# EFFECTS OF DRYING METHODS (SOLAR AND CABINET) AND PACKAGING MATERIAL (LDPE AND HDPE) ON RETENTION OF β-CAROTENE IN DEHYDRATED CARROT (*Dacus carota)*

by

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# Effects of Drying Methods (Solar and Cabinet) and Packaging Material (LDPE and HDPE) on Retention of β-Carotene in Dehydrated Carrot (*Dacus Carota)*

***A dissertation submitted to the Department of Food Technology, Central Campus of Technology, Tribhuvan University, in partial fulfillment for the degree of B.Tech. in Food Technology***

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## Approval Letter

**This *dissertation* entitled *Effects of Drying Methods (Solar and Cabinet) and Packaging Material (LDPE and HDPE) on Retention of β-Carotene in Dehydrated Carrot (Dacus Carota)* presented by Saurab Sanjel has been accepted as the partial fulfillment of the requirement for the B. Tech. degree in Food Technology**

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# Abstract

Carrots are a root vegetable also known as *Daucus carota*, a member of the Umbelliferae family and thus related to parsley, dill and celery.The aim of this study was to study the retention of β-carotene at solar and cabinet drying conditions and storage of dehydrated carrot. The fresh carrot (*Daucus carota)* of 8 weeks after sowing was taken and washed with clean water and cubed into uniform thickness of 1 cm × 1cm × 1cm. The cubes were blanched at 98°C water for 0, 30, 60, 90, 120, 150, 180 and 210 s to optimize the blanching time by peroxidase test. Then the carrot cubes were dried at cabinet drier at 60±5°C for 8 h and solar drier until equilibrium moisture content was obtained. Similar drying was done for unblanched carrot cubes. After drying the drying condition was optimized according to the retention of β-carotene content. Then the rehydration of dried carrot was done to study rehydration properties. And, the optimized sample was powdered and powdered samples (250 g) were stored in Low-Density Polyethylene (LDPE) of 40μ and High-Density Polyethylene (HDPE) of 50μ packaging at 27ºC and β-carotene retention was studied at interval of 10 days for 60 days.

The optimized blanching condition was found to be at 98°C water for 3.5 min. The higher β-carotene retention of 30.21 mg/100 g was found for blanched carrot sample dried at cabinet dryer at 60°C for 8- h. The desorption rate was higher for the blanched cabinet dried sample. The rehydration properties of all the samples (solor and cabinet dried carrot) were not found to be significantly difference. During storage of carrot powder in LDPE packaging material and HDPE packaging for 60 days, β-carotene destruction was high for LDPE packaging (26.06 mg/ 100 g to 8.88 mg/ 100 g) than that of HDPE packaging (26.06 mg/ 100 g to 15.89 mg/ 100 g). So, it can be concluded that β-carotene can be retained more by drying blanched carrot in cabinet dryer at 60±5°C for 8 h.

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## List of Abbreviations

| Abbreviations | Full form |
|---|---|
| AHA | American Heart Association |
| $a_w$ | Water activity |
| CCT | Central Campus of Technology |
| HIV | Human Immuno Deficiency Virus |
| HTST | High temperature short time |
| LTLT | Low temperature long time |

# Part I

# Introduction

## 1.1 General introduction

Carrots (*Daucus carota)* are the most common and popular vegetable in the world. They are good source of natural antioxidants, especially carotenoids, which are a group of fat-soluble pigments characterized by a linear, long-chain polyene structure. The presence of high concentration of antioxidants, carotenoids, especially β-carotene, may account for the biological and medicinal properties of carrots but the loss of β-carotene during processing and storage is well established (Demiray and Tulek, 2016).

Drying is one of the oldest methods of food preservation. It is a simultaneous heat and mass transfer operation in which moisture is removed from food material and carried away by hot air (Sogi *et al.*, 2003). Longer shelf-life, product diversity and volume reduction are the reasons for the popularity of dried fruits and vegetables. Several degradation reactions that affect the color, nutrient properties, texture and flavor of fruits and vegetables during drying (Koca *et al.*, 2007). Degradation of β-carotene not only affects the color of carrot but also its nutritive value and flavor. The stability of β-carotene during carrot drying is a very important objective to make the final product acceptable. Kinetic parameters including reaction order, rate constant, $Q_{10}$ value, half-life time and activation energy are significant predict the quality of foods when they are processed. The effect of drying on carrot quality has been studied by several researchers(Demiray and Tulek, 2014). However, the literature contains few references on the degradation kinetics of β-carotene in carrot during drying (Hiranvarachat *et al.*, 2011).

The enzymes commonly found to have deteriorative effects in carrots are peroxidases (PODs) and catalase. In order to minimize deteriorative reactions, fruits and vegetables are heat treated or blanched to inactivate the enzymes. Blanching of fruits and vegetables are done either in hot water, steam or selected chemical solutions. Blanching in calcium chloride solution is used to increase the firmness of fruits and vegetables, because of the activation of pectinmethylesterase when immersed in hot calcium chloride solution. The inactivation of POD is usually used to indicate blanching sufficiency as POD is ubiquitous and considered to be among the most heat-resistant plant constitutive enzymes. While

blanching leads to some favorable factors, like the inactivation of enzymes, expelling trapped air in the intracellular regions and reducing any initial infections, it also causes loss of nutritional quality. Therefore, the optimization of the blanching process with respect to nutrient retention (β-carotene, vitamin C loss) and product yield should be considered along with the inactivation of enzymes. The variables, such as temperature and time of treatment, and concentration and nature of the acid or salt in the blanching solution, determine the effectiveness of the blanching process (Shivhare *et al.*, 2009).

## 1.2 Statement of problems

Carrots (*Daucus carota*), one of the important root vegetables, are known for their nutrient contents viz. β-carotene besides appreciable amount of vitamins and minerals (Walde *et al.*, 1992). Dehydrated vegetables, when exposed to air, lose color due to oxidation of highly unsaturated molecules. The degradation of β-carotene is reportedly associated with the development of off-flavors in dehydrated carrots and sweet potato flakes (Walter *et al.*, 1970). Lipoxygenases are the major enzymes involved in carotene degradation; they are thermostable (Kalac and Kyzlink, 1980) and capable of forming reactive radicals that destroy carotenoids in vegetables (Holden, 1970). The activities of these enzymes can be decreased by blanching (Reeve, 1943). Goldman *et al.* (1983) demonstrated that beta-carotene retention curves are sigmoidal with three regionsinitiation, acceleration, and retardation which are typical of autocatalytic radical reactions.

Several deteriorative reactions that affect the color, nutrient properties, texture, and flavor of dehydrated products are initiated during processing (blanching, drying, rehydration), and continue during storage. Color is one of the most important attributes of dried food products, since it influences consumer acceptability. Dehydrated vegetables also change their color due to the oxidation of highly unsaturated molecules upon exposure to air during processing. Particularly, carotenoids are subjected to rapid decomposition in the presence of oxygen. In case of carrots, the color is determined by the concentration of principle components: α- and β-carotene, as they constitute over 90% of all carotenoids. Therefore, a loss of natural color of carrot tissue depends on thermal destruction of these key carotenoids. Degradation of carotenoids affects not only the color of food products but also their nutritive value and flavor (Zielinska and Markowski, 2012).

Blanching followed by freezing is an effective preservation technique for the retention of β-carotene in fruits and vegetables. Frozen food products maintain most of the physical, chemical and sensory properties of β-carotene. But, many of the physical, chemical, enzymatic and microbial changes which contribute to frozen food quality are highly dependent on storage conditions namely the combined effects of time and temperature. It is well known that abusive temperature conditions during storage and handling may lead to frozen products of inferior quality (Dutta *et al.*, 2005).

The study on retention of β-carotene of carrot by blanching followed by drying is very less. So, this study is carried out to know about the retention of β-carotene during blanching and drying of carrot.

## 1.3 Objectives

### 1.3.1 General objective

The general objective of this study is to study the effect of drying methods (solar and cabinet) and packaging materials (LDPE and HDPE) on retention of β-carotene in dehydrated carrots.

### 1.3.2 Specific objectives

a. To optimize the blanching time for carrot cube.
b. To study the desorption isotherm of carrot samples at different drying methods.
c. To study the β-carotene retention at different drying methods of carrot samples.
d. To study the rehydration properties of carrot samples dried at different drying methods.
e. To study the β-carotene retention during storage of dried carrot samples in different packaging materials (LDPE and HDPE).

## 1.4 Significance of study

The role of β-carotene has been subjected to vigorous studies in the recent years. Numerous epidemiological studies under diverse conditions have repeatedly demonstrated that populations that consume large amount of fruits and vegetables rich in β-carotene have dramatically lower risk of contracting various cancers (Wald *et al.*, 1988). β-carotene is also claimed to protect against Alzheimer's disease (Zaman *et al.*, 1992) and act as a

suppressor of the HIV (Garewal *et al.*, 1992). The nutritional properties of β-carotene have been studied extensively, and its role as an antioxidant has been widely reported (Palozza and Krinsky, 1992). The tissue maintenance function of vitamin A is apparently related to its antioxidant function, most or all of which can be taken over by β-carotene. β-carotene is the principal precursor of vitamin A, which is involved in vision, cell differentiation, synthesis of glycoproteins, mucus secretion from the epithelial cells, and overall growth and development of bones (Wolf, 1980). Diets that are deficient in vitamin A have precipitated the death of children from measles, diarrhea, and other diseases because of impaired immunity (Sommer *et al.*, 1983). So, the retention of β-carotene in carrot is essential during preservation by drying.

## 1.5 Limitations of the study

1. Only cabinet and solar drying were performed for drying of carrot.
2. Storage stability was only studied for 60 days due to time limitation.
3. Other functional components were not studied due to time limitation.

# Part II

## Literature review

### 2.1 Carrot

The carrot (*Daucus carota* subsp. *sativus*) is a root vegetable, usually orange in colour, though purple, black, red, white, and yellow cultivars exist. Carrots are a domesticated form of the wild carrot, *Daucus carota*, native to Europe and southwestern Asia. The plant probably originated in Persia and was originally cultivated for its leaves and seeds. The most commonly eaten part of the plant is the taproot, although the stems and leaves are eaten as well. The domestic carrot has been selectively bred for its greatly enlarged, more palatable, less woody-textured taproot (Sifferlin, 2013).

The carrot is a biennial plant in the umbellifer family Apiaceae. At first, it grows a rosette of leaves while building up the enlarged taproot. Fast-growing cultivars mature within three months (90 days) of sowing the seed, while slower-maturing cultivars are harvested four months later (120 days). The roots contain high quantities of alpha- and beta-carotene and are a good source of vitamin K and vitamin B6, but the belief that eating carrots improves night vision is a myth put forward by the British in World War II to mislead the enemy about their military capabilities (Anon., 2018a).

#### 2.1.1 Origin and history

It is believed that the Carrot originated some 5000 years ago in Middle Asia around Afghanistan, and slowly spread into the Mediterranean area. The first recorded carrots (ad 900 Afghanistan) were mainly purple or yellow, with some white or black - not orange. The Orange colour, so familiar today, was not clearly mentioned until the 1500's although some interpretations of early manuscripts and drawings therein, leave that possibility open (Anon., 2016).

Home of carrots and its numerous cousins can be tracked to dry and hot lands of Iran and Afghanistan. Earliest evidence of its use there was dated to 3000 BC. From there, carrot seeds were picked, carried and sold via caravans to neighboring Arabian, African and Asian lands, who all accepted carrots immediately and started crossbreeding and creating new types of this famous root. Even in those ancient times, many colors of carrots

were present and used – black, white, red and purple. Interestingly, orange colors that we use today were not present. The most telling sign of how popular carrots were in those ancient times come from Ancient Egypt, where numerous carrots were placed in the tombs of dead Pharaohs and the drawings of the carrot harvest and processing can be found in numerous hieroglyph paintings. The most popular color of carrots that was cultivated in Egypt was purple, and it was used not only for eating but also for medicine (Anon., 2018b).

Tradition of medicinal carrot usage moved from Egypt to Greece and Rome in 1st millennia BC. There, bitter and hard to eat carrots were used as a healing remedy for many illnesses and was especially used as a sexual aphrodisiac (the most famous recorded instance of such use happened during the reign of Roman emperor Caligula). As for eating in regular meals, Romans were known to boil carrots and eat it with live dressings and various herbs (Anon., 2018b).

By 13th century carrots traveled from Persia to Asia, reaching distant Japan. During same time, European carrot started being cultivated in gardens and fields of France and Germany. Those carrots were biter, but they were nutritious and its popularity enabled quick spread across entire Europe. In 1609, English settlers of the New World started cultivating Carrots in their first city of Jamestown, Virginia (20 years later production moved to Massachusetts. Brazil was the first South American country to receive carrots in mid-17th century, and not much later carrot arrived to Australia (Anon., 2018b).

Modern yellow carrot appeared in Netherlands during 17th century as a tribute to the ruling House of Orange. After years of selective breeding, Dutch yellow carrot was engineered to be without bitterness, increased sweetness and minimal wooden core. This carrot type named "*Daucus carota*" quickly became popular across entire Europe (Anon., 2018b).

American cuisine did not include carrots for the longest of times. It was accepted to the American homes only after World War I when soldiers returning home brought stories and seeds of incredible French and other European cuisine which greatly help them to survive war years. Modern popularity of carrot and its presence in both savory and sweet meals can be traced to World War 2 England, where government actively encouraged home growing of carrots (Anon., 2018b).

Currently, the largest producer and exporter of carrots in the world is China. In 2010, 33.5 million tons of carrots and turnips were produced worldwide, with 15.8 million tons in China, 1.3 million tons in United States, 1.3 million tons in Russia, 1 million tons in Uzbekistan and less than a million in Poland, United Kingdom and Ukraine (Anon., 2018b).

### 2.1.2 Anatomy of carrot root

The roots of certain vegetable crops are important as food. Roots typically originate from the lower portion of a plant or cutting. They possess a root cap, have no nodes and never bear leaves or flowers directly. The principal functions of roots are to absorb nutrients and moisture, to anchor the plant in the soil, to furnish physical support for the stem, and to serve as food storage organs. The purpose of a root is to anchor the plant to the ground and to absorb water and nutrients. The example of this is carrot root (Booth, 1951).

Plants have two different types of transport tissue: the xylem (core) transports water and solutes from the roots to the leaves, and the phloem (flesh) transports food from the leaves to the rest of the plant. Transpiration is the process by which water evaporates from the leaves, which results in more water being drawn up from the roots. The majority of the carotenoid content is contained in the phloem (outer flesh) (Booth, 1951).

The tap common root type of carrot root system develops from the hypocotyl with secondary lateral roots branching from the xylem. Together, the hypocotyl and the tap root form the carrot root. At the center of the root is the light coloured and woodier xylem surrounded by the deep orange and sugar loaded phloem (Thompson, 1969).

The periderm skin is composed of suberin and other waxy substances. Optimum root growth occurs at 60-70°F. Temperatures into the 50’s will affect the colour development and favour longer, more slender roots (Thompson, 1969).

The root normally comprises 6 elements:

#### 2.1.2.1 The root cap

Conical covering of the tip of the root which covers the apical meristem (undifferentiated cells). It protects against scratches while moving through the soil and excretes a mucus like

substance called mucigel that allows the root to move through the soil easily (Anon., 2017).

#### 2.1.2.2 Epidermis (skin)

Is the hard-outer layer on a root absorbing water from surrounding soil through osmosis. It is also known as the Peel, or periderm. Roots take water from the capillary spaces between soil particles. This function is carried out by the young portions of the roots at the location of minimal cutinisation of the epidermis and at maximum surface area. This location is found in the root-hair zone just proximal from the growing root tip. Thus roots take in their water through very fine roots located at the drip-line of the plant's canopy (Anon., 2017).

#### 2.1.2.3 Root hairs

These are small, microscopic hairs on the outside of the epidermis and serve to increase the surface area of the root. They only survive for only a few days (Anon., 2017).

#### 2.1.2.4 The cortex

Is located below the epidermis. Makes up the bulk of the primary root. Main purpose is to store starches. The sugar and carotene are contained in the Cortex.The Cortex is comprised of the phloem, or nutrient conducting tissue - phloem conducts photosynthate from the leaves to the root tips. The metabolism of roots growing in the dark of the soil is essentially dependent upon respiration. This process requires carbohydrate or other organic molecules as fuel. It also requires a supply of oxygen, which is why soil needs to drain well for good plant growth (Anon., 2017).

#### 2.1.2.5 Endodermis

This is the thin layer of cells in the center of the cortex surrounding the xylem and phloem. It forces minerals into the xylem and phloem (Anon., 2017).

#### 2.1.2.6 Central Core

The Central Core comprised of xylem (a water conducting tissue, transporting water from root to leaf) All Roots contain xylem to conduct water from the soil up the plant and out through the leaves. These xylem tracheids and/or vessels are connected to others in an end-

to-end design allowing soil water and minerals to be lifted up to the leaves. The evaporation of water from the leaves is the major pull of water through the xylem, but roots can also develop "root pressure" osmotically when the soil is well-watered and the plant has sufficient reserves (Anon., 2017).

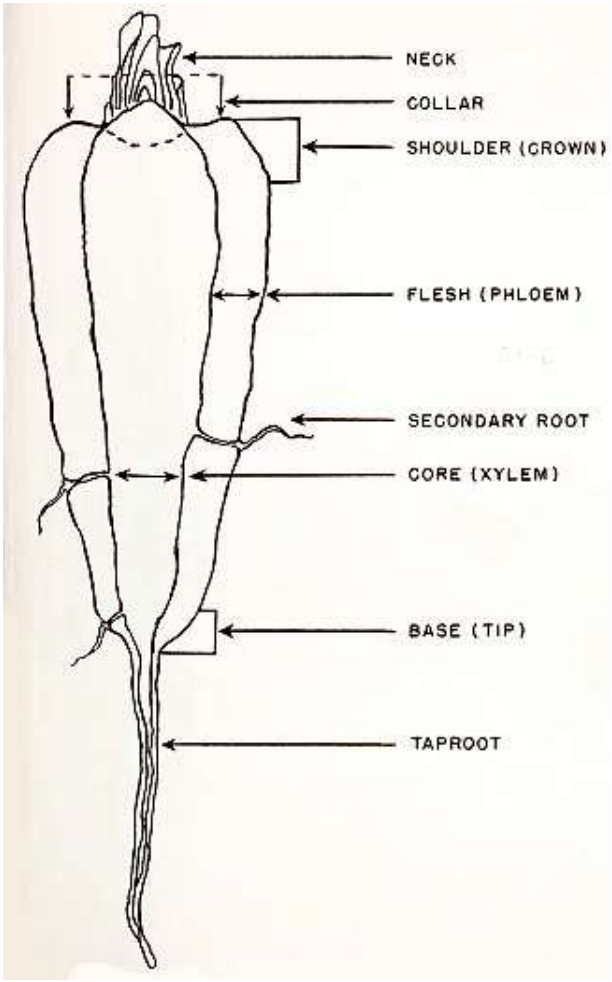


**Fig. 2.1** Anatomical structure of carrot root

Source: Anon (2017)

### 2.1.3 Chemical composition

The moisture content of carrot varies from 86 to 89% (Howard *et al.*, 1962). Carrots are a good source of carbohydrates and minerals like Ca, P, Fe and Mg. Gopalan *et al.* (2012) have reported the chemical constituents of carrot as moisture (86%), protein (0.9%), fat (0.2%), carbohydrate (10.6%), crude fiber (1.2%), total ash (1.1%), Ca (80 mg/100 g), Fe (2.2 mg/100 g) and P (53 mg/100 g) whereas, the values reported by Holland *et al.* (1991) for most of these parameters are different i.e. moisture (88.8%), protein (0.7%), fat (0.5%),

carbohydrate (6%), total sugars (5.6%), crude fiber (2.4%), Ca (34 mg/100 g), Fe (0.4 mg/100 g), p (25 mg/100 g), Na (40 mg/100 g), K (240 mg/100 g), Mg (9 mg/100 g), Cu (0.02 mg/100 g), Zn (0.2 mg/100 g), carotenes (5.33 mg/100 g), thiamine (0.04 mg/100 g), riboflavin (0.02 mg/100 g), niacin (0.2 mg/100 g), vitamin C (4 mg/100 g) and energy value (126 kJ/100 g). The edible portion of carrots contains about 10% carbohydrates having soluble carbohydrates ranging from 6.6 to 7.7 g/100 g and protein from 0.8 to 1.1 g/100 g in 4 carrot cultivars (Howard *et al.* 1962). Kaur *et al.* (1976) have reported 1.67–3.35% reducing sugars, 1.02–1.18% non-reducing sugars and 2.71–4.53% total sugars in 6 cultivars of carrot. Simon and Lindsay (1983) reported that reducing sugars accounted for 6–32% of free sugars in 4 hybrid varieties of carrot. The free sugars identified are sucrose, glucose, xylose and fructose (Kalra *et al.*, 1987). The crude fiber in carrot roots consist of 71.7, 13.0 and 15.2% cellulose, hemicllulose and lignin, respectively (Kochar and Sharma, 1992). The cellulose content in 4 carrot varieties varied from 35 to 48% (Robertson *et al.*, 1979). The average nitrate and nitrite content in fresh carrot have been 40 and 0.41 mg/100 g, respectively (Bose and Som, 1986). The taste of carrots is mainly due to the presence of glutamic acid and the buffering action of free amino acids. Trace amounts of succinic acid, α-ketoglutaric acid, lactic acid and glycolic acid have also been reported (Kalra *et al*. 1987). Caffeic acid is the predominant phenolic acid in carrots. Thiamin, riboflavin, niacin, folic acid and vitamin C are present in appreciable amounts in carrot roots (Howard *et al*. 1962; Bose and Som 1986). The anthocyanins content in roots may vary from trace amounts in pink cultivars to 1,750 mg/ kg in black carrots (Mazza and Minizte, 1993). The major anthocyanins have been identified as cyanidin 3- (2-xylosylgalactoside), cyanidin 3-xylosylglucosylgalactoside and cyanidin 3-ferulylxylo- glucosyl galactoside (Harborne 1976).

**Table 2.1** Chemical composition of carrot

| Parameters | Value (db) |
|---|---|
| Moisture | 86% |
| Carbohydrate | 10.06% |
| Protein | 0.9% |
| Crude Fat | 0.2% |
| Crude Fiber | 1.2% |
| Total ash | 1.1% |
| Calcium | 80 mg/100 g |

Source: Gopalan *et al.* (2012)

### 2.1.4 Phytonutrients

Plant components, primarily secondary metabolites that have health promoting properties are called phytonutrients. The importance of antioxidant constituents in the maintenance of health and protection from coronary heart disease and cancer is raising considerable interest among scientists, food manufacturers and consumers as the trend of the future is moving toward functional food with specific health effects. In vitro studies indicated phytonutrients such as carotenoids and phenolics may play a significant role, in addition to vitamin in protecting biological systems from the effects of oxidative stress. Carrot is a significant source of phytonutrients including phenolics, polyacetylenes and carotenoids. Carrot is rich in β-carotene, ascorbic acid and tocopherol and is classified as vitaminized food. Due to appreciable level of variety of different compounds present, carrots are considered as a functional food with significant health promoting properties (Sharma *et al.*, 2012).

#### 2.1.4.1 Carotenoids

The importance of carotenoids in food goes beyond as natural pigments and biological functions and actions have increasingly been attributed to these pigments. Carotenoids are present intracellularly and their actions involve in the regulation of gene expression or effect cell activation. These biological effects are independent of the pro-vitamin A activity and have been attributed to the antioxidant property of carotenoids, through deactivation of free radicals and singlet oxygen quenching. In general, carotenoids in foods are classified into carotenes and xanthophylls, which give attractive red or yellow colour and contribute to food quality. Structurally, the carotenoids may be acyclic or contain a ring of 5 or 6 carbons at one or both ends of the molecule (Carle and Schiber, 2001).

Carotenoids are important micronutrients for human health. The total carotenoids content in the edible portion of carrot roots range from 6,000 to 54,800 μg/100 g. The main physiological function of carotenoids is as precursor of vitamin A. In the past decade carotenoids such as β-carotene have attracted considerable attention because of their possible protective effect against some types of cancers. In human system, the physiological activity of α- and β-carotene has been 50 and 100% of the provitamin A activity, respectively and one molecule of β-carotene yields two molecules of retinol in human system (Nocolle *et al.*, 2003).

Carotenoids have been linked with the enhancement of immune system and decreased risk of degenerative diseases such as cancer, cardiovascular disease, age related mascular degeneration and cataract formation. Carotenoids have been identified as a potential inhibitor of Alzheimer's disease (Faulks and Southon, 2001).

The presence of high concentration of antioxidant carotenoids especially β-carotene may account for the biological and medicinal properties of carrots. Carrots have been reported to have diuretic, N-balancing properties and are effective in the elimination of uric acid. Numerous animal experiments and epidemiological studies have indicated that carotenoids inhibit carcinogenesis in mice and rats and may have anticarcinogenic effects in humans. In biological systems, β-carotene functions as a free radical-trapping agent and single oxygen quencher and have antimutagenic, chemopreventive, photoprotective and immunoenhancing properties (Deshpande *et al.*, 1995).

Carrot intake may also enhance the immune system, protect against stroke, high blood pressure, osteoporosis, cataracts arthritis, heart diseases, bronchial asthma and urinary tractinfection. Carotenoids also act as free-radical scavengers and are very important for health (Seo and Yu, 2003). D'Odorico *et al.* (2000) have shown that the presence of α- and β-carotene in blood has a protective effect against atherosclerosis. Nocolle *et al*. (2003) has demonstrated that high carotenoid diets are associated with a reduced risk of heart disease.

### 2.1.4.2 Phenolics

Phenolics or polyphenols have received considerable attention because of their physiological functions, including antioxidant, antimutagenic and antitumor activities. They have been reported to be a potential contender to combat free radicals, which are harmful to our body and foods systems. Although, phenolic compounds do not have any known nutritional function, they may be important to human health because of their antioxidant potency. Phenolics are ubiquitous plant components that are primarily derived from phenylalanine via the phenylpropanoid metabolism. Phenolics in carrots are present throughout the roots but are highly concentrated in the periderm tissue. Two major classes of phenolics are hydroxycinnamic acids and para-hydroxybenzoic acids (Nagai *et al.*, 2003). Further, Zhang and Hamauzee (2004) have studied the phenolic compounds, their antioxidant properties and distribution in carrot and found that it contained mainly hydroxycinnamic acids and derivatives. Among them chlorogenic acid was a major hydroxycinnamic acid, representing 42.2–61.8% of total phenolic compounds detected in different carrot tissues. The phenolic contents in different tissues decreased in the following order peel > phloem > xylem. Although, carrot peel accounted for only 11% of the amount of the carrot fresh weight, it could provide 54.1% of the amount of total phenolics, while the phloem tissue provides 39.5% and the xylem tissue provides only 6.4%. Antioxidant and radical scavenging activities in different tissues decreased in the same order as phenolic content. These findings suggested that phenolics could play an important role in antioxidant properties in carrots and other hydroxycinnamic derivatives such as dicaffeoylquinic acids and chlorogenic acid. Therefore, the higher level of phenolics and antioxidant properties in carrot peel treated as the waste in the processing industry could be considered for value-added utilization. Oviasogie *et al.* (2009) have reported that the total phenolic content in carrot is 26.6±1.70 μg/g. Total phenols in violet carrot juice have been reported to be 772±119 mg/l by Karakaya *et al.* (2001).

#### 2.1.4.3 Dietary fibers

Dietary fiber is an indigestible complex carbohydrate found in structural components of plants. They cannot be absorbed by the body and therefore, have no calorific value however, the health benefits of eating fiber rich diet are immense including prevention of constipation, regulation of blood sugar, protection against heart diseases, reducing high levels of and prevention of certain forms of cancers. Fibers are classified into insoluble and soluble depending upon their solubility. Insoluble fibers consist mainly of cell wall components such as cellulose, hemi-cellulose and lignin and soluble fibers are non-cellulosic polysaccharides such as pectin, gums and mucilage (Yoon *et al.*, 2005). Lineback (1999) has reported that the carrot cell wall is composed of pectin (galacturonans, rhamnogalacturonans, arabinans, galactans and arabinogalactans-1), cellulose (β-4, D-glucan), lignin (trans-coniferyl alcohol, trans-sinapyl alcohol and trans-pcoumaryl alcohol) and hemi-cellulose (xylans, glucuronoxylans β-D-glucans and xyloglucans). Carrots are high in dietary fibers and these fibers play an important role in human health and diets rich in dietary fibers are associated with the prevention, reduction and treatment of some diseases such as diverticular and coronary heart diseases (Villanueva-Suarez *et al.*, 2003). Nawirska and Kwasniewska (2005) have reported the composition of dietaryfiber constituents in the fresh carrot on dry weight basis aspectin (7.41%), hemi-cellulose (9.14%), cellulose (80.94%)and lignin (2.48%). Dietary fibers are not only desirable fortheir nutritional properties but also for their functional andtechnological properties and because of these they couldbe used as food ingredients (Schieber *et al.*, 2001a).

### 2.1.5 Health benefits of carrot

Evidence suggests that eating more antioxidant-rich fruits and vegetables, such as carrots, can help reduce the risks of cancer and cardiovascular disease. Carrots are also rich in vitamins, minerals, and fiber. Here are some ways in which carrots might be healthful (Ware, 2017).

#### 2.1.5.1 Cancer

A variety of dietary carotenoids have been shown to have anti-cancer effects, due to their antioxidant power in reducing free radicals in the body. Studies have found a possible link

between diets rich in carotenoids and a lower risk of prostate cancer, but more evidence is needed to confirm whether the link is causal (Ware, 2017).

#### 2.1.5.1.1 Lung Cancer

Carrots contain beta-carotene. Past studies have concluded that beta-carotene supplementation may reduce the risk of lung cancer. A meta-analysis published in 2008 found that people with a high intake of a variety of carotenoids had a 21 percent lower risk of lung cancer, after adjusting for smoking, compared with those who did not. The same pattern was not true for any individual carotenoid, such as beta-carotenoid. Among smokers, beta-carotene supplementation may increase the risk of lung cancer (Ware, 2017).

#### 2.1.5.1.2 Colorectal Cancer

Consuming more beta-carotene may reduce the risk of colon cancer, according to researchers who studied 893 people in Japan (Ware, 2017).

### 2.1.5.2 Leukemia

A 2011 study found that carrot juice extract could kill leukemia cells and inhibit their progression (Ware, 2017).

### 2.1.5.3 Vision

Carrots contain vitamin A. A vitamin A deficiency can lead to xerophthalmia, a progressive eye disease that can damage normal vision and result in night blindness, or the inability to see in low light or darkness. According to the National Institutes of Health (NIH), a lack of vitamin A is one of the main preventable causes of blindness in children (Ware, 2017).

Vitamin A deficiency is rare in the United States (U.S.), but eating carrots contributes to vitamin A intake and helps prevent a deficiency. So, in a way, carrots do help you see in the dark. However, most people are unlikely to experience any significant positive changes in their vision from eating carrots, unless they already lack vitamin A (Ware, 2017).

### 2.1.5.4 Diabetes control

The antioxidants and phytochemicals in carrots may help regulate blood sugar. Around a quarter of the carbohydrate in carrots is sugar, but the amount of carbohydrate in carrots is relatively small. According to Harvard Health, the glycemic index of carrots is 39, meaning the impact on blood sugar is fairly low (Ware, 2017).

#### 2.1.5.5 Blood pressure

A half-cup serving of chopped carrot contains 1.8 g of fiber and 205 mg of potassium. Before the age of 50 years, men need 38 g of fiber a day, and women need 25 g. After this age, women need 21 g per day, and men need 30 g. Health authorities advise people to consume no more than 2,300 mg of sodium a day. The recommended intake of potassium is 4,700 mg (Ware, 2017).

The American Heart Association (AHA) recommend consuming a fiber-rich diet and increasing potassium while reducing sodium intake to protect against high blood pressure and heart disease. Carrots offer a good balance of these nutrients (Ware, 2017).

#### 2.1.5.6 Immune function

Carrots contain vitamin C, an antioxidant. This helps boost the immune system and prevent disease. Vitamin C can help reduce the severity of a cold, and the length of time it lasts (Ware, 2017).

### 2.1.6 Risks

Overconsumption of vitamin A can be toxic to humans. It may cause a slight orange tinge in skin color, but this not harmful to health. An overdose of vitamin A is unlikely to happen because of diet alone, but it may result from supplement use. People who are taking medications derived from vitamin A, such as isotretinoin (Roaccutane) for acne or acitretin for psoriasis, should avoid eating large amounts of carrots, as they could lead to hypervitaminosis A, an overdose of vitamin A. Anyone who is starting a new medication should check with their doctor about any recommended dietary changes (Ware, 2017).

## 2.2 Blanching

Blanching is a short heat treatment that is typically applied to vegetables prior to further processing with the aim of enhancing both safety and quality attributes (Stanley *et al.*, 2017). It imparts benefits such as the destruction of surface micro flora on vegetables and

the enhancement of the color, texture and also the keeping quality of vegetable products (Abu-Ghannam *et al.*, 2011). Blanching is essential for vegetable products destined for further storage such as freezing or drying in order to inactivate certain enzymes including lipoxygenase, polyphenololoxidase, polygalacturonase, and chlorophyllase which are associated with losses in quality and nutritional properties. Apart from blanching, other processing methodologies of vegetables, including drying and freezing, are insufficient to inactivate these enzymes thus leading to deterioration in texture, color, and flavor during storage (Busari *et al.*, 2016).

The quality of blanched products depends significantly on the time–temperature combinations of blanching and also on the vegetable type. Under-blanching speeds up the activity of enzymes and is worse than no blanching (Abu-Ghannam *et al.*, 2011). Over-blanching causes losses in texture, color, phytochemicals and minerals (Saranya *et al.*, 2017).

Generally, blanching is carried out by the application of a wet medium such as steam or hot water in order to provide uniform heating and a high-heat transfer rate (Gupta *et al.*, 2012). Both in domestic and industrial processing, several blanching methods may be employed such as conventional water blanching, microwave, or steam blanching; the regime being dictated by the nature of the raw material and the desired properties of the final product (Francisco *et al.*, 2010). Traditionally, blanching is carried out either at a low temperature (55–75°C) for long-time, typically referred to as LTLT or high-temperature short-time (80–100°C) for less than 10 min, referred to as HTST depending upon the type of vegetable (Abu-Ghannam and Crowley, 2006).

### 2.2.1 Effect on foods by blanching

The heat received by the food during blanching inevitably causes some changes to sensory and nutritional qualities (Amin and Lee, 2005). The time-temperature combination used for blanching is a compromise which ensures adequate inactivation but prevents excessive softening and loss of flavor in the foods (Fellows, 2000). Some of the effects on foods of plant origin are discussed below.

#### 2.2.1.1 Color

Blanching brightens the color of some foods by removing air and dust on the surface and thus altering the wave length of reflected light. Sodium carbonate or calcium oxide are often added to blancher water to protect chlorophyll and to retain the colour of green vegetables, although the increase in pH may increase losses of ascorbic acid (Fellows, 2000).

#### 2.2.1.2 Texture

Blanching can result in undesirable softening of vegetable tissues. However, calcium can be added to reduce the softening (Seow and Lee, 1997). A combination of low-temperature blanching and calcium addition has also been shown to be effective in firming canned vegetables (Bourne *et al.*, 1995). Texture assessment of the effects of blanching includes sensory characterization of firmness, crispness, and crunchiness (Corcuera and Cavalieri, 2015).

#### 2.2.1.3 Flavor

Blanching indirectly and directly affects the flavor of many products by inactivation of enzymes responsible for off-flavor development. The most notable is lipoxygenase in several vegetables (Williams *et al.*, 1986). Sometimes blanching increases flavor retention, and sometimes it removes undesirable bitter flavors from the product. In fruits and vegetables the change in flavor is due to complex reactions that in2volve the degradation, recombination and volatilization of aldehydes, ketones, sugars, lactones, acids, and organic acids (Corcuera and Cavalieri, 2015).

#### 2.2.1.4 Nutrients

Some minerals, water soluble vitamins and other water soluble components are lost during blanching. Losses of vitamins are mostly due to leaching, thermal destruction and to lesser extent oxidation (Fellows, 2000). The extent of vitamin loss depends upon on a number of factors including:

1. The maturity of food and variety.
2. Methods used in preparation of the food, particularly the extent of cutting, slicing or dicing.
3. The surface area to volume ratio of the pieces of food.

4. Method of blanching.

5. Time and temperature of blanching (lower vitamin losses at higher temperature for shorter time).

6. Method of cooling.

### 2.2.2 Methods of blanching

#### i) Hot water blanching

Hot water blanching is the most popular and commercially adopted blanching method, as it is simple to establish and easy to operate. In a typical hot water blanching, products are immersed in hot water (70 to 100°C) for several minutes (Schieber *et al.*, 2001b). Then blanched samples are drained and cooled before being sent to the next processing operation. In general, after a certain amount of blanching time, the blanching water needs to be replenished as it becomes saturated with nutrients leached from the products. This step does not only consume high amounts of water and energy (Xiao *et al.*, 2017). In order to preserve the color of product and inactivate microbial activity, sodium sulfite and sodium metabisulfite are often added to the blanching water (Ferracane *et al.*, 2008). This makes it more difficult to deal with the wastewater generated from the blanching operation. Water blanching usually results in a more uniform treatment, allowing processing at lower temperatures. Prolonged water blanching results in considerable losses in phytochemicals and antioxidant properties (Jaiswal and Gupta, 2012). Limitations of Hot water blanching are as:

- Losses of nutrients during blanching

The loss of nutrients during hot water blanching is caused mainly by leaching or diffusion. All water-soluble nutrients, such as vitamins, flavors, minerals, carbohydrates, sugars, and proteins, can leach out from plant tissues to the blanching water. In addition, hot water blanching can also lead to degradation of some thermal sensitive substances such as ascorbic acid, aroma and flavor compounds (Xiao *et al.*, 2017)

- Wastewater from blanching

The discharged waste water from hot water blanching contain high concentrations of biochemical, soluble solids, and chemical oxygen demand due to leaching and dissolution

of sugars, proteins, carbohydrates and water-soluble minerals. This wastewater can cause environmental pollution, e.g. eutrophication (Xiao *et al.*, 2017).

### ii) Steam blanching

Steam blanching is generally carried out in a steam blancher where the vegetable product is exposed directly to a food-grade steam typically at a temperature close to 100°C (Nartnampong *et al.*, 2016). Superheated steam is commonly used as a heating media for blanching due to its high enthalpy contents. During the early stage of steam blanching, it condenses on the surface of the products and a large amount of latent heat transfers to the material because product temperature is lower than that of steam. The temperature of the products gradually increases until reaching the critical temperature of enzymes or organisms activity, after which they are inactivated. It is believed that the steam blanching is relatively inexpensive and retains most minerals and water-soluble components when compared with water blanching due to the negligible leaching effects (Xiao *et al.*, 2017).

Steam cooking may affect the antioxidant status of tropical green leafy vegetables due to the release of more phenolic compounds and destruction or creation of redox- active metabolites (Adefegha and Oboh, 2011). During the steam blanching process, softening of the tissue and undesirable quality changes often resulted a long heating time due to the lower heat transfer in steam blanching than hot water blanching, especially when the velocity of steam is very low (Juneja *et al.*, 2009). Steam blanching results in minimum losses in phytochemicals and antioxidant capacity (Faller and Fialho, 2009). It requires less time than conventional blanching because the heat transfer coefficient of condensing steam is greater than that of hot water and it is proven to be comparatively economical as it saves energy (Jaiswal, 2015). Steam blanching is more energy-efficient and produces lower BOD and hydraulic loads than water blanching. In addition, nutrient leaching is reduced compared to water blanching (Adefegha and Oboh, 2011).

### iii) Microwave blanching

Microwave heating is three- to five-times faster than conventional heating and relies on the application of dielectric heating. This is accomplished by using microwave radiation to

heat water and other polarized molecules within the food, leading to heat generation in the entire volume at the same rate due to internal thermal dissipation of water molecule vibrations in the food. It has advantages over conventional heating methods such as precision timing, speed, and energy saving (Jaiswal, 2015). Microwave technology has been combined with water blanching to further reduce heating time (Xiao *et al.*, 2017). Limitations of microwave blanching are as:

- Loss of water during blanching
- Penetration depth of microwave is limited.
- Non uniform heating.
- Difficulities to precisely control blanching temperature.

**iv) Lye blanching**

Sodium bicarbonate is effective in maintaining green color of heat processed vegetable products but they cause changes in texture and loss of nutrients that are not desirable (Heaton and Marangoni, 1996). By displacing the phytyl and methyl groups, forming a bright green water soluble chlorophyllin sodium bicarbonate reacts with chlorophyll. In addition, improves chlorophyll stability is improves this may be due to sodium bicarbonate increases the medium pH (Srilakshmi, 2003).

## 2.3 Drying

### 2.3.1 Introduction

Drying involves the application of heat to vaporize the volatile substances (moisture) and some means of removing water vapor after its separation from the solid (Jayaraman and Gupta, 1995). The drying process is a heat and mass transfer phenomenon where water migrates from the interior of the drying product on to the surface from which it evaporates. Heat is transferred from the surrounding air to the surface of the product. A part of this heat is transferred to the interior of the product, causing a rise in temperature and formation of water vapor, and the remaining amount is utilized in evaporation of the moisture from the surface (Lopez *et al.*, 2009).

Dehydration is the oldest method of food preservation practiced by man. For thousands of year man has dried and/or smoked meat, fish, fruits and vegetables, to sustain him during out of season periods in the year. Today the dehydration section of the food industry is large and extends to all countries of the globe. Drying facilities range from simple sun or hot air driers to high capacity, sophisticated spray drying or freeze drying installations. A very large range of dehydrated foods is available and makes a significant contribution to the convenience food market. The terms dehydration and drying are used interchangeably to describe the removal of most of the water, normally present in a foodstuff, by evaporation or sublimation, as a result of the application of heat. The main reason for drying a food is to extend its shelf life beyond that of the fresh material, without the need for refrigerated transport and storage. This goal is achieved by reducing the available moisture, or water activity to a level which inhibits the growth and development of spoilage and pathogenic microorganisms, reducing the activity of enzymes and the rate at which undesirable chemical changes occur (Brennan, 2006).

### 2.3.2 General principles

Drying can be described as the process of thermally removing moisture to yield a solid product. Moisture can be found as bound or unbound in the solid. Moisture, which exerts a vapor pressure less than that of pure liquid, is called bound moisture while moisture in excess of bound moisture is called unbound moisture.

The most important thermodynamic process in food drying is heat and mass transfer. During hot-air drying, there is a simultaneous exchange of heat and mass between the food and the drying air (Maroulis *et al.*, 1995).

a) Heat transfer
   1. Convective heat (energy) transfer from the air to the food`s surface (external heat transfer).
   2. Conductive heat transfer within the food (internal heat transfer)

b) Mass transfer
   1. Moisture transport within the food toward its external surface (internal mass transfer).
   2. Evaporation and convective transfer of the vapour into the air (external mass transfer)

Since the physical structure of the drying solid is subject to change during drying, the mechanisms of moisture transfer may also change with elapsed time of drying (larbi, 2014).Energy transfer as heat from the surrounding environment to the wet solid can occur as a subsequence of convection, conduction, or radiation and in some case as a result of a combination of these effect, however convection is common and predominant mechanism (Aguilera and Stanley, 1999; Heldman and Hartel, 1997). In most cases heat is transferred to the surface of the wet solid and then to the interior. This heat transfer to the food surface increases the sample temperature and supplies the required latent heat of vaporization for both the surface water and the water within the product. At the same time, internal moisture (mass) migrates to the surface of the food and then it evaporates to the surrounding hot air (Aversa *et al.*, 2007; Ramaswamy and Marcotte, 2006).

Transport phenomena involve both external and internal resistance to heat and/or mass transfer. The factors that slow the rate of these processes determine the drying rate (Ramaswamy and Marcotte, 2006; Singh and Heldman, 2009). In other words, the resistance mechanisms control the drying rate. In general, it is accepted that the rate of the drying may be limited either by the rate of internal migration of water molecules to the surface or by the rate of evaporation of water molecules from the surface into the air, depending on the conditions of drying (Singh and Heldman, 2009). This indicates that the resistance to mass transfer is considered to be the primary rate-limiting mechanism and the resistance to heat transfer may hence be neglected. The reason for this is that within the food, heat is usually transported more easily than moisture and thus the temperature gradients inside the food can be assumed to be flat (no resistance to internal heat transfer), especially when compared to the steep moisture content gradient (Fortes and Okos, 1981). In addition, it is known that heat transfer within the food may be limited by the thermal conductivity of the product as its water evaporates (Donsi *et al.*, 1996).

The air temperature, air humidity and velocity, and exposed surface area all influence the resistance to external heat and mass transfer whereas the internal mass transfer is only affected by the physical nature of the food, its moisture content and temperature. At the beginning of drying, since the internal resistance in the food is low enough to maintain the surface at saturation, evaporation takes place at a constant rate depending mainly on external heat and mass transfer. When the drying rate starts to decrease due to insufficient water at the surface, resistance to internal mass transfer governs the process. Most foods

therefore switch from an external drying process during the initial stages to an internal drying process as the product dries out (Ramaswamy and Marcotte, 2006).

In addition, the drying rate in the food sample, which decreases from the very beginning of the process (at a constant temperature), may also indicate that the internal resistance to mass transfer controls the drying (Uddin *et al.*, 1990; Yusheng and Poulsen, 1988).

### 2.3.3 Drying mechanism

The movement of moisture during drying is shown in Fig. 2.1

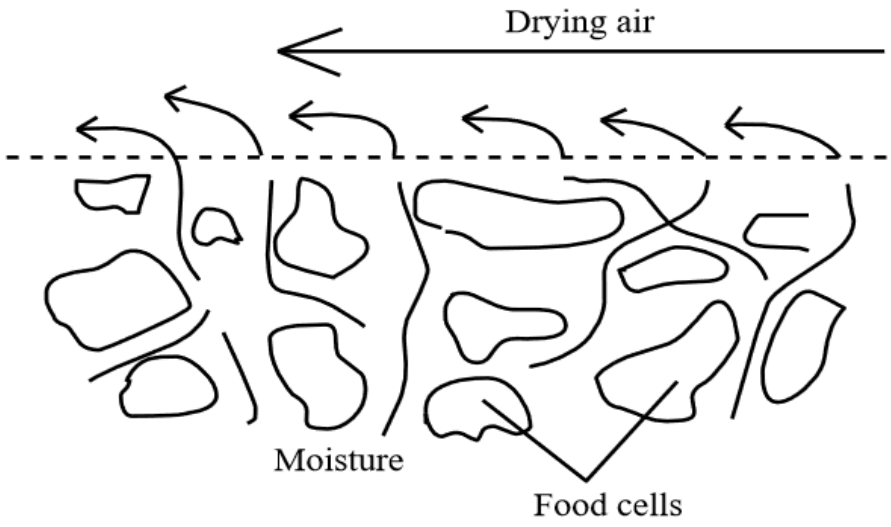


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**Fig. 2.1**Movement of moisture during drying

Source: Kharel (2006)

When hot air is blown over a wet food, heat is transferred to the surface, and latent heat of vaporization causes water to evaporate. Water vapour diffuses through a boundary film of air and is carried away by the moving air. This creates a region of lower water vapour pressure at the surface of the food, and a water vapour pressure is established from the moist interior of the food to the dry air. This gradient provides the driving force for water removal from the food (Kharel, 2006).

Water moves to the surface by the following mechanisms:

a) Liquid movement by capillary forces

b) Diffusion of liquids, caused by differences in the concentration of solutes in different regions of the food
c) Diffusion of liquid which is adsorbed in layers at the surface of solid components of the food, and
d) Water vapour diffusion in air spaces within the food caused by vapour pressure gradients.

For a given food, the total amount of moisture that can be lost will vary with the humidity and temperature of the air. As water migrates out during drying, dissolved solids (sugar, acid, salt) are carried along to the surface. Here water evaporates into the air leaving the soluble solids which concentrate and may even precipitate at the surface. As the drying proceeds, the water removal may be restrained by the drying process itself. Food tissue often sinks as it loses moisture and the structure may change and blocks the exit of water. Such a condition is known as case hardening in which the outer trough surface is formed but still moist interior remains. The hard outer surface is more impermeable to water and such a product is susceptible to microbial spoilage. Less intense drying and intermittent conditioning alleviate this problem (Kharel, 2006).

### 2.3.4 Factors affecting drying

According to Mujumdar (2006), the rate of drying is principally depend on internal and external condition.

**a) External condition**

The essential external variables are temperature, humidity, velocity and direction of air, the physical form of the solid, the desirability of agitation, and the method of supporting the solid during the drying operation. External drying conditions are especially important during the initial stages of drying when unbound surface moisture is removed. In certain cases, for example, in materials like ceramics and timber in which considerable shrinkage occurs, excessive surface evaporation after the initial free moisture has been removed sets up high moisture gradients from the interior to the surface. This is liable to cause over drying and excessive shrinkage and consequently high tension within the material, resulting in cracking and warping. In these case surface evaporation should be retarded through the employment of high air relative humidity while maintaining the highest safe rate of internal moisture movement by heat transfer (Mujumdar, 2006).

Surface evaporation is controlled by the diffusion of vapor from the surface of the solid to the surrounding atmosphere through a thin film of air in contact with the surface (Mujumdar, 2006).

**b) Internal conditions**

As a result of heat transfer to a wet solid, a temperature gradient develops within the solid while moisture evaporation occurs from the surface. This produces a migration of moisture from within the solid to the surface, which occurs through one or more mechanisms, namely, diffusion, capillary flow, internal pressures set up by shrinkage during drying. An appreciation of this internal movement of moisture is important when it is the controlling factor, as it occurs after the critical moisture content, in a drying operation carried to low final moisture contents. Variables such as air velocity and temperature, which normally enhance the rate of surface evaporation, are of decreasing importance except to promote the heat transfer rates. Longer residence times, and, where permissible, higher temperatures become necessary. The temperature gradient set up in the solid will also create a vapor–pressure gradient, which will in turn result in moisture vapor diffusion to the surface; this will occur simultaneously with liquid moisture movement (Mujumdar, 2006).

## 2.4 Drying methods

### 2.4.1 Traditional sun drying

The traditional method of drying, known as ‘sun drying’, involves simply laying the product in the sun on mats, roofs or drying floors. Because the energy requirements - sun and wind - are readily available in the ambient environment, little capital is required. Sun drying of fruits and vegetables is still practiced largely (Bux *et al.*, 2002).

During sun drying heat is transferred by convection from surrounding air by absorption of direct and diffuse radiation on the surface of crop. The converted heat is partially used to increase the temperature of food product and part of heat is used in effective moisture diffusion from interior to surface. The remaining amount of energy is used for the

evaporation of water from the surface. The evaporated water has to be removed from surrounding of the crop by natural convection supported by wind forces (Bux *et al.*, 2002).

Sun drying has the advantages of simplicity, capital and operating costs and the fact that little expertise is required. On the other hand, there are many technical problems which are uncertainties like rain and cloudiness, contamination from outer sources and lack of control over drying conditions. It requires large areas and long drying time. The final product may have relatively high moisture content; low and variable quality of products due to over- or under-drying, product may contaminate from dust and insects, birds and suffer from enzyme and microbial activity. It is limited to climates with hot sun and dry atmosphere with strong winds (Jayaraman and Gupta 2006).

### 2.4.2 Solar drying

Solar dryers have some advantages over sun drying when correctly designed. They give faster drying rates by heating the air to 10-30ºC above ambient, which causes the air to move faster through the dryer, reduces its humidity and deters insects. The faster drying reduces the risk of spoilage, improves quality of the product and gives a higher throughput, so reducing the drying area that is needed. However, care is needed when drying fruits to prevent too rapid drying, which will prevent complete drying and would result in case hardening and subsequent mold growth. Solar dryers also protect foods form dust, insects, birds and animals. They can be constructed from locally available materials at a relatively low capital cost and there are no fuel costs. Thus, they can be useful in areas where fuel or electricity are expensive, land for sun drying is in short supply or expensive, sunshine is plentiful but the air humidity is high. Moreover, they may be useful as a means of heating air for artificial dryers to reduce fuel costs (Fellows,1997).

The principle that lies behind the design of solar dryers is as follows: in drying relative and absolute humidity are of great importance. Air can take up moisture, but only up to a limit. This limit is the absolute (maximum) humidity, and it is temperature dependent. When air passes over a moist food it will take up moisture until it is virtually fully saturated, that is until absolute humidity has been reached. But, the capacity of the air for taking up this moisture is dependent on its temperature. Higher the temperature, the higher will be the absolute humidity, and the larger the uptake of moisture. If air is warmed, the

amount of moisture in it remains the same, but the relative humidity falls; and the air is therefore enabled to take up more moisture from its surrounding (Gavhale *et al.*, 2015).

### 2.4.3 Cabinet Drying

The majority of industrial drying installations rely on convectional hot-air drying at atmospheric pressure since it is the simplest and most economical among the various methods. A wide variety of food materials such as fruit, vegetables, herbs and cereal crops has therefore been dried by convectional hot-air dryers. In addition, it is easy to set and control the optimum drying conditions in these dryers, especially in cabinet dryers. Common atmospheric hot-air dryers include kiln, cabinet (tray), tunnel, and belt or conveyor dryers (Jayaraman and Gupta, 1995; Us and Khan, 2007).

The basic configuration of an atmospheric hot-air dryer is an enclosed and heated chamber where food material is placed. It is also equipped with a blower (i.e. fan) and ducts to allow the circulation of hot air around and across the food. When there is no fan the drying takes place under natural convection. The drying process in an atmospheric dryer involves both heating the product and removing water from the product surface (Rahman and Perera, 1999).

Traditional convective drying methods employ continuous constant air temperature for moisture removal from the food product. The transfer of thermal energy from the heater to the food substance occurs by means of convection. The penetration of this thermal energy is dependent on the thermal conductivity of the material. During drying, as moisture leaves the pores in the outer layers of the food, it is replaced by gas (air). This results in a decrease in the thermal conductivity of the outer layers since the thermal conductivity of air is lower than that of water. Consequently, the product surface behaves like an insulator. The penetration of the delivered heat to the inner section of the food sample is reduced progressively, and water is transferred more slowly to the surface, where evaporation occurs. Thus high heat transfer rates applied at the surface will only result in overheating or over-drying of the surface layer leading to quality problems without a significant increase in the drying kinetics (Lewis, 1987).

## 2.5 Blanching effect on carotenoid content

The initial carotenoid content of unblanched was lower than that of blanched, due to the stabilizing effect of blanching on carotenoids, which had already been observed. This effect is generally believed to be due to the inactivation of peroxidase and lipoxidase activity. These enzymes can act during the dehydration process until substrate mobility becomes a limiting factor for catalytic activity. However, the rate of carotenoid degradation was higher in blanched than in lot unblanched (Arya *et al.*, 1979). This has suggested that some substances which are responsible to stabilize the carotenoids are either degraded or leached during blanching. Alternatively, it may also be argued that blanching causes physical damage to tissues by which it became highly proned for oxidation. However, despite the mechanism reported further investigations are necessary to optimise blanching in order to maximize carotenoid retention in dehydrated carrots (Lavelli *et al.*, 2007).

### 2.6 Effects of drying on β-carotene content

The average β-carotene content of fresh carrot samples was 173.2±0.50 mg 100 g/dry matter. A large range of β-carotene contents of fresh carrots were reported in the literature, depending on the variety, maturity and extraction procedure as well as instruments used for analysis. Drying carrot cubes at 45°C resulted in a low degradation rate of β-carotene. The degradation rate of β-carotene increased with temperature. The β-carotene content of carrots dried at 45°C changed from 173.2±0.50 to 36.2±0.40 mg 100 g $dm^{-1}$ at the end of drying. But at 65°C, it dropped to 27.6±0.60 mg 100 g $dm^{-1}$. In a previous study by Suvarnakuta *et al.* (2005)., carrots (*Daucus carota* var. sativa) were dried by using hot air drying methods at 60, 70 and 80°C to obtain a product with 10% initial moisture content. β-Carotene content of carrot samples dried at 60°C for 420 min were 21.46 mg 100 g $dm^{-1}$. However, this value was reported as 22.05 mg 100 g $dm^{-1}$ for carrot samples dried at 80°C for 240 min. The authors concluded that, lipoxygenase and peroxidase are activated at the temperature around 60°C (Demiray and Tulek, 2016).

The first-order reaction was best fitted to the degradation of β-carotene. The reaction rate was greatly influenced by the temperature during drying. The activation energy value for β-carotene was 33.33±0.05 kJ $mol^{-1}$. The highest $Q_{10}$ value for β-carotene was calculated at increasing drying temperature from 45 to 55°C. Kinetic models which can be applied to predict the quality changes in carrots during drying as a function of time, temperature and moisture content were developed (Demiray and Tulek, 2016).

## 2.7 Rehydration of carrot

The rehydration properties of dried carrots have been studied by the various workers. Rehydrated tissues are characterized by strong cell wall swelling, maceration and clumping of cytoplasm. Rehydration influenced the appearance of rehydrated product. The thickness of material was an important factor to affect the rehydration coefficient (Kalra *et al.* 1987).

Stephens and McLemore (1969) reported a carrot flake and found good typical carrot flavour on rehydration. Romos *et al.* (1992) reported that a rehydration for 90 min at 60°C water gave the highest rehydration ratio (7.19), while the rehydration ratio of 6.61 was found for 60 min blanched at 50°C. The range of rehydration ratio was found small.

Rehydration ratio decreased during storage. However, 5-8% losses in rehydration ratio, which occurred during 180 days of storage at 37°C, was significant as compared to the 46-61% loss which occurred during dehydration (Baloch *et al.*, 1977). At the same dehydrated temperature pre-drying treated carrots would always yield moister finished product than untreated material. The finished product however, could also absorb less moisture, and the rehydrated ratio would be lower for treated product than for untreated material (Adhikari, 1995).

## 2.8 Storage stability of dried carrot

Previous studies in our laboratory demonstrated that the carotenoid content of minimally-processed carrots did not decrease during storage, however, these products are degraded by microbial spoilage and accelerated metabolic activity (Lavelli *et al.*, 2007).

Reduction of water activity ($a_w$) is reported to result in a longer shelf-life of carrots, though carotenoids degrade faster in dehydrated systems, through autocatalytic oxidation. The influence of aw on oxidation is complex the water contentin dry matrices may increase the rate of oxidation byenhancing the mobility of reactants and bringing catalystsinto solution. As the solid matrix swells, new surfaces forcatalysts are exposed. However, water may also slow downthe oxidation process by hydrating or diluting heavy metalcatalysts or precipitating them as hydroxides. Water mayalso counteract peroxide decomposition by hydrogenbonding with hydroperoxides and encourage radicalrecombination which could interrupt the oxidation reactionchain. The net result of all these actions is that, inmany foods, the rate of oxidation reaches a minimum inthe aw corresponding to the

monomolecular moisture content. Therefore, it is suggested that dehydratedfoods should be stored at a monolayer $a_w$ todecrease oxidative degradations and thus extend theirshelf-life (Lavelli *et al.*, 2007).

# Part III

## Materials and methods

### 3.1 Materials

#### 3.1.1 Raw materias

##### 3.1.1.1 Carrot

Fresh carrot of 8 weeks was bought from local market of Dharan.

#### 3.1.2 LDPE packaging

LDPE plastic bag (12" x14") of 40 µ was bought from local market of Dharan.

#### 3.1.3 HDPE packaging

HDPE plastic bag of 50 µ were bought from local market of Dharan.

#### 3.1.4 Equipment and chemicals used

The list of equipment used from the lab of CCT are given in Table 3.1.

**Table 3.1** List of equipment used

| S.N | Physical apparatus | Specification |
|---|---|---|
| 1. | Electric balance | Phoenix instrument, 620 g |
| 2. | Spectrophotometer | Labtronics, India |
| 3. | Soxhlet apparatus | Y.P. Scientific industries |
| 4. | Hot air oven | Victolab, India |
| 5. | Muffle furnace | Accumax, India |

The list of chemicals used are presented in Table 3.2.

**Table 3.2** Lists of chemicals used

| Chemicals | Supplier/Manufacturer | Other specifications |
|---|---|---|
| Sodium hydroxide (NaOH) | Thermo fisher Scientific India Pvt. Ltd. | Pellets, AR grade, 98% |
| Sodium sulphate ($Na_2SO_4$) | Qualigens Pvt. Ltd. | Crystal |
| Sulphuric acid ($H_2SO_4$) | Thermo fisher Scientific India Pvt. Ltd. | 97%, LR grade |
| Boric acid | Merck (India) Limited | Amorphous |
| Oxalic acid | Merck (India) Limited | crystal |
| Petroleum ether | Merck life Pvt. Ltd. | B.P. 60℃-80℃ |
| Acetone | Thermo fisher Scientific India Pvt. Ltd. | liquid |

## 3.2 Methods

### 3.2.1 Washing

Carrots were washed with clean tap water to remove dust particles.

### 3.2.2 Cutting

The cleaned carrots were then cut into cube of uniform thickness of 1 cm×1 cm×1 cm with clean knife for ease of drying.

### 3.2.3 Blanching

The slice of carrot was blanched in boiling water at 98ºC for 0, 30, 60, 90, 120, 150, 180 and 210 s respectively.The optimization of blanching was done by catalase and peroxidase test.

### 3.2.4 Drying

After blanching 500 g of sample were dried in cabinet dryer at 60±5ºC for proper drying and solar dryer until the equilibrium moisture content (for 8 h) of carrot slice was obtained. Similarly, the samples of carrot without blanching were also dried in cabinet dryer and solar dryer for the same conditions as that of blanched sample.

The flow diagram for the drying of carrot is shown in Fig. 3.1.

### 3.2.5 Storage

The dried samples were powdered and 250 g sample was stored in LDPE and HDPE for 1 month.

### 3.2.6 Rehydration

The 50 g dried samples were rehydrated in 500 ml warm water 60ºC for 90 min as per Stephens and McLemore (1969) and rehydration ratio and rehydration coefficient were calculated.

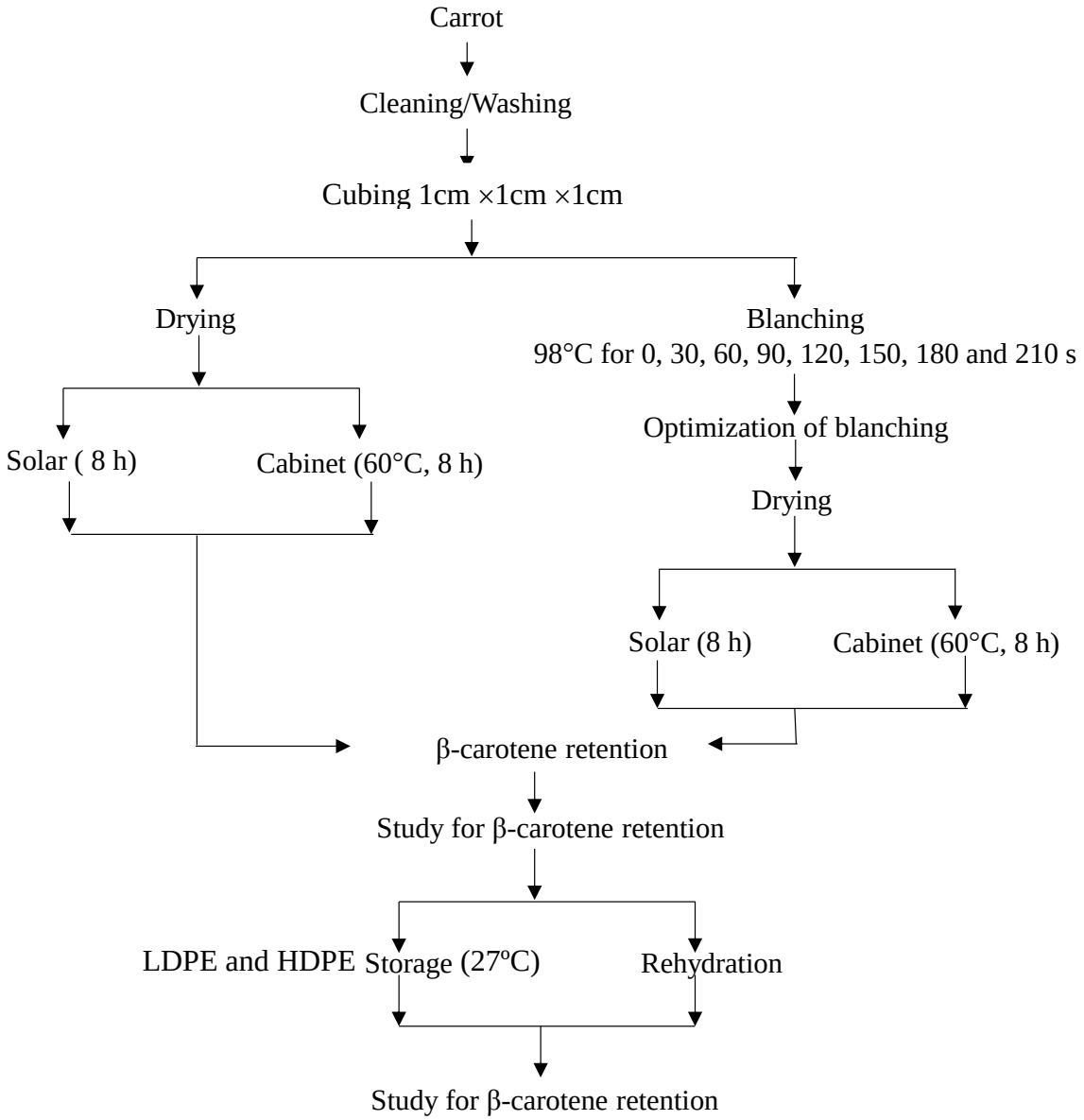


**Fig. 3.1** Flow diagram of carrot drying

### 3.2.7 Blanching accuracy test

#### 3.2.7.1 Catalase presence test

Take 1ml of extract and add 1ml of $H_2O_2$ solution. In the presence of catalase, a strong oxygen generation (effervescence) is observed for 2-3 min (IGNOU, 2007).

#### 3.2.7.2 Peroxidase test

To the same tube from catalase test to which $H_2O_2$ was added, add 0.5ml guaicol solution. The tube was kept aside for sometime for colour development. The Appearance of red colour confirms the presence of peroxidase. The steps were continued till red colour with

guaicol ceases to appear. The time taken from 0 min to the time when red colour is no more observed was called blanching time for the vegetable under study.

### 3.2.8 Chemical analysis

#### 3.2.8.1 Moisture content

Moisture content of the sample was determined by heating in an oven at 100 ± 5°C to get constant weight Ranganna (1986).

#### 3.2.8.2 Crude protein

Crude protein content of the samples was determined indirectly by measuring total nitrogen content by micro Kjeldahl method. Factor 6.25 was used to convert the nitrogen content to crude protein as per Ranganna (1986).

#### 3.2.8.3 Crude fibre

Crude fiber content of the samples was determined by the method given by Ranganna (1986).

#### 3.2.8.4 Total ash

Total ash content of the samples was determined by following the method given by Ranganna (1986) using muffle furnace.

#### 3.2.8.5 Carbohydrate

The carbohydrate content of the sample was determined by difference method as per Ranganna (1986).

Carbohydrate (%) = 100-(protein + fat + ash + crude fibre).

#### 3.2.8.6 β-carotene content

5 g sample was taken and crushed in 10.18 ml of acetone at mortal and pestle. Few crystals of anhydrous sodium sulphate were added. The supernatant was decanted into beaker. This process was repeated 2-3 times and then the residue was transferred to separating funnel where 10.15 ml of petroleum ether was added and mixed thoroughly and then separated. The upper layer was collected and volume was made up to 100 ml with petroleum ether.

The optical density was read at 452 nm of wavelength. Similarly, optical density of blank sample was also taken at the same wavelength. The β-carotene was calculated as

$$\text{retention of β-carotene (mg/ 100 g)} = \frac{\text{Optical density} \times 13.9 \times 10^4 \times 100}{\text{Wt. of sample} \times 5560 \times 1000}$$

### 3.2.9 Rehydration coefficient and rehydration ratio

The coefficient of rehydration and rehydration ratio of rehydrated samples was calculated as per Ranganna (1986) as:

$$\text{Rehydration ratio} = \frac{\text{WR}}{\text{WD}}$$

$$\text{Rehydration coefficient} = \frac{\text{WR} \times (100\text{-MD})}{\text{WD-WMd} \times 100}$$

Where: WR= Weight of sample after rehydration, WD= weight of d.ehydrated sample taken for rehydration, MD = Moisture content of material before drying (i.e., of the fresh material), WMd = Amount of moisture present in the dried sample taken for rehydration

### 3.2.10 Statistical analysis

The obtained data was analyzed statistically by Genstat Discovery Edition 12, for Analysis of Variance (ANOVA) at 5% level of significance. The data obtained from chemical analysis were subjected to one-way Analysis of Variance.

# Part IV

## Results and discussions

The fresh carrot was cleaned and sliced into uniform size (1cm×1cm×1 cm). Which is then blanched at 98°C water for 0, 30, 60, 90, 120, 150, 180, 210 s for the optimization of blanching time. Then 500 g cubes were dried in cabinet dryer at 60±5°C for 8 h and in solar dryer until the constant weight was obtained. Similarly, the samples without blanching was also dried in cabinet dryer and solar dryer. After then the dried carrot was powdered and packed in LDPE and HDPE packaging. The chemical analysis before storage and after storage were performed. The following results were obtained from the analysis.

### 4.1 Chemical analysis of carrot

The chemical analysis of raw carrot was performed and the results obtained were presented in Table 4.1.

**Table 4.1** Chemical composition of raw carrot

| Parameter | Value (db) |
|---|---|
| Moisture (%) | 85.89 (0.22) |
| Protein (%) | 0.93 (0.13) |
| Total ash (%) | 1.28 (0.07) |
| Crude fiber (%) | 1.2 (0.26) |
| Carbohydrate (%) | 9.66 (0.30) |
| β-carotene (mg/100 g) | 37.94 (0.40) |

According to Gopalan *et al.* (2012) the moisture content and protein content of carrot were 86% and 0.9% respectively this was the similar result that obtained in our study.

Gopalan *et al.* (2012) reported 1.2% of crude fiber and 1.1% of ash content which was similar to our study. Holland *et al.* (1991) reported 6% of carbohydrate which was lower than that found in our study. Similarly, Gopalan *et al.* (2012) reported 10% of carbohydrate which was similar that of our study. Nocolle *et al.* (2003) reported 60 mg/100 g total carotenoids in carrot. Similarly, Adhikari (1995) reported 36.45 mg/ 100 g of carotene content which was similar to our study.Demiray and Tulek (2016) also reported the carotene content of fresh carrot from 30.3-100.5 mg/100 g.

## 4.2 Optimization of blanching time

Proper combination of time and temperature during processing methods is important in order to minimize quality loss during processing. These methods cause undesirables changes on the physicochemical properties such as color, texture or bioactive compounds, on account of heat-induced diffusion or leaching losses. Thus, it is important to optimize the time and temperature of any processing method in order to achieve minimal loss of quality (Jaiswal and Gupta, 2012). The blanching time for carrot slice were optimized by catalase and peroxidase test. The absence of catalase and peroxidase confirms the adequacy of blanching. The result of catalase and peroxidase test was given in Table 4.2.

**Table 4.2** Catalase and peroxidase test for optimization of blanching time

| Blanching time (s) | Catalase test | Peroxidase test |
|---|---|---|
| 0 | + | + |
| 30 | + | + |
| 60 | + | + |
| 90 | + | + |
| 120 | + | + |
| 150 | - | + |
| 180 | - | + |
| 210 | - | - |

(+) represents positive test (-) represents negative test

The optimized blanching condition was 98°C for 210 s. The blanching condition was reported by Adhikari (1995) was 300 s at 98°C during blanching of carrot.

### 4.3 Desorption behavior of carrot

The dehydration characteristics of carrot for blanched and unblached samples were presented in Fig. 4.1.

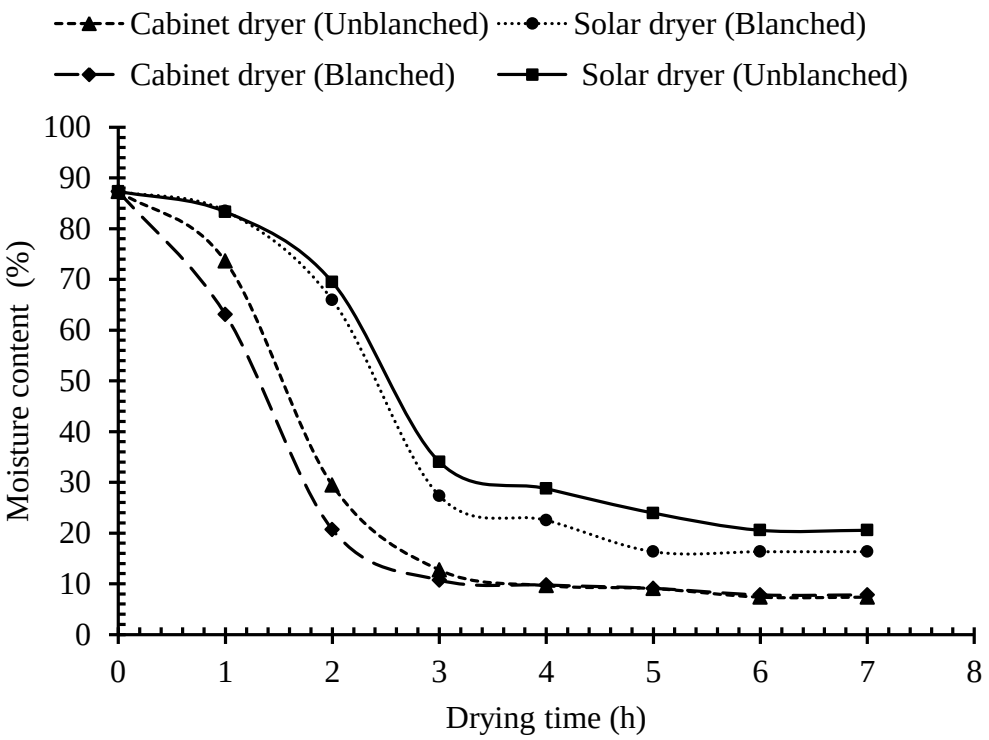


**Fig. 4.1** Dehydration characteristics of blanched and unblanched carrot

The moisture loss of carrot was faster at cabinet dryer than that of solar dryer. Also, the moisture loss for blanched sample was faster than that of unblanched sample. The similar type of result was obtained by Adhikari (1995) during drying of carrot at cabinet dryer at 60°C. Similarly, Phoungchandang and Wongwatanyoo (2010) observed the similar type of graph for desorption of carrot during dehydration at cabinet dryer.

The rapid loss of moisture in cabinet dryer than solar dryer may due to the high air velocity in cabinet dryer than that of solar dryer.Similarly during blanching the tissues may rupture which leads to rapid moisture loss from the tissue of carrots so, the loss is significantly high in blanched sample than that of unblanched sample (Lavelli *et al.*, 2007).

### 4.4 β-carotene retention during drying

The drying of carrot with blanching and without blanching were performed in cabinet and solar dryer and the β-carotene retention were studied for these samples. The β-carotene retention was found more in blanched sample drying in cabinet dryer than unblanched sample. The result for β-carotene retention is presented in Fig. 4.2.

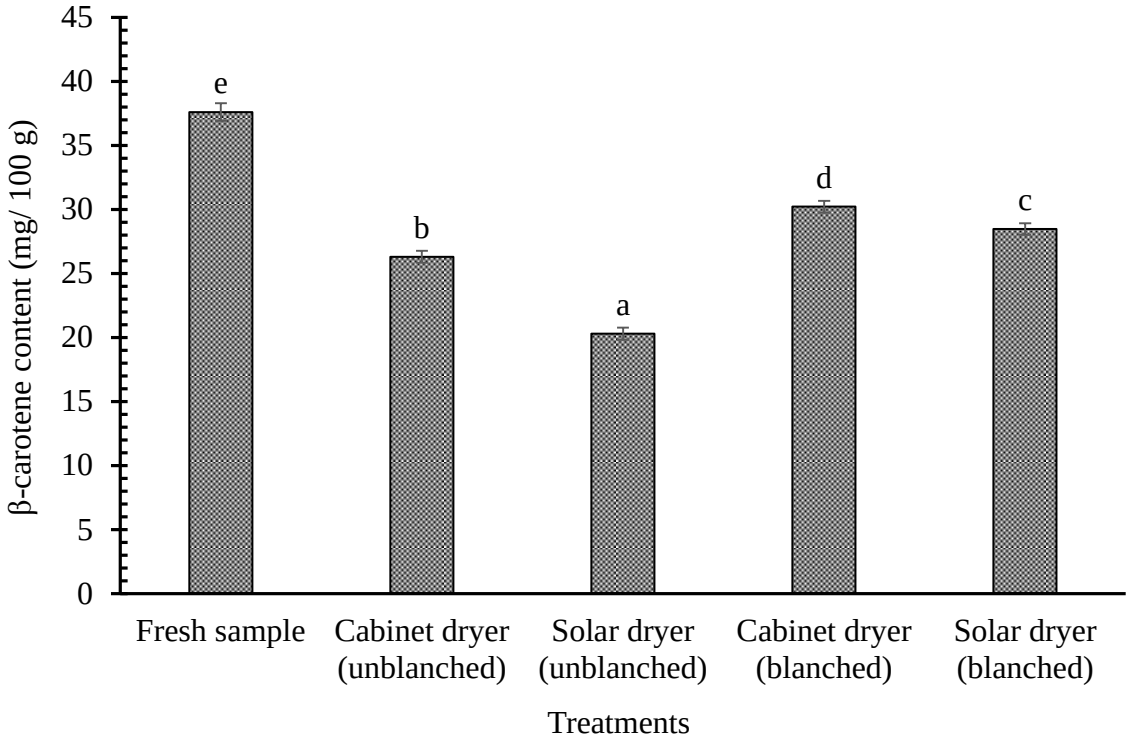


**Fig. 4.2** β-carotene retention of carrot during various treatments

The above graph shows that the β-carotene content decreased after drying. Similar results obtained by Demiray and Tulek (2016). In a previous study by Suvarnakuta *et al.* (2005)., carrots (*Daucus carota* var. sativa) were dried by using hot air drying methods at 60, 70 and 80°C to obtain a product with 10% initial moisture content. β-carotene content of carrot samples dried at 60°C for 420 min were 21.46 mg 100 g $dm^{-1}$. This was similar to our study. However, this value was reported as 22.05 mg 100 g $dm^{-1}$ for carrot samples dried at 80°C for 240 min(Demiray and Tulek, 2016).

The retention was more in blanched sample than unblanched sample. This was similar to the result obtained by Arya *et al.* (1979). Similarly, Adhikari (1995) also reported that the retention of β-carotene was higher in blanched sample than that of unblanched sample.

This may be due to the stabilizing effect of blanching on carotenoids, which had already been observed (Arya *et al.*, 1979). This effect is generally believed to be due to the inactivation of peroxidase and lipoxidase activity. These enzymes can act during the dehydration process until substrate mobility becomes a limiting factor for catalytic activity (Lavelli *et al.*, 2007).

The retention of carotene was higher in cabinet dryer than solar dryer. Adhikari (1995) also reported the similar result during drying of carrot. Carotene is highly unsaturated compound and undergoes oxidation very quickly. The catalytic activity of carotene oxidation depends on oxygen tension (Goldman *et al.*, 1983). During the drying period, it was exposed in air, and oxidation process accelerated. It is apparent that prolonged exposure to drying conditions result more damage to β-carotene (Adhikari, 1995). In solar drying the carrot was exposed in air so, high carotene oxidation occurs in solar dryer than in cabinet dryer.

So, it can be concluded that the retention of β-carotene was high at cabinet dryer of blanched sample. This sample was further stored in plastic pouch and retention of β-carotene was studied which was used to determine the shelf life of dried carrot.

### 4.5 Rehydration properties of dehydrated carrot

All the samples were rehydrated and their rehydration ratio and rehydration coefficient were determined. From one-way ANOVA it was found that there was no significant difference in rehydration ratio and rehydration coefficient of the samples. The result is presented in Table 4.3.

**Table 4.3** Rehydration ratio and rehydration coefficient of dried carrot

| Samples | Rehydration ratio | Coefficient of rehydration |
|---|---|---|
| Unblanched and cabinet dried | 2.46[a] (0.08) | 0.34[a] (0.011) |
| Unblanched and solar dried | 2.31[a](0.16) | 0.31[a] (0.02) |
| Blanched and cabinet dried | 2.35[a] (0.13) | 0.32[a] (0.041) |
| Blanched and solar dried | 2.45[a] (0.21) | 0.32[a] (0.09) |

The rehydration ratio and rehydration coefficient obtained in our study was similar to that reported by Adhikari (1995). But, Phoungchandang and Wongwatanyoo (2010) reported 13.88 rehydration ratio of dried carrot. This value was greater than that obtained from our study. The low rehydration ratio could be due to the damage of cells due to high drying temperature (Phoungchandang and Wongwatanyoo, 2010).

There was no significant difference in rehydration ratio and rehydration coefficient of blanched and unblanched carrots. The similar results were obtained by Phoungchandang and Wongwatanyoo (2010). Adhikari (1995) also reported the similar rehydration ratio of carrot samples dried at different temperatures.

The lower rehydration rate may be due to the effect of drying temperature and loss of soluble solids during rehydration. This may be also due to the excessive shrinkage, rupture, twisting and case hardening of dried carrot. The denaturation of protein by heat or localized high concentration of soluble constituents, gelatinization of starch and crystallization of cellulose might have contribute in lowering rehydration rate (Adhikari, 1995).

### 4.6 β-carotene retention during storage

The blanched and cabinet dried sample was stored in LDPE and HDPE packaging materialfor 60 days and β-carotene retention was studied for 60 days at 10 days interval of time. The β-carotene content retention was shown in Fig. 4.3.

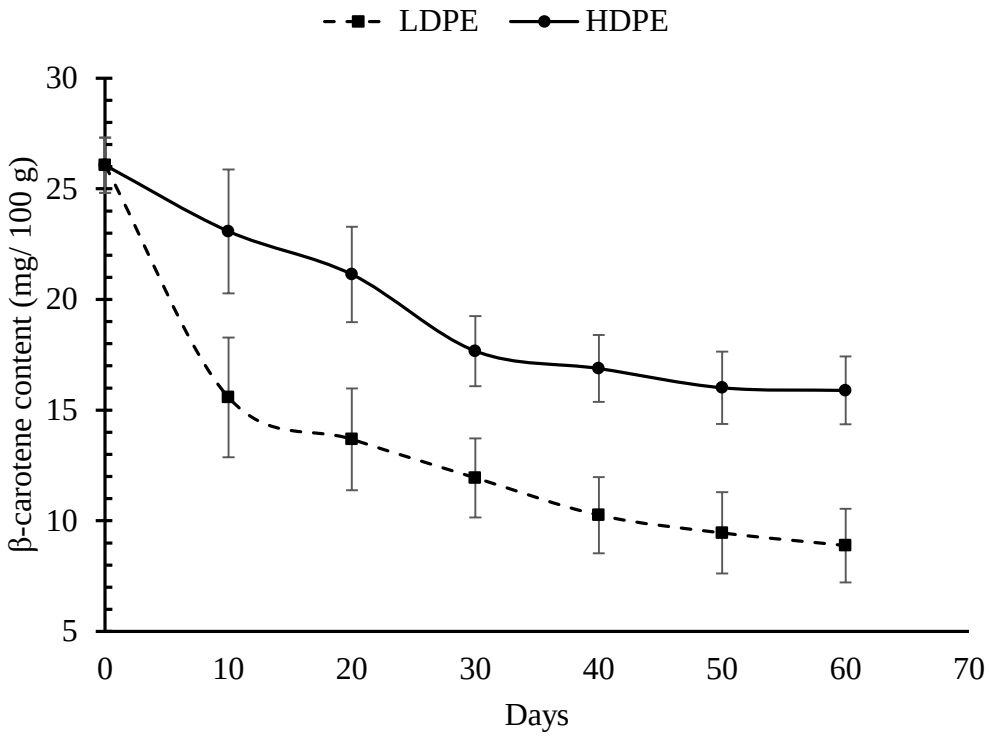


**Fig. 4.3** Storage stability of dried carrot

Vertical error bars represent the standard deviations.

The above graph shows that the β-carotene content decreases rapidly during 10 days of storage and the decreasing rate declines after 10 days. Similar pattern was obtained by Adhikari (1995) for total carotene content during storage of dried carrot samples. Lavelli *et al.* (2007) reported that carotenoid decreased by following pseudo-first-order kinetics during storage of carrot at 40°C. The decrease in β-carotene may be due to Oxygen pressure and water activity ($a_w$). As, LDPE seems to be permeable to water vapour (Athalye, 1992).

There is direct relationship between the moisture and oxygen gain and carotene destruction in carrot powder. At moisture content below than 10%, the rate of carotene destruction was faster, but above this level the carotene destruction became slower. Carotenoid were relatively more stable in the range of 0.32-0.57 $a_w$; maximum stability was near 0.43 $a_w$ (Arya *et al.*, 1979).

The rate of carotenoid destruction has been found to decrease continuously with increasing $a_w$. The increase in the rate of carotenoid destruction at higher $a_w$ might be due

to stabilization of catalysts present and exposures of new sites on solid matrix as a result of swelling of matrix. Alternatively, it may also be argued that at low $a_w$, catalytic activity may become limited on account of inadequate substrate mobility (Lavelli *et al.*, 2007).

Similarly, the carotene retention was higher in HDPE than that of LDPE packaging. As oxidation causes the degradation of carotene content (Lavelli *et al.*, 2007). HDPE packaging is less permeable to gas and water as compared to LDPE packaging. So, in HDPE packaging there is less chance of degradation of carotene than that of plastic packaging.

# Part V

## Conclusions and recommendations

### 5.1 Conclusions

On the basis of the results obtained following conclusion were done

1. Optimization of blanching condition of carrot slice was performed. The optimized blanching condition for carrot slice was obtained in water at 98°C for 210 s.
2. The desorption of blanched carrot at cabinet dryer was faster than that of other carrot samples (Unblanched carrot).
3. The retention of β-carotene was higher for blanched carrot in cabinet dryer dried at 60°C than solar dryer.
4. The rehydration ratio and rehydration coefficient were similar for blanched and unblanched carrot samples dried both at solar and cabinet dryer.
5. The β-carotene retention was lower at LDPE packaging than that of HDPE packaging.

### 5.2 Recommendations

1. Carrot can be dried at cabinet dryer at 60±5°C by blanching at 98°C for 210 s to retain higher β-carotene content.
2. β-carotene retention of carrot by drying at different conditions can be studied.
3. β-carotene retention of carrot during storage using different packaging materials can be studied.

## Summary

Carrot (*Daucus carota* L) is one of the popular root vegetables grown throughout the world and is the mostimportant source of dietary carotenoids.Up to now, β-carotene has been the most studied carotenoid. Beside its provitamin A activity other physiological roles such as cell-to-cell communication, immunomodulatory effect, and UV skin protection have been documented. The xanthophylls lutein and zeaxanthin are the only carotenoids present in the macula region of the retina, probably functioning as blue light filters and singlet oxygen quenchers. The carotenoid content of minimally-processed carrots did not decrease during storage, however, these products are degraded by microbial spoilage and accelerated metabolic activity.

The fresh carrot was washed with clean water and cubed into uniform thickness of 1 cm × 1cm × 1cm. The cubes were blanched at 98°C water for 0, 30, 60, 90, 120, 150, 180 and 210s to optimize the blanching time. After optimization of blanching time of the carrot cubes were dried at cabinet drier at 60±5°C for 8 h and solar drier until equilibrium moisture content was obtained. Similar drying was done for unblanched carrot cubes. Drying pattern of all samples were studied. After drying the drying condition was selected according to the retention of β-carotene content. Then the rehydration of dried carrot was done to study rehydration properties. And, the optimized sample was powdered and stored in LDPE packaging and HDPE packaging and β-carotene retention was studied at interval of 10 days for 60 days.

The moisture content, protein content, fat content, ash content, crude fiber content, carbohydrate content and β-carotene content of carrot were 85.89%, 0.92%, 1.03%, 1.28%, 1.2%, 9.66% and 37.94 mg/100 g respectively. The β-carotene content for unblanched and blanched sample dried in cabinet dryer were 26.3 mg/100 g and 36.21 mg/100 g respectively. Similarly, the β-carotene content for unblanched and blanched sample dried in solar dryer were 20.28 mg/100 g and 28.46 mg/100 g respectively. During storage the β-carotene decline from 26.06-8.88 mg/100 g in 60 days.

The optimized blanching condition was found to be 98°C water for 210 s. The higher β-carotene retention of 30.21 mg/100 g was found for blanched carrot sample dried at cabinet dryer at 60°C for 7 h. The desorption rate was higher for the blanched cabinet dried sample. The rehydration properties of all the samples were found to be

similar. During storage of carrot powder in LDPE packaging and HDPE packaging material for 60 days β-carotene destruction was high during 10 days and after 10 days the destruction rate declines. Also, retention of β-carotene was higher in HPDE packaging than LDPE packaging. So, it can be concluded that β-carotene can be retained more by drying blanched carrot in cabinet dryer at 60°C for 8 h.

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## Appendix

**Table A.1** ANOVA for β-carotene content for different drying conditions

| Source of variation | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| Treatments | 4 | 461.5239 | 115.381 | 1453.16 | <.001 |
| Residual | 10 | 0.794 | 0.0794 | | |
| Total | 14 | 462.3179 | | | |

**Table A.2** ANOVA for rehydration ratio

| Source of variation | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| Sample | 3 | 0.05159 | 0.0172 | 0.79 | 0.031 |
| Residual | 8 | 0.17336 | 0.02167 | | |
| Total | 11 | 0.22496 | | | |

**Table A.3** ANOVA for coefficient of rehydration

| Source of variation | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| Sample | 3 | 0.001521 | 0.000507 | 1.07 | 0.413 |
| Residual | 8 | 0.003774 | 0.000472 | | |
| Total | 11 | 0.005295 | | | |

# Color plates

**Plate 1.** Carrot samples

**Plate 2.** Analysis of carrot