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Effect of ohmic heating on color, rehydration and textural characteristics of fresh carrot cubes

Sandeep Dattatraya Bhale

Louisiana State University and Agricultural and Mechanical College

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EFFECT OF OHMIC HEATING ON COLOR, REHYDRATION AND TEXTURAL CHARACTERISTICS OF FRESH CARROT CUBES

A Thesis

Submitted to the Graduate Faculty of the
Louisiana State University and
Agricultural and Mechanical College
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Master of Science in Biological and Agricultural Engineering

In

The Department of Biological & Agricultural Engineering

By
Sandeep Dattatraya Bhale
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ABSTRACT

Carrot cubes were ohmically heated with 2 different frequencies 1 Hz and 60 Hz to evaluate change in color, texture and rehydration properties. Carrot samples were stored under 4 different relative humidity (RH) conditions 11.1 %, 32.7%, 55.7 % and 75.3 %. Experiments were conducted to monitor the textural parameters of hardness, fracturability, adhesiveness, cohesiveness and chewiness and color changes in terms of CIE color values. Results showed that the hardness, fracturability and adhesiveness of 1-Hz samples stored at 75.3 % RH were different from those at 55.7 % RH. The adhesiveness, cohesiveness and chewiness of 1-Hz samples were different from the control at 55.7 % RH. There was significant correlation between cohesiveness and chewiness and moisture content of the rehydrated samples. For the moisture content after ohmic heating a negative correlation was observed with properties of chewiness, hardness and adhesiveness. Color lightness (L*) values of rehydrated carrots decreased (i.e. became darker) with the increase in storage time. At both 1-Hz and 60-Hz the difference in the L values of fresh and rehydrated carrots was significantly different from that of the control. The degree of redness (a*) of 1-Hz rehydrated samples after 1 Hz treatment were different from the control stored at 55.7 % RH. The water absorption capacity values decreased throughout the six-day storage period for both the treated and control carrot samples. Thus there exists a great potential to enhance mass and heat transfer properties in food process engineering using ohmic heating, particularly because ohmic treatment has been shown to significantly alter rehydration, texture and color efficiencies. This study demonstrated that ohmic treatment significantly affects color, texture and rehydration properties of carrots stored under different RH environments.

CHAPTER 1

GENERAL INTRODUCTION

Food process engineering involves a combination of processes termed as unit operations. Processing by heat transfer is one of the unit operations used for shelf life extension of foods, causing destruction of microbes and enzymes, and also effective in excess water removal. Electrical heating of foods influences their mass transfer properties. This phenomenon has important implications for food process engineering as heat and mass transfer forms an integral part of food process engineering study. This explains the use of ohmic heating in blanching, evaporation, dehydration, fermentation, and other food processing operations. Heat processing by electricity can also be termed as aseptic processing; the sole purpose of it is to obtain a sterile product with a sterile packaging in order to preserve the perishable food material for a long duration of time (Sandrine *et al.*, 1999). In aseptic processing heat transfer is achieved either by conduction, convection or radiation. But there are certain limitations to sterilize the center of the target product as it often takes a long time and the process can overcook the product.

Food processing by heat treatment is convenient and relatively simple. It is basically divided according to the medium of heat application; processing with water includes blanching, pasteurization, heat sterilization, evaporation and distillation. Heat processing by hot air comprises of dehydration, baking and roasting, processing by oil is termed as frying, whereas processing involving pressure is called extrusion. Last but not least is heat processing achieved by energy transfer like di-electric heating, ohmic heating, chilling, freezing etc. (Fellows, 2000). Methods used to achieve these processes include infrared, microwave, radio frequency, and ohmic heating processes.

The processing of foods is helpful in retaining the nutritional quality and preserving the product for long-term use. It is very helpful in case of perishable foods with the added advantage of quality retention.

Ohmic heating, a thermal electrical heating method, is also termed as resistance heating, which uses electrical resistance in the foods and converts it in to heat. Ohmic heating is direct heating method where food is in contact with the electrodes, it has been extensively used in the past for commercial processing as reported by Paniappan *et al*. (1990) for the pasteurization of milk. The emphasis on the ohmic heating research slowed down during 1930s to 1960s, due to the electricity cost constraints. Ohmic heating is very often used in pasteurization/sterilization of food products resulting in excellent quality. It is also used in rapid cooking of potatoes and vegetables blanching (Mizrahi, 1996). Past research as done by Lima *et al.* (1999) also underlines the role of ohmic heating technique enhancing the air-drying rate. But more research is needed for the acceptance of ohmic heating method for use in particulate foods.

Thermal processing has a huge impact on the textural attribute of the final food product, and texture is a major factor contributing the overall quality of fruits and vegetables. In general consumers prefer processed vegetables with firmer structure than that of conventionally processed products, as food is consumed not only for its nutritional value but for pleasure. Due to the increasing consumer demand for crisp, firm, succulent textured fruits and vegetables, the research has been concentrated on modifying processing techniques in order to retain textural qualities of fresh products (Bourne, 1989). Past research has proven that the texture of fruits and vegetables is greatly influenced by the temperature and the thermal processing of the product (Bourne, 1978 and Quintero-Ramos *et al.*, 1992). In the fruits and vegetables the presence of pectic polysaccharides, which forms a major portion of the primary wall and also in middle labella between the cells, are mainly responsible for most of the texture (Jarvis, 1984). With the knowledge of fracture, toughness, and fracture energy it is possible to relate texture with the structure of food as it happens in the biting/chewing/mastication processes. The work done by Imai *et al*. (1995) on white radish confirmed that heating of the sample at low frequency resulted in the same breaking strength as that of the raw samples.

In food processing technology drying is equally an important step to remove water from the food product. The removal of water is in view of halting or slowing down the growth of food spoilage microorganisms. Further it is also helpful in controlling chemical reactions taking place in the food, which may affect the food quality (Humberto *et al.*, 2001). Rehydration is another important process in food processing technology, which is generally followed after drying. Rehydration is replacement of water in dehydrated processed foods including fruits and vegetables, also termed as "refreshing, and reconstitution". The process of rehydration is assimilation of the original water present in food material. There is no standard procedure for rehydration process but the main parameters to seek are Water absorption capacity and rehydration ability which furnishes information on rehydration properties of the product.

Paniappan and Sastry (1991) have found that food undergoing heating affects a lot of internal and external changes like cell rupture, tissue shrinkage, phase changes, dehydration, starch gelatinization etc. These changes have an impact on the physical properties, electrical properties, and the overall quality of the food.

The work done in the past on ohmic heating has been conducted mostly with 60-Hz alternating current (in US) and 50 Hz for those studies done in Europe and UK. Imai *et al.* (1995) concluded with their experiment on Japanese white radish that increasing frequency from 500 Hz-1000 Hz and field strength (FS) of 40v/cm, there was gradual increase in time for radish to reach end point temperature of 80°C. Further Kim and Pyun (1995) found that altering the frequency and waveforms of Alternating Current (AC) during ohmic heating has a direct effect on heat and mass transfer properties of the food material undergoing ohmic heating. It was found in previous research that the direct current (DC) resulted in less mass transfer enhancement than low frequency AC current (at 15 V/cm, 250 Hz < DC < 50 Hz) during ohmic heating and concluded that a monopolar electric charge (DC) is not effective when compared to a bipolar electric charge, thus resulting less effect than low frequency alternating current (Kulshrestha, S. and S. Sastry. 2003). Thus the present research work was done by the use of 1 Hz and 60 Hz frequencies Another work by Eliot *et al.* (1999) elaborates the usefulness of ohmic heating as alternative technique to high temperature/short time sterilization of cauliflower clorets. As observed by Lima *et al*. (2001) the heat generation rate obtained during the process of ohmic heating is proportional to the electrical conductivity (with voltage gradient at a constant value) has a great impact on heat transfer rates. Further in their experiment with beet dye they also observed that ohmic heating had a 40 % enhanced diffusion effect on the Beet dye with a linear relationship with the electrical field strength.

The vegetables like carrots have significant color and texture characteristics which consumer look out for while buying the minimal processed or fresh carrots. As rightly observed by Segerlind *et al.* (1977) the storage time of carrot tissues, their retention of quality characteristics like crispiness and hardness are little or not known about. Their study dealt with the relationship between moisture content of carrots and textural characteristics. Roy *et al*. (2001) did work on effect of blanching and freezing on firmness and ultrastructural changes in carrots, Quintero-Ramos *et al*. (1992) did the work on the effect of low temperature blanching on the firmness of carrots, but no conclusive research in the past has been devoted to determine the effects of ohmic heating on texture profile analysis (TPA). No significant literature is available on the color changes during rehydration and extended textural (mouthful) characteristics of carrot tissues during storage. This research was based on the need to study effect of heat on different characteristics of food like color, rehydration and texture properties. Prior research suggests that the color of rehydrated dried vegetable tissues like carrots can be improved by utilizing thermal processing techniques like rapid heating or altering the drying temperatures (Bolin, H.R and Huxsoll, C.C., 1991). The work done by Imai *et al.* (1995) on white radish also concluded that the use of ohmic heating helped to retain the breaking strength of radish and improved internal texture of the samples.

No comprehensive work in the past has been dedicated to the effect of ohmic heating on changes in color, texture and dehydration characteristics in general and correlation between texture and moisture properties of the food product in particular. Lima (Dissertation 1996) visually observed the texture and color of the ohmically heated rehydrated samples were better than raw samples. This initiated the research work to find the effect of rehydration on ohmically heated carrot tissues in retaining the color and texture of the product.

The objectives of this research were

- To perform ohmic heating on carrot samples with two different frequencies 1 Hz and 60 Hz.
- To determine rehydration characteristics of ohmically heated carrot tissues.
- To determine effect of ohmic heating on the textural properties of carrot samples by Texture profile analysis.
- To measure color change in carrot cubes after ohmic heating and rehydration processes stored under different RH conditions.

CHAPTER 2

INTRODUCTION

2.1 OHMIC HEATING

Ohmic heating has been used for many years in different industries and proved to be a promising food processing technology. Ohmic heating is also referred to as direct electrical resistance heating, electro heating, and electro conductive heating. A large number of applications of ohmic heating have a tremendous potential in the fields of blanching, evaporation, dehydration, fermentation, and extraction. Ohmic heating is already being used in Japan for processing of whole fruits and so also in United Kingdom. In the United States it is used in the application of liquid egg processing.

In ohmic heating electrical properties like electrical conductivity, field gradient and voltage of the foods play a major role. Foods, which contain water and ionic salts in abundance, are most suitable to use in applications of ohmic heating (Palaniappan and Sastry, 1991). Information on conductivity measurements therefore may prove effective in product formulation and process control. Following properties play a important role during ohmic heating of foods type of food product, solid or liquid phase, size and shape of the particles, moisture content of the solids if present, solids/liquids ratio, viscosity of liquid component, amount and type of electrolysis, pH, specific heat, and electrical conductivity (Fellows, 2000).

Electrical conductivity is the one of the important property; it can be expressed as inverse of specific electrical resistance. But this resistance is different from electrical resistance as this specific resistance decreases with rise in temperature. Prior studies have also confirmed that the precision in the ohmic heating depends mainly on the electrical conductivity of the foods (Sastry, 1991). Dependence of ohmic heating on electrical conductivity is due to its influence on the heat and mass transfer properties. Further it can also be noted that conductivity of foods shows a linear increase with temperature at sufficiently high electric field strength. Electrical conductivity of the mixture and the amount of voltage applied significantly affects the heating rate of the solid-liquid mixtures during ohmic heating. And in this process, a simultaneous and uniform heating of solid and liquid phases can be achieved, thus reducing the danger of under processing as well as nutritional loss.

The electrical conductivity of foods increases with temperature, applied voltage, concentration of the electrolytes, food particle size and type of pretreatment (Palaniappan and Sastry, 1992). Work done by Lima *et al.* (1999) showed that frequency and waveform of applied voltage affects the electrical conductivity values and the process of heating the samples. Some studies (Lima *et al.*, 2001) also suggested that with low frequency electrical conductivity values were high and further electrical conductivity of turnip tissue used in the experiment was significantly higher for sine and saw tooth waves as compared to the square waves at 4 Hz. The electrical conductivity does depend on the temperature, ionic breakup and microstructure setup of the food material undergoing heating and field strength of the experimental setup (Parrott, 1992). When solid particles suspended in a fluid medium both have similar electrical conductivities, the component among them having lower heat capacity will have the tendency to heat faster. Foods having high densities and high specific heat values are conducive to slower heating. Fluid viscosity also influences ohmic heating; higher viscosity fluids tend to result in faster ohmic heating than lower viscosity fluids.

The applied voltage level, a function of applied electric field gradient significantly affects the rate of change of electrical conductivity. One of the goals of this project was also to determine the voltage change-taking place during the heating.

Ohmic heating is a useful tool for value-added processing, and it has great potential for use in a wide variety of food processing operations involving heat and mass transfer. Ohmic heating is a continuous high temperature, short time (HTST) sterilization process (De Alwis, 1990). Many studies (Cho and others, 1996) have suggested that mild electroporation during ohmic heating may contribute to cell inactivation that is owing to the fact that presence of mild electroporation, can improve transfer of substrates at the early stages of fermentation.

An experiment conducted by research scholars on ohmic treatment with a variety of low-acid, high- acid shelf stable products and refrigerated extended-shelf-life products (Zoltai and Swearinger, 1996) found that the final product had a texture, color, flavor, and nutritional value same or better than that with traditional processing methods such as freezing, retorting, and aseptic processing (Zoltai and Swearinger, 1996).

The main advantages of Ohmic Heating are as follows:

- Temperature required for UHT processing can be achieved
- No problem of surface fouling or over heating of the product
- Useful in Pre-heating products before canning
- Energy conversion efficiencies are very high
- Suitable for continuous processing
- Lower capital investment as compared to microwave heating and conventional heating

- Large-scale process can be carried out in heavy-duty ohmic cookers or batch ohmic heaters (Fellows, 2000).

Ohmic heating can be used for ultra high temperature (UHT) sterilization of foods, and especially those that contain large particles (up to 2.5 cm) that are difficult to sterilize by other means. A mild electroporation process can occur during ohmic heating according to recent literature and research (Imai *et al*., 1995; Kuang and Nelson, 1998; Sastry and Barach, 2000). Electroporation is the formation of holes in a cell membrane due to individual ion pressure, which cause change in permeability of cell membrane, due to the varying the electric field (Weaver, J. 1987). The low frequency used in ohmic heating (50-60Hz) allows cell wall to build up charges and form pores, which is not the case with high frequency methods such as microwave heating, where the electric field is reversed before sufficient charge buildup occurs at the cell walls. The past researchers also found that electricity applied later during the microbial growth cycle can prove hazardous, possibly due to the enhanced transport of inhibitory substances across the cell membranes.

2.2 CARROTS

The carrot (*Daucus carota*) gets its name from the French word *carotte*, which in turn comes from the Latin word *carota*. The carrot varieties with a deep orange color are rich in carotene, or provitamin A, found also in other yellow vegetables and in green leaves. Vitamin A is found in such foods of animal origin as fish-liver oils, butter, and egg yolks. Beta-carotene is an orange pigment found in carrots and other fruits and vegetables. It belongs to a group of compounds called carotenoids and has antioxidant properties that may reduce the incidence of cardiovascular disease and certain types of cancer. It is also an important source of vitamin A, which is necessary for normal vision, bone growth and tooth development (www.USDA.org). Carrots have the highest carotene content among most of the human foods (Bao and Chang, 1994). This property has increased the importance of dried carrot slices as an excellent source for developing an oil free, healthy snack food provided the nutritional quality could be retained. The other use of minimally processed carrots is in carrot juice, which is becoming popular due to its high vitamin A contents. The vegetable juice available in the stores have a portion of carrot juice as a major constituent.

A study conducted by Paniappan and Sastry in 1992 with carrots demonstrated that the electrical conductivity values for carrots increase with higher temperatures and also increases with the voltage gradient and has a linear relationship most of the times. The changes in the electrical conductivity values may be as due to high temperature heating there is dissolution of cell wall components and dissolution of protopectin (expulsion of non-conductive bubbles, softening) increase in ionic mobility affecting the electrical conductivity values (Bruniche-Olsen 1962; Bean *et al*. 1960).

2.2.1 CARROT PRODUCTS

Carrots are processed and used in a wide variety of food products, including dehydrated soup mixes, chips, carrot juice, carrot nut muffins, and also in oil and other skin care products. Among these carrot chips are quite popular and are available at all the leading food stores. Carrot juice has been very useful in the treatment of severe illness, especially cancer. Raw carrots are high in beta-carotene, vitamin B-complex, C, D, E, K, iron, calcium, phosphorous, sodium, potassium, magnesium, manganese, sulfur, and copper (all in absorbable, organic forms).

TABLE 1. NUTRITIONAL COMPOSITION OF CARROTS

	Nutrient	**Mean**	**±**	**SEM**	**n**	
Proximate Analysis	Protein	1.03	±	0.01	(182)	g
	Total lipid (fat)	0.19	±	0.02	(28)	g
	Carbohydrate, by difference	10.14				g
	Ash	0.87	±	0.026	(46)	g
	Energy	43.0				kcal
	Water	87.79	±	0.07	(237)	g
	Energy	180.0				kj
	Fiber, total dietary	3.0				g
Minerals	Calcium, Ca	27.0	±	0.667	(235)	mg
	Iron, Fe	0.5	±	0.019	(241)	mg
	Magnesium, Mg	15.0	±	0.348	(236)	mg
	Phosphorus, P	44.0	±	0.803	(236)	mg
	Potassium, K	323.0	±	2.68	(238)	mg
	Sodium, Na	35.0	±	1.218	(243)	mg
	Zinc, Zn	0.2	±	0.024	(222)	mg
	Copper, Cu	0.047	±	0.002	(90)	mg
	Manganese, Mn	0.142	±	0.007	(229)	mg
	Selenium, Se	1.1	±	0.355	(6)	mcg
Fat Soluble Vitamins	Vitamin A, IU	28129.0	±	152.919	(162)	IU
	Vitamin A, RE	2813.0	±	15.292	(162)	mcg_RE
	Vitamin E	0.46				mg_ATE
Water Soluble Vitamins	Vitamin C, ascorbic acid	9.3	±	0.168	(162)	mg
	Thiamin	0.097	±	0.002	(179)	mg
	Riboflavin	0.059	±	0.001	(177)	mg
	Niacin	0.928	±	0.082	(23)	mg
	Pantothenic acid	0.197	±	0.02	(11)	mg
	Vitamin B-6	0.147	±	0.013	(21)	mg
	Folate	14.0	±	0.874	(9)	mcg
	Vitamin B-12	0.0				mcg
Amino Acids	Tryptophan	0.011				g
	Threonine	0.038				g
	Isoleucine	0.041				g
	Leucine	0.043				g
	Lysine	0.04				g
	Methionine	0.007				g
	Cystine	0.008				g
	Phenylalanine	0.032				g
	Tyrosine	0.02				g
	Valine	0.044				g
	Arginine	0.043				g
	Histidine	0.016				g

Table 1 continued from last page

	Alanine	0.059				g
	Aspartic acid	0.137				g
	Glutamic acid	0.202				g
	Glycine	0.03				g
	Proline	0.029				g
	Serine	0.035				g
Lipids	Cholesterol	0.0				mg
	Fatty acids, saturated	0.03				g
	4:0	0.0				g
	6:0	0.0				g
	8:0	0.0				g
	10:0	0.0				g
	12:0	0.002				g
	14:0	0.001				g
	16:0	0.023				g
	18:0	0.001				g
	18:1	0.006				g
	18:2	0.067				g
	18:3	0.01				g
	20:4	0.0				g
	22:6	0.0				g
	16:1	0.002				g
	18:4	0.0				g
	20:1	0.0				g
	20:5	0.0				g
	22:1	0.0				g
	22:5	0.0				g
	Phytosterols	12.0				mg
	Fatty acids, monounsaturated	0.008				g
	Fatty acids, polyunsaturated	0.077				g

Values are expressed per 100 g edible portion by USDA.

TABLE 2. COMPOSITION OF CARROT TISSUE

Water (%)	88
Energy (Kcal)	43
Protein (g)	1.0
Fat (g)	0.2
Carbohydrate (g)	10.1
Fiber (g)	1.0
Ca (mg)	27
P (mg)	44
Fe (mg)	0.5
Na (mg)	35

TABLE 2 (continued)

K (mg)	323
Vitamin A (IU)	28,129
Thiamine (mg)	0.10
Riboflavin (mg)	0.06
Niacin (mg)	0.93
Ascorbic Acid (mg)	9.3
Vitamin B6	0.15

2.3 DRYING PROCESS

Drying is a process, which removes water from the food material in order to halt the growth of spoilage microorganisms, and avoid any further chemical reactions.

It has been illustrated in the previous works by Lima *et al.*(1999) that the drying rate of ohmically heated vegetables is high as compared to that of the non-treated (not ohmically heated) further also increasing juice extraction yields, which is a important quality implications in long term perspective.

2.4 TEXTURE ANALYSIS

The sensations experienced involved as food material deforms and fractures during biting and chewing governs the overall acceptance or rejection of a particular product by consumers. Thus texture retention has become an important part of food processing research (Doloros *et al.*, 2000). Texture is considered most important quality attribute especially in the case of canned carrots. In processing operations like drying and freezing, the temperature causing the enzyme inactivation could result in loss of texture in certain vegetables. As carrots have proven to possess high carotene content, the importance of thermal processing on storage, retaining texture of carrots has attracted a lot of attention. Generally the texture of vegetables is expected to be tender, but solid, no excessive toughness, softness or mushiness (Lee *et al.*, 1979). The canned carrots have to go through a chain of preliminary thermal processing operations before the canning process. The problem with carrots is they become excessively soft with less firm texture after processing (Lee *et al.*, 1979).

It has also been proven that the texture of vegetables is greatly influenced by temperature and thermal processing (Anantheswaran *et al.*, 1986). The high temperature may possibly cause heat damage or injury to the vegetable tissue which may affect texture and structure of the food material. Structure and composition of cellular tissues mainly determine the texture of vegetables. Previous works done by Eliot *et al*. (1999) have demonstrated that the ohmic heating is good treatment for aseptic processing of vegetables like cauliflower. The cell wall is the main constituent tissue that affects mostly the overall texture (Van Buren J. P., 1979).

Over the years food industry has developed several methods to determine textural quality of food products in conjunction with the biting/chewing method employed by the human beings (Doloros *et al*., 2000). Thus the knowledge of texture properties like fracture, toughness, and fracture energy will enable to correlate texture with the structure of food as it happens in the biting/chewing/mastication processes and effect of the Ohmic treatment on the above discussed parameters.

Fruit and vegetables are important components of a healthy diet, and their textural along with physical appearance characteristics like color are considered important to the consumers and they play an important role in determining consumer's choice. The food industry needs reliable instrumental methods to measure the textural quality of fresh produce, and also needs to ensure that the instruments measure characteristics important to consumers.

Texture profile analysis (TPA) is an objective method of sensory analysis first used by Szczesniak in 1966 to define the textural parameters. The definition of individual parameters is furnished below.

2.4.1 SENSORY MASTICATION PROCESS (Marsilli, R., 1993)

- Hardness: Place sample between molar teeth and bite down evenly, evaluating the force required to compress the food.
- Cohesiveness: Place sample between molar teeth; compress and evaluate the amount of deformation before rupture.
- Fracturability: Place sample between molar teeth and bite down evenly until the food crumbles, cracks or shatters, evaluating the force with which the food is moved away from the teeth
- Adhesiveness: Place sample on tongue, press it against the palate and evaluate the force required to remove it with the tongue.
- Chewiness: Place sample in the mouth and masticate at one chew per second at a force equal to that required to penetrate a gum drop in 0.5 seconds, evaluating the number of chews required to reduce the sample to a state ready for swallowing.

2.5 COLOR STUDY

Color changes are very significant when the food material undergoes different thermal treatments. The color of the food alters during processing, drying or dehydration basically because of migration of moisture and certain chemical changes. According to a study Anthocyanins, is the largest group of water-soluble pigments present in the plants mainly responsible for most of the red, blue, and purple colors of fruits, vegetables, flowers, and other plant tissues (Takeoka, 2001). An experimental study conducted by Camelo *et al*. (2003) showed that the red color in case of tomatoes was mainly due to the presence of lycopene in addition to other pigments that are present during the ripening process of fruits such as phytoene (colorless) and β-carotene (pale yellow), β-carotene (orange); and xanthophylls (yellow). Oezkan *et al*. (2003) reported that there is a linear relationship between different color variables and moisture contents at 15.49-30.20%. It was observed that in case of dried apricots with increase in the moisture content, the L* (lightness), b* (yellowness), c and h color values were increased while only a*(redness) value was decreased at all the intermediate moisture levels.

Thus all these prior works show the intimate relationship of color in fruits and vegetables and the factors responsible in alteration of these colors during processing such as drying. Prior research also suggests that the color of rehydrated dried carrots can be improved by employing certain thermal processing techniques including rapid heating or altering drying temperatures. Color is often an important attribute when it comes to selection of fresh fruits and vegetables by consumers.

Color is represented by the 1976 CIE L*, a*, b* values. L* is the lightness of the color. This refers to the relation between reflected and absorbed light. A value equals to zero represents black color and 100 represents white color.

Color values of a* and b*, where a* is the degree of color depending on the range 0 to 60 represents degree of redness whereas the values between 0 to - 60 represents degree of greenness and b * is the amount of yellowness (0 to 60) or blueness (0 to - 60). Thus the color can be defined in terms of L* a* and b* and the individual values represent the color characteristics of the carrot tissue.

2.5.1 Hue

Hue can be described in words such as green, blue, yellow, or red. This perception of color is the result of difference in absorption of radiant energy at various wavelengths. As in wavelengths of 400-500nm are reflected to a greater extent than other wavelengths then the color is described as blue. Hue is $H^o = \tan^{-1}(b^*/a^*)$

An angle of 90 represented a yellow hue (when b* is yellowness measured). Objects in the high range of hue angles are greener while low hue angle denotes orange-red.

In 1991, Bolin, H.R and Huxsoll, C.C worked with carrots and suggested that the color of rehydrated dried vegetable tissues like carrots can be improved by utilizing thermal processing techniques like rapid heating or altering the drying temperatures. Color and texture often expresses the quality of fruits and vegetables, which can undergo several changes during different processing steps. The color is evaluated in the form of L* a* b* values with the help of calorimeter (Minolta camera Co. ltd., chroma meter II reflectance meter (Chan *et al*., 2002).

2.6 REHYDRATION

Rehydration is an important unit operation in food processing to study the dried processed product and its characteristics. The property and the quality of rehydrated material are mainly factor of pre-drying process, drying process and the actual rehydration process (Lewicki, 1998). Rehydration also often called as process to moisten the dry material (Bolin, H.R and Huxsoll, C.C., 1991). Mostly rehydration process uses an abundant amount of water. In particular rehydration cannot be termed as a process merely opposite to dehydration. Dry material, subjected to rehydration, undergoes many chemical and physical changes owing to the property of water imbibition and solute loss. Imbibition of water by dry material is mainly dependent on the porosity of the material which is related to drying and the predrying processes involved (Karathanos *et al*., 1993). The other factor contributing the rehydration of a dried tissue is presence of trapped bubbles in the material. Further the amorphous regions are most accessible to the moving fluid or medium; in this stage a decrease in volume of rehydrating material can be expected (Karathanos *et al*., 1993). Water once entered decreases viscosity of the food material and pores start to collapse, collapse and shrinkage may cause in expelling the entrapped air. In case of carrot tissues (Grote and Fromme, 1984) it is observed that the intercellular spaces were enlarged and increased when observed under microscope, after the process of drying and rehydration. The protoplasm being at the center of the cells after rehydration does not regain its original size (Grote and Fromme, 1984).

The studies conducted with potatoes have shown that rehydration characteristics are dependent on the degree of dryness of the product. The work conducted by Funebo *et al*. (2000) explains the shrinkage of the food product during dehydration during processing is a factor of bulk density and shrinkage, which varies with the processing technique employed and the process conditions. As here we are using ohmic heating as a processing technique to achieve dehydration of the carrot tissues. Further the study conducted by Funebo *et al*. (2000) also confirms that the degree of shrinkage in a food is correlated with the firmness of the product, a vital textural attribute an important quality parameter for the consumers.

CHAPTER 3

MATERIALS AND METHODS

3.1 SAMPLE PREPARATION AND METHODOLOGY

The whole carrot tissues used in the experiment were obtained from a local market, South Side Produce, Baton Rouge, Louisiana. They were then sorted manually based on their size, washed with Hydrogen peroxide (1 %) and then with distilled water and dried on tissue paper to remove excess water.

Carrots were first washed to make sure the carrot tissues were free of mud particles and other extraneous material. The carrots were then peeled using a sterile manual peeler and cut into cubes of 1.2 cm^3 with a French fry cutter having blades separated by width of 12mm and a sterile knife. The carrots were diced in to a rectangular shape in order to fit in the French fry cutter and after passing through the French fry cutter the dices were cut in cubes of dimensions 12*12*12 mm. Once the samples were cut and weighed color analysis was done before subjecting the samples to ohmic heating. The samples were ohmically treated immediately after being analyzed for color. The samples were then sandwiched between 2 titanium electrodes and then a thermocouple wire was pierced at the center of the carrot cube to monitor the temperature rise during ohmic heating and then after the ohmic treatment the samples were weighed and stored in the desiccators with different RH of 11.32 %, 33.72 %, 55.7 % and 75.32 %. The samples were paced in a aluminum dish and in each dish 4 carrot cubes were kept. In each desiccator an iron mesh was used to keep the dishes and allow circulation of air in the dessicator. The humidity conditions were obtained by mixing the specified amount of salts with water as shown in the table below.

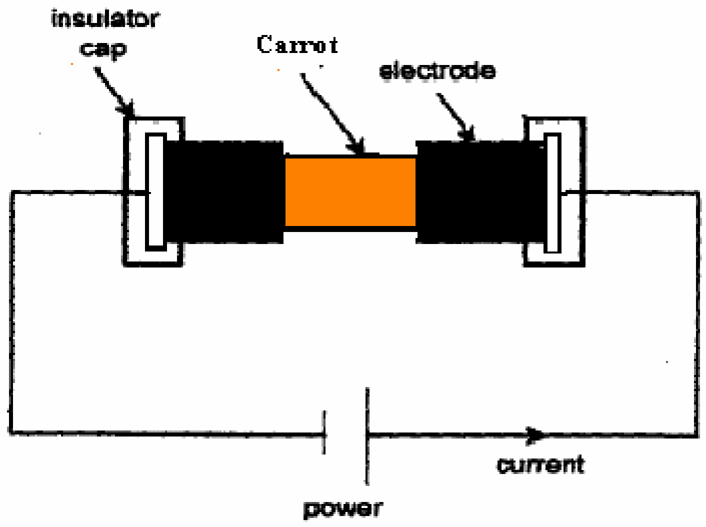
3.1.1 SATURATED SALT SOLUTIONS

Saturated salt solutions prepared in desiccators using distilled water to maintain following relative humidity. (Rockland, 1987)

TABLE 3. SALT SOUTIONS

SALT	QUANTITY		% RH
	Salt (g)	Water (mL)	
LiCl	150	85	75.32
$MgCl_2$	200	25	55.7
NaBr	200	80	32.73
NaCl	200	60	11.15

3.2 OHMIC HEATING PROCESS



Schematic diagram of an ohmic heating process

Figure # 1: Ohmic heating circuit

The samples were placed between the titanium electrodes (coated by the APV Company, Devon, England). A power supply of 60 Hz and an alternator was used for the experiment. Voltage and current transducers (Ohio Semitronics Inc., Hilliard, OH) were used to change from Volts to Amperes and vice-versa. A Teflon coated k-type thermocouple was used to monitor the geometric center temperature of the sample. The samples were of sine 1.2 * 1.2 * 1.2 cm carrot tissue cubes. The voltage, current and temperature were continuously measured using a CR 10X data logger which was connected to a computer. During all experiments, constant length and cross sectional area of the sample were maintained. The voltage, current, time and temperature data were continuously measured and logged every 0.125s by a data logger (CR 10X, Measurement and Control Module, Campbell scientific instruments) linked to a computer. When sample reached the desired end point temperature the power was switched off and the data was obtained for the sample to reach the desired end point temperature of 40^{o}C.

For ohmic heating the sample cubes were placed between the two specially coated titanium electrodes taking care that sides of the sample cubes had good contact with the electrodes. A 120 V power supply was used to provide alternating current of frequencies 1Hz or 60Hz and to heat the samples until its geometric center reached the desired end-point temperatures (EPT) which are 40^{o}C. The thermocouple was placed into the geometric center of the sample to monitor temperature during heating. Raw (untreated) samples were also drilled with the thermocouple to ensure all the samples are comparable for weight and color studies.

The carrot samples used for the experiments were considered identical. The electrical field strength used was 40 V/1.2 cm and the temperature to which the center of the samples was heated was up to 40°C. The end point temperature was kept at 40°C so as to process the samples without overheating. The core temperature or end point temperature and the voltage data from the Campbell scientific data logger was recorded by the computer program. The transformer was turned off soon as the core temperature of the sample reached 40°C for both (60 Hz and 1 Hz) treatments. The 40°C was selected by studying previous references and it was the optimum temperature at which the cubes could be heated without burning the samples. The second set of experiment was followed 3 days after the first set of the experiment was done.

3.2.1 STORAGE

Figure # 2. Dessicator with the samples

The samples were subjected to 2 treatments 1 HZ and 60 Hz ohmic heating. The heated samples were weighed and then transferred to an aluminum dish and marked. This aluminum dish was then placed in desiccators maintained at 4 different RH environments. Raw untreated samples were used as control and placed in the desiccators in same way as the treated samples. In each desiccator 36 samples were kept for each of the two 1 Hz and 60 Hz ohmic treatments. Then the samples were analyzed starting from the day one, from each dessicator 6 samples were drawn each day, 2 samples were used for moisture determination (at 104°C in the oven) and the remaining 4 samples were rehydrated, from which 2 went to texture and 2 were sent to moisture determination for rehydrated samples. For all the above samples color analysis was done before and after rehydration. The above procedure was repeated for six days and the data was obtained. The heated samples were transferred to an aluminum dish and marked. This aluminum dish was then placed in desiccators maintained at various RH environments. Raw untreated samples were used as control and placed in the desiccators in same way as the treated samples. The RH was obtained with saturated salt solutions of Magnesium chloride (55.7 % RH), lithium chloride (75.3 % RH), sodium chloride (11.1 % RH) and sodium bromide (32.7 % RH Appendix); the desiccators were arranged with increasing range of RH from 11.15 % to 75.32 %. For each frequency, voltage and temperature combination moisture content of the samples (duplicates) were measured using oven maintained at 104°C for 24hrs.

Six samples were removed from the desiccators on 1st, 2nd, 3rd, 4th, 5th and 6th day for color, rehydration and texture analysis. From these after color analysis two samples were put in oven to determine the moisture, the remaining four samples were rehydrated, of these four samples two each were used for texture and moisture content analysis.

3.3 COLOR STUDIES

Color was measured with the help of Minolta color meter or spectrophotometer (Model CM-508d, Minolta Camera Co. Ltd., Osaka, Japan) with 10^{o} standard observer and D_{65} illuminant. Results were recorded as L*, a*, b*, H^{o} (hue angle), where L* is lightness, a* redness (-a* greenness), b* yellowness and H^{o} is hue angle, can be represented as $H^{o} = \tan^{-1} (b^*/a^*)$. The L*, a*, b* expresses the color on the basis of luminance, which is description of color not visible to human eyes

Total color change is given by $\Delta E = [(\Delta L^*)^{2} + (\Delta a^*)^{2} + (\Delta b^*)^{2}]^{1/2}$

3.4 TEXTURE PROFILE ANALYSIS

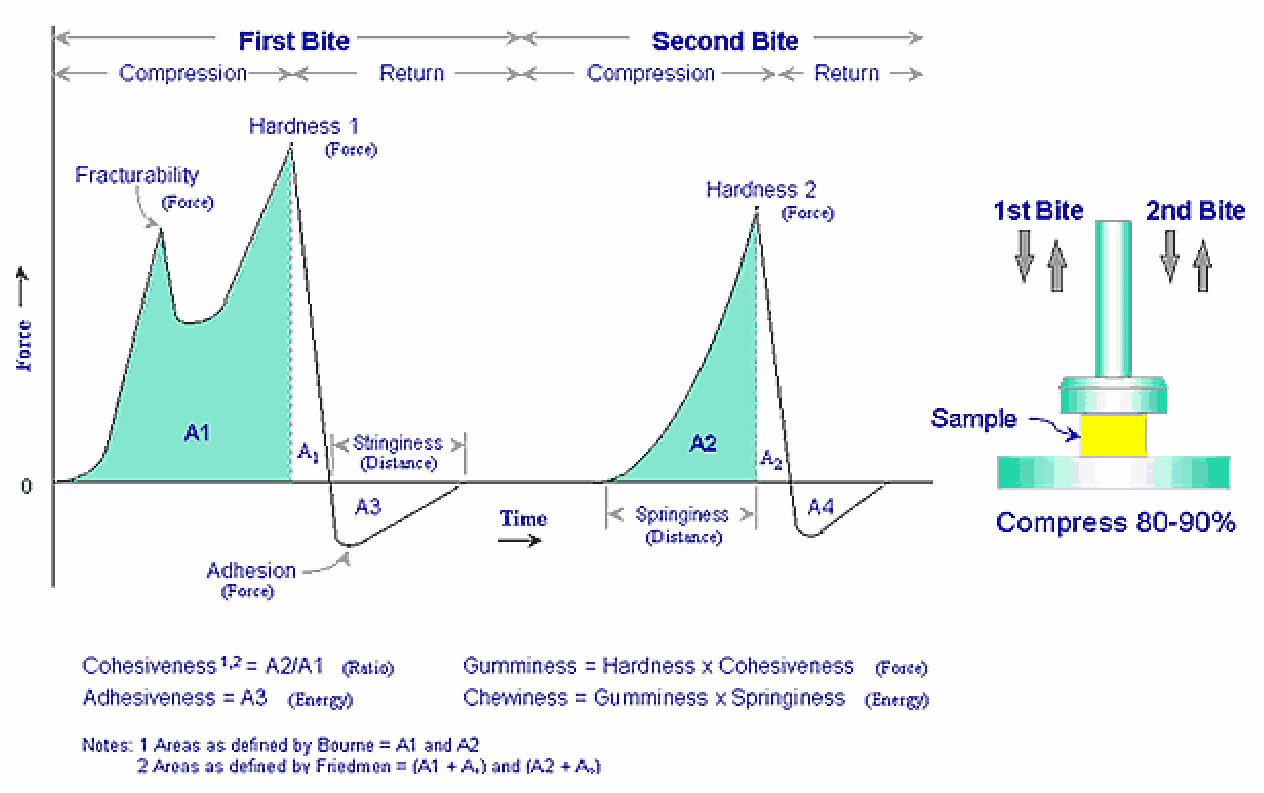


Figure # 3 TPA graph (www.Instron.com)

3.4.1 TPA (2 BITE COMPRESSION TEST)

Instrumental Texture Profile Analysis (TPA) was done using a TA-XT2 plus texture analyzer (Texture Technologies Corp., New York). TPA involves a double compression test using a flat plate or a cylindrical probe having dimensions greater than the sample dimensions i.e., greater than 12mm. For this experiment a cylindrical probe TA-25 compression platen with 2-inch diameter was used. The probe height was calibrated at 14 mm from the base and the force calibration was performed with the help of weight of standard reference. The samples were compressed to 75 % their original height by two consecutive compressions using a cylindrical probe of diameter two inch (TA-25). The first cycle completed a compression of 50 % and 2 cycle the remaining 25 %. The crosshead speed was maintained at 5 mm/s (105). The waiting time between the two-cycles of the TPA tests was 5 seconds. Forces vs. time and Force Vs strain curves were obtained. It was made sure that the sample did not to the probe while going back after first compression as it may alter the values/parameters. Finally the samples were analyzed on a texture analyzer for Texture Profile Analysis (TPA). The texture analyzer was calibrated for weight and height everyday before starting the TPA tests. Each day 2 samples from each RH environment were subjected to TPA test.

The TA-XT2 plus was equipped with a texture exponent software which gives the results in 8 parameters and the graph is force Vs time. The software detects the particular peak for the respective cycle and once it is defined the parameters are displayed in the results box on the computer screen connected to the hardware. The software uses macros which can be set according to the particular vegetable specifications; a separate macro program was created in this case for carrot tissues.

3.5 MOISTURE ANALYSIS

Moisture content of the carrot cubes was determined by drying the samples in an oven at 104 °C for 24 hours (Wang and Sastry 1997). Two replicates of each sample were used for this purpose.

3.6 REHYDRATION

Ohmically heated samples and control (raw carrots) samples were subjected to rehydration and placed in desiccators maintained at above mentioned 4 different relative humidity conditions. Ohmic heated samples were rehydrated by filling aluminum dishes with distilled water at 25°C and for a fixed time of 30 min. For rehydration measurements the wet cubes were transferred to the filter paper on a Buchner funnel. A large Erlenmeyer's flask equipped with a connection for vacuum suction supported the Buchner funnel. Vacuum pump was started for 30 seconds on each side of the cube to remove excess water from the cubes and the filter. Raw untreated samples used as control were rehydrated in the same way for reference. Moisture content and texture analysis was carried out as explained above. Finally the samples are analyzed on a texture analyzer for Texture Profile Analysis.

3.7 SAMPLING

Sampling was done in 2 experimental batches for the two treatments 1 HZ and 60 Hz. In each of the 4 RH storage conditions 36 samples were stored, thus total 144 samples for each batch were stored.

In all total 432 samples were stored, 144 each for the 2 treatments and 144 for raw control samples. Starting from the first day 6 samples were drawn from all the each treatments from the respective RH storage conditions. From these samples 2 were kept for moisture determination and the remaining 4 samples were subjected to rehydration, these samples were further evaluated for texture analysis and rest for moisture determination. This procedure was followed for the 6 days of storage.

3.8 STATISTICAL ANALYSIS

The statistical analysis was performed with the help of SAS (2002) version 8.12 software package. The GLM (analysis of variance) test was used to test the hypothesis, and tukeys studentized range test was applied to determine the significant difference between the samples. The significance was established at $p \leq 0.05$. The correlation coefficient was determined between by the use of Pearson's correlation procedure. The statistical analysis was performed on either day basis, the basis of RH environments, or so on the basis of different treatments 1 Hz, 60 Hz and untreated samples to find the effect of individual treatment on per day basis.

CHAPTER 4

RESULT AND DISCUSSIONS

The results are discussed as in the format of Color, Texture and Rehydration. Based on the statistical significance ANOVA and Tukeys studentized tests the color and rehydration results are explained in 2 parts (a) Comparison between 4 different RH environments for the individual treatments and raw samples on day basis. (b) Comparison between different treatments and control samples on day basis for individual RH environments.

The 60 Hz and 1 Hz frequency were selected as they are the upper and lower extremes of AC current and are used in most of the previous work and references. The effect of ohmic heating is different depending on the type of RH condition the samples are stored. Results, which were not significantly different, are not noted and discussed in the results section, so the significantly different readings are reported and figures suggesting a definite trend are shown and discussed in this section.

4.1 TEXTURE

4.1.1 HARDNESS

Effect of RH environment Hardness values of carrots for both the frequencies (60 Hz and1 Hz) at 75.32 % RH were found to be significantly different from those at 55.7 % RH; however no change was observed at the other two RH conditions.

Effect of Frequencies: Hardness values figures (Figures 1, 2, 3, 4) of ohmically treated carrot samples were found to be lower than the raw sample values stored under same conditions for all six days. The third day and fourth day values for both frequencies when compared with raw were found to be statistically different at 32.73 % and 55.7 % RH.

For samples treated at 60 Hz frequency, as seen in figure 1.1a, the hardness values were relatively consistent at 32.73 % RH throughout the 6 day storage period. There is a sudden drop in hardness value on 3 rd day at 55.7 % RH, which may be due to the extra shrinkage of the sample (may have been exposed to air for long time) .

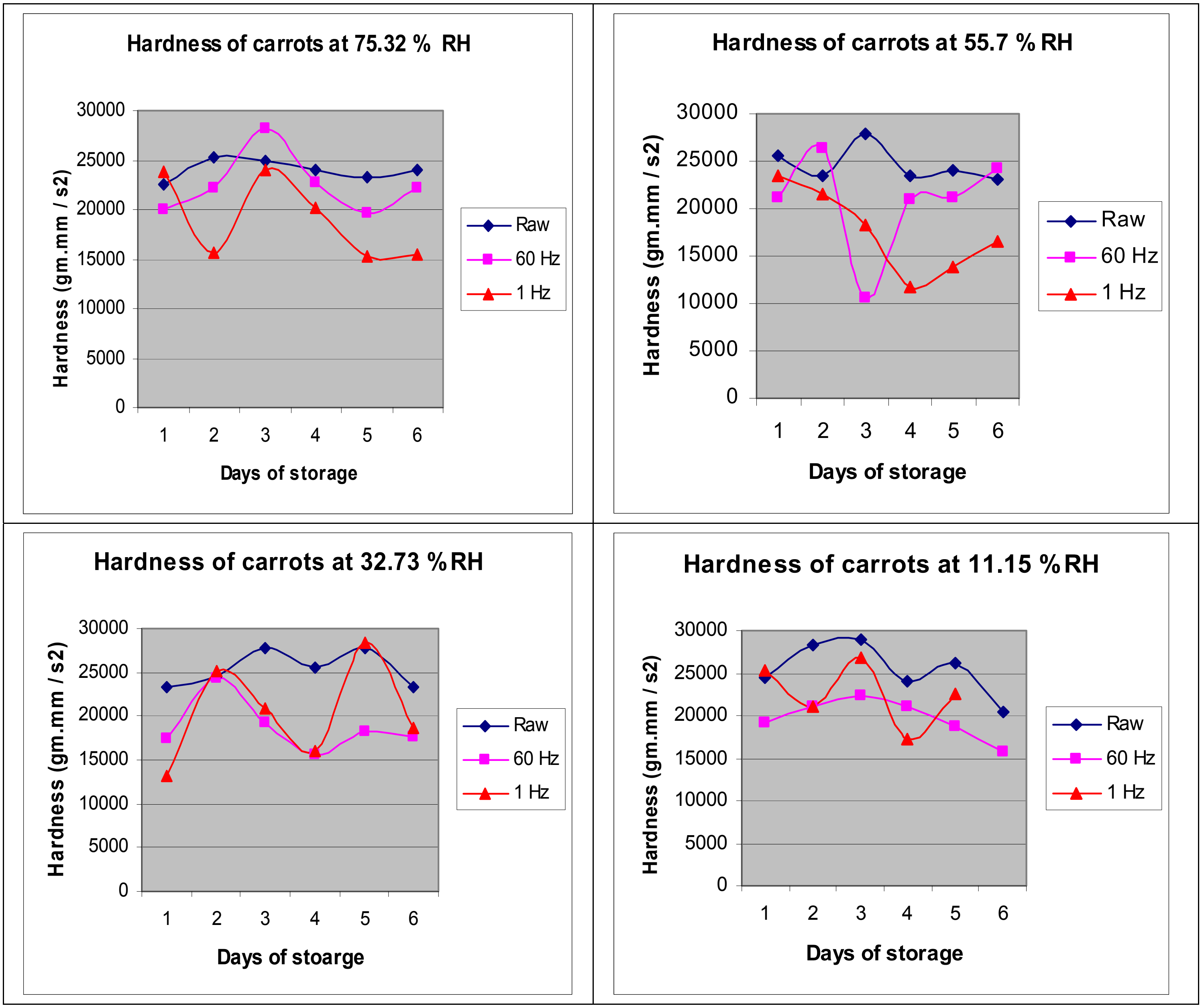


Figure # 4 Change in hardness values at different RH conditions

4.1.2 FRACTURABILITY

4.1.3

Effect of RH environment No significant difference was found between the fracturability values for 60Hz and raw at all RH for all 6 days except that in 1Hz, where on 3rd day and 4th day the values were found to be different under all RH conditions.

Effect of Frequencies the fracturability values show that the untreated samples require a high force to fracture the samples as compared to the treated samples from 1 to 6 days of storage. When statistically compared the values of treated samples were found to be different from raw samples at 55.7 % RH moreover the effect was evident from 2nd day onwards. For all other RH conditions no difference was observed.

The fracturability values as shown in figure 1.2a, untreated samples require a high force to fracture the sample as compared to the treated samples from 1 to 6 days of storage.

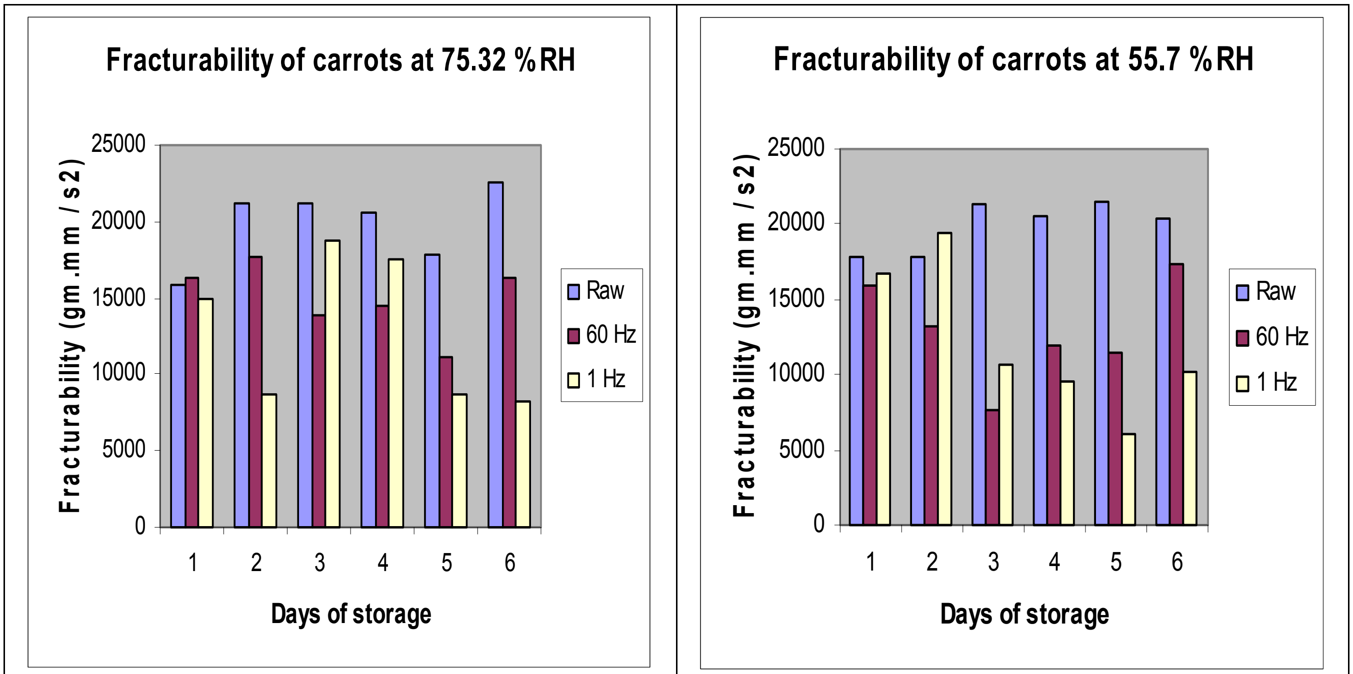


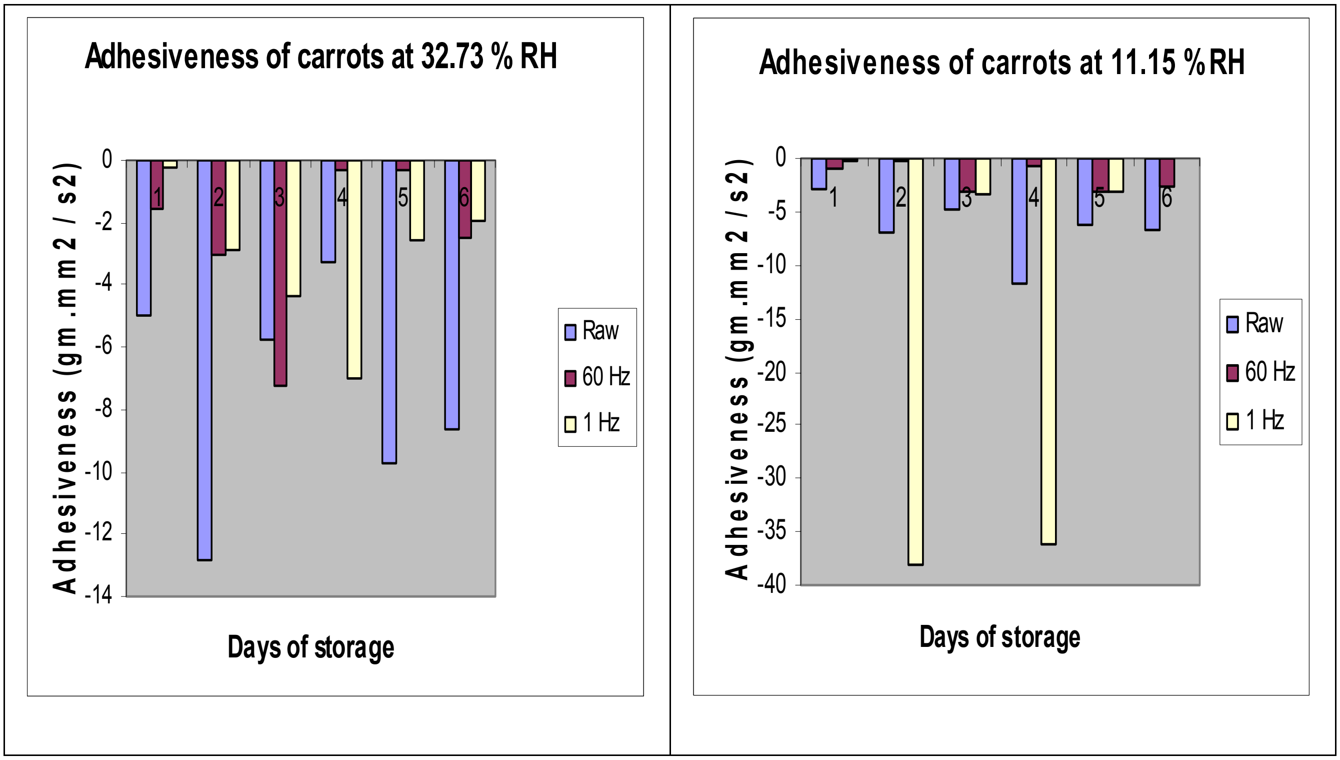
Figure # 5 Fracturability trends at 2 different RH conditions.

4.1.3 ADHESIVENESS

Effect of RH environment The adhesiveness values for 1Hz frequency at 55.7% RH were different from 75.32 % RH and 11.3 % RH; the effect was more evident during 2nd and 3rd day of storage.

Effect of Frequencies The adhesiveness values of the carrot samples with 1 Hz treatment were significantly different from control samples at higher relative humidity environments of 55.7 % RH and 75.3 % RH.

When adhesiveness values after rehydration were plotted against storage time in days as shown in figure 1.3a, a slight increase in adhesiveness was observed for the 60Hz frequency treated samples compared with raw samples at 11.1 % RH and 32.7% RH.



Figures # 6 Trends in property of adhesiveness of carrots in 11.15 & 32.73 % RH

4.1.4 COHESIVENESS

Effect of RH environment No substantial effect on cohesiveness parameter was observed for treated samples at all the salt concentrations unlike raw samples whose values were different only on the 6th day.

Effect of Frequencies The cohesiveness values of 1Hz treated samples were found to be significantly different when compared with control samples at relative humidity conditions of 75.32 % RH and 55.7 % RH.

During the 6-day storage time both the treated samples had higher cohesiveness values compared with control as seen in figure 1.4a.

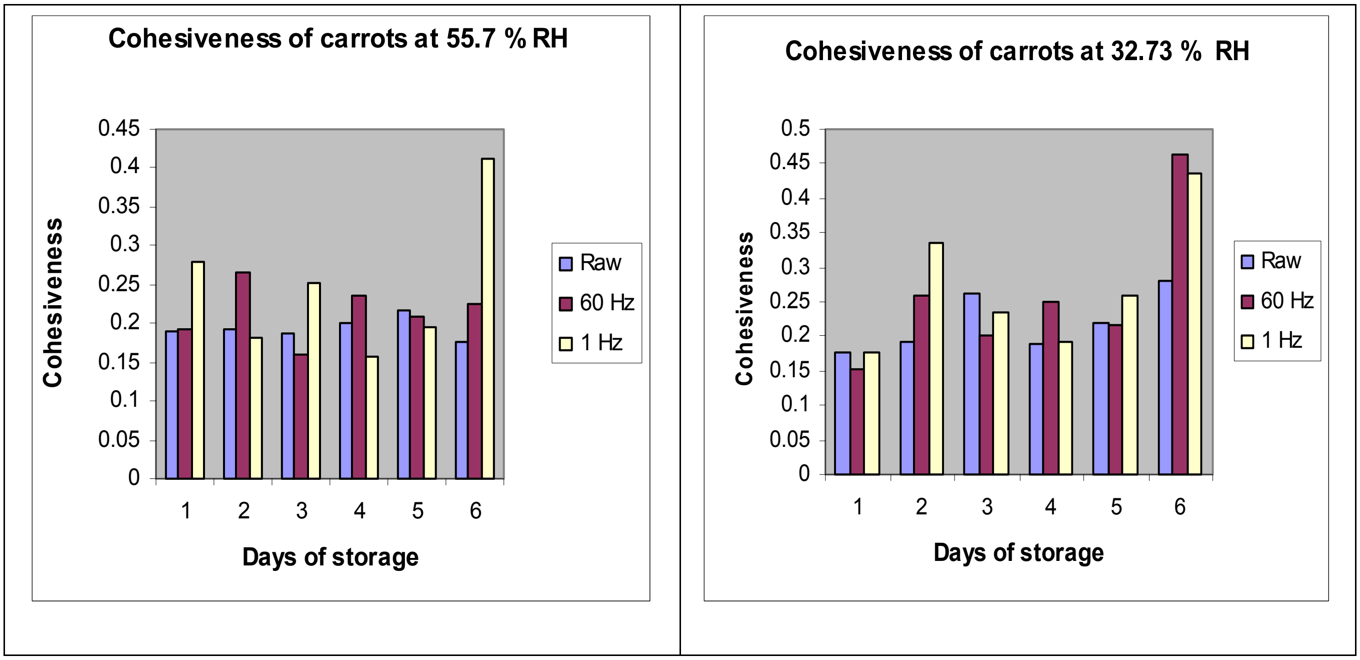


Figure # 7 Change in cohesiveness of carrots over time at 32.73 and 55.7 % RH

4.1.5 CHEWINESS

Effect of RH environment The chewiness parameter was not significantly influenced by all the relative humidity conditions.

Effect of treatment Chewiness is a product of hardness, cohesiveness and springiness of the sample so it is affected by change in any one of these parameters. Just as cohesiveness and hardness property the chewiness was also found to be significantly different in 55. 7 % RH than the control for both the treatments (1 Hz and 60 Hz) chewiness values were higher than the control samples.

The 1 Hz treatment as shown figure 1.5a, at 55.7 % RH and 32.73 % RH storage conditions have high chewiness values when compared to both 60 Hz and control samples, this may be due to improvement in Chewiness properties of samples over time.

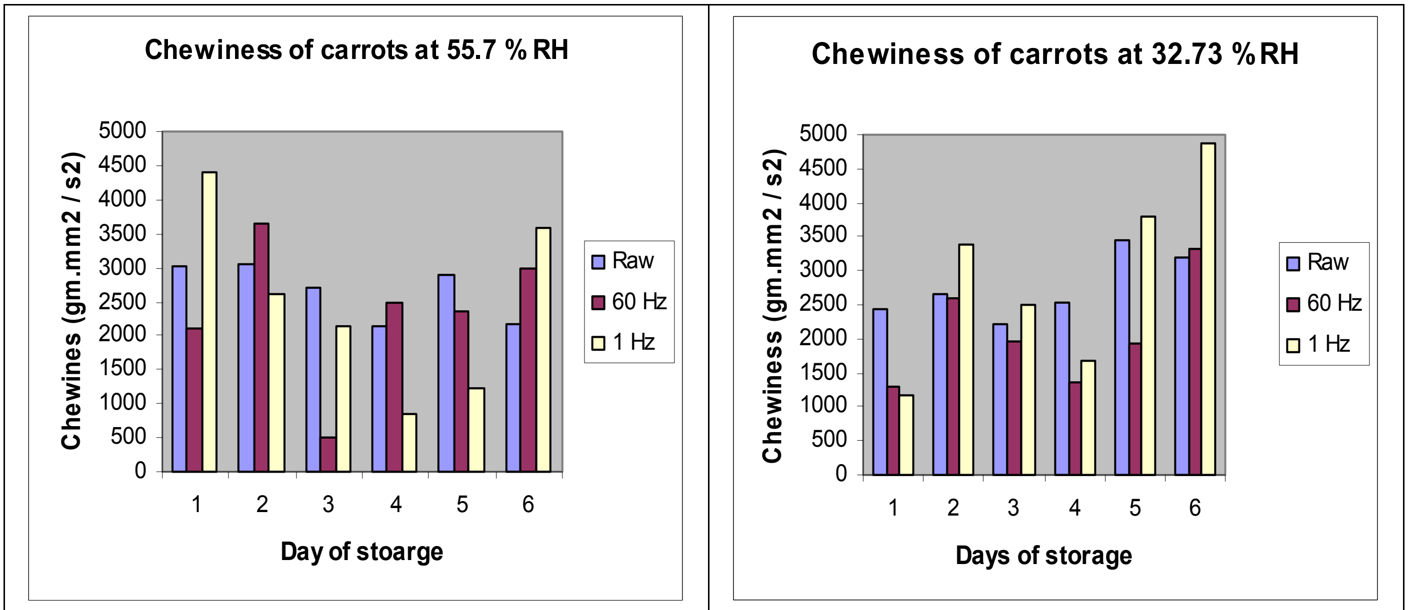


Figure # 8 Chewiness property changes at 32.73 and 55.7 % RH

4.1.6 DISCUSSION

For the consumption of carrots in the dehydrated state, the hardness is not an important parameter as the carrots are consumed in the rehydrated form (Funebo *et al*., 2000). The hardness value of the samples was found to be less in case of 1 Hz and 60 Hz frequency treated samples than the control. The same was true about the fracturability values. The hardness/firmness values for fresh carrots from the previous studies (Roy *et al*., 2001) were in the range of 17324.97 to 19,833.48 gm.mm/s^2 and the values of rehydrated carrots in this study were in the range of 10,000 to 31000 gm.mm/s^2 for both the frequencies. The fracturability value for the fresh carrots used in the study were in the range of 14350 to 16850.54 gm.mm/s^2, the adhesiveness values ranged from -8.45 to – 43.0 gm.mm^2/s^2, the cohesiveness values were in the range of 0.134 to 0.173, and chewiness values were in the range of 1801.09 gm.mm^2/s^2 to 1890.17. The overall comparison of the samples over time suggested that the 1Hz frequency treated samples differed significantly for properties of adhesiveness, cohesiveness and chewiness when compared with control. This may be owing to the fact that the 1 Hz ohmic heating may have altered the microstructure of the carrots affect a change in individual cell functionalities. The rehydrated samples had enhanced rupturing property, which highlights the improved cohesiveness when treated with 1 Hz and after undergoing rehydration. The consumers as refereed earlier look for a product which resembles to the fresh product with a crisp (good rupturing property), firm, succulent textured carrots, As here the cohesiveness of the vegetable like carrot tissue is generally related to the rupture property of the product. The 1-Hz treatment showed improvement in certain textural properties when compared to untreated carrot samples. Thus the retention of the fresh product properties is of importance that determines consumer’s choice.

4.2 COLOR

The results in this section are reported in terms of difference between the respective L* a* b* H^o values as the number 1 represents the difference between the fresh carrot color and the ohmically treated sample color whereas the number 2 represents difference between the fresh sample color and the rehydrated (ohmically treated) sample color. The number 1 denotes the difference between fresh and treated parameter and the 2 stands for difference between fresh and rehydrated treated color parameter. The difference in color values of ohmically heated and the rehydrated carrot samples from the fresh carrot is used in the analysis due to the fact that purchase intent of the consumers is guided by the comparison of color of processed carrots with those characteristics of the fresh carrots.

4.2.1 L* (Color Lightness)

The difference in color values DL1 (after ohmic heating) and DL2 (after ohmic heating and rehydration) values in the 1 Hz and 60 Hz treatments were significantly different from control for the first 3 days of storage at 32.73 % RH which shows that heating and rehydration resulted in change in lightness values. For other RH conditions no difference was observed.

The graphical representation of respective RH storage conditions as shown in the figure 2.1a shows a major change in case of 1 Hz treatment when compared to untreated and 60 Hz treatments throughout the whole storage period which implies that the lightness values became darker. The change was observed in RH condition of 75.3 % and 32.7 %.

4.2.2 a*

The a^* represents degree of redness of the samples if value lies between 0 to 60 or greenness if value lies from 0 to -60.

For the 1 Hz treated samples, difference in color values Da1 (after ohmic heating) and Da2 (after ohmic heating and rehydration) values were significantly different from the control samples stored under RH condition of 55.7 %; there was no effect found in case of samples treated with 60 Hz frequency. The raw samples color (L*) value is lighter than the treated 1 Hz samples.

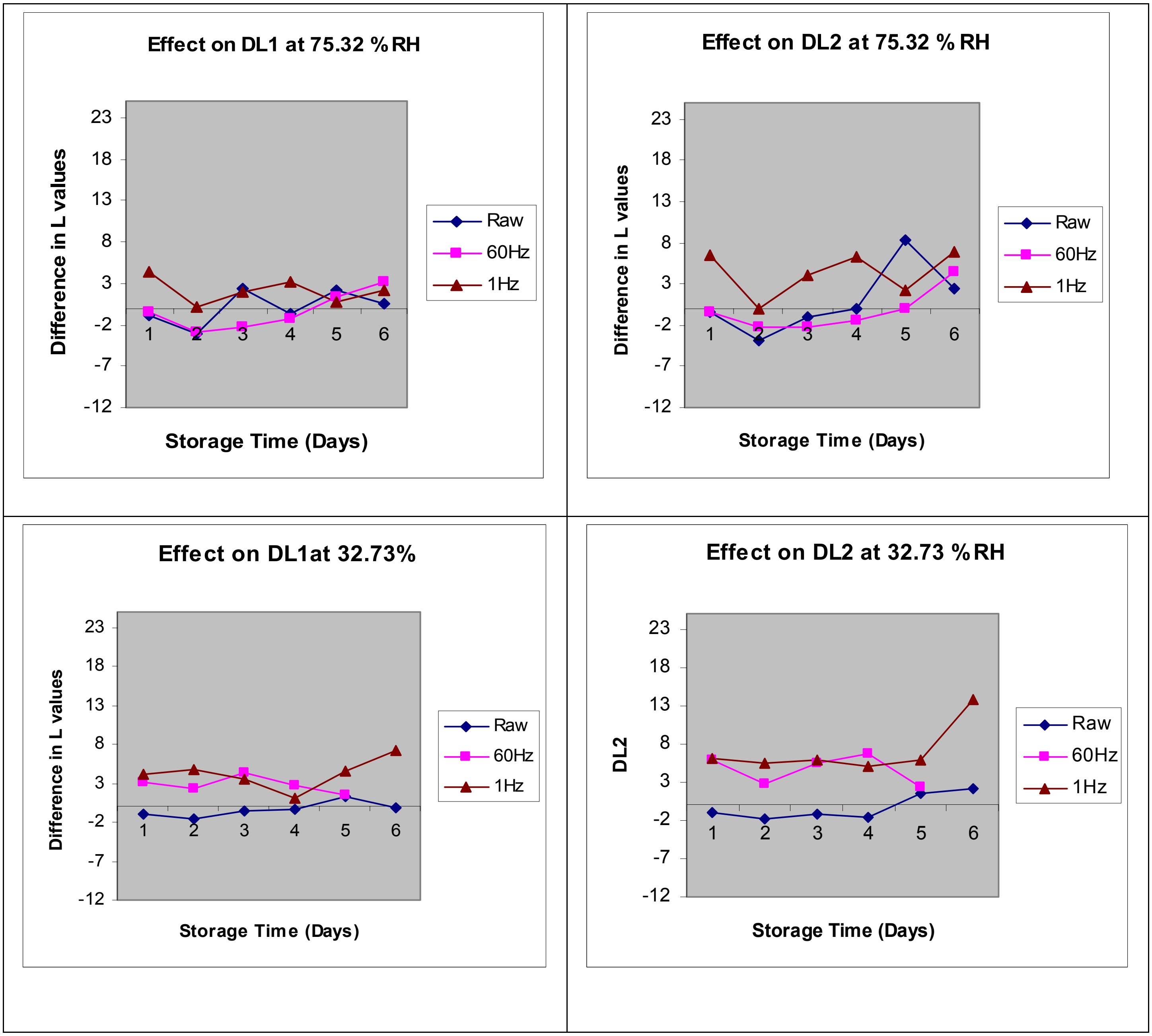


Figure # 9 Comparison in color lightness (DL1 and DL2) before and after rehydration of treated samples

The figure representing a* values shown in figure 2.2a, especially shows for 1 Hz treatment under 32.73 % RH the Da1 and Da2 values were showing an increasing trend during the storage period implying that the redness or reddish orange color of carrots improved for treated samples.

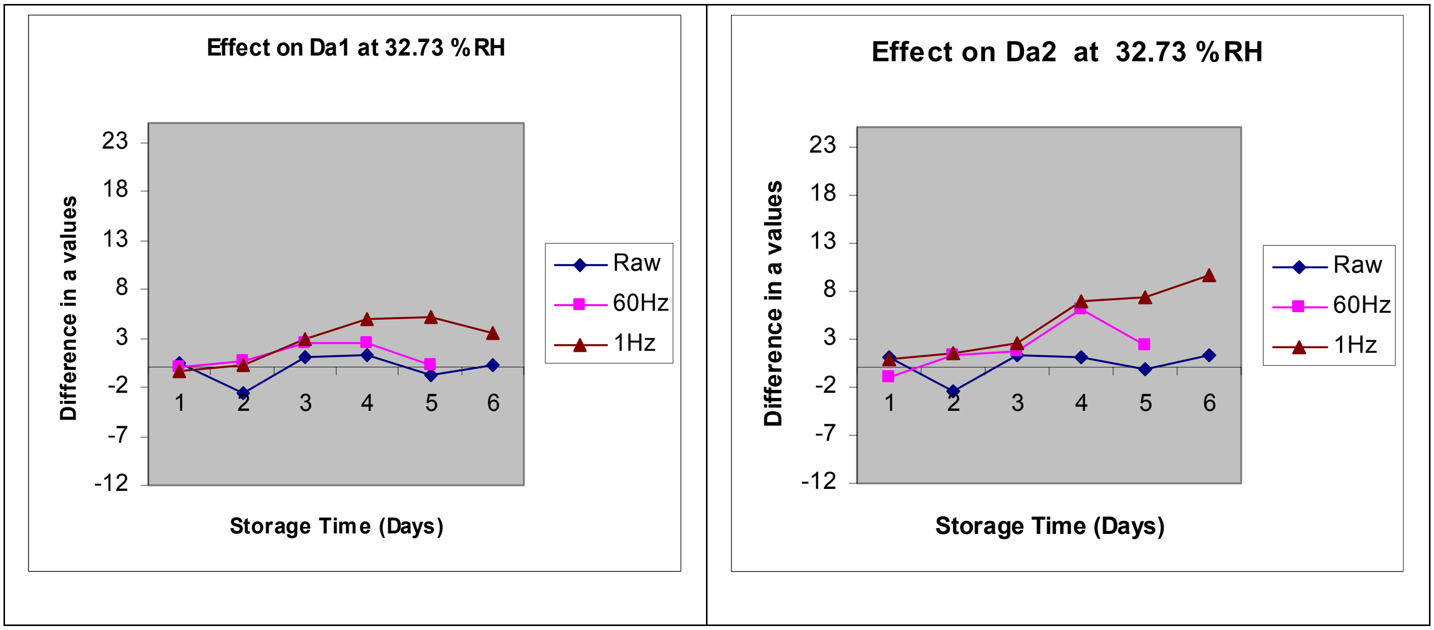


Figure # 10 Color redness trend at 32.73 % RH storage condition

4.2.3 b*

The b* color value represents the amount of yellowness if the values lie between 0 to 60 and amount of blueness in the sample if it lies between 0 to -60.

The difference in b* color values were did not showed any significantly difference when compared between treated and control samples under all the 4 RH controlled storage conditions.

Db1 (after ohmic heating) and Db2 (after ohmic heating and rehydration) values as seen from the figures 2.3a, for 1 Hz and 60 Hz predominantly showed an increasing pattern throughout the storage time which infers that the yellowness of the samples was enhanced by ohmic treatment especially under the lower RH storage conditions as 11.15 % and 32.73 %, this was not observed in case of higher RH storage conditions. From the four graphs the raw control samples showed a similar trend for Db1 and Db2.

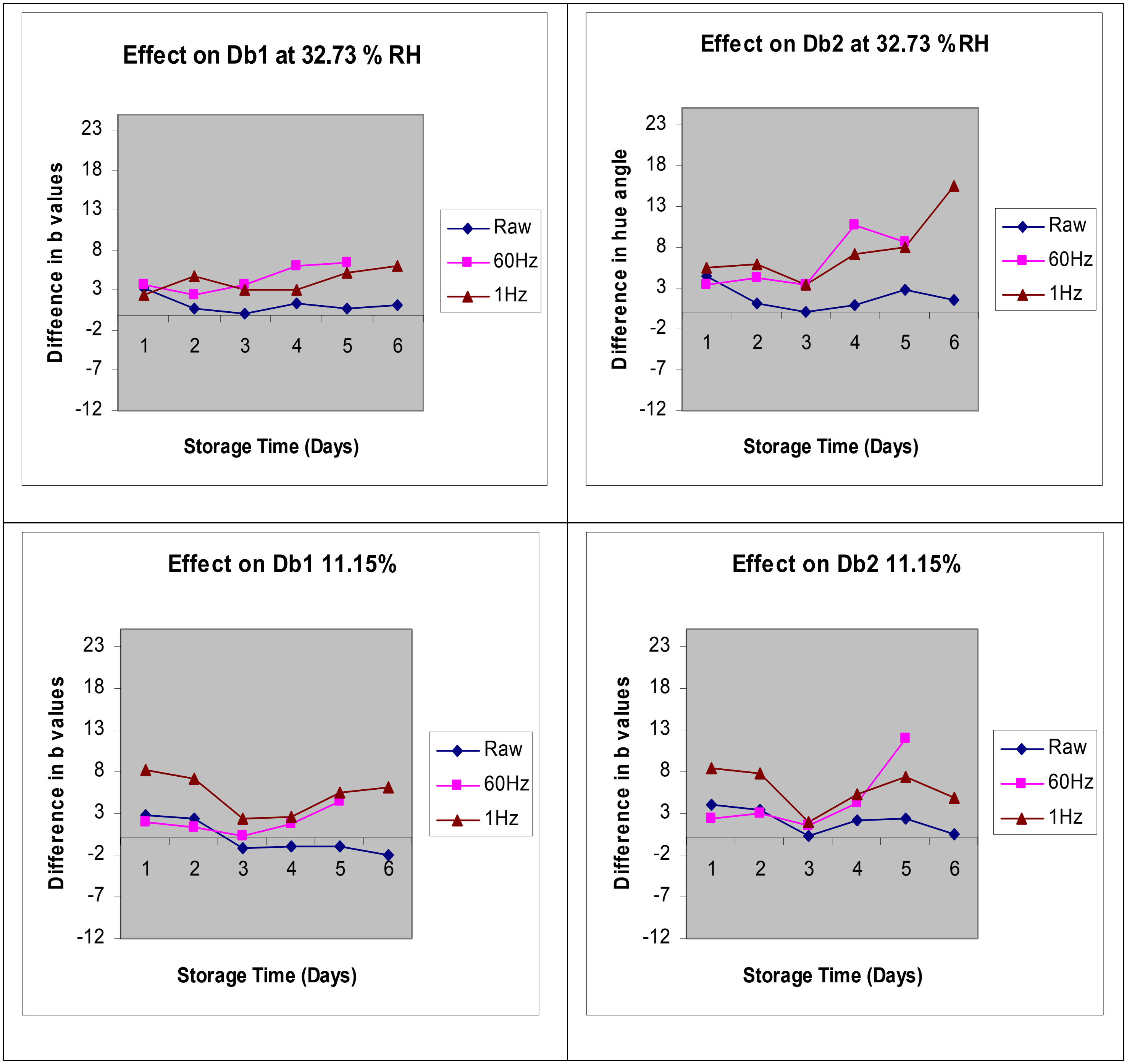


Figure # 11 Comparison in degree of yellowness at 11.15 % and 32.73 % RH storage conditions

4.2.4 H° (Hue angle)

The H° or Hue angle is represented by H° = $\tan^{-1}$ (b*/a*) and an angle of 90 ° represents a yellow hue (when b* is yellowness measured). Objects in the high range of hue angles are greener while low hue angle denotes orange- red.

The difference in hue angle Dh1(after ohmic heating) values with 60 Hz ohmic treatment were significantly different when compared to the raw control samples under the RH storage condition of 11.32 % this was true for Dh2 (after ohmic heating and rehydration) in the same RH storage conditions only on third and fifth day of storage.

The Dh1 and Dh2 values at 11.32% RH for 60Hz frequency treated samples were statistically different when compared with raw samples. All other RH had no impact on the treated and untreated samples. Plotted graphs in figure 2.4a, show a uniform decrease in Dh1 values for 1Hz treatment at 55.7% RH which is shown in the figure below whereas other RH storage conditions, there was no particular trend observed.

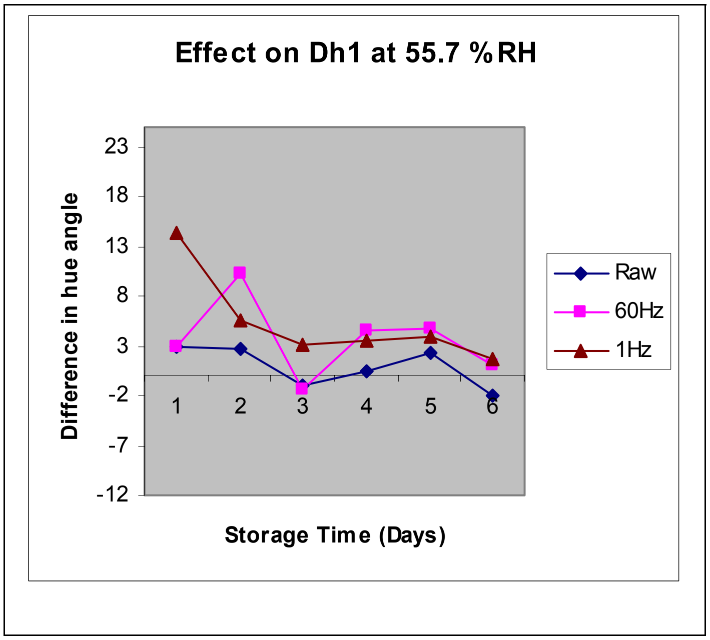


Figure # 12 Change in Dh1 at 55.7 % RH storage condition

4.2.5 DISCUSSION

The lightness (L*) values of the rehydrated carrots were seen to decrease (were darker) with increase in the storage period. The improvement in red color when observed visually after rehydration was not very evident owing to the leaching property of vegetables. The degree of redness (a*) of samples treated with 1Hz frequency especially after rehydration showed an increase in redness or reddish orange color of carrots that may be due to the treatment effect. The yellowness of the samples (b*) improved over time for both the treatments with respect to control with graphical representation but no statistical difference was found. The more red and yellow color more it relates with the fresh carrots which can help to attract consumers.

Also 1 Hz frequency treated carrots were found to be loosing the lightness (became darker side) and having the reddish orange tinge towards the end of storage period. The overall comparison with considering difference between 1 Hz and 60 Hz ohmic treatment did showed certain characteristics but this cannot be related with the frequency as lot of other factors contributed which were electric field, voltage of the current supplied and electrical conductivity of the carrots, for that matter all these factors are to be investigated separately.

4.3 REHYDRATION

The moisture content of the treated samples at both frequencies 1 Hz and 60 Hz were found to be more after rehydration of the sample suggesting the improvement in the rehydration property of the carrot cubes due to the process of the ohmic heating and so also the RH condition.

Effect of RH environment The moisture content of the samples before and after rehydration at 60 Hz treatment kept under the RH condition of 11.15% were notably different from each of 33.73%, 55.7 % and 75.32 % RH conditions in the last days of storage. The same effect was visible with raw samples only on the last day of storage. The 1 Hz treated samples remain unaffected.

Effect of Frequency The moisture content M2 of the samples stored in 33.73 % RH and treated with 60 Hz were significantly different when compared with the control, no change was reported in case of 1 Hz treated samples. The moisture content (M1) of samples stored in 75.32 % treated with 1 Hz was significantly different from the control, which underlines the role of ohmic heating as a dehydration process in the processing of the carrots.

Correlation The sample treated with 60 Hz frequency ohmic heating had a ($\gamma = 0.71$) correlation with the fracturability values indicating the effect of ohmic heating on the fracturabillity of carrots, even though no such effect was observed in case of 1 Hz ohmically treated samples. The Moisture content after rehydration had no positive correlation with textural parameters, but certain RH conditions showed a negative correlation. There was significant correlation ($\gamma= 0.81$)between RH environment of 32.73 % and 75.32 % in case of cohesiveness and chewiness with M2 (Moisture content of treated samples after rehydration) at 60 Hz frequency.

The samples undergoing a treatment had high moisture content after rehydration as compared to those before rehydration, which may be due to many small cell separations in the ohmically treated samples. The high rehydration capacity may be owing to the cell damage to the heating when compared to the untreated samples (Funebo *et al*., 2000).

It was also observed that the raw samples stored in 32.73 % RH and 55.7 % RH were seen to be acquired mold growth on the 5th and 6th day of storage. This may be due to the RH condition; this observation was more evident in 1 Hz frequency ohmically treated samples. The properties of Water Absorption Capacity and Rehydration ability are discussed below.

4.3.1. WATER ABSORPTION CAPACITY

Water absorption capacity (WAC) gives the information regarding the amount of water a material can absorb. The value generally ranges from 0 to 1.

Water absorption capacity graphs are shown in figure 3.1a, WAC values showed no definite trend when compared between two treatments and the control, but the values at 1 Hz are seen to increase towards the end of RH especially in case of 55.7 %. The water absorption capacity is calculated with the help of rehydration ability and also dry matter holding capacity of the product undergoing rehydration. The terminology of rehydration ability and dry matter holding capacity are explained in the appendix. Here we are going to discuss the rehydration ability of carrot samples stored at four different RH conditions and for two different frequencies and also for raw control samples. In the same way the water absorption capacity of the samples are discussed with the respective values against the storage time in days.

4.3.2 REHYDRATION ABILITY

The Rehydration ability takes in to account the ability of material to absorb water (WAC) and Dry matter holding capacity (DHC). The values of RA also lie in the range from 0 to 1 (see Appendix).The Rehydration ability values shown in the graphs shown in figure 3.2b are seen to be high in case of 1 Hz and control for 55.7 % and 11.15 % RH.

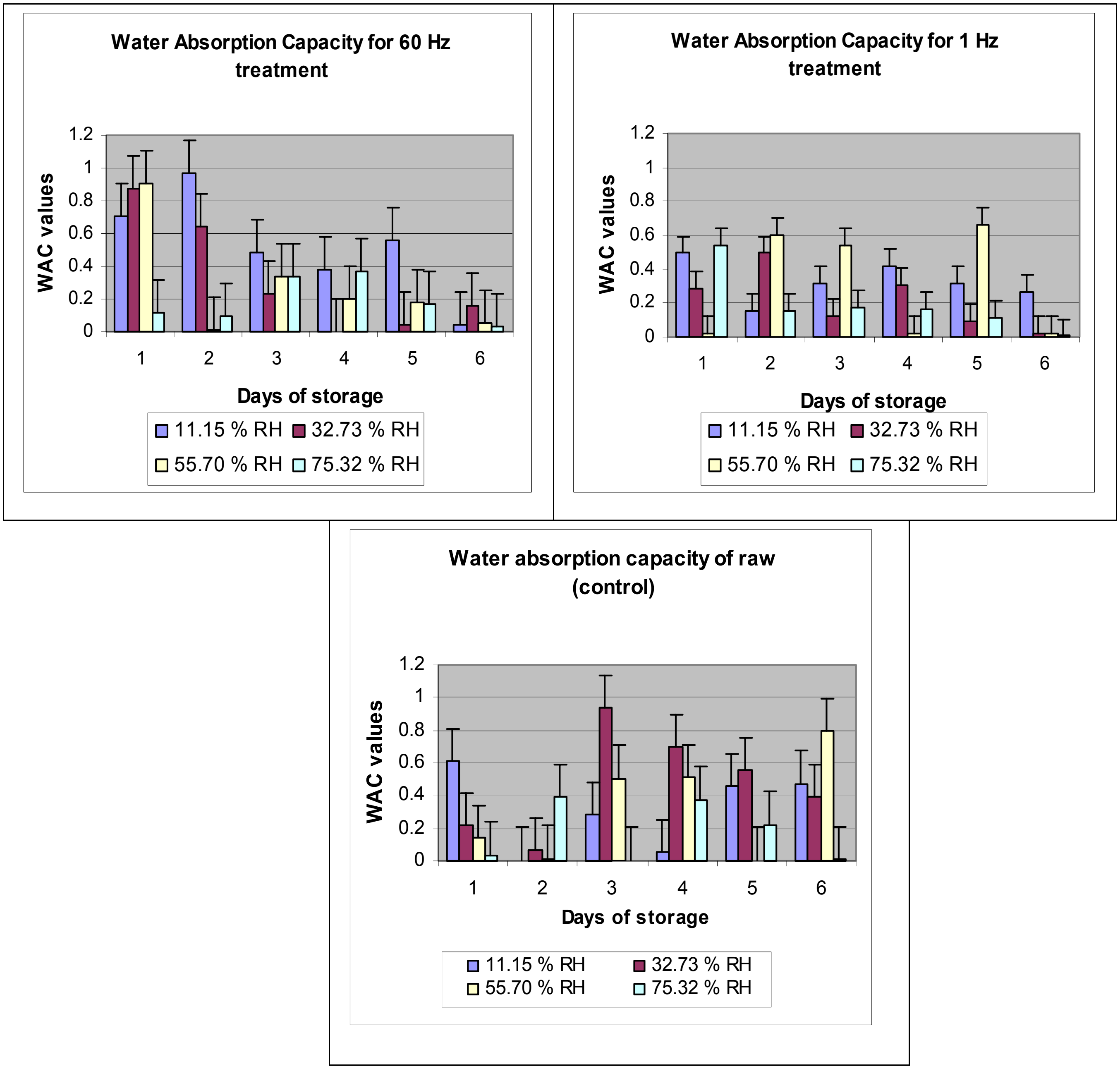


Figure # 13 Water absorption capacity for 2 treatments and raw control for different RH storage conditions.

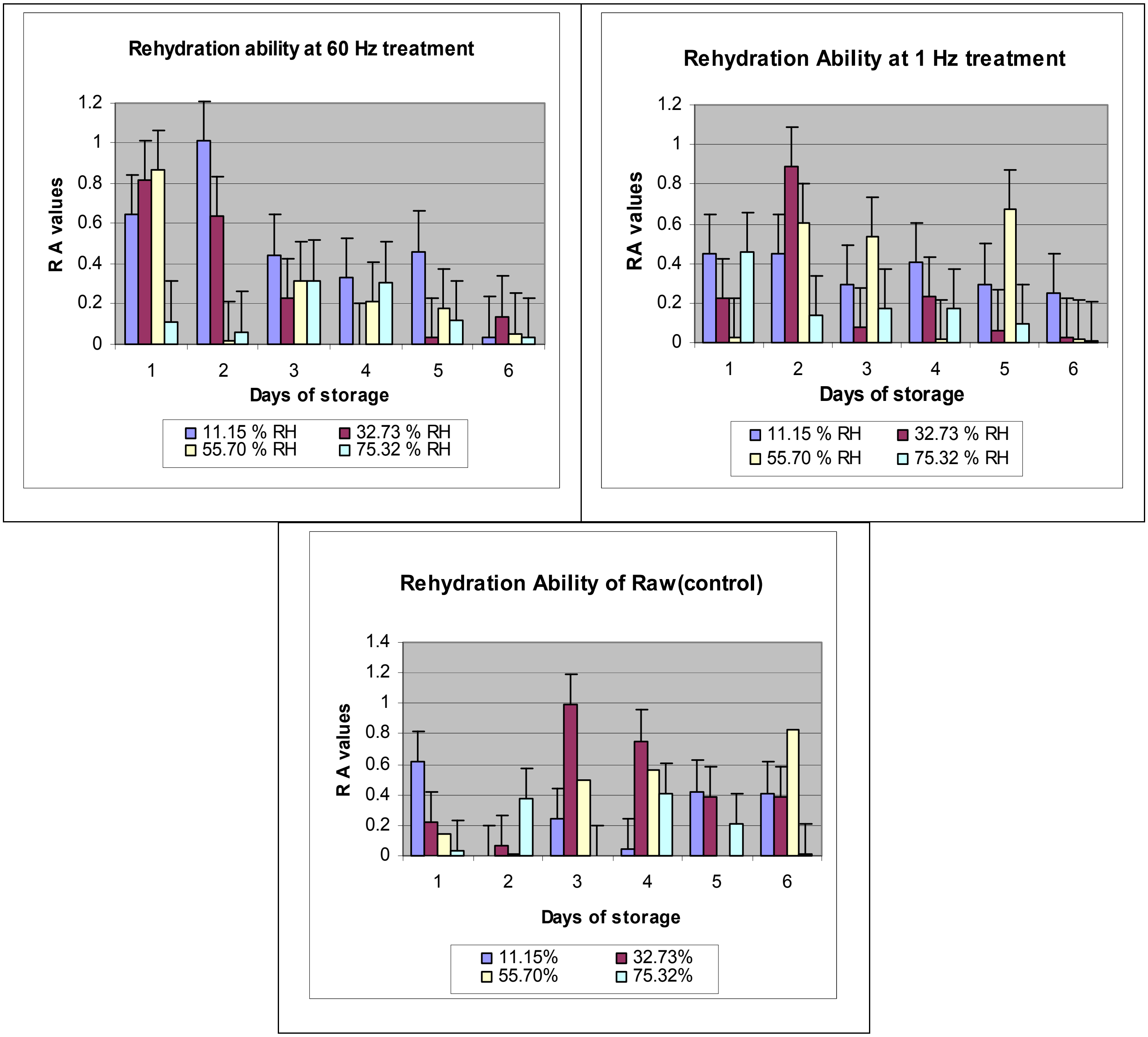


Figure # 14 Rehydration ability of carrots for 2 treatments and raw control at different RH storage conditions.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

The discoloration in the peeled carrots is very dominant phenomenon due to increase in respiration and other chemical changes. The discoloration may be avoided to some extent by ohmic heating and controlled RH conditions. During course of study the control samples (raw) were observed to have a whitish tinge towards the end of storage time. The darker color of the carrots, decreased redness and hardness values after the ohmic heating may suggest a decrease in cartenoid content of the carrots and further the time required for the center core of the carrot cubes to reach 40°C for 1 Hz was less when compared to 60 Hz. The different RH conditions along with the ohmic heating treatment may have served as a contributor in limiting the discoloration of carrots by retaining the surface moisture on carrots by preventing whitening of carrot cubes, further it was more evident at higher RH of 32.7 %, 55.7 % and 75.3 %. Thus the study demonstrated that ohmic treatment significantly affected the color, texture and rehydration properties of carrots under different RH environments.

The raw control samples stored under the lower RH storage condition (32.7 % RH and 11.1 % RH) showed mold growth at the end of the storage period. This may have happened due to the controlled moisture conditions in the desiccators and also due to the absence of surface moisture on the surface of the samples. The surface moisture along with the controlled RH storage condition played an important role in retaining the texture and the color of the samples in case of ohmically treated carrot samples. Ohmic heating is used in industrial processes with batch ohmic heaters, which had been used in the past;

and can be utilized effectively in carrots processing for improving the color and texture of the carrot tissues.

FOLLOWING ARE THE AREAS OF POSSIBLE FUTURE WORKS

1) The development of procedure to evaluate effect of ohmic heating on retaining moisture of carrots, and further to explore use of ohmic heating in increasing juice yield of carrots used as a vegetable juice.
2) Quantifying the effect of applied electric field, frequency used ohmic heating on rehydration, and the retention of color texture properties.
3) Developing a correlation equation between the color changes, texture and rehydration characteristics and electrical properties of the process design used for ohmic heating of carrots.

REFERENCES

1. Anonymous 2003, www.texturetechnologies.com 10/8/2003.

2. Anonymous 2003, www.instron.com/applications/food/benefits.asp 8/8/2003.

3. Anonymous 2001 http://www.usda.gov/nass/pubs.htm 8/8/2003.

4. Texture technologies handout for TA-X2 plus texture analyzer 2001. Published by stable microsystems, ltd. Godalming, UK.

5. Ahmed, E.M, Mirza, S., and Arreola, A.G. 1991. Ultra structural and textural changes in processed carrot tissue. Journal of food quality, 14, 321-330

6. Anantheswaran R.C., Sastry S.K., Beelman R.B., Okereke, A. and Konanayakam, M. 1986. Effect of processing on yields, color and texture of canned mushrooms. Journal of food science, 51, 1197-1200.

7. Takeoka, Gary; Dao, Lan. 2002. Western Regional Research Center, Agricultural Research Service, U.S. Department of Agriculture, Albany, CA, USA. Editor(s): Hurst, William Jeffrey. Methods of analysis for functional foods and nutraceuticals, 219-241. Publisher: CRC Press LLC, Boca Raton, Florida.

8. Bean, E.C., Rasor, J.P. and Porter, G.C. 1960. Changes in electrical conductivities of avocados during ripening. Year Book of Californian avocados Soc. 44, 75-78.

9. Bolin, H.R and Huxsoll, C.C. 1991. Control of minimally processed carrot (Daucus carota) surface discoloration caused by abrasion peeling. Journal of Food science. 56 416-418.

10. Bourne, M.C. 1978. Texture profile analysis. Food technology 32(7), 62-66, 72.

11. Bourne, M.C. 1989. Applications of chemical kinetic theory to the rate of thermal softening of vegetable tissue, 9, in quality factors of fruits and vegetables: chemistry and technology, J.J.Jen (Ed.) p.98-110. American chemical society: Washington, DC (14).

12. Bruniche-Olsen, H. 1962. Structure and permeability of beet tissue. In solid liquid extraction, NFA, Arnold Busck, Copenhagen.

13. Camelo, A.L., Gomez, P., Francisco, A-C. 2003. Use of a* and b* color parameters to assess the effect of some growth regulators on carotenoid biosynthesis during post harvest tomato ripening. Balcarce Research Station, INTA (National Institute for Agricultural Technology), Balcarce, Argentina. Acta Horticulturae, 599 305-308.

14. Chan, C.R. and Ramaswamy, H.S. 2002. Color and texture change kinetics in ripening bananas. Lebensm.-wiss.u.-technology, 35, 415-419.

15. De Alwis, A.A.P., and Fryer, P. J. 1990. The use of direct resistance heating in the food industry. Journal of food engineering. 11, 3-27.

16. Doloros A.M., Saunders, D.E.J, Vincent J.F.V., and Jeronimidis G. 2000. An Engineering method to evaluate the crisp texture of fruits and vegetables. Journal of texture studies, 31, 457-473.

17. Eliot, S. C., Goullieux, A., Pain, J-P. 1999. Processing of cauliflower by ohmic heating: influence of precooking on firmness. Journal of food Science and agriculture 79, 1406-1412(1999).

18. Fellows, P.J. 2000. Food processing technology-principles and practice (2nd Edition) CRC Press, Boca Raton Boston New York Washington, DC Woodhead Publishing Limited, Cambridge England.

19. Fiszman, S.M. and Damasio, M.H. 2000. Suitability of single- compression and tpa tests to determine adhesiveness in solid and semi-solid foods. Journal of texture studies. 31: 55-68.

20. Funebo, T., Ahrne, L., Kidman, S., Langton, M., Skjoldebrand, C. 2000. Microwave heat treatment of apple before air dehydration—effects on physical properties and texture. Journal of food engineering 46, 173-182.

21. Grotte, M. and Fromme, H.G. 1984. Electron microscope investigations of the cell structure in fresh and processed vegetable carrots and green bean pods. Food microstructure, 3, 55-64.

22. Horn, G.R. and Sterling, C. 1982. Studies on the rehydration of carrots. Journal of science of food and agriculture 33:1035-1041

23. Howard, L.R., and Griffin, L.E. 1993. Lignin formation and surface discoloration of minimally processed carrot sticks. Journal of food science 56, 1065-1067, 1072.

24. Humberto, V., Marcela, M.G., Gustavo, V.B. 2001. Advances in dehydration of foods. Journal of food engineering, 49, 271-289.

25. Imai, T., Uemera, K., Ishida, N., Yoshizaki, S. and Noguchi, A. 1995. Ohmic heating of Japanese white radish *Rhaphanus sativus* L. International Journal of food science and technology, 30, 461-472.

26. Jarvis M.C. 1984. Structure and properties of pectin gels in plant cell walls. Plant, cell and environment, 7,153-164.

27. Karathanos, V., Angela, S. and Karel, M. 1993. Collapse of structure during drying of celery. Drying technology 11 1005-1023.

28. Kilcast, D. and Fillioon, L. 2001. Understanding consumer requirements for fruit and vegetable texture. Nutrition and food science, 31 (5), 221-225.

29. Kim, J. and Pyun, Y. 1995. Extraction of soy milk using ohmic heating .Abstract, 9th congress of food science and technology, Budapest, Hungary.

30. Krokida, M.K., Kiranoudis, C.T. and Maroulis, Z.B. 1999. Viscoelastic behavior of dehydrated products during rehydration. Journal of food engineering, 40, 269-277.

31. Kulshreshta, S. and Sastry, S. 2003. Frequency and voltage effects on enhanced diffusion during moderate electric field (MEF) treatment. Innovative food science and engineering technologies, 4, 189-194.

32. Leach, G., Pule, L. and Niranjan, K. 1995. Effectivity of total solids and pectic substances from apple tissue. International journal of food science and technology 29 687-697.

33. Lee C.Y., Bourne, M.C. and Van buren, J.P., 1979. Effect of blanching treatments on the firmness of carrots. Journal of food science: 44(2) 615-616(11).

34. Lenart, A. 1991. Effect of saccharose on water sorption and rehydration of dried carrot. In Drying' 91 Mujumdar, A. S., and Filkova, I Eds. Elsevier Science Publisher, Amsterdam, pp. 489-498.

35. Lewicki, P.P. 1998. Effect of pre-drying treatment, drying and rehydration on plant tissues properties: A review. International journal of food properties, 1(1), 1-22.

36. Lewicki, P.P. 1998. Some remarks on rehydration of dried foods. Journal of food engineering, 36, 81-87.

37. Lima, M., and Sastry, S. K. 1996. Diffusion of beet dye during electrical and conventional heating at steady state temperature. PhD dissertation, The ohio state university, Columbus, OH.

38. Lima, M., and Sastry, S. K. 1999. The effects of ohmic heating frequency on hot-air drying rate and juice yield. Journal of food engineering, 41, 115-119.

39. Lima, M., Heskett, Brian, F and Sastry, S.K. 1999. The effect of frequency and waveform on the electrical conductivity-temperature profiles of turnip tissue. Journal of food process engineering, 22, 41-54.

40. Lima, M., Heskett, Brian, F. and Sastry, S.K., 2001. Diffusion of beet dye during electrical and conventional heating at steady-state temperature. Journal of food process engineering, 24, 331-340.

41. Luis, C-Z., Salveit, M. E., and Krochta, J.M. 1995. Mechanism of surface white discoloration of peeled (minimally processed) carrots during storage. Journal of food science, 60(2), 320-323.

42. Luis, C-Z., Salveit, M. E., and Krochta, J.M. 1997. Hygroscopic coatings control surface white discoloration of peeled (minimally processed) carrots during storage. Journal of food science, 62(2), 363-366, 398.

43. Mohsenin, N.H. 1979. Application of Engineering Techniques to Evaluation of Texture of Solid Food Materials. Journal food texture studies, 1, 133. M.C.

44. Oezkan, M., Kirca, A., Cemeroglu, B. 2003. Effect of moisture content on CIE color values in dried apricots. European food research and technology, 216(3), 217-219.

45. Palaniappan, S., Richter, E. R. and Sastry, S. K. 1990. Effects of electricity on microorganisms: A review. Journal of food processing and preservation, 14, 393-414.

46. Parrott, D.L. 1992. Use of ohmic heating for aseptic processing of food particulates. Food technology, 46, 239-241, 245.

47. Roy, S.S., Taylor, T.A. and Kramer, H.L. 2001. Textural and ultrastructural changes in carrot tissue as affected by blanching and freezing. Journal of food science,66, 176-180.

48. Marsilli, R., Food product design magazine, August 1993.

49. Sastry S.K and Paniappan, S. 1992. Ohmic heating of liquid particle mixtures. Food technology, 46 (12) 64-67

50. Segerlind, L.J., Snobar, B.A. and Heldman, D.R. 1977. Compression and relaxation properties of carrots. Journal of texture studies 7, 451-456.

51. Sevugan Paniappan and Sastry, S.K. 1991. Journal of food process engineering14, 221-236, Electrical conductivity of selected solid foods during ohmic heating.

52. Sulaeman, A., Keeler, L., Giraud, D.W., Taylor, S.L., Wehling, R.L., Driskell, J.A. 2001. Cartenoids content and physiochemical and sensory characteristics of carrot chips deep-fried in different oils at several temperatures. Journal of food science 66(9), 1257-1264.

53. Szczesniak, A.S. 1966. Texture measurements. Food technology, 20(50), 55-88.

54. Texture technologies Inc. Handout

55. Van buren J.P. 1979. The chemistry of texture in fruits and vegetables. Journal of texture studies 10:1-23 (1979).

56. Voisey, P.W. and Kloek, M. 1975. Control of deformation in texture tests, Journal of texture studies, 6, 489-506.

57. Wang W-C and Sastry S.K. 1993. Salt diffusion into vegetable tissue as a pretreatment for ohmic heating: electrical conductivity profiles and vacuum infusion studies. Journal of food engineering, 20, 299-309.

58. Weaver, J. 1987. Transient aqueous pores: a mechanism for coupling electric fields to bilayer and cell membranes. In Blank, M. and Findl, E. Mechanistic approaches to Interactions of electric and electromagnetic fields with living systems (pp. 249-270). New york: Plenum press.

APPENDIX A

MOISTURE CALCULATIONS

WAC = $\frac{Mr(100-sr)-Md(100-sd)}{Mo(100-so)-Md(100-sd)}$

$DHC = \frac{(Mr)(sr)}{(Md)(sd)}$

RA= WAC * DHC

d- Dried sample

M- Mass of dry matter

r- Rehydrated sample

m- Moisture content of sample

s- % dry matter content of sample

Where, WAC is Water absorption capacity and gives the information regarding the amount of water a material can absorb. The value generally ranges from 0 to 1.

DHC is Dry matter holding capacity and is the ability of material to hold dry solubles. It gives information on the tissue damage and tissues permeability to solubles. The more the tissue damage is smaller is the index. This value also lies from 0 to 1.

RA- Rehydration ability

APPENDIX B

TEXTURE PROFILE ANALYSIS

TPA is based on the recognition of texture as a multi-parameter attribute. The test consists of a biting the food twice in a reciprocating motion that imitates the action of the jaw that resembles the sensory evaluation of those parameters [Texture Technologies Inc. Handout]. The Individual Parameters are explained as below

1. Hardness is defined as the maximum peak force during the first compression cycle (first bite) and has often been substituted by the term firmness.
2. Fracturability (originally called brittleness) is defined as the force at the first significant break in the TPA curve.
3. Cohesiveness is defined as the ratio of the positive force area during the second compression to that during the first compression. Cohesiveness may be measured as the rate at which the material disintegrates under mechanical action.
4. Adhesiveness is defined as the negative force area for the first bite and represents the work required to overcome the attractive forces between the surface of a food and the surface of other materials with which the food comes into contact, i.e. the total force necessary to pull the compression plunger away from the sample.
5. Chewiness, tenderness and toughness are measured in terms of the energy required to masticate a solid food. They are the characteristics most difficult to measure precisely, because mastication involves compressing, shearing, piercing, grinding, tearing and cutting, along with adequate lubrication by saliva at body temperatures. Chewiness should be reported for solids and gumminess for semisolids.

APPENDIX C

TEXTURE ANALYZER SETTINGS (TA-XT2 PLUS)

Pre-test speed: 1.00 mm/s

Test speed: 1.00 mm/s

Post test speed: 1.00 mm/s

Target mode: Strain

Waiting time: 5 sec

Trigger type: Auto

Trigger force: 50 Gms

Tare mode

Advanced options- on

VITA

Sandeep Dattatraya Bhale was born on October 16, 1975, at Parbhani, India, to Dattatraya L.Bhale and Indumati Bhale. He was formally educated at Saraswati Bhuvan English School at Aurangabad, India. He completed Bachelor of Technology degree in Agriculture Engineering from Dr.A.S.College of Agriculture Engineering, Mahatma Phule Agricultural University, India, in July 1997. He held the position of Plant Manager in JK Agri-genetics, Hyderabad, India, from 1998 to 2001. He joined as a master's student in the department of Biological and Agricultural Engineering, Louisiana State University, Baton Rouge, Louisiana. He has started his PhD in Food Science at Louisiana State University in January 2004. He is a member of the American Society of Agriculture Engineers, Institute of Food Technologists and Indian Society of Agriculture Engineers.