2.04bc	3.20a	2.39b	2.34b	1.85c	2.00c	2.79a	2.27ab	1.92bc	1.83bc	1.55c
Stearic acid	0.20ab	0.15b	0.21ab	0.16ab	0.33a	0.15ba	0.14b	0.17ba	0.14b	0.19a	0.14b	0.12b	0.19a	0.13b	0.15ab	0.13b	0.11b	0.16b	0.13b	0.20a
Oleic acid	0.42a	0.26b	0.30b	0.26b	0.55b	0.31a	0.20b	0.23b	0.19b	0.24b	0.30a	0.15bc	0.22b	0.14c	0.145c	0.29a	0.17b	0.21ab	0.20ab	0.31a
Linoleic acid	7.12a	5.00b	4.60b	4.28b	4.81b	4.58a	4.02a	3.73ab	2.94b	3.77ab	4.55a	3.45b	3.42b	2.82b	3.42b	4.20a	3.46ba	3.84ab	2.92b	3.10ba
Linolenic acid	8.10a	5.10b	4.83b	4.48b	5.35b	7.76a	6.62a	5.97ab	4.59b	6.41ab	8.01a	5.61b	5.52b	4.50c	6.00b	7.50a	5.68b	5.28b	4.64b	5.51b
Total	20.95a	14.00b	13.29b	12.36b	14.86b	17.29a	15.06a	13.75ab	10.90b	14.78ab	18.10a	13.13b	13.16b	10.72b	13.73b	16.61a	13.10b	12.81b	11.02b	12.72b
%oil	3.83a	3.63c	3.64c	2.76d	3.73b	3.41a	3.58a	3.86a	3.84a	3.64a	3.74a	3.50b	3.48b	3.31b	3.31b	3.41a	3.39a	3.30ab	3.12b	3.28ab

*C: Control; FR: Freezer, RF: Refrigerator, R:Room temperature, ET: Elevated temperature. a, b, c, d, e denote significantly different concentrations of fatty acids (mg/g dried cilantro) (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.

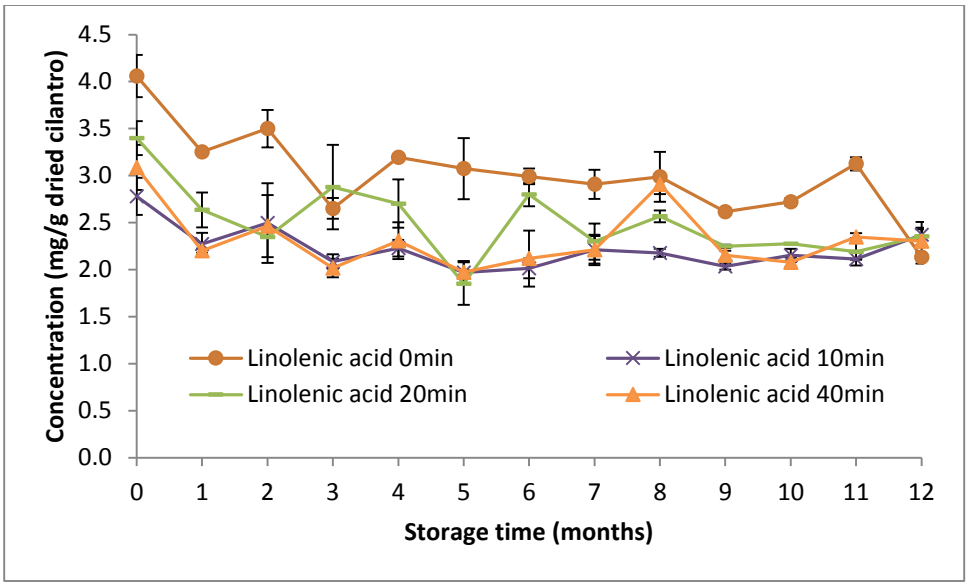

Figure C1. Effect of storage in freezer on the concentration of α-linolenic acid in large flakes (derived from cilantro dried at 40°C) extracted for 0, 10, 20 and 40 min.

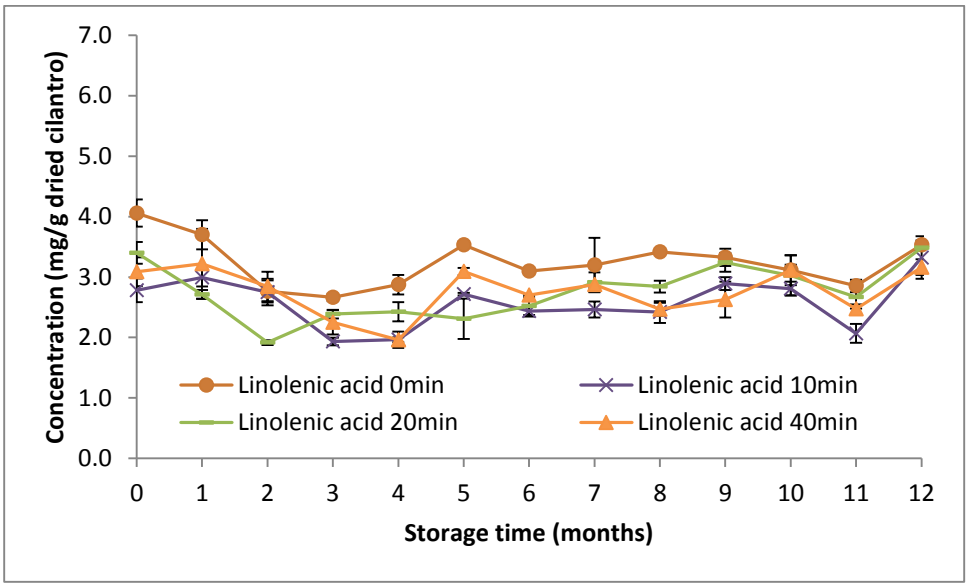

Figure C2. Effect of storage at elevated temperature on the concentration of α-linolenic acid in large flakes (derived from cilantro dried at 40°C) extracted for 0, 10, 20 and 40 min.

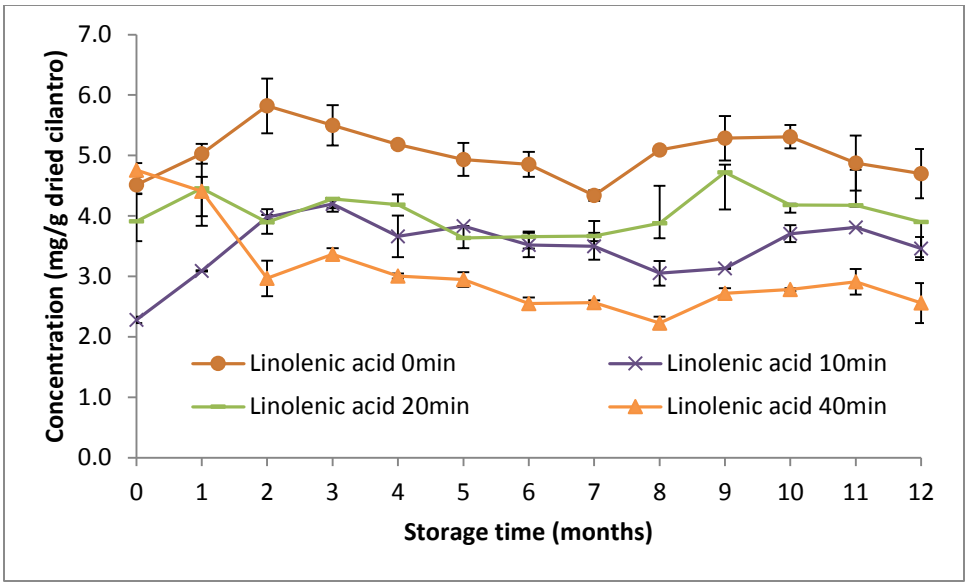

Figure C3. Effect of storage in freezer on the concentration of α-linolenic acid in small flakes (derived from cilantro dried at 40°C) extracted for 0, 10, 20 and 40 min.

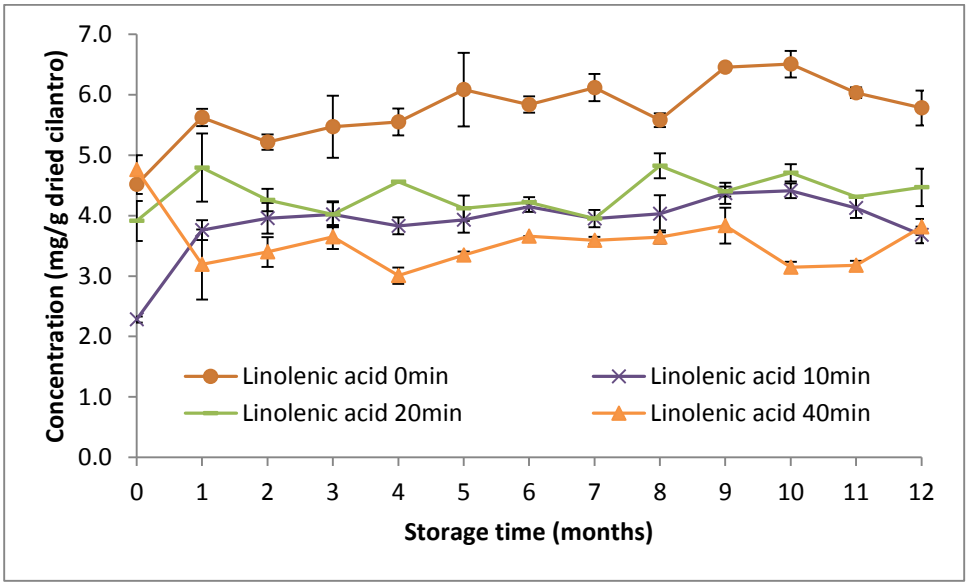

Figure C4. Effect of storage at elevated temperature on the concentration of α-linolenic acid in small flakes (derived from cilantro dried at 40°C) extracted for 0, 10, 20 and 40 min.

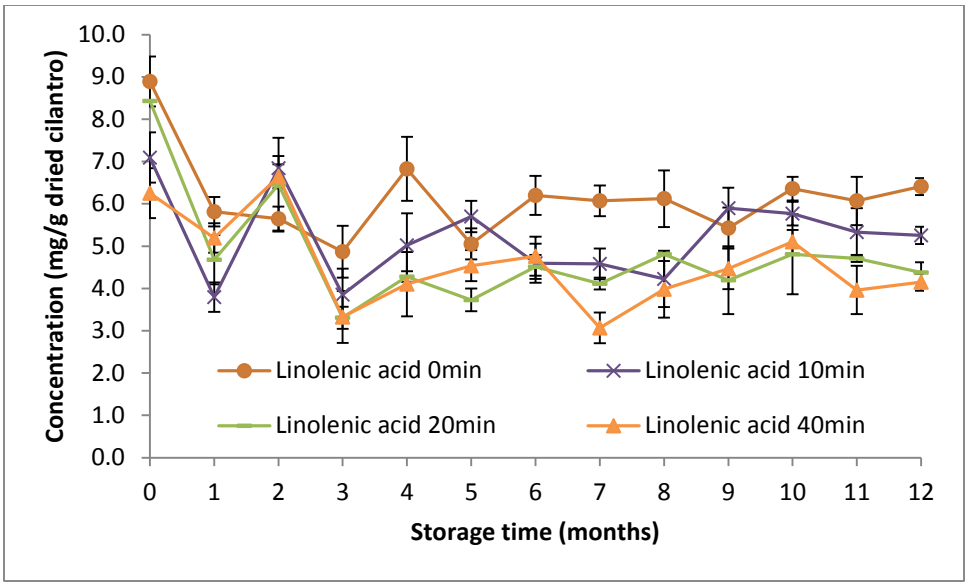

Figure C5. Effect of storage in freezer on concentration of α-linolenic acid in coarse powder (derived from cilantro dried at 40°C) extracted for 0, 10, 20 and 40 min.

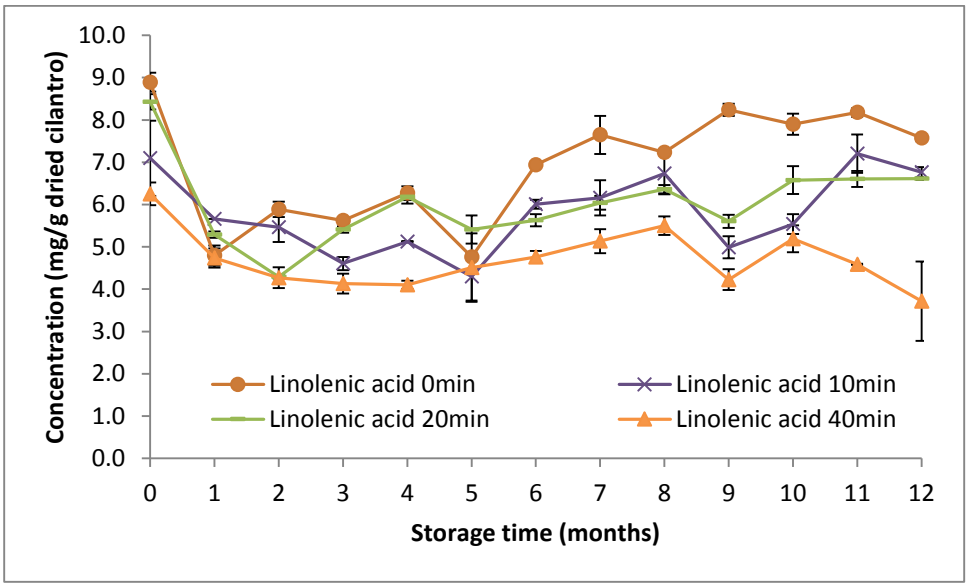

Figure C6. Effect of storage at elevated temperature on concentration of α-linolenic acid in coarse powder (derived from cilantro dried at 40°C) extracted for 0, 10, 20 and 40 min.

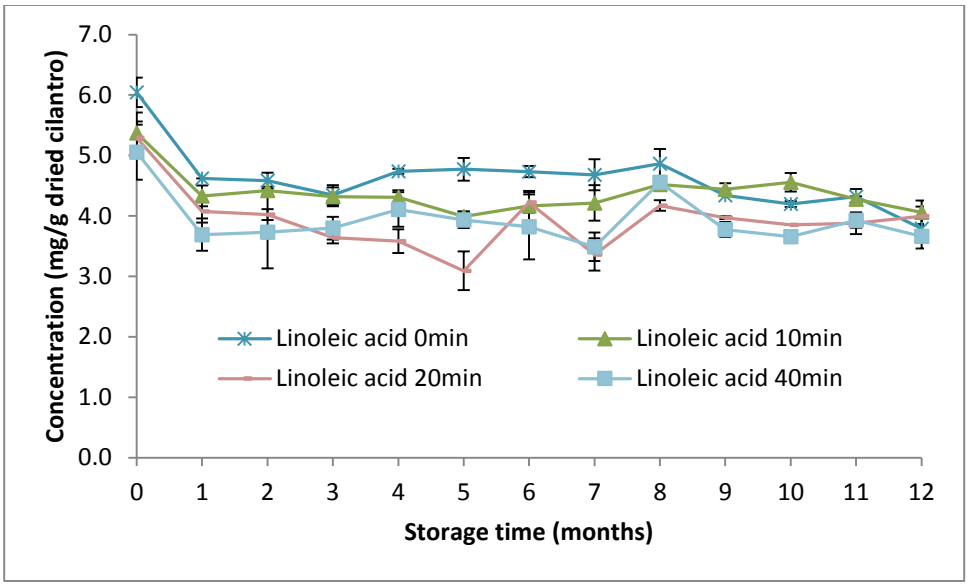

Figure C7. Effect of storage in the freezer on concentration of linoleic acid in large flakes (derived from cilantro dried at 40°C) extracted for 0, 10, 20 and 40 min.

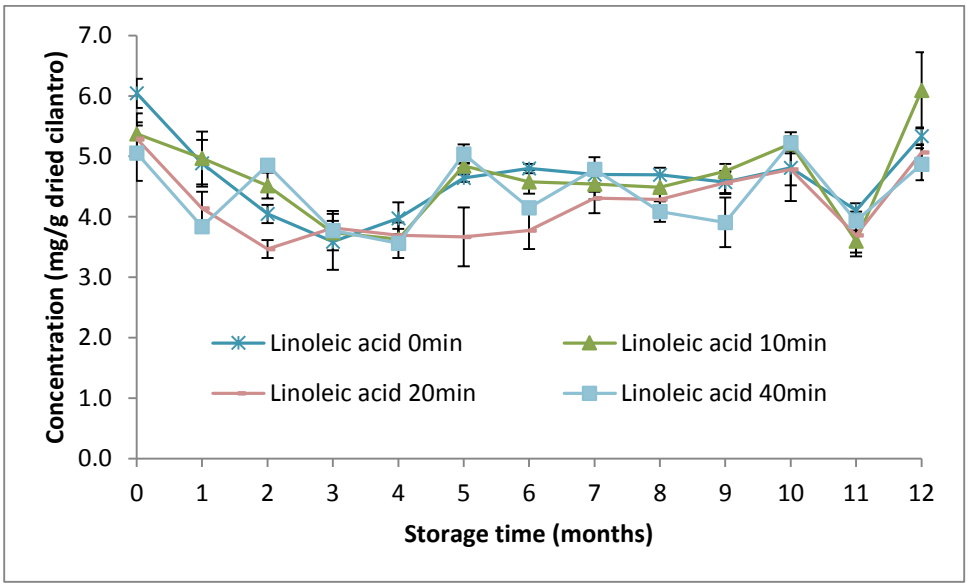

Figure C8. Effect of storage at elevated temperature on concentration of linoleic acid in large flakes (derived from cilantro dried at 40°C) extracted for 0, 10, 20 and 40 min.

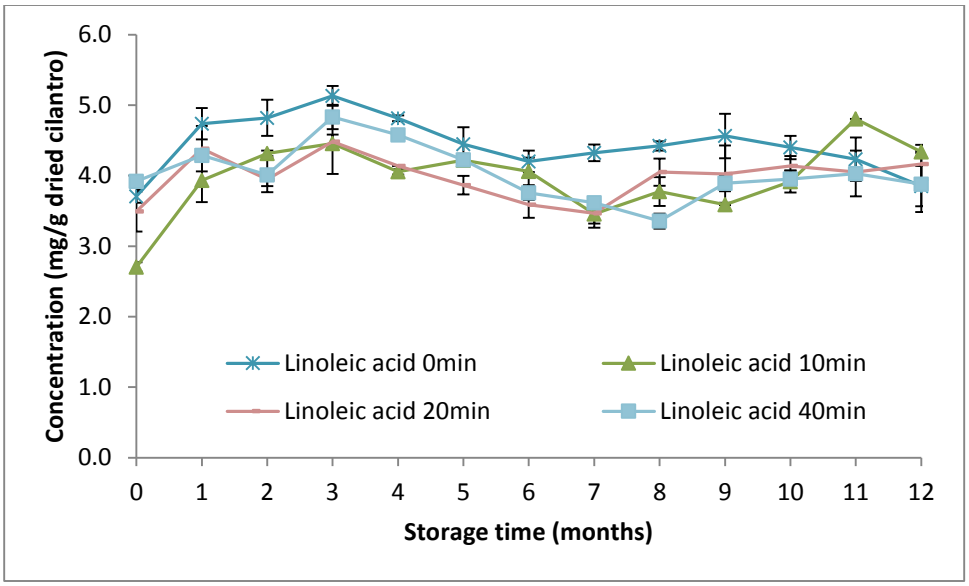

Figure C9. Effect of storage in the freezer on concentration of linoleic acid in small flakes (derived from cilantro dried at 40°C) extracted for 0, 10, 20 and 40 min.

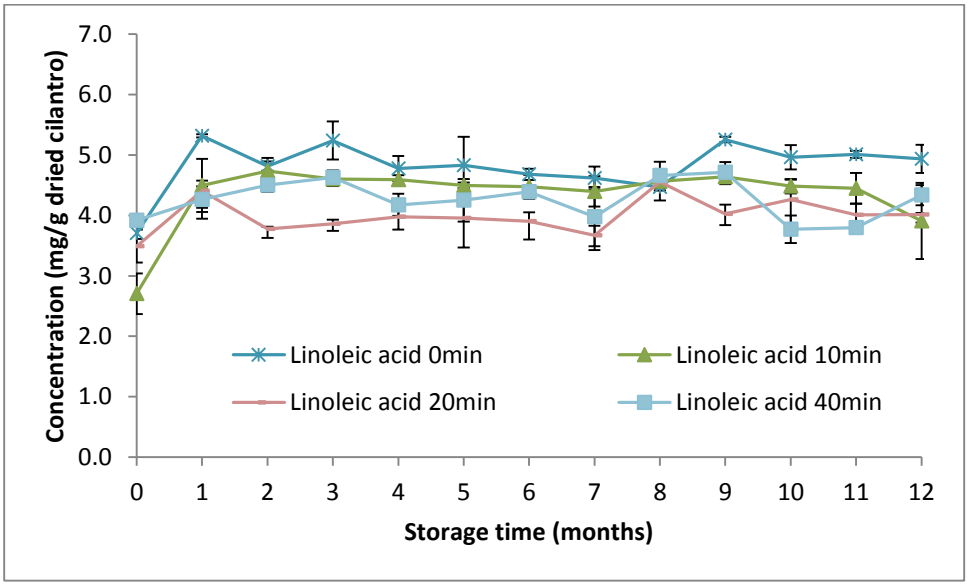

Figure C10. Effect of storage at elevated temperature on concentration of linoleic acid in small flakes (derived from cilantro dried at 40°C) extracted for 0, 10, 20 and 40 min.

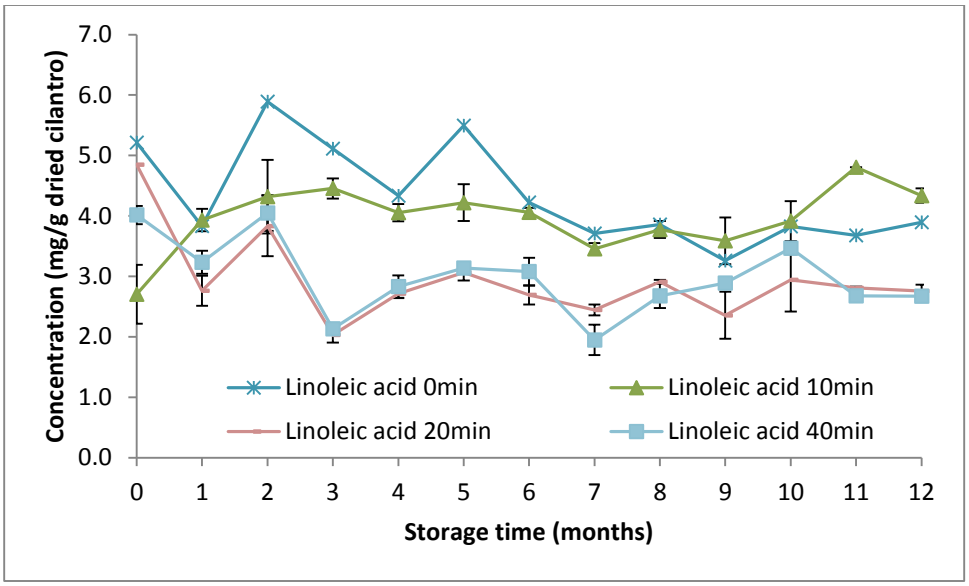

Figure C11. Effect of storage in the freezer on concentration of linoleic acid in coarse powder (derived from cilantro dried at 40°C) extracted for 0, 10, 20 and 40 min.

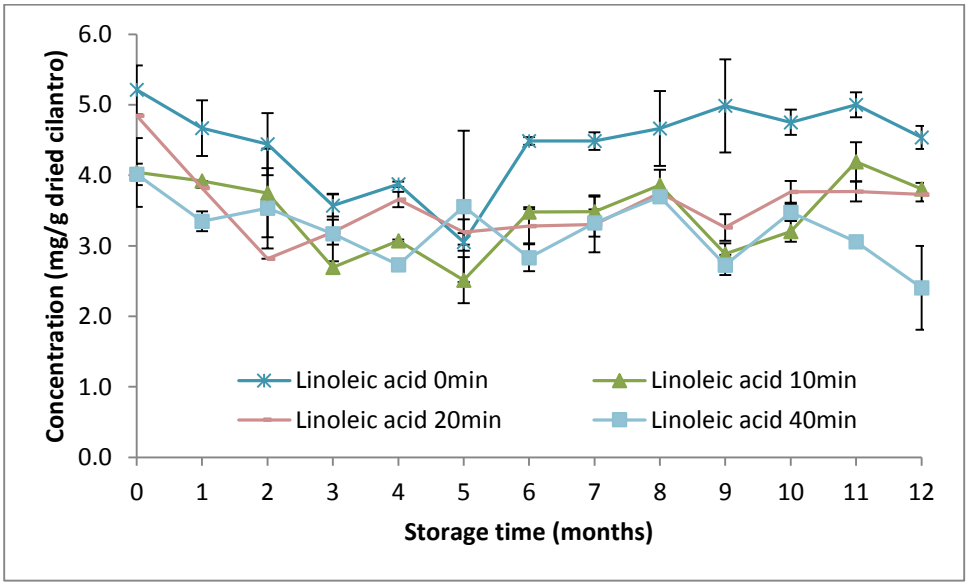

Figure C12. Effect of storage at elevated temperature on concentration of linoleic acid in coarse powder (derived from cilantro dried at 40°C) extracted for 0, 10, 20 and 40 min.

VITA

Jasreen Kaur Sekhon

Candidate for the Degree of

Doctor of Philosophy/Education

Thesis: EFFECT OF DRYING TEMPERATURE, SIZE REDUCTION, PROPANE EXTRACTION, AND STORAGE TEMPERATURE ON THE QUALITY AND SHELF LIFE OF CILANTRO (*CORIANDRUM SATIVUM* L.)

Major Field: Biosystems Engineering

Biographical:

Education:

Completed the requirements for the Doctor of Philosophy/Education in your major at Oklahoma State University, Stillwater, Oklahoma in May, 2013.

Completed the requirements for the Master of Science/Arts in Processing and Food Engineering at Punjab Agricultural University, Ludhiana, Punjab/India in September, 2006.

Completed the requirements for the Bachelor of Science in your Food technology at Sant Longowal Institute of Engineering and Technology, Longowal, Punjab/India in July, 2004.

Experience:

Research Associate, Department of Horticulture & Landspace Architecture, Oklahoma State University.

Graduate Teaching Assistant, Department of Biosystems & Agricultural Engineering, Oklahoma State University.

Graduate Research Assistant, Department of Biosystems & Agricultural Engineering, Oklahoma State Unviersity.

Professional Memberships:
American Chemical
American Society of Agricultural and Biological
Vice President, Biosystems & Agricultural Engineering Graduate Student
Phi Kappa Phi