

COLOR, TEXTURE AND REHYDRATION CHARACTERISTICS OF
OHMICALLY TREATED SWEET POTATOES

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ABSTRACT

Ohmic heating has been shown to affect the drying rate and texture of foods. This research was designed to determine the effect of ohmic heating on rehydration, color and texture properties of sweet potatoes. Three combinations: 60Hz, 40V, 60Hz, 60V and 1Hz, 40V were applied to ohmically heat sweet potato cubes. The ohmic treated cubes and untreated cubes or controls were stored for six days in four different %relative humidity of 11.15%, 32.73%, 57.70% and 75.32%. Results showed that there was no significant difference in the rehydration properties of ohmic treated samples and control samples. The % moisture gain varied between a minimum of 0.1% and a maximum of 40.7% in the case of ohmically treated samples and 0.71% to 32.41% for control samples. The color lightness values increased with increase in storage time for both ohmically treated and control samples. The 60Hz, 40V ohmically treated samples had less increase compared to control samples. The degree of redness (a*) and degree of yellowness (b*) values were significantly higher for ohmically treated samples during storage. A significant loss of color pigments into rehydrating water was observed during rehydration for ohmically treated samples. The 60Hz, 40V treated samples retained color and appearance compared to other treatments. Texture analysis showed that the ohmic treated samples (60H, 60V) had higher hardness, springiness and chewiness values than the control samples. At lower humidities the firmness or hardness values increased with increase in storage time. Positive correlations were obtained between the moisture content of the samples after rehydration and the hardness and chewiness values. This study demonstrated that ohmic heating played a pivotal role in retaining rehydration

properties, color attributes and some of the texture attributes of the sweet potato samples when appropriate combinations of frequency and electrical field strength were used.

CHAPTER 1: INTRODUCTION

The goal of food preservation is to increase the time for keeping food safe while retaining quality and nutrients. Fruits and vegetables play an important role in human diet and nutrition but are highly perishable due to their high moisture content. Decreasing the moisture content of fresh foods to make them less perishable is a simple way to preserve these foods. This and other preservation methods result in the availability of a greater variety of fruits and vegetables. Dehydration increases the storage stability of fruits and vegetables making them available throughout the year. Dehydrated products also play a great role in processed foods of all kinds (i.e., in soups) and ways to achieve high quality dehydrated products are desired. New techniques like infrared processing, microwave, radio frequency, acti-Joule and ohmic heating processes are developed to achieve the same. These rapid heating methods will be useful in reducing the product residence time during processing.

Ohmic Heating involves the passage of an alternating electric current through an electrically conducting food product. The food sample responds by generating heat internally due to its inherent electrical resistance (Sastry, 1994). If uniform heating occurs throughout a food, process times can be shortened resulting in improved flavor and nutrient retention (Palaniappan & Sastry, 1991).

Yongsawatdigul (1995) found that ohmic heating with a rapid heating rate was an effective method for maximizing gel functionality (gel strength in terms of shear stress and strain) with out the addition of enzyme inhibitors. Imai et al. (1995) studied the change of hardness in white radish when ohmic heating was used and found that the

ohmic heated sample had almost the same breaking strength as the original raw sample but was soft inside and had an improved texture after being treated at low frequency.

Dehydrated sweet potato (SP) has been produced in the United States since the early 1900s. In hot climates the storage life of sweet potato is short (1 to 2 months), and energy efficient means of preserving them are important (Diamante, 1991). It is expected that drying methods will result in lesser cost for preservation compared to canning and freezing. Few experiments have been conducted on ohmic heating of sweet potatoes. Lima and Sastry (1999) found that the lower the frequency of alternating current used in ohmic heating, the faster the hot-air drying rate of sweet potato. Wang and Sastry (2000) showed that the treating of sweet potatoes by ohmic heating prior to drying increased the hot air drying rate significantly compared to raw, conventionally treated and microwaved samples. Zhong and Lima (2003) found that the vacuum drying rate of ohmically treated SP samples was faster than the raw samples.

The texture of the vegetables is determined by the structure and composition of cellular tissue. The cell wall is the constituent of the tissue, which most affects this property (Szczesniak, 1963). Research shows that the texture of fruits and vegetables is greatly influenced by thermal processing (Bourne, 1982 and Quintero- Ramos *et al.*, 1992). Cell rupture, tissue shrinkage, changes in membrane permeability, phase changes, dehydration, starch gelatinization, etc., occur in foods during heating. The dissolution of protopectin and cell wall components results in loss of cell rigidity (Linehan and Hughes 1969). When cellular tissue is heated ohmically, the electrical conductivities increase linearly with an increase in voltage. Palaniappan and Sastry (1991) found that the electrical conductivities of potato, carrot and sweet potato increased with an increase in

electric field strength and hypothesized that this was due to an electro-osmotic effect. They also suggested that the enhanced osmotic motion of fluids may contribute to membrane rupture and pore-formation in the cell membrane increasing permeability. This phenomenon is electroporation. It can be reversible i.e., the cell membranes if not damaged or destroyed, can revert to their original structure when the electric field strength is removed. Halden et al. (1990) reported that melting of fat, starch transition and cell structural changes occur during ohmic heating. All these may result in textural changes in ohmically treated vegetables. Eliot, Goullieux and Pain (1999) applied ohmic heating to cauliflower florets that were pre-processed in salt water. They observed that the firmness of all the florets decreased with pre-cooking and ohmic heating. Moreover only large florets withstood the ohmic heating process with out texture damage. They also visually observed that the color of the florets changed to yellow.

Halden et al. (1990) observed an increase in beet dye diffusion during ohmic heating. Schreier et al. (1993) demonstrated that the diffusion enhancement with ohmic heating is a linear function of applied voltage and is directly proportional to the surface area of the food particle. They found that the betanin diffusion from beetroot into surrounding solution to be greater during electrical heating (50Hz) than during conventional heating. These investigators hypothesized that the enhanced diffusion could be the result of increased transport through the cell membrane, electro osmotic effect. Thus, applied electric fields influenced the mobility of color in beetroot.

All these studies show that ohmic heating may affect the structure and color of the food products. Moreover SPs are nutritious but there is lack of SP products in the market place, the major reason being the lack of development of products with consistent color,

texture and flavor. Lima (1996) visually observed that the texture and color of the rehydrated sweet potato samples, which were treated by ohmic heating process, appeared to have the same texture and color as fresh samples. This observation led to the present study to determine if dehydrated products produced by ohmic treatment can result in producing high quality rehydrated products.

The present study was conducted to determine the influence of ohmic heating on sweet potato when stored at various relative humidities.

The objectives of this experiment were

- To determine effect of rehydration on ohmic heated sweet potato.
- To measure color change of sweet potatoes after storage and rehydration.
- To determine textural properties of sweet potato samples by texture profile analysis.

CHAPTER 2: LITERATURE REVIEW

Sweet Potatoes (SP) or *Ipomoea batata. Lama* are the seventh most important food crop in the world (Thompson, H. C. 1929). They are native to South America and are a member of the convolvulaceae or morning glory family. Sweet Potatoes are widely distributed throughout the world, but chiefly in tropical countries and sub-tropical countries where they are considered as major vegetable crop including United States (Thompson, H. C. 1929).

Many people refer to sweet potatoes as yams, but yam is a starchy tropical root crop of Asian or African origin and is not related to sweet potato family. But what is marketed in the United States as a “yam” is a type of sweet potato. True yam has no relationship to the sweet potato (www.ers.usda.gov/briefing/vegetables/sweetpotatoes).

Sweet Potatoes are an important crop grown extensively in United States. Except for California, the United States sweet potato industry is largely concentrated among southeastern States: North Carolina, Louisiana, California, Mississippi and Alabama are the top five producing States respectively. Louisiana was the leading producer of sweet potatoes from 1943 to 1969, and ranked second in the annual crop production in 2001 only next to North Carolina. (www.ers.usda.gov).

2.1. Sweet Potato Annual Production

The preliminary season 2002 (fall) resulted in a 12% decline of production, mainly due to tropical storm Isadore, Hurricane Lili and heavy rains. The areas in Mississippi also reported extensive acreage loss due to extensive rains. But during the period of 1999-2001 the United States sweet potato production was around 13.5 million cwt (hundredweights long) in which about 79% of the crop produced from top three states; North Carolina (37% of crop), Louisiana (24%), and California (18%). The sale

resulted in \$214 million for the country and for Louisiana at \$46 million sweet potatoes sale accounted for 57% of total states vegetable sale. (www.ers.usda.gov).

Sweet potatoes grown in the United States are canned, frozen, and/or dried. 2/3rd of SP grown in the Unites States are sold as fresh (raw) produce; the other 1/3rd is processed. Around 25% is processed into canned foods including baby foods, 4% into frozen foods, 2%-3% is chipped or dehydrated leaving about two-thirds of sweet potato sales for fresh market. (www.ers.usda.gov).

2.2. Sweet Potato Varieties

Many commercial varieties of sweet potatoes are available in United States. A few of these are listed in Appendix A (a); Beauregard and Hernandez are varieties developed by Louisiana Agricultural Experiment Station. Both cultivars have high yields and deep orange flesh. The jewel variety developed by North Carolina State University is a leading commercial variety and is considered the current Queen of sweet potatoes (<http://members.aol.com/SPVine/garden/garden3.html>). It produces a very high yield of 6 SP per plant.

2.3. Sweet Potato Composition

Water: 70-80%

Carbohydrates: 20-25%

Lipids: 0.1-0.4%

Protein: 1-2%

Fiber: 2.5%

Sugar composition varies significantly among cultivator selections but it was found that there was no relationship between sugar composition and textural properties.

(Truong et al. 1998). Sweet potato provides good quality protein for non-meat eaters or those economically forced to consume such a diet. (Walter A. Hill, Philip A. Loretan and Conrad K. Bonsi.)

Beauregard, Hernandez and Jewel (orange flesh) are moist type sweet potato varieties popular in southern United States, while oriental yam (yellow flesh) is the typical Asian or African sweet potato (intermediate moisture) available in Nigeria, China, Japan, Malaysia, Philippines and many other countries.

2.4. Sweet Potato Nutritional Composition

SP roots are excellent sources of nutrients such as carbohydrates, fiber, pro-vitamin A, ascorbic acid, carotenes, thiamine, riboflavin, niacin, calcium, iron, potassium, and zinc.

Sweet Potato Chemical Composition (Per Serving of one medium 5 inch long SP; 130g)

Calories	:	130
Calories from fat	:	0.39 g
Protein	:	2.15 g
Carbohydrate	:	31.56 g
Dietary Fiber	:	3.9 g
Sodium	:	16.9 mg
Potassium	:	265.2 mg
Calcium	:	28.6 mg
Folate	:	18.2 mcg
Vitamin C	:	29.51 mg (excellent source)
Vitamin A	:	26081.9 IU (excellent source)
Cholesterol	:	0

Source: National Agricultural Library (NAL), part of the Agricultural Research Service of the US Department of Agriculture [South Side Produce Market].

Foods that are an “excellent source” of a particular nutrient provide 20% or more of the Recommended Daily Value, based upon United States Department of Agriculture (USDA) guidelines. Foods that are a “good source” of a particular nutrient provide between 10 and 20% of the USDA Recommended Daily Value.

According to the North Carolina Sweet Potato Commission, one cup of sweet potato provides the same amount of beta-carotene as 23 cups of broccoli. A 4-ounce serving has about 115 calories and virtually no fat or cholesterol. The amount of beta-carotene depends on the variety.

The Center for Science in the Public Interest (CSPI) a non-profit organization ranks vegetables based on their nutritional content; dietary fiber, naturally occurring sugars and complex carbohydrates, protein, vitamins A and C, iron and calcium. The higher the rank for the vegetable the more nutritious the food is considered and sweet potato is ranked as the #1 most nutritious vegetable higher in nutrients than broccoli and spinach (www.sweetpotato.org).

2.5. Sweet Potato Products

The development of processed products from sweet potato presents one of the most important keys to expanded utilization of the crop. Just like white potatoes, sweet potatoes are multipurpose vegetables. The development in sweet potato research (R&D), has transformed the crop from a simple staple food to an important commercial crop with multiple uses e.g., as a snack, complementary vegetable and ingredient in various foods.

Sweet potato flakes (called sweet potato buds) with an increased Vitamin A were produced in Guatemala to conquest Vitamin A deficiency in children (Lopez et al. 2001). Fresh- market sweet potatoes can be baked, microwaved, broiled, grilled, and baked. In some countries alcohol is distilled from sweet potatoes. They can also be used in green salads, casseroles, pasta sauces, plate garnishes, dipping vegetables (fresh- cut sticks), sautéed vegetables, soups, stews, and stir-fry (Dawkins et al. 1991). They can be processed as follows:

- Frozen: slices, dices, french fries, patties.
- Dried/dehydrated: flakes, flour, chips.
- Canned: cut/ sliced, candied, mashed, baby foods, pie fillings.

Sweet Potatoes are also used as an ingredient in ice creams, pie fillings, cakes, icing, cookies, custards and various other bread products (Dawkins et al. 1991). As drying technology progressed, sweet potatoes began to be pureed and then dried to produce flakes, which can be easily reconstituted for direct use in various products like mashed sweet potato, pies and other products.

2.6. Processing Techniques

Food processing involves a combination of procedures to achieve intended changes to the raw material. These processing technologies in the food industry are into 2 main groups.

- Processing of foods with non-thermal methods. Examples include: High pressure processing, Pulsed electric field (PEF), Electronic beams etc.,
- Processing of foods with thermal methods/heat.

2.6.1. Processing of Foods with Thermal Methods/Heat

Heat treatment is one of the important methods used in food processing to extend the shelf life of foods either by destroying the enzymatic and microbial activity or by removing water to inhibit deterioration. The advantages of heat processing are (Fellows, 2000):

- Simple control of processing conditions
- Production of shelf-stable products that need no refrigeration
- The enhancement of availability of nutrients for human consumption (e.g. improves digestibility of proteins and gelatinization of starches)
- The destruction of anti-nutritional factors (e.g. trypsin inhibitor in some legumes)

Processing by application of heat can be carried out using four methods. They are:

- a. Heat processing using water or steam e.g., blanching, and pasteurization
- b. Heat processing using hot air e.g., dehydration, baking and roasting
- c. Heat processing using hot oils e.g., frying
- d. Heat processing by direct and radiated energy e.g., Dielectric heating, Infrared heating and Ohmic heating

2.6.2. Heat Processing by Direct and Radiated Energy

Processing of foods by this method can be carried out in two ways:

- a. Indirect Method: Depends on the heat that is generated externally by radiation and applied to the surface of the food e.g., Infrared heating
- b. Direct Method: Heat is generated within the product e.g., Dielectric heating (microwave and radio frequency), ohmic heating

The dielectric and infrared are two forms of electromagnetic energy in which the transmitted waves penetrate into the food and are then absorbed and converted to heat whereas ohmic heating uses the electrical resistance of the foods to directly convert electricity to heat (Fellows, 2000).

2.6.3. Infrared Heating

Infrared energy is electromagnetic radiation emitted by hot objects which when absorbed, gives up energy to heat materials. The main commercial applications of radiant energy are in drying low moisture foods like breadcrumbs, cocoa, flours, pasta products, malt and tea and in baking and roasting (Fellows, 2000). Because of limited depth of penetration, it is not used as a single source of energy for drying large pieces of food. The rapid surface heating results in sealing of moisture and flavor compounds.

2.6.4. Microwave Heating

This refers to the use of electromagnetic waves of certain frequencies to generate heat in a material (Datta & Davidson, 1996) and is mainly used for defrosting and low pressure drying. Microwave processing uses two frequencies of 2450MHz and 915MHz. For home ovens 2450MHz is used and in industry both frequencies are employed. Heating with a microwave involves two mechanisms - dielectric and ionic. When a microwave frequency is applied the dipoles in water attempt to align themselves to the electric field just as a compass in a magnetic field. But the electromagnetic radiation with high frequencies produce oscillations (electric field changes from positive to negative) and dipoles attempt to follow these oscillations creating frictional heat. This results in the heating of water molecules and ions in the food to produce heat until the water evaporates (Datta & Davidson, 1996).

Microwave heating is preferred to conventional heating for pasteurization and sterilization of food as it is rapid, consumes less energy, requires less time to heat to a desired temperature with no color change, and cost saving. This is particularly true for solid and semi-solid foods that depend on the slow thermal diffusion process in conventional heating, for example, vegetable pieces in soup or meat piece (Datta & Davidson, 1998). Microwave heating can also achieve bacterial destruction but thermal degradation of the desired components is reduced. Microwave heating is also used as a pretreatment before conventional drying. The drying parameters involved are dielectric power and exposure time to microwave radiation.

2.6.5. Radio Frequency Heating

Unlike microwave processing radio frequency heating operates at lower frequencies and is mostly used to heat or evaporate moisture from a product. In this method food is passed between electrodes and a radio frequency voltage is applied across the electrodes (Fellows, 2000). This result in very rapid heating compared to microwave but there is restriction on the thickness of the food, which is an important limitation of the method.

2.6.6. Differences

Dielectric heating (microwave and radio frequency heating) is applied to various foods because of the advantage of high heating rates and absence of surface changes to food. Most important industrial applications include thawing, tempering, dehydration and baking of foods (Rosenberg and Bogl, 1987a). Blanching and pasteurization are less successful because of low depth of penetration in large food pieces and evaporative cooling at the surface, which results in survival of micro-organisms i.e., the microwave

and radio frequency energy have no direct effect on microorganisms. The main differences between dielectric, ohmic and infrared energy are summarized in Appendix A (b).

2.6.7. Ohmic Heating

2.6.7.1. Theory

Foods contain water and ionic salts that are capable of conducting electricity but also have a resistance, which generates heat when an electric current is passed through them. The electrical resistance of a food is the most important factor in determining how quickly food will heat (Fellows, 2000). Electrical resistance of a food is measured using a multimeter connected to a conductivity cell. The measured resistance is converted to conductivity using equation (Palaniappan and Sastry 1991):

$$\sigma = (L/A) (1/R)$$

σ → Specific Electrical Conductivity (S/m)

L → Length of the sample (m)

A → Area of cross-section of the sample (m²)

R → Resistance of the sample (ohm)

The resistance (R) determines the current that is generated in the product by the equation:

$$= V/I$$

V → Voltage applied to the sample (volts)

I → Current passing sample (amps)

(field strength) in the field, and the electrical conductivity. The method is also termed as ‘resistance heating’ or ‘electro heating’.

$$\sigma = (L/A) (1/R)$$

This method was first used during the 19th century and early 20th century to heat flowable materials and to pasteurize milk (Sastry and Palaniappan 1992). The technology gradually disappeared due to lack of suitable electrode materials and adequate control systems. Early designs used of ohmic heater used DC power, which resulted in electrolysis (corrosion of electrodes and product contamination) and also had expensive electrodes (Fellows, 2000). But as discussed by Sastry (1994) interest in ohmic heating has been revived due to availability of improved electrodes and its capability to heat multiphase mixtures uniformly.

While many studies were focused on ohmic heating of liquid-particle mixtures (Halden, 1990; Sastry & Palaniappan, 1991; Sastry, 1992), others used ohmic heating as a treatment to alter food properties in a desirable way e.g., to increase mass transfer properties (Lima 1996 & Lima et al. 1999) or to increase juice yield (Lima et al. 1999). Henderson et al. (1993) observed that the ohmic thawing has lower operational costs and sensory properties with this process were similar to the conventional thawing.

Ohmic heating is more efficient than microwave heating because nearly all of the energy enters the food as heat. Wang (1997) found that ohmic heating (at 60Hz) resulted in significantly higher hot air drying rates than did microwave heating (2450Hz). Another important difference is that both microwave and radio frequency heating have a finite depth of penetration into a food whereas ohmic heating has no such limitation (Fellows, 2000). However microwave heating requires no contact of the food but ohmic heating

requires contact of the food with the electrodes. Moreover microwave or frequency heating does not allow to build up charges on cell walls and form pores as the electric field is reversed before sufficient charge builds up (Sastry & Barach, 2000).

A consortium of 25 partners from industry, government and academia developed a wide variety of shelf stable low-acid, high-acid products and refrigerated extended-shelf-life products by ohmic heating accompanied by a carrier medium (Zoltai and Swearingen, 1996). They found the products to have texture, color, flavor, and nutrient retention that was comparable to or exceeding that of traditional processing methods such as freezing, retorting, and aseptic processing. Ohmic heating costs were found by Allen et al. (1996) to be comparable to those of freezing and retort processing of low acid products.

2.6.7.3. Advantages of Ohmic Heating

Research has been done on the ohmic heating liquids or sufficient liquids with particulate matter. The advantages observed were as follows (Fellows, 2000):

- Temperature required for UHT processing can be achieved
- Surface fouling, over heating and burning of the product can be prevented or minimized
- Multiphase mixtures are not subjected to shearing forces as in scraped surface heat exchangers
- Provides uniform heating resulting in less thermal damage
- Suitable for continuous processing
- Less time consuming than the conventional heating
- Energy conversion efficiencies are very high
- Lower capital cost than the microwave heating

2.6.7.4. Factors Effecting Ohmic Heating

The following factors affect heating characteristics of the product during ohmic heating (Fellows, 2000)

- Size and shape of the particles
- Moisture content of the solids
- Solids/liquid ratio
- Viscosity of liquid component
- Amount and type of electrolysis
- pH
- Specific heat
- Thermal conductivity

Ohmic heating is used for sterilization and pasteurization of a number of products. The process can be used for UHT sterilization of particulate foods in liquid medium that are difficult to sterilize by other means. This method is in commercial use in Europe, the USA and Japan in aseptic processing, pasteurization and preheating of particulate foods before further processing e.g., hot filling or packaging e.g., caning. Ohmic heating is currently used in Japan and United Kingdom for processing of whole fruits (Sastry and Barach, 2000). One commercial facility in the United States uses ohmic heating for the processing of liquid egg.

2.6.7.5. Regulation

No ohmic heating systems have been developed for use in the home. In order for the ohmic “UHT processing of particulate foods to be accepted by the regulatory authorities, it is necessary to ensure that the coldest part of the slowest heating particle in

the food has received sufficient heat to ensure sterility” (Fellows, 2000). The process must demonstrate that the solid particles are heated to an equal or greater extent than the liquid surrounding it. This can be done by adjusting the electrical properties of each component but the data is not available for non-homogenous particles (e.g., meat pieces), which have variable resistance.

2.7. Controlled Atmosphere

The traditional way of maintaining a controlled atmosphere to condition the materials to a standard water content in the laboratory is by using use of salt solutions either saturated or unsaturated, in small, sealed containers or desiccators. Any salt at a definite concentration and at constant temperature is in equilibrium with a fixed partial vapor pressure of water and hence defines a fixed relative humidity (Ramana et al. 1992). Diamante and Munro (1990) determined water desorption isotherms for two varieties of sweet potatoes by exposing the samples to relative humidities ranging form 6% to 81%.

The time to reach equilibrium depends on:

- 1) The ratio of free surface area of solution to chamber volume;
- 2) The amount of air circulation;
- 3) The absorbing properties of the sample;
- 4) The agitation of the salt solution- diffusion controlled mixing results in concentration gradients.

2.7.1. Precautions

Following precautions are to be followed while preparing saturated solutions:

- 1) The chamber should be made up of non-hygroscopic materials to prevent adsorption of moisture by the walls with a consequent delay in achieving equilibrium;
- 2) Concentrated salt solutions should be kept out of contact with metals to avoid corrosion;
- 3) The chamber should be kept leak proof;
- 4) The whole chamber and its contents should be brought to thermal equilibrium i.e., they should be maintained at constant temperature;
- 5) The salt solutions should have a large a surface area as is practical.

2.7.2. Saturated Salt Solutions

Saturated salt solutions can be prepared in desiccators using distilled cold water to attain a range of relative humidities of 11.15% to 90.26%. The following table shows few R.H%, which can be maintained (Rockland, 1987).

Table 2: Preparation of Saturated Salt Solutions at 25°C

Salt	Relative Humidity%	Quantity	
		Salt (g)	Water (mL)
LiCl	11.15%	150	85
Mgcl ₂	32.73%	200	25
NaBr	57.70%	200	80
NaCl	75.32%	200	60

2.8. Rehydration

2.8.1. Introduction

“Rehydration is a complex process aimed at the restoration of raw material properties” (Krokida et al. 1999). It is the replacement of water in dehydrated foods. Synonymous terms are “refreshing”, “recovery”, “restoration” and “reconstitution” (Loesecke 1955). This process assimilates a large percentage of the original water.

Because of inherent differences in their chemical composition all products do not reconstitute 100%.

Most dehydrated products are rehydrated at their final use (corn flakes, soups, etc.) therefore it is important to know their compression behavior after rehydration. The rehydration characteristics of the materials are influenced by processing conditions, sample composition, sample preparation and detrimental effects occurring during drying or dehydration (Loesecke 1955). The extent of rehydration also depends on storage temperature.

The rate of rehydration is an important quality parameter for dried products. Lewicki (1998) found that the pre-drying treatments, subsequent drying and rehydration causes many changes in structure and composition of plant tissues. If there are no adverse effects on the material due to drying then the tissue or the material should absorb water to the same moisture content as it initially was. However, the nature of the internal porous structure and mechanical and elastic properties of the dried material will influence the moisture uptake rate. The loss of moisture, product shape and color can be restored or reversed to a certain extent but textural changes (due to methylation of pectin in vegetables e.g., browning in apples) of the product and loss of nutrition (if any) cannot be recovered. For certain vegetables e.g., potatoes, the color change due to browning reaction cannot be reversed. Krokida et al. (1998 &1999) considered rehydration as a measure of the injury to the material caused by drying and treatments preceding dehydration. Moreno-Perez et al. (1996) rehydrated dried cubes of sweet potato and tested toughness. There was no significant difference between the samples dried at 70°C and 85°C.

2.8.2. Methods

There are many methods for rehydrating vegetables. Most vegetables are soaked (rehydrated) in cold water or hot water or added to a product with lots of liquid like soup or stew before consumption. The ratio between the dry material mass and water mass varies from 1:5 to 1:50 and time of rehydration varies from 2 minutes to 24 hours. Rehydration water is either still or stirred occasionally. Rehydrated material is blotted with tissue paper, filtered off on filter paper with a slight vacuum or drained on a sieve. In no case is the initial water content of the dry material is taken into account (Lewicki 1998).

2.8.3. Model of Rehydration

Assuming that perfect rehydration would yield a product with a composition exactly that of the raw material the following indices are suggested by Lewicki (1998).

2.8.3.1. Water Absorption Capacity (WAC)

This gives information on the ability of the material to absorb water. The more the water absorption capacity is lost during dehydration the smaller the index. The index can be calculated from the formula:

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

Where,

M → the mass

s → the dry matter content (%) and subscripts d, o, and r refer to dry, before drying and rehydrated respectively. The value ranges from 0 to 1 (Lewicki 1998).

2.8.3.2. Dry Matter Holding Capacity (DHC)

This expresses the ability of the materials to hold solubles. The DHC index shows the extent of tissue damage and its permeability to solubles. DHC can be calculated by the following formula:

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

The more the tissue is damaged the smaller the index. The value ranges between 0 and 1.

2.8.3.3. Rehydration Ability (RA)

Lewicki found that as both the indices express the damage incurred to tissue by drying, their product could be a measure of the ability of product to rehydrate. Hence RA is calculated from the following formula:

$$RA = WAC * DHC$$

The index range is 0 to 1. The more the tissue damaged, the smaller the index.

2.9. Color

Color and discoloration of many foods are important quality attributes in marketing. Though they do not reflect nutrition or flavor, they are important as they relate to consumer preference based on appearance. Color measurement is a critical objective parameter that can be used as quality index measurements of raw and processed foods in quality control documentation, for determination of food quality and for analyses of quality changes as a result of food processing and storage (Giese, J 2000). Color is often used to determine ripeness of fruit e.g., green color in tomatoes, peaches, and yellow

color in banana (Chan & Ramaswamy 2002) etc., and in many cases, is controlled by reducing sugar content, by storage conditions and subsequent processing e.g., potato chips.

The color of the food material changes during processing, drying or dehydration due to the evaporation of water and certain enzymatic and non-enzymatic reactions. Enzymatic reactions include the formation of brown color pigments called melanins due to oxidation of phenols present in fruits and vegetables when exposed to air, in the case of potatoes or pears. Non-enzymatic reactions are those caused due to Maillard reaction during heating and storage e.g., brown discoloration occurs in turkey during freezing. These color changes (into brown) are desirable in case of meat and bakery products but are undesirable for fruits and vegetables. Therefore color measurement is important for consumer acceptability.

Color is the stimulus that results from the detection of light after it has interacted with an object. The light may be reflected, transmitted, absorbed, or refracted by an illuminated object. If all the radiated energy is reflected back then the object is opaque and appears white and similarly if all the energy is absorbed then it appears black (Lewicki & Duszczuk 1998). Therefore color arises from the presence of light in greater intensities at some wavelength than others and is mainly determined by the reflected light.

The color appearance can change depending on amount of light, the light source, the observer's angle of view, size, and background differences (Giese, J 2000). The visual color results can be affected by all these factors and therefore instrumentation to measure color provides a subjective and consistent method of color quality.

2.9.1. CIE XYZ

CIE (Commission Internationale de l' Eclairage) in 1931 introduced CIE system for describing any color, visible or invisible to human eye in three components X, Y and Z called tristimulus values. It offered the knowledge of spectral response of the human eyes, based on the statistic data collected by human observers i.e., based on human eye's perception (Perez-Magarino et al. 2003). This system uses the concept that any color in the system can be obtained by combining three primary colors: red, blue and green. But found that it is not always possible. So, the CIE has redefined the model by introducing CIE L*, a*, b* notation.

2.9.2. CIE L*, a*, b*

Color representation by the L*, a*, b* notation was recommended by the CIE (Commission Internationale de l' Eclairage) in 1976. The calculation of L*, a*, b* for each color is based on CIE XYZ values (Perez-Magarino et al. 2003). They are commonly used in food industry.

L* is the degree of lightness of the color. This refers to the relation between reflected and absorbed light. L* values equals to zero for black and 100 for white.

a* (red-green) is the degree of redness (0 to 60) or greenness (0 to -60) and b *(yellow-blue) is the degree of yellowness (0 to 60) or blueness (0 to -60).

2.9.3. Hue

Hue is the aspect of the color we describe in words such as green, blue, yellow, or red. This perception of color results from differences in absorption of radiant energy at various wavelengths. For example if shorter wavelengths of 400-500nm are reflected to a

greater extent than other wavelengths then the color is described as blue. A darkness factor b^*/a^* was used to quantify possible discoloration. The hue angle, H^* , was obtained as:

$$H^* = \tan^{-1} (b^*/a^*)$$

An angle of 90° represented a yellow hue (when b^* is yellowness measured). It is expressed in degrees: 0° (red), 90° (yellow), 180° (green) and 270° (blue). Objects with higher hue angles are greener while lower angles are more orange- red. Hue and chroma are the qualities or attributes of any color.

Color can be measured using a calorimeter or a spectrophotometer. In case of calorimeters “tristimulus filter are designed to reproduce the psycho-physical sensation of the human eye’s view of color” (Giese, 2000). For this purpose glass filters with standard observer angle are used. The light reflected from an object is measured using a photo cell and meter in terms of X, Y, and Z values. Colorimeters can be used for quick quality check during processing.

Spectrophotometers measure a ratio of light reflected or transmitted from a food product to that from a known reference standard. These are more accurate and expensive than the colorimeters.

2.10. Texture

Texture is one of the most important parameters connected to product quality. It is defined as the sensory manifestation of the structure of a food and the manner in which that structure reacts to the applied force (Meullenet et al., 1997).

Texture analysis involves measuring the properties related to how a food feels in our mouth. Characterization of food texture falls into sensory and instrumental method of analysis. A sensory analysis includes use of the senses of smell, taste, sound and touch. Sometimes it is preferable to use instrumental methods for assessing food texture rather than sensory analysis as they can be carried out under more strictly defined and controlled conditions. Moreover the sensory analysis is costly and time consuming. Instrumental methods can save time, reduce costs, and provide more consistent, objective results.

2.10.1. Instrumental Techniques

Instrumental techniques of studying the textural behavior of foodstuffs can be classified into three groups,

- Fundamental tests- a simple force versus time curve resulting from compression of food products
- Empirical tests- a flow meter to measure viscosity of a product
- Imitative tests – texture profile analysis

Instrumental texture measurements that relate to human perception are both imitative and empirical in nature. Imitative tests (imitate biting and chewing) involve instrument simulation of conditions under which sensory properties of the sample are assessed by humans. Thus, the imitative tests should have the most consistent correlation with sensory evaluation. (Szczesniak, 1963). These tests generate several instrumental parameters e.g., hardness, springiness, chewiness etc., unlike empirical, which generates only one. In case of empirical tests special instrument is designed to measure a particular parameter e.g., to measure springiness for gels (Yongsawatdigul, 1995).

The breakthrough in food texture evaluation came with the development of the General Food texturometer designed to simulate the mastication action of the human mouth. The General Texturometer generated a force as a function of time curve, which is known as texture profile. Instrumental Texture Profile Analysis first developed for the General Food Texturometer (1963) is an example of an imitative test.

2.11. Texture Profile Analysis

Texture Profile Analysis (TPA) is an imitative test designed to subject food to severe crushing and breaking similar to that which occurs during chewing. The method is based on a system of classification and definition of different textural characteristics (or attributes). Szczesniak (1963) suggested that textural characteristics be classified into three main groups:

- Geometrical attributes;
- Attributes related to moisture and fat content;
- Mechanical attributes.

2.11.1. Geometrical Characteristics

These characteristics fall into two categories: those related to particle size and shape such as gritty, grainy, or coarse, and those related to shape and orientation such as fibrous, cellular, or crystalline (Szczesniak, 1963).

2.11.2. Characteristics Related to Moisture and Fat

Moisture content and fat content are the primary parameters and oiliness and greasiness are the secondary parameters that determine texture. These parameters usually

show the degree of moistness or dryness, oiliness or greasiness of a product (Szczesniak, 1963).

2.11.3. Mechanical Characteristics

The mechanical characteristics are most important in determining the manner in which the food behaves during mastication in the mouth. These characteristics are a result of the reaction of food to applied stress. The mechanical characteristics are divided into five primary parameters and three secondary properties (Szczesniak, 1963, 1975). The first four primary parameters in the table below are related to forces of attraction between particles of food that oppose disintegration, and the adhesiveness is that related to surface properties. The secondary properties are composed of two or more of the primary parameters.

Table 3: Mechanical Texture Parameters

Primary Parameters	Secondary Characteristics	Defined Terms	Examples
Hardness		Soft, firm, hard	Hard candy
Cohesiveness	Brittleness	Crumbly, crunchy, brittle	Raisins
	Chewiness	Tender, chewy	Caramel
	Gumminess	Short, mealy, pastry, gummy	Hot dog
Viscosity		Thin, viscous	
Springiness		Plastic, elastic	Marshmallows
Adhesiveness		Sticky, tacky, gooey	Peanut butter

2.11.4. Definitions of Mechanical Characteristics

2.11.4.1. Primary Properties

Hardness: Hardness is the force required to compress a substance between the molar teeth or between the tongue and the palate. Measured as force necessary to attain a given deformation e.g., hard candy (Szczesniak, 1975).

Cohesiveness: The degree to which a substance is compressed between the teeth before it breaks. Measured as the extent to which a material can be deformed before it ruptures e.g., Raisins.

Viscosity: Rate of flow per unit force e.g., liquids.

Springiness: Degree to which a product returns to its original shape once it has been compressed. Measured as the rate at which a deformed material goes back to its undeformed condition after the deforming force is removed e.g., marshmallows, gel.

Adhesiveness: Work necessary to overcome the attractive forces between the surface of the food and the surface of the other materials with which the food comes in contact e.g., peanut butter.

2.11.4.2. Secondary Properties

Fracturability: Force with which a material fractures: a product of high degree of hardness and low degree of cohesiveness e.g., cracker.

Chewiness: Length of time required to chew a sample to a consistency suitable for swallowing. A product of hardness, cohesiveness, and springiness e.g., caramel

Gumminess: Energy required to disintegrate a semi-solid food to a state ready for swallowing: a product of a low degree of hardness and a high degree of cohesiveness e.g., hot dog

Textural properties are usually related to mechanical tests that examine the viscoelastic behavior of the material. Agricultural products that exhibit characteristics of both solid and liquid are referred to as viscoelastic (Szczesniak, 1963). Mechanical properties such as hardness, springiness, fracturability are those having to do with the behavior of the material under applied forces.

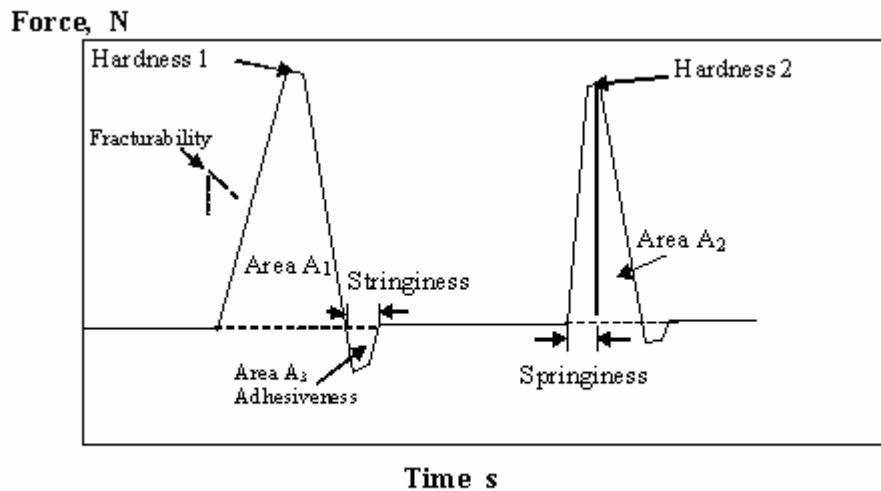


Fig1: A Typical Force versus Time Texture Profile Analysis Curve

A compression test is one of the most common techniques for the estimation of textural properties. The viscoelastic behavior can be determined by compression tests. The simplest approach is to measure the maximum applied force or stress at the fracture of the material. These tests are performed by applying a constant deformation rate while recording force and deformation. The compression test is continued until the specimen

fractures. The quantification of the complex terms such as hardness and chewiness has been made possible by a methodology called Texture Profile Analysis (Szczesniak, 1963).

CHAPTER 3: MATERIALS AND METHODS

3.1. Experimental Design

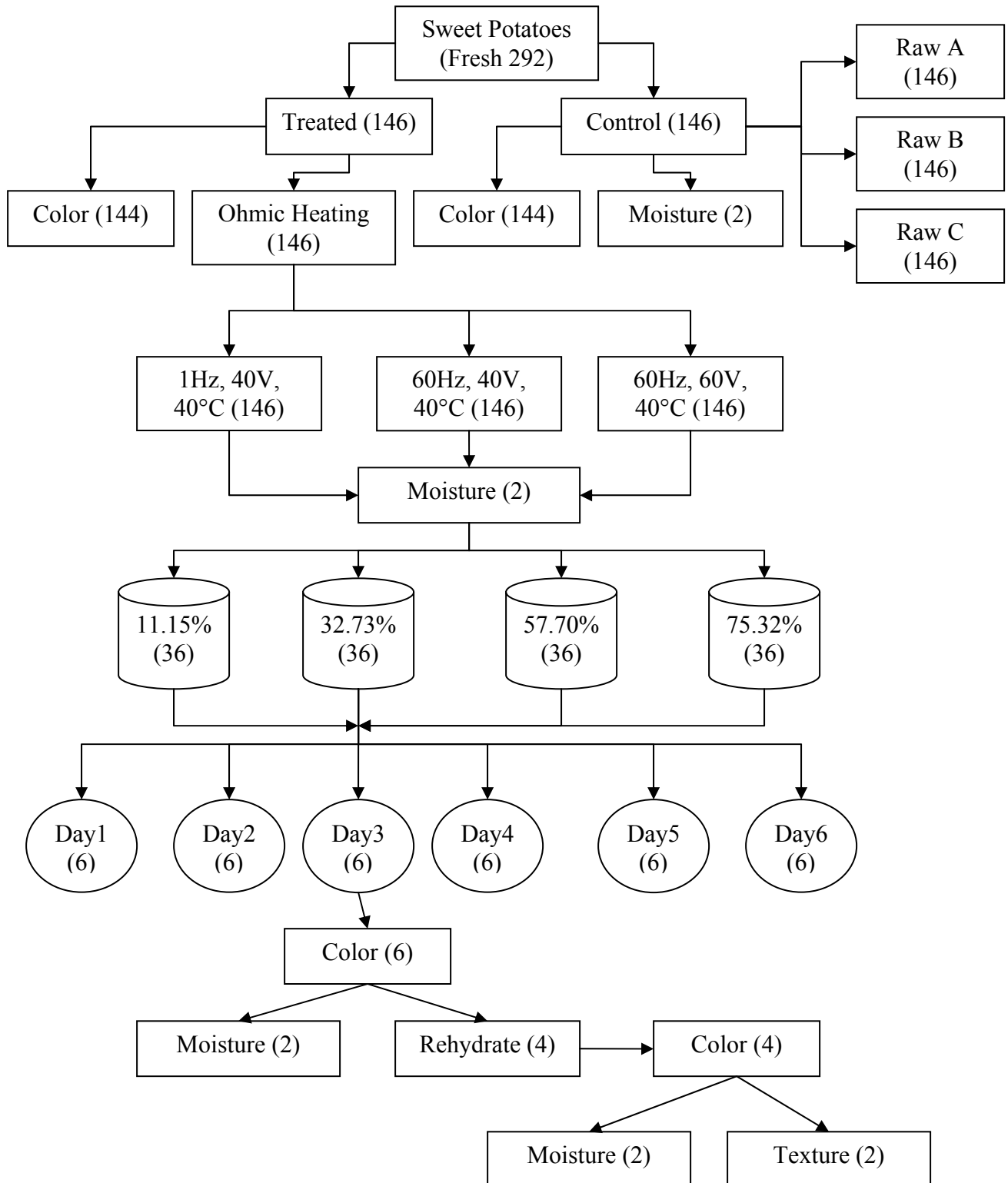


Fig. 2 Experimental Design

3.2. Sample Preparation

Centennial sweet potatoes (*Ipomoea batata. Lama*) were purchased from local markets, South Side Produce food store in Baton Rouge, Louisiana. The individual weights of sweet potatoes were checked so that their values are close to one another. They were washed in running water to remove the surface dirt, dipped in 3% hydrogen peroxide, followed by proper wash in distilled water. They were then removed from the water and spread on a paper towel and blotted to remove excess surface water.

A Steel manual peeler, a french fry cutter with 12 mm width, a steel knife and a scale were used. All were cleaned with hydrogen peroxide and then with distilled water before cutting the samples.

Sweet potatoes were peeled using steel manual peeler and middle portions were cut perpendicular to the long axis into 14-mm thick sections. These sections were then cut into long pieces with a French fry cutter with blades of width 12 mm. The long individual pieces were trimmed to cubes of 12 mm using clean steel knife. Thus the entire sweet potato was used for sample preparation. The samples were taken from the inner tissue of the roots at about 4 mm from the root skin. The cubes were then immediately heated by ohmic treatment after checking individual weights and determining color parameters CIE L*, a*, b*, chroma, hue angle.

3.3. Ohmic Heating

For ohmic heating the sample cubes were placed between the two specially coated titanium electrodes (coating applied by APV Company, Devon, England); it was imperative that sides of the sample cubes had full contact with the electrodes in order to ensure uniform heating. A 120 volt power supply was used to provide alternating current

of frequencies 1Hz and 60Hz and to heat the samples until its geometric center reached the desired end-point temperatures (EPT) of 40°C and 70°C. Voltages of 40V and 60V were applied. A Teflon-coated K-type thermocouple (cleaned with hydrogen peroxide and distilled water) was placed into the geometric center of the sample to monitor temperature during heating. Raw (untreated/control) samples were also drilled with the thermocouple to ensure that all the samples were comparable.

Calibrated voltage and current transducers (Ohio Semitronics Inc., Hilliard, OH) were used to measure voltage and current in the samples. A uniform electric field was assumed since the electrodes were in excellent contact with the food solid. The voltage, current, time and temperature data were continuously measured and logged every second by a data logger (CR 10X, Measurement and Control Module) linked to a personal computer. Care was taken to see that the sample reached appropriate EPT. When samples reached the desired temperature the power was switched off. The heated samples were weighed and transferred to a coded aluminum dish. The ohmic treatments and there respective controls are shown below:

<u>Treatments</u>	<u>Controls</u>
1Hz, 40V	Raw A
60Hz, 60V	Raw B
60Hz, 40V	Raw C

3.4. Moisture Studies

- **Method**

The weights of the sweet potato samples used for experiments were between 1.5290gm and 2.2876gm depending from which part of sweet potato the 12-mm cube

was taken. Moisture content (MC) data was obtained by weighing samples after ohmic heating, on each day for six days, after rehydration and also after removing them from oven. The MC was determined on wet basis. The experimental design for moisture studies is shown in Table 4.

Table 4: Treatments and replications in moisture studies

Treatment	60Hz, 40V, 40C; 60Hz, 60V, 40C; 1Hz, 40V, 40C; Controls: Raw A; Raw B; Raw C							
Relative Humidity	11.15%		32.73%		57.70%		75.32%	
MC	Day	AR	Day	AR	Day	AR	Day	AR
Replications	2	2	2	2	2	2	2	2

where, AR = after rehydration

The relative humidities of 11.15%, 32.73%, 57.70% and 75.32% were attained using saturated solutions prepared at 25°C from LiCl, MgCl₂, NaBr and NaCl respectively as described by Rockland (1987).

3.4.1. Moisture Content

Moisture content of the sweet potato samples was determined by drying samples in an oven at 104°C for 24 h (Wang and Sastry 1997).

$$\% \text{ Moisture} = \frac{(\text{Original sample weight(grams)} - \text{Dried sample weight(grams)})}{\text{Original sample weight(grams)}} * 100$$

The moisture content was determined for fresh, stored and rehydrated samples on wet basis. In all cases two replicates of each sample were used for determining the moisture content.

3.4.2. Dry Matter Content

Moisture content results were expressed in terms of dry matter basis for doing rehydration calculations. To determine % dry matter content, % moisture determined by dry air oven method was subtracted from 100.

$$\text{Dry matter content} = 100 - \% \text{Moisture}$$

3.5. Humidity Environments

The aluminum dishes with ohmic treated and the control samples (raw/untreated) were then loaded into desiccators maintained at four different relative humidity environments, and the weight of the sample monitored daily. Relative humidity control was obtained using saturated salt solutions, which were prepared corresponding to a range of relative humidities from 11.15% to 75.32% as described in Rockland (1987), and transferred to desiccators. To avoid moisture exchange between desiccators and the ambient environment, vacuum grease was used to ensure proper sealing. The temperature of the room where desiccators were placed was maintained at 19°C.

For each frequency, voltage and end point temperature combination, the moisture content of the samples (duplicates) were measured daily using oven maintained at 104°C for 24hrs. The samples were removed from the desiccators daily for 6 days for rehydration, color and texture analysis.

3.6. Rehydration Analysis

3.6.1. Method

Ohmically heated samples were rehydrated by filling aluminium dishes containing four samples from each RH with 40 ml of distilled water at 20°C and soaking for 30 min. The wet cubes were then transferred to a filter paper on a Buchner funnel.

The Buchner funnel is supported by a large Erlenmeyers flask equipped with a connection for vacuum suction. Vacuum pump was started for 30 seconds on each side of the cube to remove excess water from the cubes and the filter. Raw samples or control samples with no ohmic heating were rehydrated in the same way for reference.

3.7. Color Studies

The CIE LAB color space model was used to measure the color of sweet potato samples. The color of the treated and control samples was measured in terms of L^* , a^* , b^* parameters. The experimental design for the analysis of color parameters is shown in Table 5.

Table 5: Experimental design for measuring color parameters

Treatment	60Hz, 40V, 40°C; 60Hz, 60V, 40°C; 1Hz, 40V, 40°C; Control: Raw A; Raw B							
%RH	11.15%		32.73%		57.70%		75.32%	
Color	BR	AR	BR	AR	BR	AR	BR	AR
Replications	4	4	4	4	4	4	4	4

Where, BR = before rehydration AR = after rehydration

Objective color measurements of the samples were performed with a spectrophotometer/colorimeter (Minolta CR-200, Minolta Co., Osaka, Japan) that has an 8-mm diameter viewing area. It consists of six silicon photocells (three for measurement and three for controlling illumination) to detect stimulus values of red, green and blue. The instrument has chromaticity of +/- 0.0002 and a standard deviation of 0.07 (www.Minolta.com). The calibration was done with a standard white plate CD-A223 ($L^*=97.26$, $a^*=0.13$, $b^*=1.71$) provided by the manufacturer. The light source for the spectrophotometer was a pulsed xenon arc lamp and the observer angle used was 10° . The colorimeter measures the reflected light from the sample using primary color sensors

i.e., blue, green and red that have the same sensitivity as human eye. The CIE lightness values (L^*) and the chromaticity values (a^* and b^*) were recorded always on the same side of the sample (opposite side of the thermocouple insertion) averaging five color measurements on the surface for the fresh, after storage and after rehydration samples.

The chroma value is calculated as

$$\text{Chroma} = \sqrt{a^{*2} + b^{*2}}$$

The hue angle is derived as

$$H^* = \tan^{-1} (b^*/a^*)$$

3.8. Texture Studies

The experimental design for the texture analysis is shown in Table 6.

Table 6: Treatments and replications in texture studies

Treatment	60Hz, 40V, 40C; 60Hz, 60V, 40C; 1Hz, 40V, 40C; Controls: Raw A; Raw B; Raw C			
Relative Humidity	11.15%	32.73%	57.70%	75.32%
Texture	AR	AR	AR	AR
Replications	2	2	2	2

Where, AR = after rehydration

3.8.1. TPA Analysis

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 12 mm.

The samples were compressed to 75% of their original height by two consecutive compressions using a cylindrical probe of diameter two-inch (TA-25). The crosshead

speed was maintained at 1.00 mm/s. The waiting time between the two-cycles of the TPA tests was 5 seconds.

3.8.2. Calibration

The texture analyzer was calibrated daily for force and height before doing the analysis. Force calibration was done by using a 2 kg weight provided by the manufacturer and height was calibrated to 14 mm. A load cell of 30 kg capacity was used.

3.8.3. Texture Analyzer Settings

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: 5sec

Trigger Type: Auto (Force)

Trigger Force: 50gm

Tare Mode: Auto

Advanced Options: on

3.8.4. Testing

Compression takes place in following simple steps

1. The probe approaches the sample (sweet potato cube) from the calibrated height (14mm) with the pre-test speed;
2. Compresses it to 50% of the original height with test speed (first compression);
3. Probe returns to the original distance and holds for specified waiting time of 5 seconds;

4. Probe travels with test speed for remaining 25% compression (second compression) and travels back to the original position.

Once the test was over, the crushed sample was removed and the platform surface was cleaned to remove the extracted moisture or water. Then, the next sample was placed underneath the probe. This was done every day for all the 16 samples (2 from each relative humidity of treatment and control).

Care was taken to ensure the sample separated from the probe when the probe completed the second compression cycle and returned to its initial position. A curve of forces vs. time was produced for all the samples and all the parameters were obtained from the result file.

3.8.5. Data Analysis

The TA-XT2 plus texture analyzer consists of texture expert exponent software which has a test program specially designed for TPA analysis. When the food sample was placed and was compressed, then relaxed and compressed again, seven text parameters result from the analysis of a force versus time curve obtained by the compression test. Data collection and calculation were accomplished using XTRAD software of the TA-XT2 plus (Texture Expert Exceed) texture analyzer. Instrumental texture parameters recorded from the force versus time curves were hardness, chewiness, cohesiveness, adhesiveness, gumminess and springiness. The definitions of the parameters in terms of force can be explained as follows (Szczeniak, 1975):

Hardness: Measured as force necessary to attain a given deformation e.g., hard candy

Chewiness: Length of time required to chew a sample to a consistency suitable for swallowing. A product of hardness, cohesiveness, and springiness e.g., caramel

Cohesiveness: Measured as the extent to which a material can be deformed before it ruptures e.g., Raisins.

Adhesiveness: Work necessary to overcome the attractive forces between the surface of the food and the surface of the other materials with which the food comes in contact e.g., peanut butter.

Gumminess: Energy required to disintegrate a semi-solid food to a state ready for swallowing: a product of a low degree of hardness and a high degree of cohesiveness e.g., hot dog.

Springiness: Measured as the rate at which a deformed material goes back to its undeformed condition after the deforming force is removed e.g., marshmallows, gel.

3.8.6. Statistical Analysis

Analysis of variance for moisture, color and texture values was computed using PROC GLM of Statistical Analysis System (SAS). Significant differences among means were determined by Tukey's test and a Student's t-test (two- tail) to know if the mean values were same or different after rehydration. Pearson's correlation coefficients were calculated between moisture content and texture attributes using PROC CORR. All comparisons were made at $\alpha = 0.05$.

CHAPTER 4: RESULTS AND DISCUSSIONS

The results and discussion chapter is divided into four major parts:

1. Ohmic Heating Profiles
2. Moisture Studies
3. Color Studies
4. Texture Studies

The ohmic heating profiles are not a part of the focus of the research but are included as additional data of importance for future reference and for completeness.

The 60Hz, 40V, 70°C treatments the samples were overcooked. Therefore these samples were discarded and are not considered in the results and discussions. Moreover visual observations showed that the samples were soft, sticky and showed a breakdown of texture. This could be due to gelatinization of starch in SP. Though gelatinization effect could not be directly observed from heating curves or electrical conductivity data it was observed that after samples reached a certain temperature around 55°C there was sudden rise of temperature to 65°C-90°C. Research shows that this could be due to a change in heat flow through the samples after that temperature (Wang and Sastry 1997). The gelatinization effect of samples can be observed in a typical heat flow (mW) versus temperature (°C) graph known as the DSC (Differential Scanning Calorimetry) thermogram. This was not performed for the present research.

4.1. Ohmic Heating Profile

Temperature profiles were obtained for all the treatments during the ohmic heating process. A total of 146 profiles for each treatment were obtained (Fig. 3). With the increase in electrical field strength from 33.3V/cm (40V/1.2cm) to 50V/cm

(60V/1.2cm) the heating time was shortened. This result is the same as that obtained from past research (Zhong and Lima 2003).

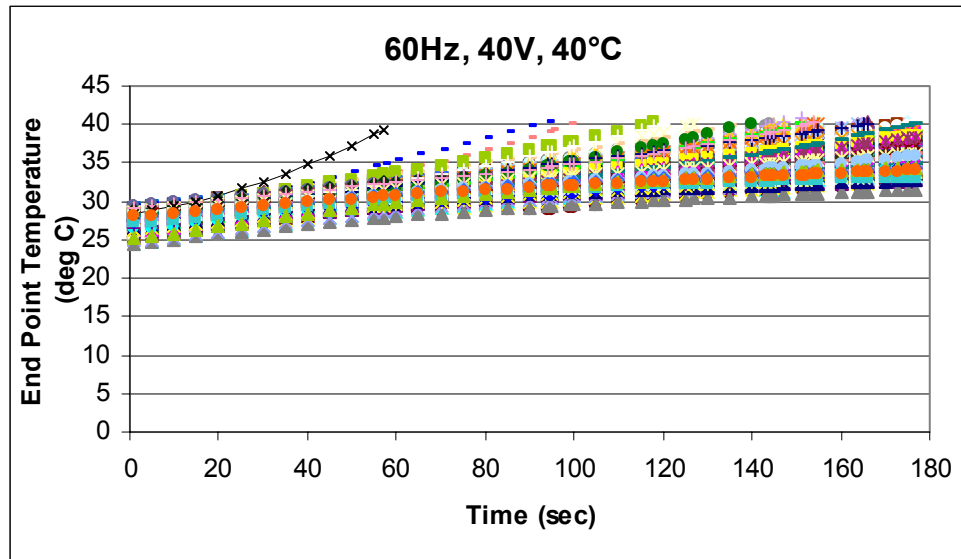


Fig. 3: Temperature profile at 60Hz, 40V, 40°C for all 146 samples

All the curves shown in the figures can be expressed in the form of regression equation:

$$Y = Ax^2 + Bx + C$$

This equation is similar to heating equation:

$$\frac{dT}{dt} = \sigma |\Delta V|^2$$

For all the treatments $A > 0$ values were obtained but for some samples in the 60Hz, 40V, 40°C treatment the A value was negative. The reason for this is unknown. These non-linear heating curves had increasing slopes. This could be due to the increase in electrical conductivity of the samples with increase in temperature (Palaniappan & Sastry 1991).

The summary of temperature curves for SP during ohmic heating for all the treatments is shown in Fig. 4.

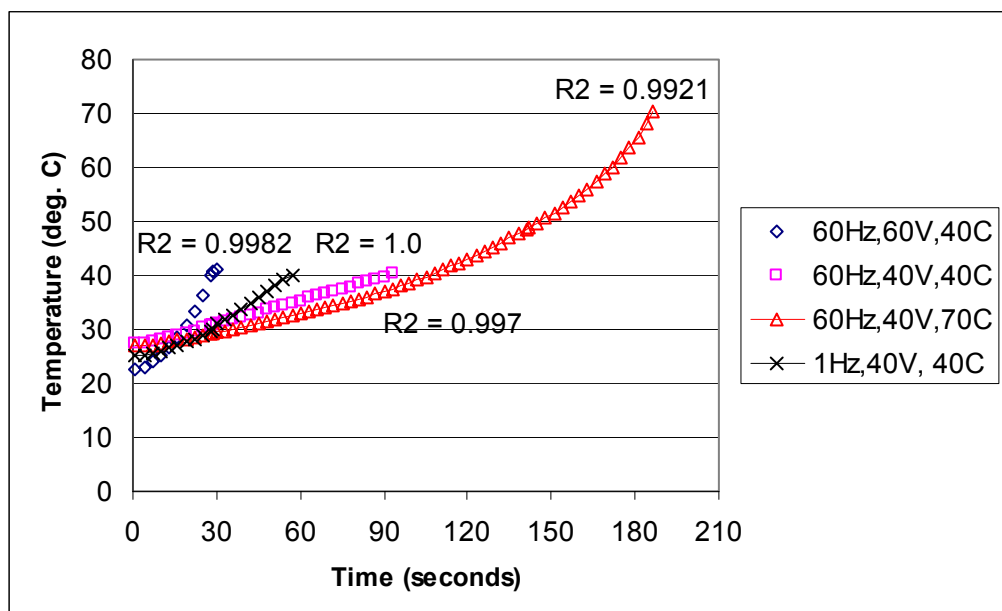


Fig. 4: Temperature profiles of sweet potato for all treatments

The regression equations for the 60Hz, 60V, 40°C; 60Hz, 40V, 40°C; 60Hz, 40V, 70°C and 1Hz, 40V, 40°C were respectively found to be

$$y = 0.0175x^2 + 0.1195x + 22.33;$$

$$y = 0.0001x^2 + 0.1294x + 26.956;$$

$$y = 0.0012x^2 - 0.0124x + 28.479;$$

$$y = 0.003x^2 + 0.0846x + 24.954.$$

Temperature profiles showed that with increase in electrical field strength the samples heating times was shortened and the end point temperatures were difficult to control. For example, the EPT once reached 42.4°C in the case of the 60Hz, 60V and 40°C treatment.

The detailed heating profiles of individual ohmic treatments are shown in Appendix C.

The treatments and their respective controls discussed in the results are shown below. While discussing results instead of showing all the controls and treatments only one of the controls was shown in figures.

<u>Treatments</u>	<u>Controls</u>
1Hz, 40V	Raw A
60Hz, 60V	Raw B
60Hz, 40V	Raw C

4.2. Moisture Studies

When %weight loss of the samples was calculated after ohmic heating it was found that 60Hz, 40V treatment had a greater weight loss when compared to 60Hz, 60V, while 1Hz, 40V had the least. This moisture loss result is different from past research observed by Lima and Sastry (1999) in which the drying rate increased with decrease in frequency and increase in electrical field strength.

While conducting the experiments, some samples exhibited mold growth and had to be discarded, resulting in the unavailability of samples for analysis for the final days. More explanation about this is given in results. The data that was not available is indicated in Table 7 by “×”. For 60Hz, 40V treatment data was available through out six days.

- **Results**

In general there was no significant effect of ohmic treatment on %moisture content values of the samples during storage and after rehydration (AR) in all the relative humidity conditions. But graphical representation showed that after rehydration the 60Hz, 40V treatment had higher %moisture content values than the other ohmically treated and

control samples. In some cases this result was also supported by statistical analysis. Always 60Hz, 40V ohmically treated samples had higher moisture absorption than the control samples. The results are explained in detail in next few pages.

Table 7: Days showing unavailability of data

Treatments	Days					
	1	2	3	4	5	6
60Hz, 60V						
11.15%	√	√	√	√	√	√
32.73%	√	√	√	√	√	√
57.70%	√	√	√	√	√	×
75.32%	√	√	√	√	×	×
1Hz, 40V						
11.15%	√	√	√	√	×	×
32.73%	√	√	√	√	√	×
57.70%	√	√	√	√	√	×
75.32%	√	√	√	√	×	×

“×” indicates the unavailability of samples.

4.2.1. Influence of Treatments

There was no significant difference in effect of heating treatments on the %moisture content values for the first three days of storage for all the relative humidity environments. The differences that were observed during fourth day and sixth day were due to 60Hz, 40V treated samples having higher %moisture content values than other ohmic treated samples and lesser %moisture values than control samples (Table 8).

The null hypothesis states that all the ohmic treated and control samples had same mean %moisture content values and an alternate hypothesis stating that null is false. So, the hypothesis below compares moisture content mean values of ohmic treated and control samples.

$$H_0: \mu_{60\text{Hz}, 40\text{V}} = \mu_{60\text{Hz}, 60\text{V}} = \mu_{1\text{Hz}, 40\text{V}} = \mu_{\text{Controls (Raw A; Raw B; Raw C)}}$$

Ha: H₀ is false

Table 8: Probability values indicating the influence of Treatments on %Moisture Content before Rehydration

%R.H.	Days					
	1	2	3	4	5	6
11.15%	0.0738 ^a	0.0324 ^a	0.0344 ^a	0.001 ^b	0.0652 ^a	0.0411 ^a
32.73%	0.4759 ^a	0.0793 ^a	0.0416 ^a	0.1 ^a	0.1023 ^a	0.5374 ^a
57.70%	0.2953 ^a	0.3583 ^a	0.3444 ^a	0.0588 ^a	0.1593 ^a	0.0654 ^a
75.32%	0.0787 ^a	0.2499 ^a	0.1652 ^a	0.0334 ^c	0.092 ^a	0.0034 ^d

The p-values of the treatments with the same or common superscript “a” are not significantly different at $\alpha = 0.05$.

The control samples and treated samples had no significant differences (Table 8).

The graphical representation shows the closeness of MC mean values during storage (Fig.

5).

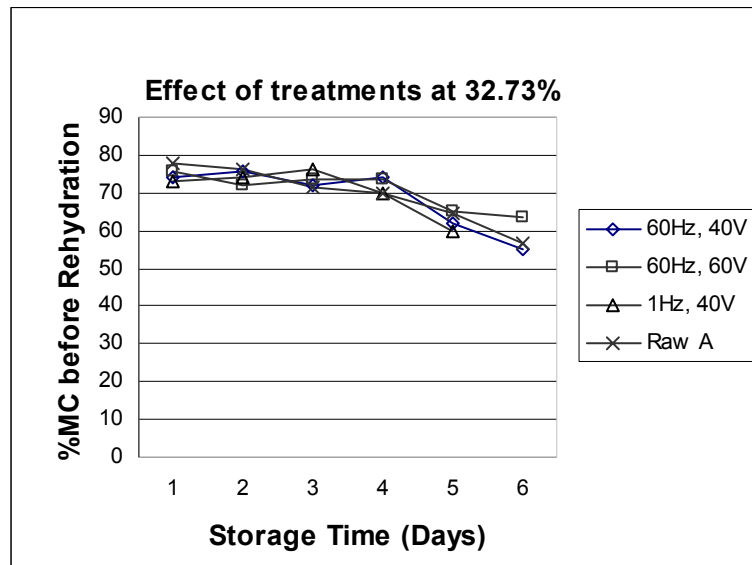


Fig. 5: Influence of treatments on %moisture content of samples during storage at 32.73% R.H

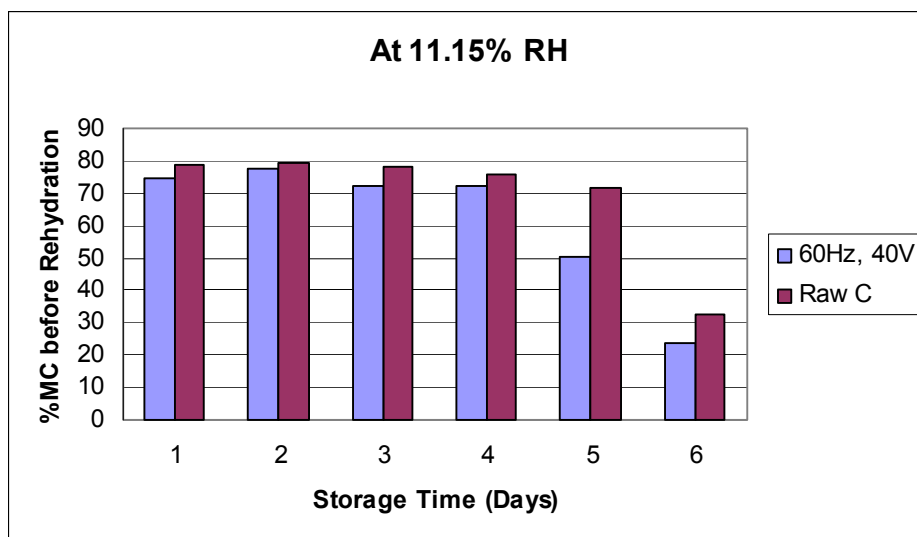


Fig. 6: Change in %moisture content for 60Hz, 40V and control samples during storage at 11.15%

As expected the control samples had a higher %moisture content value at the end of sixth day compared to all ohmic treated samples (Fig. 6) because of the loss of moisture from the treated samples during ohmic heating. Fig. 6 shows the mean %moisture values comparison of control and 60Hz, 40V treated samples.

On the fourth day for the lowest R.H. the %moisture content values of 1Hz treatment before and after rehydration was significantly different from 60Hz, 40V; 60Hz, 60V and also from the control samples (Table 9). These differences were not observed in fifth and sixth days because of shortage of samples due to spoilage.

$$H_0: \mu_{60\text{Hz}, 40\text{V}} = \mu_{60\text{Hz}, 60\text{V}} = \mu_{1\text{Hz}, 40\text{V}} = \mu_{\text{Controls (Raw A; Raw B; Raw C)}}$$

Ha: H0 is false

Statistical analysis showed that the %moisture content after rehydration for the samples treated by 60Hz, 40V and 1Hz, 40V were different from the control samples after third day for lowest and highest humidities (Table 10). There was no significant effect of 60Hz, 60V on %moisture content during storage and after rehydration.

Table 9: Influence of treatments on %moisture content after rehydration

%R.H.	Days					
	1	2	3	4	5	6
11.15%	0.0928 ^a	0.0244^e	0.6997 ^a	0.0017^b	0.0037	0.9854 ^a
32.73%	0.9381 ^a	0.2278 ^a	0.0926 ^a	0.1684 ^a	0.4423 ^a	0.0002^e
57.70%	0.1721 ^a	0.0221^e	0.03^e	0.483 ^a	0.0113^d	0.8317 ^a
75.32%	0.3769 ^a	0.6087 ^a	0.4155 ^a	0.0027^c	0.3249 ^a	0.0164^d

The p-values of treatments with the same or common superscript “a” are not significantly different at $\alpha = 0.05$; other superscripts with the same alphabet had same differences at $\alpha = 0.05$

Table 10: Mean (S.D) values of %moisture content after rehydration at 11.15%

Treatments	Days					
	1	2	3	4	5	6
%R.H.						
1Hz, 40V	79.78 (1.82)	76.71 (2.35)	78.44 (2.62)	66.00 (2.98)	.	.
60Hz, 40V	80.65 (1.96)	83.94 (0.78)	78.52 (3.03)	82.53 (0.81)	71.07 (0.99)	64.15 (1.08)
Raw A	80.85(1.37)	79.7 (3.38)	77.09 (4.36)	77.23 (1.23)	61.84 (2.67)	62.31(5.07)
Raw B	76.36 (1.09)	76.43 (0.44)	78.66 (2.58)	77.21(1.87)	78.32 (3.71)	62.31(5.07)
Raw C	82.72 (2.53)	79.72(1.74)	79.29(0.29)	78.12 (0.33)	75.72 (1.17)	62.79 (0.22)

“.” = Data was not available due to spoilage

However the graphical representation shows the values to be close to each other (Fig. 7). Therefore different ohmic treatments did not result in significantly different %moisture content values after rehydration at $\alpha= 0.05$ though graphical representations did show that 60Hz, 40V treatment had resulted in higher %moisture content values after rehydration compared with control and other treated samples.

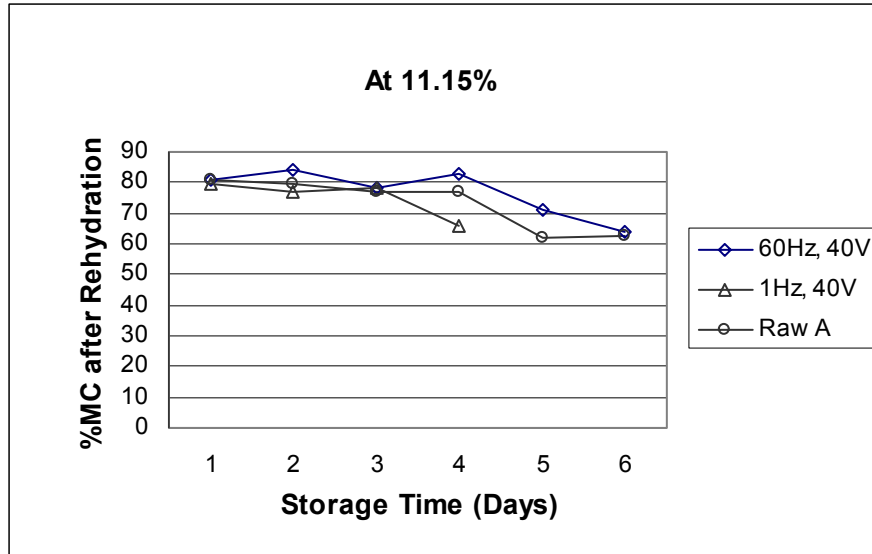


Fig. 7: Effect of treatments on %moisture content values after rehydration at 11.15% R.H.

4.2.2. Influence of Relative Humidity

- **Effect on ohmic treated samples**

The relative humidity environments had a significant influence on the ohmically treated samples. For the 60Hz, 60V treated samples on third day 19 samples stored in 75.32% R.H and 2 samples in 57.70% environments had mold growth. On the fourth day four samples in 57.70% RH were spoiled. The mold growth was not found during other days and never in lower humidity environments (11.15% and 32.73%). This is because during ohmic heating the moisture present in the sweet potatoes might have traveled to the surface of the cubes and resulted in mold growth. The ohmic heating calculations showed that 60Hz, 60V treated samples had less weight loss after ohmic heating than 60Hz, 40V samples. But, past research indicated that with increase in electrical field strength there will be increase in moisture loss in the samples (Lima & Sastry 1999). Therefore, the moisture on surface instead of evaporating was still on the surface and resulted in spoilage. Studies also showed that ohmic heating causes more mobile

moisture, increases ionic mobility, which in turn increases electrical conductivity and ohmic heating (Wang and Sastry 1997). This moistness on the surface of samples was not observed during storage in lower humidity environments.

Past research (Lu et al. 1989) has shown that SP spoils easily at high moisture contents (greater than 70% R.H.) and results in decreasing starch content. This in turn induces more starch degrading enzymes, which results in formation of more metabolic water.

Table 11: Number of samples that had mold growth for 1Hz, 40V during storage

%R.H.	Days					
	1	2	3	4	5	6
11.15%	0	11	1	0	0	0
32.73%	0	2	4	0	0	0
57.70%	0	9	2	1	0	0
75.32%	0	7	5	0	0	0

In the case of 1Hz, 40V treated samples both lower and higher relative humidity environments had significant effect on the storage of samples (Table 11). Because of this the samples were not available for analysis during all the other days. However there was no spoilage in case of 60Hz, 40V treated samples.

- **Effect on Control Samples**

Raw samples A, B, C were considered as controls during treatments of 1Hz, 40V; 60Hz, 60V and 60Hz, 40V respectively. There was no significant difference in mean %moisture content values of these samples when stored in four different relative humidity conditions before and after rehydration (Table 12).

H0: $\mu_{11.15\%} = \mu_{32.73\%} = \mu_{57.70\%} = \mu_{75.32\%}$

Ha: H0 is false

Table 12: Probability values indicating the influence of %RH on %moisture content before rehydration

Treatments	Days					
%R.H.	1	2	3	4	5	6
Raw A	0.2746 ^a	0.7262 ^a	0.034^b	0.2542 ^a	0.062 ^a	0.0488 ^a
Raw B	0.5442 ^a	0.0419 ^a	0.0891 ^a	0.0191^b	0.3237 ^a	0.0488 ^a
Raw C	0.2571 ^a	0.0408 ^a	0.0013^c	0.6058 ^a	0.1642 ^a	0.0013^c

The p-values of the R.H.'s with the superscript "a" are not significantly different at $\alpha = 0.05$; other superscripts with same alphabets irrespective of row or column had same differences

There were occasional differences in %moisture content values were observed on specific days and at R.H. For example, in control Raw C during day 3 and day 6 there was difference from lower humidity's 11.15% and 32.73% with higher humidity's 57.70% and 75.32% (Table 12). These differences were not observed after the samples were rehydrated implying all the samples responded in the same way to the changing relative humidity and had similar physical properties for rehydration (Table 13).

Table 13: Probability values indicating the influence of %R.H on %moisture content after rehydration

Treatments	Days					
%R.H.	1	2	3	4	5	6
Raw A	0.6072 ^a	0.9114 ^a	0.814 ^a	0.3088 ^a	0.0042^b	0.1064 ^a
Raw B	0.8154 ^a	0.3515 ^a	0.5815 ^a	0.8215 ^a	0.7089 ^a	0.1064 ^a
Raw C	0.336 ^a	0.7241 ^a	0.1897 ^a	0.6398 ^a	0.3113 ^a	0.1039 ^a

The p-values of treatments of R.H.'s with the superscript "a" are not significantly different at $\alpha = 0.05$; other superscripts with same alphabets irrespective of row or column had same differences

- **Effect on %Moisture Content Values**

For all the treatments there was no significant difference in the %moisture content values of the samples for the first three days of storage in all relative humidities (Table 14).

Table 14: Mean values (S.D) of %moisture content before rehydration for 60Hz, 40V treatment

%R.H.	Days					
	1	2	3	4	5	6
60Hz, 40V						
11.15%	74.88 ^a (0.00)	77.51 ^a (2.48)	72.17 ^a (1.27)	72.25^{ab} (1.75)	50.54^{ab} (5.03)	23.45^b (1.04)
32.73%	74.17 ^a (4.56)	75.52 ^a (0.63)	72.18 ^a (2.21)	74.08 ^a (0.04)	61.71^{abc} (0.04)	54.8 ^a (6.7)
57.70%	75.42 ^a (7.35)	74.24 ^a (5.08)	74.76 ^a (4.24)	75.78 ^a (1.78)	77.51^{ac} (3.39)	67.45 ^a (3.28)
75.32%	73.61 ^a (0.47)	79.01 ^a (0.5)	75.81 ^a (3.08)	79.17^{ac} (1.08)	73.54^{abcd} (1.03)	64.27 ^a (2.56)

With in the column the mean values of treatments with the same or common superscript are not significantly different at $\alpha = 0.05$

In the case of 60Hz, 40V during the fourth, fifth and sixth days the %moisture values for samples stored in 11.15% were different from 57.70% and 75.32% and these differences persisted even after rehydration (Table 15). But differences were not observed for 60Hz, 60V and 1Hz, 40V treatments, as there were no samples left for the analysis.

The null hypothesis states that samples in all four relative humidities had same mean %moisture content values and an alternate hypothesis stating that null is false. So, the hypothesis below compares %moisture content mean values of four relative humidities.

H0: $\mu_{11.15\%} = \mu_{32.73\%} = \mu_{57.70\%} = \mu_{75.32\%}$

Ha: H0 is false

Table 15: Probability values indicating the influence of %R.H on %moisture content before rehydration

Treatments	Days					
	1	2	3	4	5	6
60Hz, 40V	0.9746 ^a	0.4487 ^a	0.5533 ^a	0.0278^b	0.0031^c	0.0012^d
60Hz, 60V	0.5208 ^a	0.4288 ^a	0.6323 ^a	0.333 ^a	0.4844 ^a	0.02
1Hz, 40V	0.9914 ^a	0.1074 ^a	0.066 ^a	0.0004^e	0.3415 ^a	.

The p-values of treatments with the superscript “a” are not significantly different between R.H’s at $\alpha = 0.05$; other superscripts with same alphabets irrespective of row or column had same differences

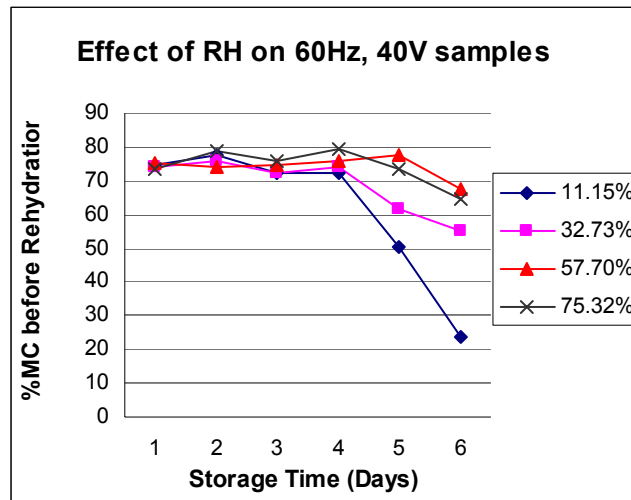


Fig. 8: Variation of %moisture content for 60Hz, 40V treatment

Fig. 8 shows that %MC values were greater when samples are stored at higher humidities than at lower humidities because of the greater absorption of moisture from the environment.

H0: $\mu_{11.15\%} = \mu_{32.73\%} = \mu_{57.70\%} = \mu_{75.32\%}$

Ha: H0 is false

Table 16: Probability values indicating the influence of % R.H on %moisture content after rehydration

%MC	Days					
	1	2	3	4	5	6
Treatments						
60Hz, 40V	0.7117 ^a	0.6318 ^a	0.5472 ^a	0.1132 ^a	0.0241^c	0.0068^d
60Hz, 60V	0.8528 ^a	0.0377 ^a	0.2715 ^a	0.9061 ^a	0.3352 ^a	0.7801 ^a
1Hz, 40V	0.2431 ^a	0.1293 ^a	0.8742 ^a	0.0026^e	0.5255 ^a	.

The p-values of the treatments with the superscript “a” are not significantly different at $\alpha = 0.05$ between %R.H’s; other superscripts with same alphabets irrespective of row or column had same differences

Table 16 shows that there was no significant difference in mean %moisture content values after rehydration of treatments when stored in different relative humidity environment.

4.2.3. Moisture Gain

- **Influence of Treatment**

The amount of moisture gain with rehydration was studied. As expected there was an increase in %moisture content after rehydration for all the ohmic treated samples and control samples.

The %moisture gain varied between minimum 0.1% to maximum of 40.7% incase of ohmic treated samples and 0.71% on first day to 32.41% for control samples. Both the minimum and maximum values for the treated samples were observed in case of 60Hz, 40V. It was found that ohmically treated samples had greater %moisture gain compared to control samples at the end of six-day period (Fig. 9).

Of all the treated samples 60Hz, 40V samples exhibited the biggest %moisture gain in the six days period. The %moisture gain was more clearly seen at $\alpha = 0.05$ during third, fourth and fifth days for 60Hz, 40V treatment in 11.15% R.H (Fig. 10).

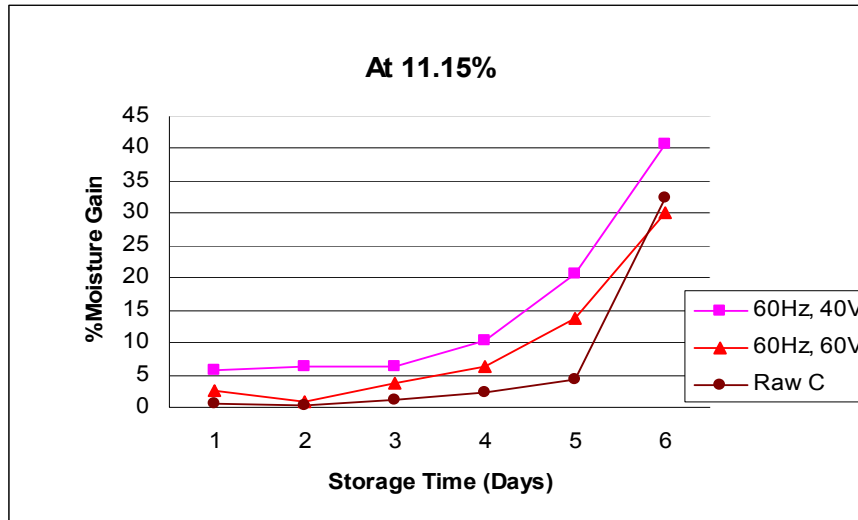


Fig. 9: % Moisture gain after rehydration for treatments at 11.15% R.H

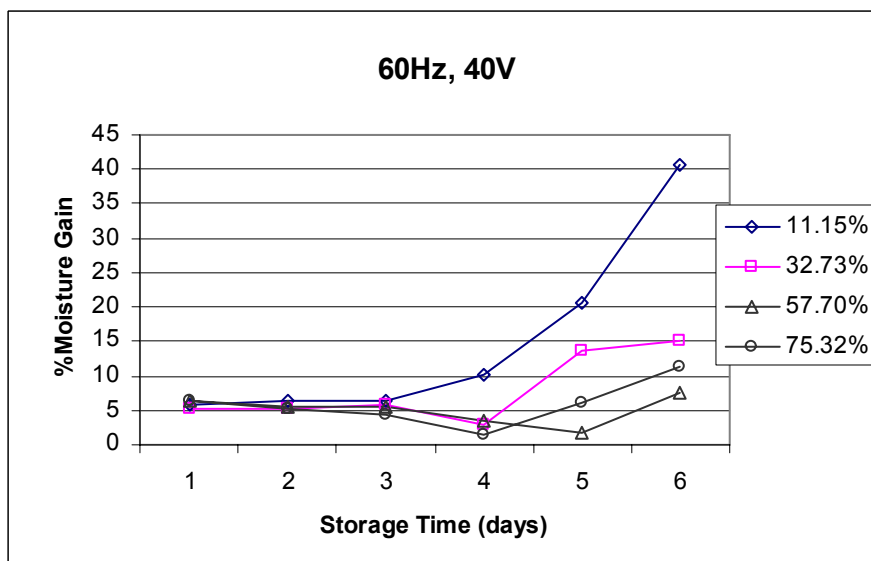


Fig. 10: %Moisture gain after rehydration for 60Hz, 40V for all R.H

- **Influence of %RH**

The graphical representation of %moisture gain with storage time shows that all treatments including control samples stored in 11.15% relative humidity had a consistent increase with increase in storage time (Fig. 11).

The %moisture gain values of control samples and 60Hz, 40V treated samples stored in 32.73%, 57.70% and 75.32% relative humidity were very close to one another.

When Student's t-test ($p \leq 0.05$) was performed the results showed that there was no significant gain in %moisture content after rehydration for all the treatments at all R.H conditions (Table 17).

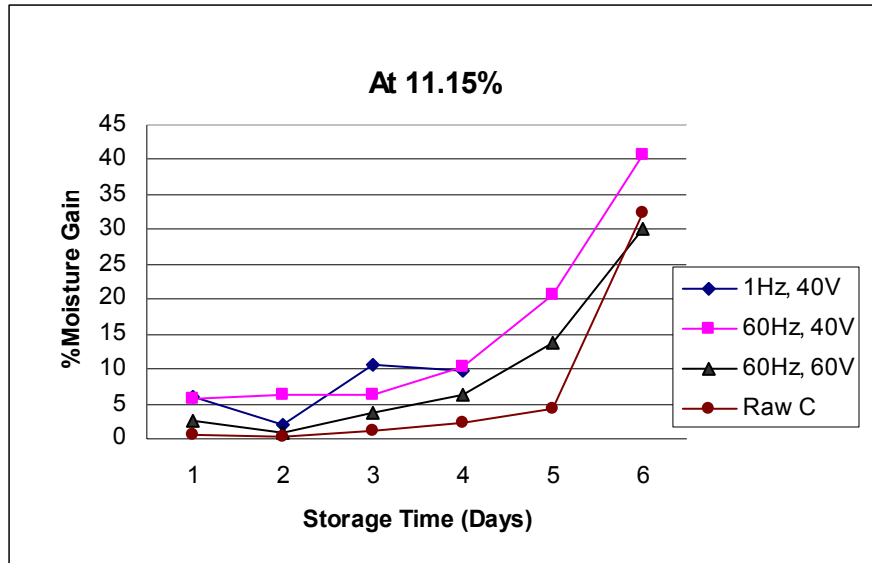


Fig. 11: %Moisture gain for treatments at 11.32%

Table 17: The p-values of the student's t-test results for 60Hz, 40V treatment

%R.H.	Days					
	1	2	3	4	5	6
60Hz, 40V						
11.15%	0.1498 ^a	0.1177 ^a	0.2839 ^a	0.1111 ^a	0.0880 ^a	0.0234^b
32.73%	0.1265 ^a	0.0424^b	0.2798 ^a	0.1043 ^a	0.0535 ^a	0.1472 ^a
57.70%	0.5050 ^a	0.3629 ^a	0.3271 ^a	0.1537 ^a	0.1048 ^a	0.0796 ^a
75.32%	0.0181 ^a	0.5023 ^a	0.1693 ^a	0.0514 ^a	0.0700 ^a	0.1714 ^a

The p-values with same superscript have no significant difference in %moisture content before and after rehydration

The null hypothesis for the Table 17 states that the mean %moisture content values before rehydration is same as the value obtained after rehydration.

H₀: $\mu_{\text{Moisture BR}} = \mu_{\text{Moisture AR}}$

H_a: H₀ is false

BR = Before rehydration AR = After rehydration

For the control samples (Raw B) a significant difference in %moisture gain was observed during the fifth day (for 11.15% and 32.73%) and sixth day (for 57.70% and 75.32%). But such differences were not observed for the other two raw control samples.

4.2.4. Rehydration Properties

The change in weight of the samples during rehydration is due to absorption of water and leaching of solutes from the samples. The weight calculations do not give information about these therefore Lewicki (1998) proposed a new method to measure the rehydration capacity. Water absorption capacity (WAC), dry matter holding capacity (DHC) and rehydration ability (RA) were calculated using this model.

Fig. 12 shows the WAC, DHC and RA graphs obtained for treated and control samples. The graphs show that the rehydration indices sometimes had values greater than 1 and less than 0. This is not possible since the all the indices lie in the range of 0 and 1. Past research (Lewicki 1998) shows that to get high precision for the values of rehydration indices, a precise measurement of moisture and dry matter content is necessary. The moisture content for this research was calculated by the oven method. The appropriate procedure to measure the moisture and dry matter content for indices calculations was not given in the research paper.

As the previous technique of measuring the rehydration indices failed in obtaining proper results a different procedure for measuring rehydration properties was used which was suggested by Utilization Research of the U. S. Department of Agriculture (Loesecke 1955). Rehydration ratio parameter was determined by this procedure (Appendix B (c)).

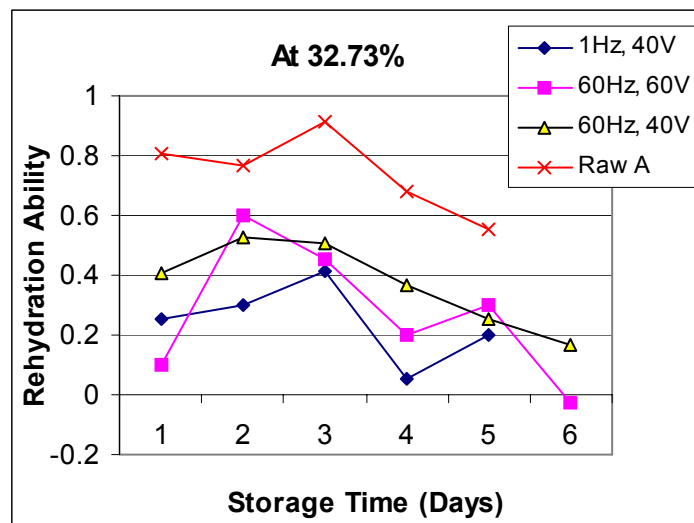
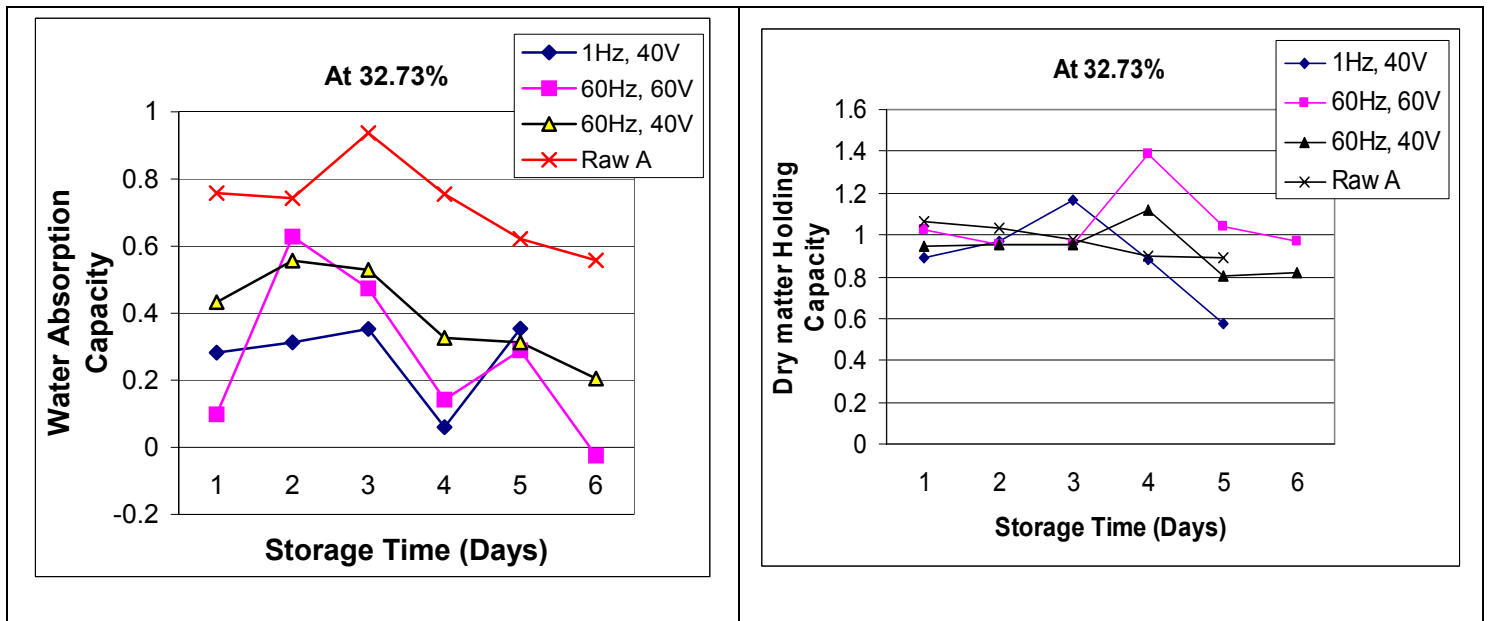


Fig. 12: Water absorption capacity, Dry matter holding capacity and Rehydration ability of sweet potato cubes

- **Rehydration Ratio**

Tukey's test was conducted to determine significant difference in mean values of rehydration ratio (RR) among treatments. The ohmic treatments and relative humidities had no significant effect on the mean rehydration ratio values of the samples.

Table 18: Mean Values (S.D) of rehydration ratio at 32.73%R.H

32.73%	Days					
Treatments	1	2	3	4	5	6
1Hz, 40V	1.14 ^a (0.18)	1.10 ^a (0.03)	1.18 ^a (0.00)	1.16 ^a (0.04)	1.18 ^a (0.05)	.
60Hz, 40V	1.19 ^a (0.07)	1.16 ^a (0.05)	1.26 ^a (0.03)	1.16 ^a (0.01)	1.23 ^a (0.06)	1.39 ^a (0.03)
60Hz, 60V	1.06 ^a (0.00)	1.07 ^a (0.01)	1.15 ^a (0.06)	1.10 ^a (0.04)	1.23 ^a (0.06)	1.27 ^a (0.07)
Raw A	1.15 ^a (0.01)	1.14 ^a (0.04)	1.12 ^a (0.02)	1.21 ^a (0.01)	1.30 ^a (0.13)	1.38 ^a (0.01)
Raw B	1.11 ^a (0.33)	1.13 ^a (0.01)	1.15 ^a (0.06)	1.45^b (0.11)	1.51 ^a (0.00)	1.56 ^a (0.16)
Raw C	1.14 ^a (0.02)	1.12 ^a (0.03)	1.16 ^a (0.01)	1.13 ^a (0.005)	1.23 ^a (0.04)	1.23 ^a (0.04)

Within a column mean values of the treatments with same superscript are not significantly different.

The graphical representation (Fig. 13) showed that the RR values increased with increase in storage time for the ohmic treated and control samples. Moreover the 60Hz, 40V ohmic treated samples always had higher rehydration values than the control and other treated samples. This shows that ohmic heating can result in better rehydration products. The mean values of RR are shown in the Appendix D.

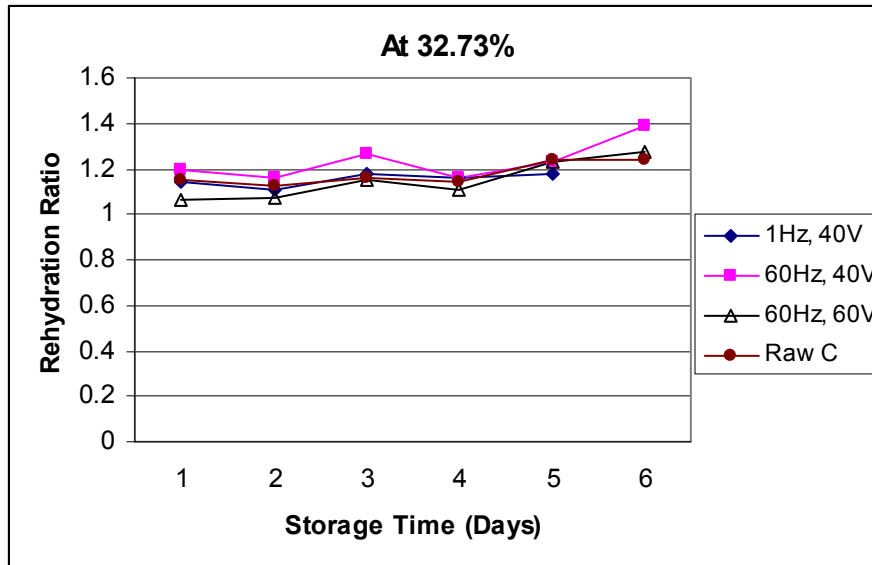


Fig. 13: Effect of treatments on rehydration ratio at 32.73%

- **Summary of Moisture Studies**

The analysis of moisture studies showed that ohmic treatment did not result in statistically different rehydration properties (also moisture content values or moisture gain) than the control samples at $p \leq 0.05$ though the graphical representation showed that the 60Hz, 40V treated samples had better %moisture content values after rehydration and also had better rehydration ratio values than the control samples and other ohmic heated treatments. More research should be done on the rehydration properties of ohmic treated samples with more replications to get substantial results.

4.3. Color Studies

For color calculations the three ohmic treated samples and two control samples were considered. There was an experimental error while conducting the color measurements for the raw samples for Raw C. Therefore this control is not considered in color studies. As all the experiments were not conducted on a single day i.e., sweet

potatoes were bought thrice for the experiments on three different days. Therefore one-way ANOVA and Tukey's test was performed on L^* , a^* , b^* , chroma and hue angle values of all raw samples that were used for the experiments to determine if there are any initial differences in color parameters of the different fresh samples used. It was observed there were significant differences in all the color parameters, which may contribute in predicting incorrect results. To avoid this, results were expressed in terms of difference in CIE color parameters with respect to fresh samples i.e.

$$DL1 = L^*_{\text{Fresh}} - L^*_{\text{BR}} \text{ (BR} \rightarrow \text{ before rehydration)}$$

$$DL2 = L^*_{\text{Fresh}} - L^*_{\text{AR}} \text{ (AR} \rightarrow \text{ after rehydration)}$$

$DL = DL1 - DL2$. This gives the color change in samples after rehydration. Similarly, $Da1$, $Da2$, Da , $Db1$, $Db2$, Db , $Dc1$, $Dc2$, Dc , $Dh1$, $Dh2$ and Dh are defined.

Results

4.3.1. Influence of Treatments

$$H_0: \mu_{60\text{Hz}, 40\text{V}} = \mu_{60\text{Hz}, 60\text{V}} = \mu_{1\text{Hz}, 40\text{V}} = \mu_{\text{Controls (Raw A; Raw B)}}$$

H_a : H_0 is false

- **Effect on “ L^* ” value**

Statistical Analysis showed that there were significant differences in $DL1$ values of 60Hz, 40V with 1Hz, 40V and 60Hz, 40V at lower humidity levels during storage. These differences were also observed after rehydration of the samples (Table 19). In most of the days the 60Hz, 40V lightness values were different from the control sample values. The differences in mean lightness values seen among controls before rehydration were absent after rehydration.

The null hypothesis states that all the ohmic treated and control samples had same mean D(L2) values and an alternate hypothesis stating that null is false.

$$H_0: \mu_{60\text{Hz}, 40\text{V}} = \mu_{60\text{Hz}, 60\text{V}} = \mu_{1\text{Hz}, 40\text{V}} = \mu_{\text{Controls (Raw A; Raw B)}}$$

Ha: H0 is false

Table 19: Probability values indicating the influence of treatments on lightness values after rehydration

%R.H.	Days					
DL2	1	2	3	4	5	6
11.15%	0.0001 ^{ab}	0.0005 ^{ab}	0.0006 ^{ab}	0.0025 ^{bc}	0.0001 ^b	0.0034
32.73%	0.0007 ^{ab}	0.0023 ^{ab}	0.0644	0.0001 ^{ab}	0.0001 ^{ab}	0.0003 ^b
57.70%	0.0001 ^{ab}	0.0001 ^{ab}	0.0001 ^{ac}	0.8279	0.0008 ^b	0.0457
75.32%	0.0001 ^{ab}	0.0053	0.1566	0.0387	0.0039	0.0002

The p-value of treatments with same or common superscripts “a” implies significant difference between 60Hz, 40V with 1Hz, 40V; “b” between 60Hz, 40V with 60Hz, 60V; “c” between 1Hz, 40V and 60Hz, 60V at $\alpha = 0.05$.

The graphical representation (Fig. 14) of the difference in lightness values of fresh and stored samples clearly shows that ohmic treated samples were darker than the fresh samples during storage at all humidity environments. This could be due to changes in surface moisture on the samples during storage.

In Fig. 15 it's clearly seen that the lightness values of the 60Hz, 40V treated samples on the fourth and sixth days had almost same values as the fresh samples. The differences in lightness values were clearly seen between 60Hz, 40V treated samples and control samples. Moreover though there is decrease in lightness values in treated samples

visual observation showed that the pretreated samples had not become black after storage and rehydration.

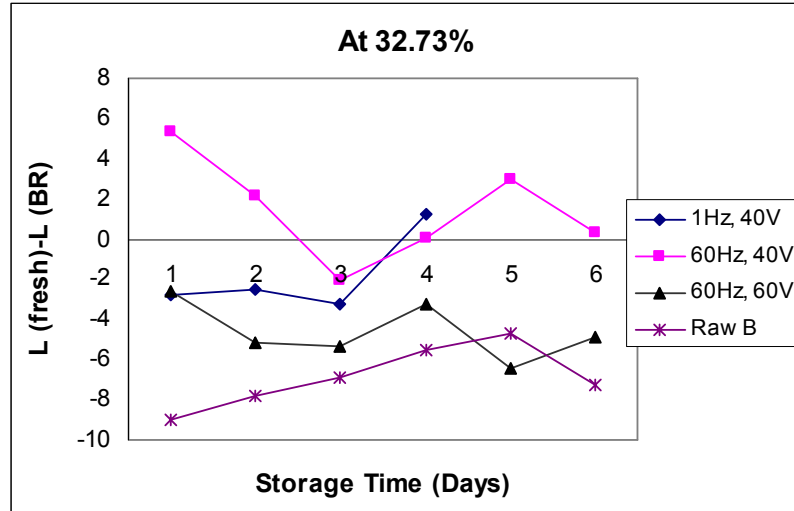


Fig. 14: Effect of heating treatments on lightness values at 32.73% R.H. before rehydration

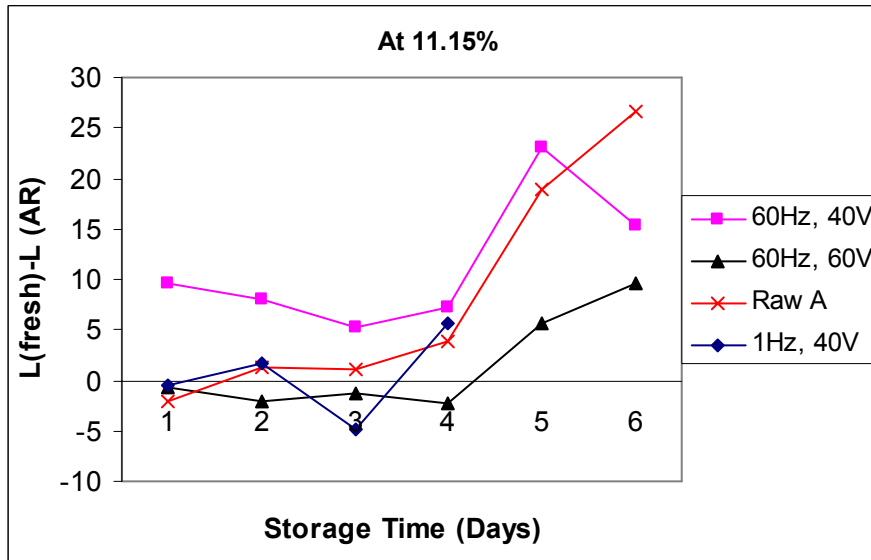


Fig. 15 Effect of treatments on lightness values after rehydration at 11.15%

Chen et al. (2001) and Lee et al. (2003) found an increase in L* values with increase in storage for bananas and orange juice respectively. They explained the reason being the ripening of bananas and lightening of orange juice during storage. In the case of

sweet potatoes, Ameny et al. (1997) found a decrease in L* values with blanching, lye peeling and cooking because of changes in carotenoids, caramelisation, oxidation, or phenol action. In the present research the sweet potatoes samples are not heated to higher temperatures and long time boiling and visual observations did not show any starch degradation. Therefore the decrease in lightness values may be due to changes in carotenoids.

After rehydration 60Hz, 60V treated samples resulted in retaining lightness values as fresh samples better than the 60Hz, 40V treated samples.

- **Effect on “a*” value**

The 60Hz, 40V treatment resulted in significantly different Da1 values than the 1Hz, 40V for samples stored in the 11.15% and 32.73% humidity levels till the fourth day. After rehydration these differences were restricted only till second day and were found in 57.70% also (Table 20). Always the ohmic treated samples had significantly different Da1 and Da2 values from control samples.

Table 20: Probability values indicating the influence of treatments on redness values after rehydration

%R.H.	Days					
	1	2	3	4	5	6
Da2						
11.15%	0.0002 ^{ab}	0.0003 ^{ab}	0.0001 ^{ac}	0.0443	0.003 ^b	0.0082
32.73%	0.0024 ^a	0.0026 ^a	0.0057	0.0001	0.0001 ^{ab}	0.0001 ^b
57.7%	0.0012 ^{ac}	0.0001 ^{ab}	0.0001 ^{bc}	0.0001 ^a	0.0001	0.0001
75.32%	0.0001 ^{abc}	0.0001 ^c	0.0068	0.0034	0.0001	0.0006

The p-value of treatments with the same or common superscript “a” implies significant difference between 60Hz, 40V with 1Hz, 40V; “b” between 60Hz, 40V with 60Hz, 60V; “c” between 1Hz, 40V and 60Hz, 60V at $\alpha = 0.05$.

The graphical representation (Fig. 16) shows that the 60Hz, 40V treated samples were more orange in color compared to control samples. In the case of 11.15% and 32.73% R.H. these differences became less with an increase in storage time whereas at higher humidities the difference persisted (Fig. 17). These differences were less observed after the samples were rehydrated (Table 20).

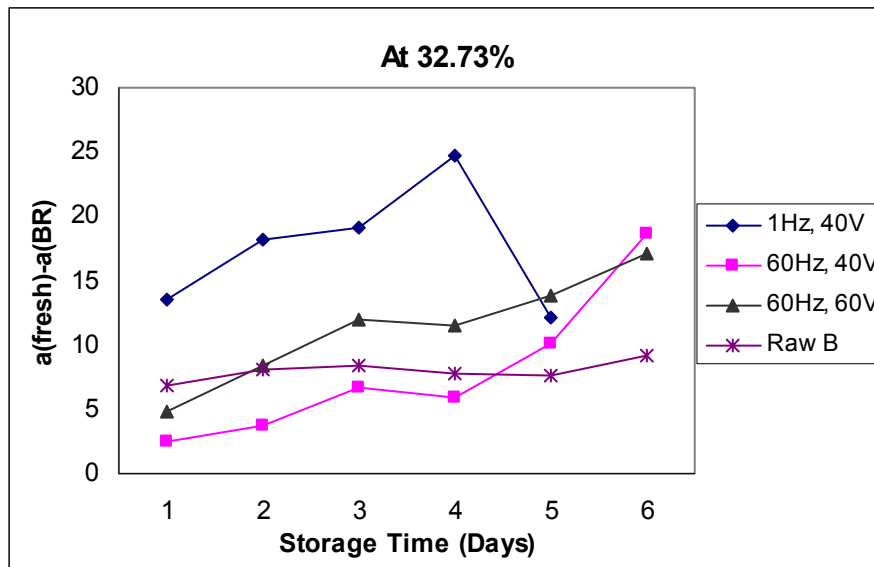


Fig. 16: Effect of heating treatments on orange color of SP cubes at 32.73% R.H. before rehydration

For 60Hz, 60V treated samples before rehydration had the same “Da” values as the control samples at 11.15% R.H and higher orange values at other humidity conditions.

In general the “a*” (red/orange) values decreased with increase in storage time for both the treated and control samples at all humidities. The 60Hz, 40V treated samples had higher a* (red/orange) values than the 1Hz, 40V, 60Hz, 60V and control samples before rehydration. After rehydration the 60Hz, 60V treatment resulted in higher “a*” (red/orange) values when compared to other ohmic treated treatments (Fig. 17). This

could be due to loss of carotenoids during rehydration from the samples treated by 60Hz, 40V. The higher a values of 60Hz, 60V could be due to that treated samples having more carotenoids (Ameny et al. 1997). Ahmed and Scott (1962) also showed a high degree of correlation between “a*” values and carotenoids content of raw roots and processed samples from a series of breeding lines of sweet potatoes.

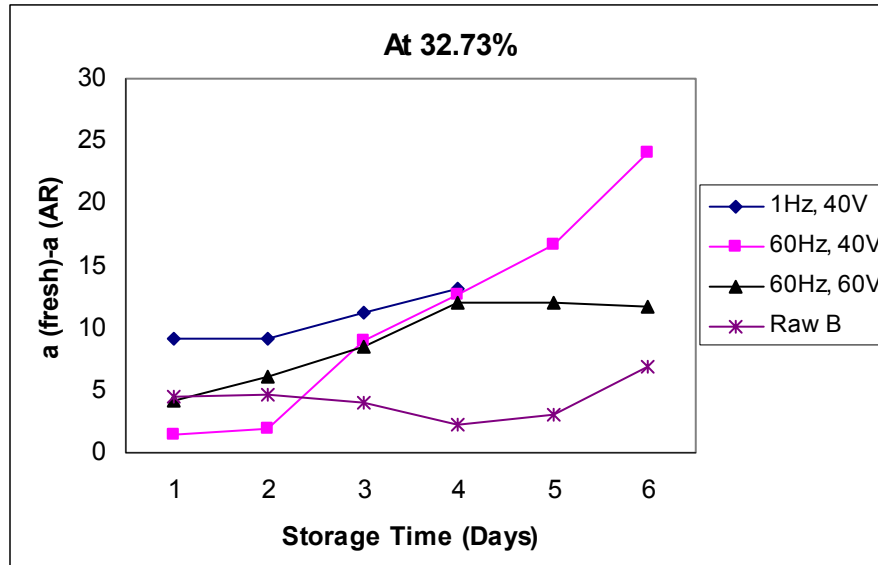


Fig. 17: Effect of heating treatments on the orange color of SP cubes at 32. 73 % R.H. after rehydration

Though the ohmically treated samples had higher orange values than the controls during storage or before rehydration, the values were always less than control samples orange values after rehydration. This may be due to loss of carotenoids from the ohmic treated samples into the rehydrating water. During the experiments visual observations of rehydrated water showed that the color of water had yellowish orange color after the samples were removed. This could be due to diffusion of carotenoids or leaching of solutes from the sweet potato cubes into water. This diffusion was also observed by Halden et al (1990) for ohmic heating of beet root in which there was an increase in beet dye diffusion during ohmic heating.

- **Effect on “b*” value**

Before rehydration, differences among 60Hz, 40V with 1Hz, 40V and 60Hz, 60V were found in the first two days of storage for all the relative humidity’s and consistently there was difference between 60Hz, 40V and 60Hz, 60V through out six days in 32.73% R.H. But the differences were less consistent after rehydration (Table 21).

Table 21: Probability values indicating the influence of treatments on yellowness after rehydration

%R.H.	Days					
	1	2	3	4	5	6
Db2						
11.15%	0.001 ^{ab}	0.0001 ^{ab}	0.0001 ^{ab}	0.003 ^c	0.0001 ^b	0.0074
32.73%	0.0003 ^{ab}	0.0001 ^{ab}	0.1115	0.0001	0.0001	0.0001 ^b
57.70%	0.0001 ^{ab}	0.0001 ^{ab}	0.0001 ^b	0.0001 ^{ac}	0.0001 ^b	0.0001
75.32%	0.0001 ^{ab}	0.0008 ^c	0.057	0.0019 ^a	0.0001	0.0028

The p-value of treatments with same or common superscripts “a” implies significant difference between 60Hz, 40V with 1Hz, 40V; “b” between 60Hz, 40V with 60Hz, 60V; “c” between 1Hz, 40V and 60Hz, 60V.

There was a decrease in “b*” values for all the treatments and controls, which shows that the color shifted slightly from yellow toward blue, probably due to isomerisation of carotenoids (Ameny et al. 1997). The graphical representation showed that the 60Hz, 40V treatment retained more degree of yellowness in the SP cubes than the other treated samples and control samples before rehydration. This is seen in 11.15%, 32.73% and 57.70% R.H. The 60Hz, 60V treated samples showed better color retention at higher humidity (75.32%) environment during storage.

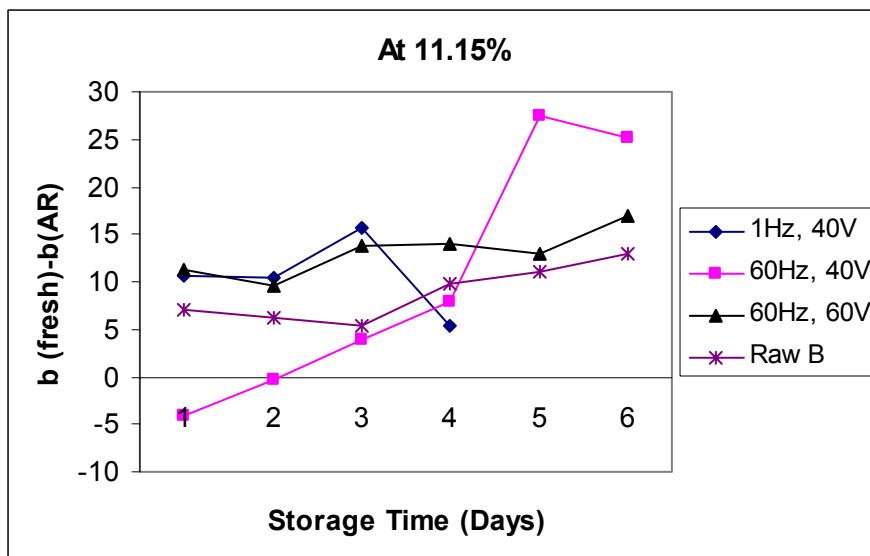


Fig. 18: Effect of heating treatments on the degree of yellowness of SP cubes after rehydration

The 60Hz, 40V treated samples had higher “b*” or yellowness values after rehydration than the other ohmic treated samples (Fig. 18). When compared with control samples they had almost close yellowness values at all humidities. During the first three days of storage the 60Hz, 40V treated samples after rehydration resulted in yellowness values similar or better than the fresh samples in all R.H. Therefore ohmic heating at 60Hz, 40V did result in better “b*” values after rehydration until the third day three days of storage in certain cases.

- **Effect on “Chroma” value**

Significant difference among treatments i.e., 60Hz, 40V with 1 Hz, 40V and 60Hz, 40V with 60Hz, 60V were observed before and after rehydration for the first 2 days of storage for samples stored in all relative humidities. The differences between the controls observed before rehydration were less after rehydration (Table 22). This could be due to the differences that were observed in “a*” and “b*” values as the chroma value is determined from “a*” and “b*” values.

Table 22: Probability values indicating the influence of treatments on chroma values after rehydration

%R.H.	Days					
	1	2	3	4	5	6
Dc2						
11.15%	0.0001 ^{ab}	0.1302	0.0001 ^{ab}	0.0088 ^b	0.0001 ^b	0.0041 ^b
32.73%	0.001 ^{ab}	0.0005 ^{ab}	0.0288	0.0001	0.0001 ^{ac}	0.0002 ^b
57.7%	0.001 ^{ab}	0.0001 ^{ab}	0.0001 ^c	0.0001 ^{ac}	0.0005	0.0011
75.32%	0.0001 ^{ab}	0.0008 ^{ac}	0.057	0.0019 ^a	0.0001	0.0028

The p-value of treatments with same or common superscripts “a” implies significant difference between 60Hz, 40V with 1Hz, 40V; “b” between 60Hz, 40V with 60Hz, 60V; “c” between 1Hz, 40V and 60Hz, 60V at $\alpha = 0.05$.

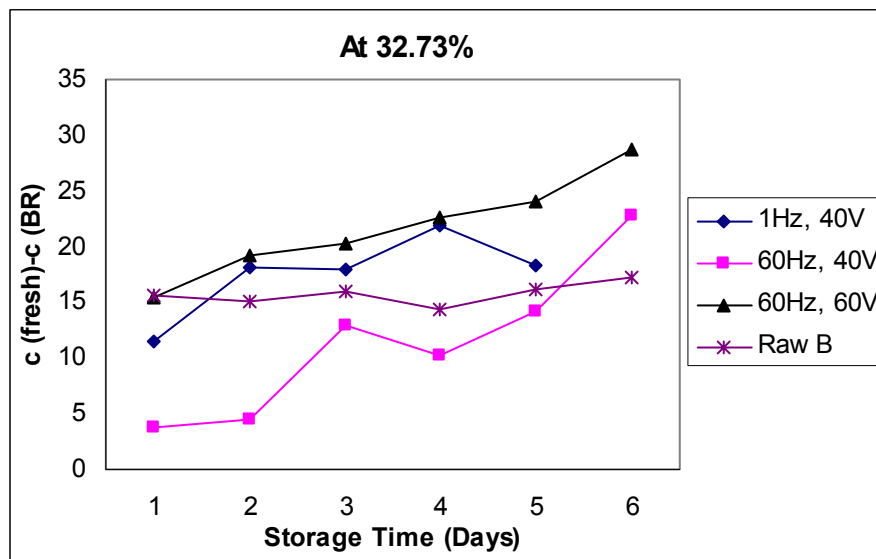


Fig. 19: Effect of heating treatments on the chroma values of SP cubes at 32.73% R.H

The graphical representation (Fig. 19) shows that the chroma values, which represents color intensity for the treatments and also control samples decreased constantly with increase in storage time. The 60Hz, 40V treated samples had less decrease in brightness compared to control and treated samples.

The ohmic 60Hz, 40V treated samples retained more chroma intensity when compared to other ohmic treated or control samples before rehydration. But after rehydration the control samples had better chroma values than the ohmic treated samples.

- **Effect on “Hue Angle” value**

Significant differences were observed between 60Hz, 40V with 1Hz, 40V and 60Hz, 60V before and after rehydration but not consistently (Table 23 & 24). The treatment effects on hue angle were very few when compared to their effect on other CIE values.

Table 23: Probability values indicating the influence of treatments on hue angle before rehydration

%R.H.	Days					
	1	2	3	4	5	6
Dh1						
11.15%	0.0001 ^{ab}	0.0001 ^{ab}	0.0002 ^{ab}	0.0001 ^{ab}	0.0001 ^b	0.6636
32.73%	0.009 ^{bc}	0.0001 ^{ab}	0.0001 ^b	0.0966	0.0001 ^{bc}	0.6255
57.7%	0.0001 ^b	0.0001 ^{ab}	0.0005	0.00003 ^c	0.0402	0.0036
75.32%	0.0001 ^{bc}	0.2241	0.0001	0.0001 ^a	0.0001	0.1402

The p-value of the treatments with same or common superscript “a” implies significant difference between 60Hz, 40V with 1Hz, 40V; “b” between 60Hz, 40V with 60Hz, 60V; “c” between 1Hz, 40V and 60Hz, 60V at $\alpha = 0.05$.

For the 60Hz, 40V treated samples there was an increase in hue angles after storage and rehydration when compared with fresh samples which shows that the treated samples are more orange- red than the fresh cut samples and the control the samples.

Fig. 20 shows that the value of hue angles of 60Hz, 40V treated samples are better than the fresh samples (since close to X-axis, zero) during all days. This was observed at

all relative humidities. There was a decrease in hue angle for 60Hz, 60V; 1Hz, 40V and control samples. This shows that these treatments had a more orange-red color than the fresh samples.

Table 24: Probability values indicating the influence of treatments on hue angle after rehydration

%R.H.	Days					
	1	2	3	4	5	6
11.15%	0.0001 ^{abc}	0.0263	0.0002 ^{ab}	0.0004 ^b	0.0001	0.0714
32.73%	0.0001 ^{bc}	0.0001 ^{ab}	0.0001 ^{bc}	0.0007 ^{bc}	0.3975	0.0002
57.7%	0.0001 ^{bc}	0.0013 ^{ab}	0.009	0.0002 ^{bc}	0.0282	0.7119
75.32%	0.0001 ^{abc}	0.0001 ^{ab}	0.0138	0.0001 ^a	0.0001	0.0402

The p-value of treatments with same or common superscripts “a” implies significant difference between 60Hz, 40V with 1Hz, 40V; “b” between 60Hz, 40V with 60Hz, 60V; “c” between 60Hz, 40V and 60Hz, 60V at $\alpha = 0.05$.

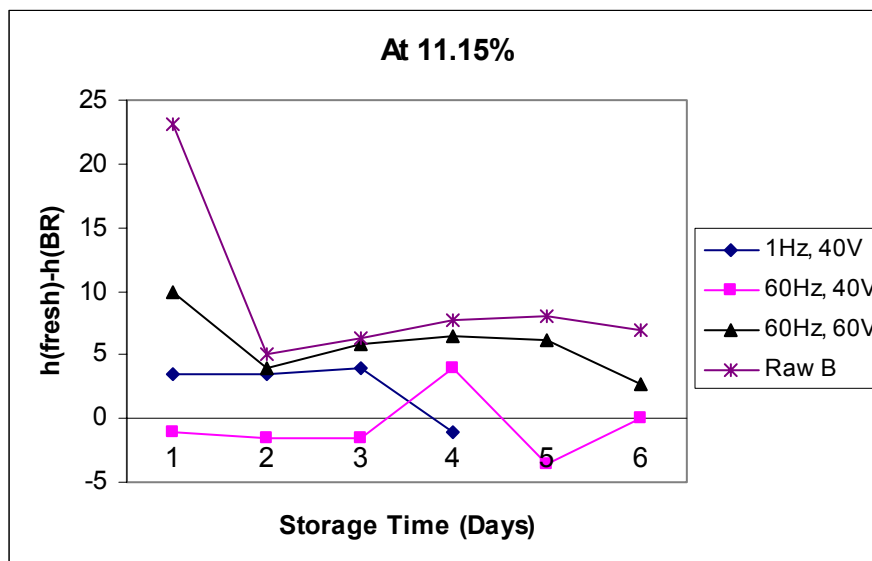


Fig. 20: Effect of heating treatments on hue angle at 11.15% R.H.

Rehydration also resulted in better hue angles than the fresh. This shows that ohmic heating at 60Hz, 40V can result in orange-red color similar to fresh samples and better color for when using other ohmic treatments.

4.3.2. Influence of Relative Humidities

- **Effect on Control Samples**

There were no significant effects of relative humidities on CIE color values for control samples. Fig. shows at fifth and sixth days the DL2 values stored at 11.15% were significantly different from DL2 values of samples stored in other salts the mean DL2 values (after rehydration).

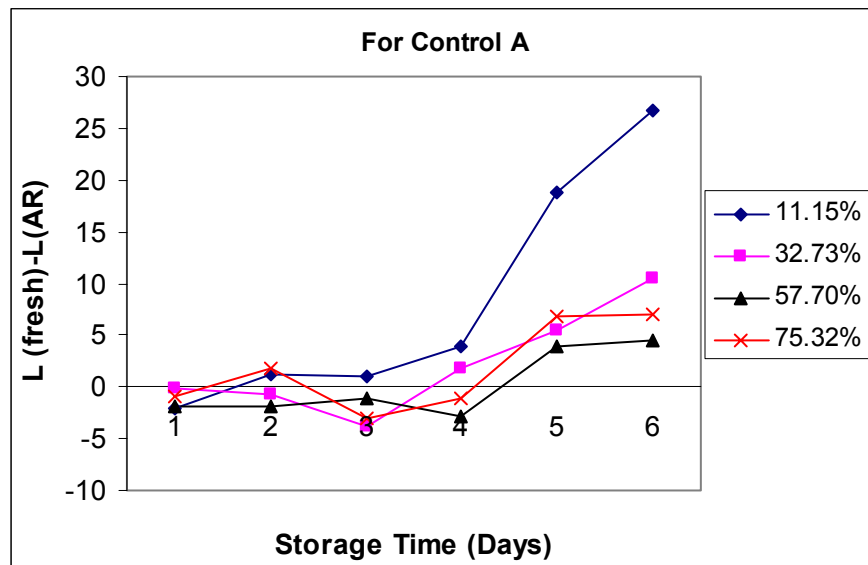


Fig. 21: Effect of R.H. on lightness values after rehydration for Control A

- **Effect on 60Hz, 40V**

All the CIE color values had a significant effect depending on the relative humidity they were stored. The differences are more clearly seen after rehydration.

$$H_0: \mu_{11.15\%} = \mu_{32.73\%} = \mu_{57.70\%} = \mu_{75.32\%}$$

Ha: H0 is false

Table 25: Probability values indicating the influence of relative humidity on color values before rehydration

60Hz,40V	Days					
	1	2	3	4	5	6
DL1	0.2032	0.0002 ^A	0.0005 ^B	0.0002 ^C	0.0004	0.0141
Da1	0.860	0.0034	0.0020 ^B	0.0014 ^C	<0.0001 ^D	<0.0001 ^B
Db1	0.6234	<0.0001 ^A	<0.0001 ^B	0.0050 ^C	<0.0001 ^D	<0.0001 ^B
Dc1	0.0799	<0.0001 ^A	0.0373 ^B	0.0041 ^C	0.0006 ^D	0.0353

Table 26: Probability values indicating the influence of relative humidity on color values after rehydration

60Hz,40V	Days					
	1	2	3	4	5	6
DL2	0.2296	0.0087 ^A	0.0078	<0.0001 ^C	<0.0001 ^B	0.2160
Da2	0.0003	0.0024 ^A	0.0007 ^B	0.0009 ^B	<0.0001 ^B	<0.0001 ^B
Db2	0.0003	0.0002 ^A	0.0006 ^B	0.0020 ^C	<0.0001 ^D	0.0001 ^B
Dc2	0.0001	0.0003 ^A	0.0033 ^B	0.0061 ^B	<0.0001 ^D	<0.0001

The p-value of the treatments with same or common superscript A implies significant difference between 11.15%, 32.73%, 57.70% with 75.32%; B between 11.15% with 57.70% and 75.32%; C between 11.15% with 75.32% and 32.73% with 57.70% and 75.32%; D between 11.15% with 32.73%, 57.70% and 75.32%

The samples stored in 11.15% R.H. resulted in better CIE values after rehydration for the first four days but for the fifth and sixth days samples in 57.70%R.H. and 75.32% R.H. had better values. The hue angle (orange-red) values didn't have a significant effect due to R.H.

- **Effect on 60Hz, 60V**

There was no significant difference with the % of relative humidity they were stored for CIE color values. For samples stored at 57.70% relative humidity and 75.32% relative humidities b* and chroma values were found to be significantly different during the second and third days during storage. After rehydration there were no significant differences. Samples stored in 57.70% R.H. resulted in better CIE values after rehydration when compared with the samples stored in other R.H.

- **Effect on 1Hz, 40V**

The increase in %R.H. did not show significant influence on the CIE color values for the available samples. Graphical representations showed that the samples stored in 11.15% R.H. had better CIE color values when compared to other R.H.

4.3.3. Influence of Storage and Rehydration on CIE Values

Statistical Analysis (t- test) was conducted to see if rehydration of samples had any effect on CIE values of ohmically treated and control samples. The null hypothesis states that the mean values of CIE values before and after rehydration are same.

$$H_0: \mu_{DL1} - \mu_{DL2} = 0 \text{ or } \mu_{DL} = 0 \text{ or } \mu_{DL1} = \mu_{DL2}$$

Ha: H₀ is false

- **Influence of Treatment**

- **Effect on DL**

There was significant difference between mean DL values of 60Hz, 40V with 1Hz, 40V and 60Hz, 60V at 32.73% relative humidity. These differences were observed from the third day of storage to the sixth day. The difference between 60Hz, 40V with

60Hz, 60V was also observed increase of 57.70% relative humidity from first day to fifth day. But there was no consistent difference among treatments for the DL values before and after rehydration through out six days for the 11.15% and 75.32% R.H. There was not many differences in DL values between ohmic treated and control samples.

- **Effect on Da**

No significant difference in Da values was found among treatments at 11.15%R.H. Significant differences were found between 60Hz, 40V with 60Hz, 60V and 1Hz, 40V in 32.73% RH after third day till sixth day and for 57.70% RH from second day to fourth day.

- **Effect on Db**

Significant difference of Db values between 60Hz, 40V with 60Hz, 60V and 1Hz, 40V was observed in case of 32.73% RH after third day but no other differences among R.H. were observed throughout the six-day storage period.

- **Effect on Dc and Dh**

There were no significant differences in the influence of treatments on chroma values. The differences were seen on fourth and fifth days for 60Hz, 40V with other treatments but were not consistent.

In general the differences between CIE values before and after rehydration was mostly observed between 60Hz, 40V with other treated and control samples. This is because 60Hz, 40V treated samples CIE values had significant change in there values after rehydration. These differences were mainly observed during the last 3 days of storage.

- **Influence of RH**

- **Effect on Raw Samples**

There was no significant difference in influence of four relative humidities on the difference in CIE values before and after rehydration of raw samples.

- **Effect on Treatments**

There was no significant difference in influence of the four relative humidities on difference in CIE values before and after rehydration of three ohmic treated samples. A few differences, which were obtained during the fifth and sixth days, were explained before in the influence of treatments.

- **Summary of Color Studies**

Rehydration of ohmic treated and control samples resulted in improved CIE color values when compared with the values during storage or before rehydration. Of the ohmic treated samples 60Hz, 40V treated samples had significant change in color values after rehydration during the last three days of storage. But the CIE values of 60Hz, 40V treated samples after rehydration were either very close or better than the control samples values. Storage of 60Hz, 40V treated samples in 11.15% and 32.73% relative humidities for the first four days resulted in CIE values close to fresh samples.

4.4. Texture Studies

The texture attributes were measured in grams and not in Mega Pascal or Newton. This resulted in very large standard deviation values shown in Appendix C (c). It is however easy to change from grams to Mega Pascal or Newton if desired and get small standard deviation values.

The textural parameters for fresh cut sweet potato samples were not determined because of instrumentation problems. The fresh samples were too hard for the available load cell in texture analyzer to with stand. Therefore textural properties of ohmic treated samples were compared with properties of control samples.

4.4.1. Influence of Treatments

- **Hardness**

Statistical analysis showed that at $\alpha \leq 0.05$ there were no significant difference in hardness values for all the control and treated samples at all R.H. The difference in hardness values was observed during between 60Hz, 40V with 60Hz, 60V and 1Hz, 40V in fourth and sixth days for samples stored at 11.15% RH and 32.73% RH. On these days there was even difference of hardness values between ohmic treated samples with the control samples (Table 27). The null hypothesis states that the mean hardness values for three ohmic treated samples and control samples are same.

$$H_0: \mu_{60\text{Hz}, 40\text{V}} = \mu_{60\text{Hz}, 60\text{V}} = \mu_{1\text{Hz}, 40\text{V}} = \mu_{\text{Controls (Raw A; Raw B; Raw C)}}$$

Ha: H0 is false

Table 27: Probability values indicating the effect of Heating Treatments on the Hardness values at four R.H. conditions

%R.H.	Days					
Hardness	1	2	3	4	5	6
11.15%	0.0356 ^a	0.478 ^a	0.4241 ^a	0.0359^b	0.1311 ^a	00018^b
32.73%	0.0448 ^a	0.0968 ^a	0.1009 ^a	0.0147^b	0.7288 ^a	0.0077^b
57.7%	0.0987 ^a	0.4613 ^a	0.1759 ^a	0.1257 ^a	0.1795 ^a	0.3044 ^a
75.32%	0.3324 ^a	0.0528 ^a	0.0003^b	0.1379 ^a	0.0413 ^a	0.0588 ^a

The p-values of the treatments with same or common superscript “a” are not significantly different in hardness values with respect to treatments and “b” with significant difference in 60Hz, 40V with 60Hz, 60V and 1Hz, 40V at $\alpha \leq 0.05$.

Graphical representation of hardness values of ohmic heated treatments showed that the 60Hz, 60V treated samples always had higher hardness values compared to 60Hz, 40V and 1Hz, 40V (Fig. 22). This trend was seen for samples stored in all relative humidity conditions.

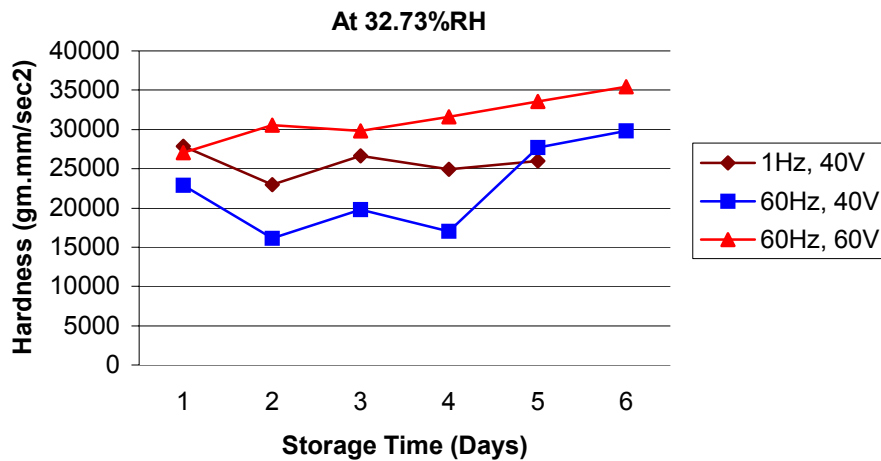


Fig. 22: Effect of Treatments on the hardness values at 32.73% R.H.

When compared with control samples the 60Hz, 60V treated samples always had higher hardness values and on certain days the 60Hz, 40V treated samples are very close to control samples (Fig. 23). 1Hz, 40V treatment always had lower hardness values than the raw samples. This implies that there was no effect of ohmic heating on hardness values with increase in voltage at 60Hz frequency moreover there was an increase in hardness values for the treated samples. This shows there was no change in the structure of SP therefore no starch degradation or no electroporation to damage the membrane and decrease hardness values. This result also shows that just like low-temp long-time

pretreatment ohmic heating can also be used to improve the firmness or hardness of SP. Sometimes to increase the hardness values during blanching of SP calcium salts are added as firming agents (Truong et al. 1998) which can be avoided if ohmic heating could produce better firmer products.

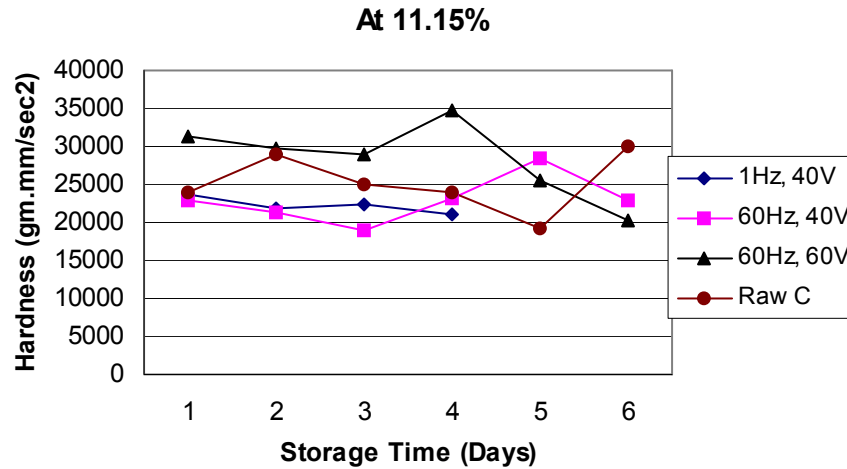


Fig. 23: Hardness values for heated and control samples at 11.15% R.H

It was also found that except for the 32.73% relative humidity the hardness values for the other humidities decreased significantly with increase in storage time (Fig. 23).

- **Springiness**

The mean springiness values had no significant change due to ohmic heating and %R.H.

The null hypothesis states that the mean springiness values for three ohmic treated samples and control samples are same.

$$H_0: \mu_{60\text{Hz}, 40\text{V}} = \mu_{60\text{Hz}, 60\text{V}} = \mu_{1\text{Hz}, 40\text{V}} = \mu_{\text{Controls (Raw A; Raw B; Raw C)}}$$

Ha: H0 is false

Table 28: Probability values indicating the effect of heating treatments on the springiness values of SP at four R.H. conditions

Springiness	1	2	3	4	5	6
11.15%	0.01^b	0.0127^b	0.3532 ^a	0.7238 ^a	0.9278 ^a	0.2205 ^a
32.73%	0.0444 ^a	0.0196^b	0.3608 ^a	0.1656 ^a	0.847 ^a	0.1497 ^a
57.7%	0.0255^b	0.4675 ^a	0.0311^b	0.432 ^a	0.0172^b	0.0033^b
75.32%	0.6775 ^a	0.1835 ^a	0.2005 ^a	0.9094 ^a	0.5265 ^a	0.0091^b

The p-values of the treatments with same or common superscript “a” are not significantly different in springiness values with respect to treatments and “b” implies significant difference either between treatments and control or among controls at $\alpha \leq 0.05$.

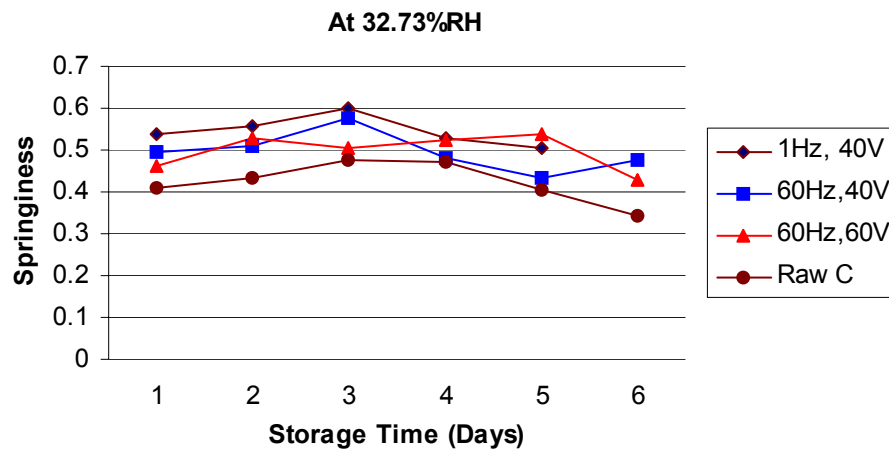


Fig. 24: Effect of treatments on springiness values at 32.73% R.H.

The springiness values of 60Hz, 40V and 1Hz, 40V were significantly different on the first 2 days of storage in 11.15% RH (Table 28). But on the same days it was found that the control samples stored during the respective treatments were also different. However, there were no other significant differences in the springiness values of the samples treated in all the four relative humidities. Therefore ohmic heating has no effect on springiness values.

The graphical representation shows that at 32.73% R.H. the ohmic treated samples had higher springiness values than the control samples (Fig. 24). This was not observed at other humidities (Table 29).

Table 29: Mean values (S.D) of springiness of SP at 11.15% R.H.

Treatments	Days					
	1	2	3	4	5	6
Springiness						
1Hz, 40V	0.38 ^{ac} (0.07)	0.63 ^{ab} (0.01)	0.55 ^a (0.03)	0.57 ^a (0.01)	.	.
60Hz, 40V	0.53 ^{ab} (0.02)	0.49 ^{ac} (0.04)	0.58 ^a (0.07)	0.54 ^a (0.11)	0.48 ^a (0.05)	0.36 ^a (0.08)
60Hz, 60V	0.44 ^a (0.03)	0.51 ^a (0.02)	0.51 ^a (0.02)	0.54 ^a (0.02)	0.53 ^a (0.13)	0.4 ^a (0)
Raw B	0.6 ^{ad} (0.03)	0.57 ^a (0.01)	0.52 ^a (0.05)	0.57 ^a (0.04)	0.53 ^a (1.26)	0.43 ^a (0.04)

Within a column the mean values of treatments with same or common superscript are not significantly different and the superscripts followed by different alphabets are significantly different at $\alpha \leq 0.05$.

- **Cohesiveness**

Significant difference in cohesiveness values was observed between treatments 60Hz, 40V and 60Hz, 60V stored in 32.73%RH during third and fourth days. However, differences were observed in there respective controls on same days. At 32.73%, 60Hz, 60V treatment had mean cohesiveness values different from that of control values. For other R.H. environments no significant difference in ohmic treated and control samples was observed.

Graphical representation (Fig.25) among treatments and Table 31 shows that the cohesiveness values of 60Hz, 60V had higher values than the other two treated and control samples. 60Hz, 40V and 1Hz, 40V treated samples almost had similar cohesiveness values at all humidity levels.

It was found that 60Hz, 60V and 1Hz, 40V ohmic treated samples had either higher or same cohesiveness values as than their respective control samples at all %R.H. But sometimes 60Hz, 40V treated samples sometimes had cohesiveness values less than there respective control samples.

Table 30: Probability values indicating the effect of heating treatments on the cohesiveness values of SP at four R.H. conditions

%R.H.	Days					
	1	2	3	4	5	6
11.15%	0.8376 ^a	0.086 ^a	0.1303 ^a	0.0266 ^b	0.1173 ^a	0.0035 ^b
32.73%	0.1486 ^a	0.0678 ^a	0.044 ^b	0.0127 ^b	0.0098 ^b	0.1358 ^a
57.7%	0.3018 ^a	0.0355 ^b	0.0987 ^a	0.1003 ^a	0.1737 ^a	0.0793 ^a
75.32%	0.1843 ^a	0.0019 ^b	0.315 ^a	0.4916 ^a	0.4619 ^a	0.2364 ^a

The p-values of treatments with same or common superscript “a” are not significantly different in cohesiveness values with respect to treatments and “b” implies significant difference between treatments and control or among controls at $\alpha \leq 0.05$.

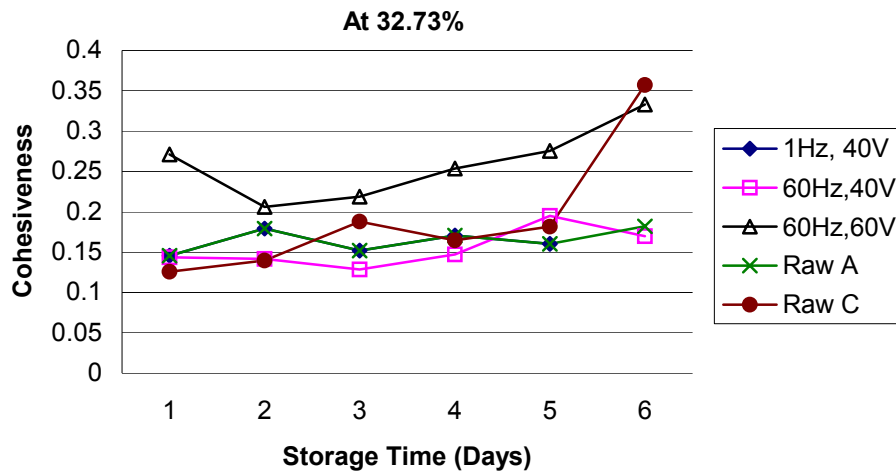


Fig. 25: Effect of treatments on cohesiveness values at 32.73% R.H

Table 31: Mean values (S.D) of Cohesiveness of SP at 57.70% R.H.

Treatments	Days					
Cohesiveness	1	2	3	4	5	6
60Hz, 40V	0.15 ^a (0.0)	0.16 ^a (0.08)	0.14 ^a (0.02)	0.16 ^a (0.01)	0.13 ^a (0.02)	0.12 ^a (0.0)
Raw C	0.17 ^a (0.02)	0.15 ^a (0.03)	0.15 ^a (0.05)	0.18 ^a (0.01)	0.13 ^a (0.02)	0.19 ^a (0.01)
60Hz, 60V	0.26 ^a (0.10)	0.21^{ab} (0.02)	0.23 ^a (0.04)	0.22 ^a (0.02)	0.24 ^a (0.03)	.
Raw B	0.2 ^a (0.04)	0.11^{ac} (0.0)	0.2 ^a (0.02)	0.19 ^a (0.03)	0.18 ^a (0.03)	0.21 ^a (0.02)

Within a column the mean values of treatments with same or common superscript are not significantly different and the superscripts followed by different alphabets are different at $\alpha \leq 0.05$.

Chewiness

Statistical analysis results showed that the influence of treatments on mean chewiness values is the same as on mean gumminess values. Table 32 shows significant difference in mean chewiness values on the fourth day for samples stored in 11.15%RH and second and fourth day in 32.73% RH. The differences were between values of 60Hz, 60V treated samples with other ohmic treated and control samples.

Table 32: Probability values indicating the effect of Heating Treatments on the Chewiness values of SP at four R.H. conditions

%R.H.	Days					
Chewiness	1	2	3	4	5	6
11.15%	0.5429 ^a	0.419 ^a	0.2432 ^a	0.0181^b	0.5239 ^a	0.2191^b
32.73%	0.0793 ^a	0.0442^b	0.0573 ^a	0.0009^b	0.567 ^a	0.7934 ^a
57.7%	0.2413 ^a	0.0473 ^a	0.005 ^a	0.138 ^a	0.0635 ^a	0.135 ^a
75.32%	0.8353 ^a	0.2348 ^a	0.6596 ^a	0.72 ^a	0.3212 ^a	0.0082^b

The p-values of treatments with same or common superscript “a” are not significantly different in chewiness values with respect to treatments and “b” implies significant difference between treatments and control or among controls.

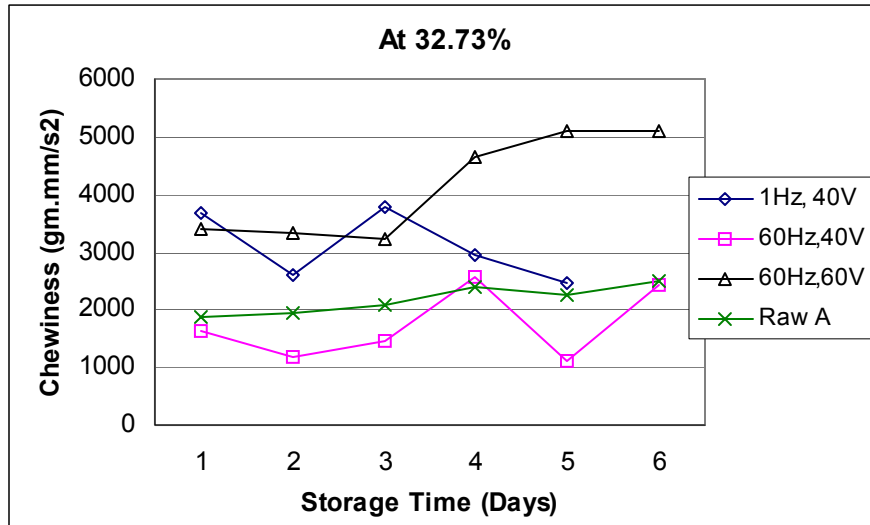


Fig. 26: Effect of Treatments on Chewiness at 32.73% R.H.

At 11.15% R.H. and 32.73% R.H. the 1Hz, 40V and 60Hz, 40V treated samples resulted in higher chewiness values than their respective controls whereas at 57.70% R.H. 60Hz, 60V treated samples had higher chewiness values than their respective control samples. Such increase in chewiness values of sweet potatoes was also obtained in research conducted by Moreno-Perez et al (1996) where with increase in blanching temperature the chewiness values increased. At higher humidities the values decreased with increase in storage time.

- **Adhesiveness**

There was no significant difference in the adhesiveness values for all the ohmic treated samples in all four relative humidity conditions. Difference was observed between the control samples during the sixth day for both 57.7% and 75.32% relative humidities (Table 33).

Table 33: Probability values indicating the effect of Heating Treatments on the Adhesiveness values of SP at four R.H. conditions

%R.H.	Days					
Adhesiveness	1	2	3	4	5	6
11.15%	0.0609 ^a	0.5651 ^a	0.1825 ^a	0.5547 ^a	0.58 ^a	0.5829 ^a
32.73%	0.1592 ^a	0.4882 ^a	0.5708 ^a	0.3082 ^a	0.022^b	0.5837 ^a
57.7%	0.4346 ^a	0.4863 ^a	0.5662 ^a	0.0002^b	0.6054 ^a	0.0001^b
75.32%	0.3088 ^a	0.1871 ^a	0.3089 ^a	0.8258 ^a	0.7573 ^a	0.0001^b

The p-values of treatments with same or common superscript “a” are not significantly different in adhesiveness values with respect to treatments and “b” implies significant difference controls

4.4.2. Influence of Relative Humidity Conditions

The null hypothesis states that the mean texture attribute values for four relative humidities are same.

$$H_0: \mu_{11.15\%} = \mu_{32.73\%} = \mu_{57.70\%} = \mu_{75.32\%}$$

Ha: H0 is false

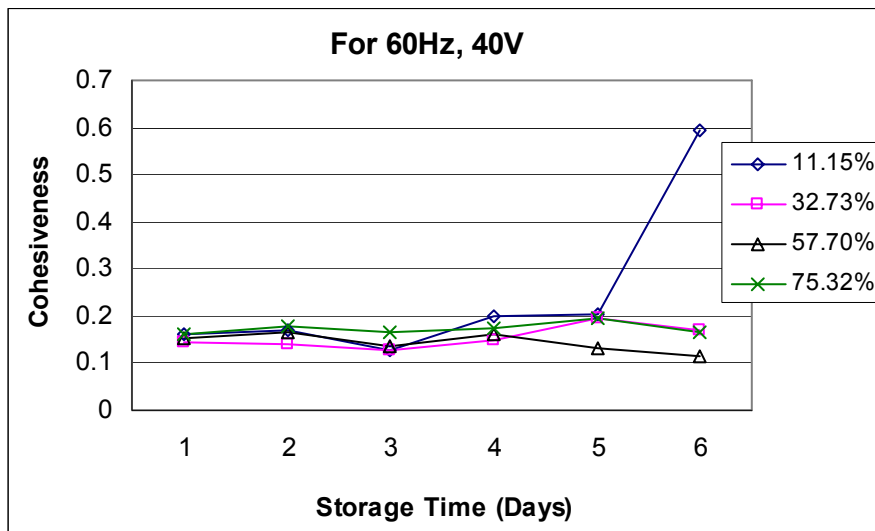


Fig. 27: Effect of relative humidity environments at 60Hz, 40V treatment

Statistical analysis resulted in no significant differences in the texture parameters with increase in relative humidity for both treated and control samples. On the sixth day of storage of control samples for all the texture parameters differences were observed between relative humidities. However these differences were not seen in case of ohmic treated samples.

The 60Hz, 40V treated samples had cohesiveness value close to one other for all relative humidities until the fifth day (Fig. 27).

Overall at higher relative humidities 57.70% and 75.32% hardness and chewiness values decreased slightly with increase in storage time. However there were no significant trends in springiness, adhesiveness and cohesiveness at those humidities. Wu et al. (1991) found that this change or decrease in the values of hardness and chewiness could be due to the action of amylase activity in sweet potatoes. To explain more clearly, the starch polysaccharides present in sweet potatoes hydrolyzed by alpha-amylase enzyme into low molecular weight dextrin's resulting in softening of the tissue at these higher humidities. At lower humidities 11.15% and 32.73% such trends were not observed. The hardness values increased with increase in storage time though there were no significant effects on springiness, adhesiveness and cohesiveness. The increase in hardness values during blanching was explained due to polymethyl esterase activity (PME) of sweet potatoes i.e., PME hydrolysis to carboxylic groups which then react with the calcium present in sweet potatoes and increases the firmness of the samples (Moreno-Perez et al 1996). The PME activity was not observed in case of all ohmic treatments the reason for which is unknown.

4.4.3. Correlation Analysis

Pearson’s correlation coefficients were calculated between moisture content and texture attributes using PROC CORR (SAS version 9.0).

- **Correlation Between Moisture Content and Texture Attributes**

The amount of water absorbed during rehydration can influence the textural properties of foods. Therefore correlations were determined between %moisture content of the samples after rehydration and the texture attributes. The %moisture content of the samples before rehydration did not show consistent correlations with texture attributes (Table 34). This is because the %moisture content values during storage or before rehydration were not significantly different for all treatments and controls (discussed in Chapter1 Moisture Studies). Therefore the correlations of %moisture before rehydration and texture parameters are not discussed in results.

Table 34: Effect of moisture content at 11.15% on texture attributes of sweet potato cubes

Treatments	Texture Attributes			
%MC (AR)	Hardness	Springiness	Cohesiveness	Chewiness
1Hz, 40V	0.39498	-0.39434	0.78733	0.25626
60Hz, 40V	-0.16444	0.5917	-0.7881	-0.6818
60Hz, 60V	0.62738	0.39573	-0.84381	-0.11144
Raw B	-0.50039	0.58802	-0.91288	-0.84106
Raw C	-0.53354	0.29936	-0.76179	-0.90831

Table 34 shows that the %moisture content was positively correlated with hardness ($r = 0.82094$, $p \leq 0.05$ at 57.70%) for the ohmic treated samples for almost all the

relative humidity conditions. The correlation coefficients did vary with the relative humidity. Negative correlations were obtained between %moisture content and cohesiveness and chewiness values for the ohmic treated samples at lower humidity levels (11.15% and 32.73%). While at higher humidities the correlations were mainly positive showing that the %moisture content after rehydration at higher humidities has significant effect on the structure of the samples. 60Hz, 60V treatment had higher positive correlation values between %moisture content and hardness values compared to other treatments. This shows that this treatment may result in products of better hardness values compared to others. Since the texture attributes depend on the %moisture content after rehydration, an increase in rehydration time from 30 minutes to 1hour or more to absorb more moisture can result in good texture attributes.

For control samples, moisture content had negative correlation with cohesiveness and chewiness (Table 35).

Table 35: Correlation Coefficients of texture attributes with %moisture content at 57.70% R.H.

Treatments	Days			
	Hardness	Springiness	Cohesiveness	Chewiness
1Hz, 40V	0.82094	0.4685	0.81127	0.83784
60Hz, 40V	0.23184	0.38291	0.0475	0.24603
60Hz, 60V	0.54875	0.65619	0.14917	0.61515
Raw B	-0.24492	0.24614	-0.3448	-0.1887
Raw C	0.39301	0.27201	-0.18596	0.21023

- **Correlation Between Texture Attributes**

Hardness values always had positive correlation with cohesiveness and chewiness attributes for the treated samples at all relative humidity conditions (Table 36). In general for all treatments hardness was positively correlated with springiness (not shown in the table) indicating as hardness of the samples increases their springiness increases. Montejano et al. (1985) obtained a positive correlation between hardness and springiness in case of gel samples and Meullenet et al (1997) obtained a negative correlation between hardness and springiness for various vegetables. This shows that significance of correlation coefficients may be relative to the type of the product being studied.

Table 36: Correlation Coefficients between texture attributes with Hardness at 57.70%

Treatments	Texture Attributes		
Hardness	Springiness	Cohesiveness	Chewiness
1Hz, 40V	-0.30329	0.95486	0.91891
60Hz, 40V	0.84279	0.52581	0.92623
60Hz, 60V	0.36723	0.82375	0.81648
Raw B	-0.20806	0.33064	0.419
Raw C	0.45906	0.12041	0.7081

The springier the samples were the more the hardness and more the chewiness of the samples, which was obtained through ohmic treatment. The cohesiveness of the samples was also highly correlated with chewiness. Ohmic heating of sweet potato samples can result in improved hardness, chewiness attributes when compared to control samples which are preferred by consumers.

CHAPTER 5. CONCLUSIONS

This research was conducted to determine the effect of ohmic heating on rehydration properties, color parameters and texture attributes of sweet potatoes.

Ohmic heated samples had higher % moisture gain and rehydration ratio than the control samples and the values increased with increase in storage time. The % moisture gain varied between a minimum of 0.1% and a maximum of 40.7% in the case of ohmically treated samples and 0.71% on the first day to 32.41% for control samples. 60Hz, 40V treated samples resulted in better rehydration properties when compared with others. The % moisture gain was more evident at 11.15% R. H. Therefore ohmic treatment can produce products with better rehydration properties and open structure by storing at lower humidities and 60Hz, 40V treatment.

Color studies showed that 60Hz, 40V treated samples had better lightness values than other ohmic treated samples but lesser values when compared to control. The visual observations showed that the ohmic treated samples were not black or dark though the lightness values are less.

The ohmic treated samples had higher “a*” (red) values when compared with control samples. 60Hz, 40V treated samples showed higher degree of orangeness/redness than 60Hz, 60V and 1Hz, 40V treated samples during storage. But rehydration resulted in better “a*” values for 60Hz, 60V. The 60Hz, 40V treated samples retained more degree of yellowness (b* value) when compared with other ohmic treatments but values decreased with increase in storage time. Higher relative humidities resulted in higher “b*” values 60Hz, 60V exhibited than other treated samples.

Ohmic heating was not effective in retaining the chroma values of samples. The chroma values decreased considerably with increasing storage time. The hue angle increased with increase in storage time in the case of the 60Hz, 40V treatment showing that the samples are more orange- red than the fresh cut and control samples. Therefore ohmic heating operated at 60Hz, 40V can result in samples with better red and yellow color properties when stored at lower humidities.

Texture analysis showed that the hardness, springiness and chewiness of the 60Hz, 60V treated samples were higher than the 1Hz, 40V and 60Hz, 40V treated and control samples. Ohmic treated samples always had higher hardness or firmness values than the control samples and the values increased with increase in storage time at lower humidities. Springiness values tended to be higher at lower humidities when compared to higher humidities. Cohesiveness values also increased with increase in storage time and were higher for 60Hz, 60V treated samples. This shows that ohmic heating can be used to obtain firmer and chewier sweet potatoes which are desirable for consumers.

The treatment combination of 60Hz and 40V was effective in obtaining higher values of rehydration properties and also in retaining the color and appearance of the samples whereas the 60Hz and 60V were more effective in retaining the texture of the samples. In all the cases the final treated samples are compared with properties of the untreated control samples.

Thus it can be summarized that ohmic heating played a pivotal role in retaining rehydration properties, color attributes and some of the texture attributes of the sweet potato samples when appropriate combinations of frequency and electrical field strength

were used. The relative humidity storage environments also acted as a contributing factor in the moisture migration and overall results of the experiment.

CHAPTER 6. RECOMMENDED FUTURE WORK

1. Ohmic heating experiments should be conducted with other wave forms and frequencies.
2. More research should be conducted on the storage of ohmic treated samples at different relative humidity environments for preventing mold growth.
3. Research should be conducted to determine the effect of rehydration method and times on color and texture attributes.
4. The experiments should be performed with a bigger sample size (more replicates) and higher capacity load cell for texture analysis.
5. A proper method to measure rehydration parameters and an accurate method for determination of the parameters used for calculating those indices should be developed.
6. Studies should be conducted on refrigeration of ohmic treated samples.

REFERENCES

- Ahmed E. M, Scott L E 1962. A rapid objective method for estimation of carotenoids content in sweetpotato roots. Proceedings of American Society of Horticulture Science, 80, 497-506.
- Allen, K., Eidman, V. and Kinsey, J. 1996. An economic-engineering study of Ohmic food processing. Journal of Food Technology, 50 (5), 269-273.
- Ameny, M. A. and Wilson, P. W. 1997. Relationship between Hunter Color Values and beta-carotene Contents in White-Fleshed African Sweet Potatoes (Ipomoea batatas Lam). Journal of Food Science and Agriculture, 73, 301-306.
- Anonymous. Economic Research Service. Commodity Highlights: Sweet Potatoes. <http://www.ers.usda.gov/briefing/vegetables/> 08/10/2003.
- Anonymous. Sweet Potatoes. Louisiana Department of Agriculture and Forestry. <http://www.sweetpotato.org/> 08/10/2003.
- Anonymous. Sweet Potato Varieties. <http://members.aol.com/SPVine/garden/garden3/> 08/10/2003
- Anonymous. Spectrophotometers. <http://www.minolta.com/> 08/10/2003.
- Bourne, M. C. 1982. Effect of temperature on firmness of raw fruits and vegetables. Journal of Food Science, 47, 440-444.
- Chen, C. R. and Ramaswamy, H. S. 2002. Color and texture change kinetics in ripening bananas. Lebensmittelwissenschaft und Technologie, 35, 415-419.
- Datta, A. K. and Davidson, P. M. 1998. Microwave and Radio Frequency Processing. Journal of Food Science (Supplement). Pg 32-41.
- Dawkins, L. N. and Lu, J. Y. 1991. Physico-Chemical Properties and acceptability of flour prepared from microwave blanched sweet potatoes. Journal of Food Processing and Preservation, 15, 115-124.
- Diamante, L. M. and Munro, P. A. 1991. Mathematical modeling of hot air drying of sweet potato slices. International Journal of Food Science and Technology, 26 (1), 99-109.

Diamante, L. M. and Munro, P. A. 1990. Water desorption isotherms of two varieties of sweet potato. *International Journal of Food Science and Technology*, 25, 140-147.

Eliot, S. C., Goullieux, A. and Pain, J. P. 1999. Processing of cauliflower by ohmic heating: influence of precooking on firmness. *Journal of Food Science and Agriculture*, 79, 1406-1412.

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.

Giese, James. 2000. Color Measurement in Foods as a Quality Parameter. *Journal of Food Technology*, 54 (2): 62, 63.

Imai, T., Uemura, K., Ishida, N., Yoshizaki, S. and Noguchi, A. 1995. Ohmic heating of Japanese white radish *Rhaphanus sativus*. *International Journal of Food Science and Technology*, 30: 461-472.

Krokida, M. K., Karathanos, V. T. and Maroulis, Z. B. 1998a. Kinetics on color changes during drying of some fruits and vegetables. *Drying Technology*.

Krokida, M. K., Karathanos, V. T. and Maroulis, Z. B. 1998b. Compression analysis of dehydrated agricultural products. *Drying Technology*.

Krokida, M. K., Kiranoudis, C. T. and Maroulis, Z. B. 1999. Viscoelastic behaviour of dehydrated products during rehydration. *Journal of Food Engineering*, 40, 269-277.

Lee, H. S. and Coates, G. A. 2003. Effect of thermal pasteurization on Valencia orange juice color and pigments. *Lebensm.-Wiss. U,-Technology*, 36, 153-156.

Lewicki, P. P. 1998. Some Remarks on Rehydration of Dried Foods. *Journal of Food Engineering*, 36, 81-87.

Lewicki, P. P. and Duszcyk, E. 1998. Color change of selected vegetables during convective air drying. *International Journal of Food Properties*, 1(3), 263-273.

Lima, M and Sastry, S. 1996. Diffusion of beet dye during electrical and conventional heating at steady-state temperature. Ph.D. dissertation, The Ohio State University. Columbus, OH.

Lima, M. and Sastry, S. K. 1999. The effects of ohmic heating frequency on hot-air drying rate, desorption isotherms and juice yield. *Journal of Food Engineering*, 41, 115-119.

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.

Linehan, D. J. and Hughes, J. C. 1969. Texture of cooked potato. III: Intercellular adhesion. *Journal of Science and Food Agriculture*, 20(2),119- 123.

Loesecke, V and Willard, H. 1955. *Drying and dehydration of foods*. Reinhold Publishing Corporation, 283-291.

Lopez, C. Y., Carlos, V. C., Schwartz., Bulux, J. and Solomons, N. W. 2001. Sweet Potato buds: the origins of a “designer” food to combat hypovitaminosis A in Guatemala. Processing, vitamin A content and preservation characteristics. *Nutrition Research*. 21: 61-70.

Lu, J.Y., Miller, P. and Loretan, P. A. 1989. Gamma radiation dose rate and sweet potato quality. *Journal of Food Quality*, 12 (5), 365-376.

Meullenet, J-F. C., and Gross, J. 1999. Instrumental single and double compression tests to predict sensory texture characteristics of foods. *Journal of Texture Studies*, 30, 167-180.

Meullenet, J-F. C., Carpenter, J. A., Lyon, B. G. and Lyon, C.E. 1997. Bi-cyclical instrument for assessing texture profile parameters and its relationship to sensory evaluation of texture. *Journal of texture studies*, 28, 101-118.

Montejano, J. G., Hamann, D. D. and Lanier, T. C. 1985. Comparison of two instrumental methods with sensory texture of protein gels. *Journal of texture studies*, 16, 403-424.

Moreno-Perez, L. F., Gasson-Lara, J. H. and Ortega-Rivas, E. 1996. Effect of low temperature-long time blanching on quality of dried sweet potato. *Journal of Drying Technology*, 14(7/8): 1839-1857.

Palaniappan, S. and Sastry, S. K. 1991b. Electrical conductivity of selected juices: influence of temperature, solids content, applied voltage, and particle size. *Journal of Food Process Engineering* 14, 247-260.

Perez-Magarino, S. and Gonzalez-Sanjose, M. I. 2003. Application of absorbance values used in wineries for estimating CIELAB parameters in red wines. *Journal of Food Chemistry*, 81, 301-306.

Quintero- Ramos, A., Bourne, M. C., and Anzaldua- Morales, A. 1992. Texture and rehydration of carrots as affected by low temperature blanching. *Journal of Food Science*, 57, 1127.

Rahman, M. S. 1999. Preserving foods with electricity: ohmic heating. In: M. S. Rahman (ed.) *Handbook of food Preservation* Marcel Dekker, New York, pp.521-532, 173- 216.

Ramana, S. V., Wright, C. J. and Taylor, A. J. 1992. Measurement of firmness in carrots tissue during cooking using dynamic, static and sensory tests. *Journal of Science and Agriculture*, 60, 369-375.

Rockland, L. B. and Beuchat, L. 1987. Water activity: theory and applications to food, 226-227.

Rosenberg, U. and Bogl, W. 1987a. Microwave thawing, drying and baking in the food industry. *Journal of Food Technology (USA)*, 6, 92-99.

Sastry, S. K. and Palaniappan, S. 1992. Mathematical modeling and experimental studies on ohmic heating of liquid-particle mixtures in a static heater. *Journal of Food Process Engineering*, 15, 241-261.

Sastry, S. K. 1992. A model for heating of liquid- particle mixtures in a continuous flow ohmic heater. *Journal of Food Process Engineering*, 15, 263.

Sastry, S. K. 1994. Ohmic heating. In: R. P. Singh and F. Oliveira (eds) *Minimal Processing of Foods and Processing Optimisation: an interfase*. CRC Press, Boca Raton, FL, pp. 17-34.

Sastry, S. K. and Barach, J. T. 2000. Ohmic and Inductive Heating. *Journal of Food Science*, 65(4), 42-46.

Schreier, P., Reis, D., Fryer, P., 1993. Enhanced diffusion during the electrical heating of foods. *International Journal of Food Science and Technology*, 28, 249-260.

Stirling, R. 1987. Ohmic heating- a new process for the food industry. *Journal of Power Engineering*, 6, 365.

Szczesniak, A. S. 1963. " Classification of Textural Characteristics." *Journal of Food Science*, 28, 85-389.

Truong, V. D., Walter, W. M., Jr. and Hamann, D. D. 1998. Relationship between instrumental and sensory parameters of cooked sweet potato texture. *Journal of Texture Studies*, 63(4), 739-743.

Walter A. Hill, Philip A. Loretan and Conrad K. Bonsi. The sweet potato for space missions-controlled environmental life support systems pg 21.

Wang W-C and Sastry, S. K. 1997. Changes in electrical conductivity of selected vegetables during multiple thermal treatments. *Journal of Food Engineering*, 20, 499-516.

Wang W-C and Sastry, S. K. 2000. Effects of thermal and electro thermal pretreatments on hot air drying rate of vegetable tissue. *Journal of Food Process Engineering*, 23(4), 299-319.

Wu, J. Q., Schwartz, S. J., and Carroll, D. E. 1991. Chemical Physical and Sensory Stabilities of prebaked frozen sweet potatoes.

Yang, T. C. S., Cohen, J. S., Kluter, R. A. and Driver, M. G. 1994. Feasibility of applying ohmic heating and split-phase aseptic processing for ration entrée preservation. Technical report, pp.18-24, U.S. Army Soldier System Command, Natick RD&E Center, Natick/TR-94/021.

Yongsawatdigul, J., Park, J. W., Kolbe, E., AbuDagga, Y., and Morrissey, M. T. 1995b. Ohmic heating maximizes gel functionality of pacific whiting surimi. *Journal of Food Science*, 60: 10-14.

Zhong, T. and Lima, M. 2003. The effect of ohmic heating on vacuum drying rate of sweet potato tissue. *Bioresource Technology*, 87, 215-220.

Zoltai, P. and Swearingen, P. 1996. Product development considerations for ohmic processing. *Journal of Food Technology*, 50(5), 263-266.

APPENDIX A. MISCELLENEOUS

a. Sweet Potato Varieties

1. **Beauregard:** This is high yielding variety released by Louisiana Agricultural Experiment Station release. It has light rose or copper skin or red-orange with dark orange flesh and is uniformly shaped. Consumers prefer the Beauregard sweet potato to any other sweet potato grown in the United States.
2. **Hernandez:** Developed by Louisiana Agricultural Experiment Station. This cultivar has high yield and excellent baking and processing qualities. Flesh is a deep orange.
3. **"Bunch" Porto Rico:** Also called "Bush" and "Vineless." Puerto Rico has copper-colored outside skin and light red flesh. It has delicious "old-fashioned" flavor and is an excellent baking potato.
4. **Centennial:** This is soft-fleshed smooth sweet potato with a deep orange (Carrot color) flesh. This has high yield and is America's leading sweet potato. (This variety was used for the experiments).
5. **Jewel:** "The current Queen of sweet potatoes," was developed by North Carolina State University. Jewel is still the leading commercial variety planted in North Carolina. The variety is a "yam-type" (moist, soft, yellow-fleshed when baked) with a light copper skin and orange flesh. It produces a very high yield. It needs 120-135 days growing time for maximum yield.
6. **Excel:** This variety has attractive light copper skin and orange flesh. It has well shaped roots earlier than most cultivars and yields about 15% more than Jewel. Developed by USDA-ARS and Clemson University.

7. **Sumor:** Sumor has similarities to that of an Irish potato. It has a smooth, light tan skin, white to yellow flesh and high dry matter content. This variety has only a fraction of the beta-carotene found in orange varieties but it does contain more Vitamin C than most tomatoes. This was developed by USDA-ARS and Clemson University SCAES.
8. **Vardaman:** A bush variety with deep orange flesh. Released by the Mississippi Agricultural Extension Service in 1981. Is considered the best short-vined variety for eating. This has dark golden yellow skin with bright orange color inside.

b. Differences between dielectric, infrared and ohmic heating.

	Dielectric Heating (Microwave and Radio frequency)	Infrared Heating	Ohmic Heating
Heat Production	Due to molecular friction in water molecules	Energy is absorbed and converted	Due to electrical resistance of a food
Depends on	Moisture content of the food	Surface characteristics and color of the food	Electrical resistance of the food
Purpose	To preserve foods	Usually to alter the eating qualities by changing color, flavor and aroma	To preserve foods
Energy	Produced at specified bands	Has a wider range of frequencies	Uses mains frequency electricity
Depth of penetration	Related to frequency i.e., less frequency more penetration	Related to frequency	Penetrates throughout the food instantly

c. Rehydration Calculations

Rehydration Ratio

$$RR = \frac{\textit{Weight of the sample after rehydration}}{\textit{Weight of the sample after drying}}$$

Coefficient of Rehydration

$$CR = \frac{\textit{Weight of the sample after rehydration}}{(\textit{Weight of the sample after drying} - \textit{Moisture Content of the dehydrated samples}) * 100} \\ [100 - \textit{Original Moisture Content}]$$

APPENDIX B. OHMIC HEATING PROFILES

The six curves that are shown in Figures 29 to 32 were randomly selected from 146 curves obtained from each treatment.

60Hz, 40V, 40°C

The time taken by the 146 samples to reach an end point temperature (EPT) of 40°C varied from 58 sec to 531sec. Most samples had heating times between 200 sec to 350 sec; 23 samples took more than 400 sec of which 8 samples exceeded 500 sec. The end-point temperature of the cubes was always within $\pm 0.5^\circ\text{C}$ of the target temperature (Fig. 29).

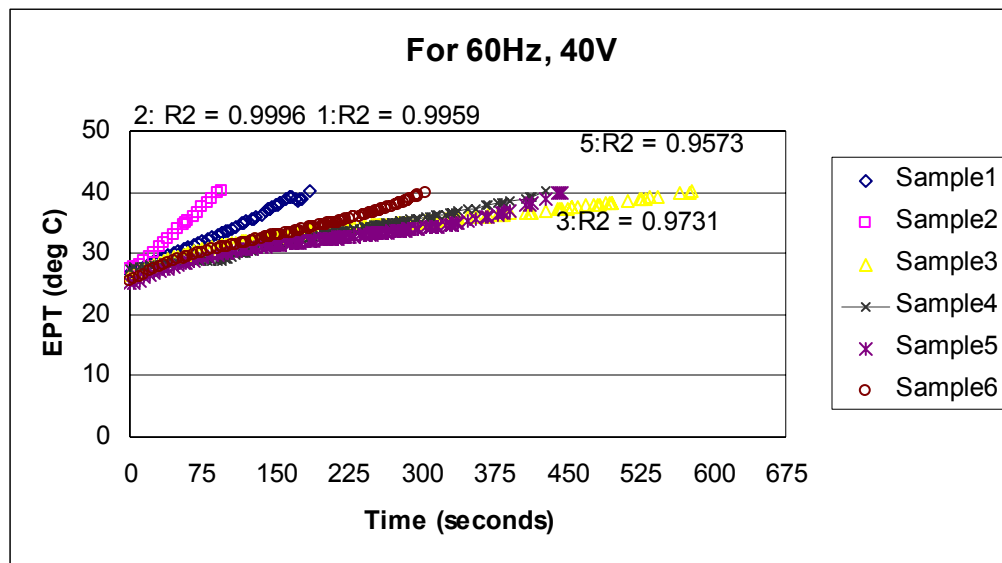


Fig. 29: Temperature profile of sweet potato at 60Hz, 40V, 40°C

For 60Hz, 40V, 70°C

The heating time taken by the samples to reach EPT of 70°C was between 172 sec to 674 sec. Only 8 samples took more than 600 sec and most of the samples were in 250-

375 sec time period. The end-point temperature of the cubes was always within $\pm 1.0^{\circ}\text{C}$ of the target temperature (Fig. 30).

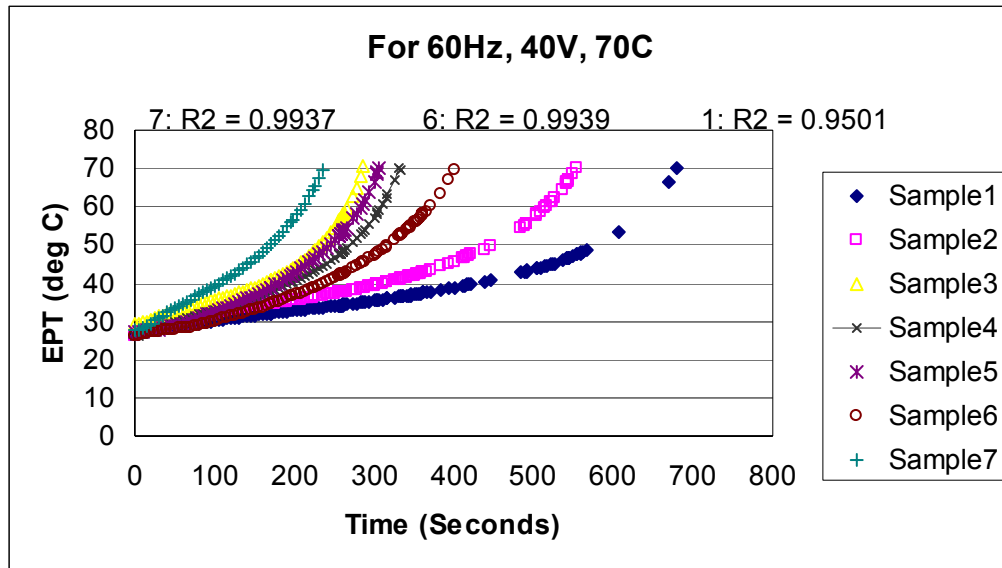


Fig. 30: Temperature profile of sweet potato at 60Hz, 40V, 70°C

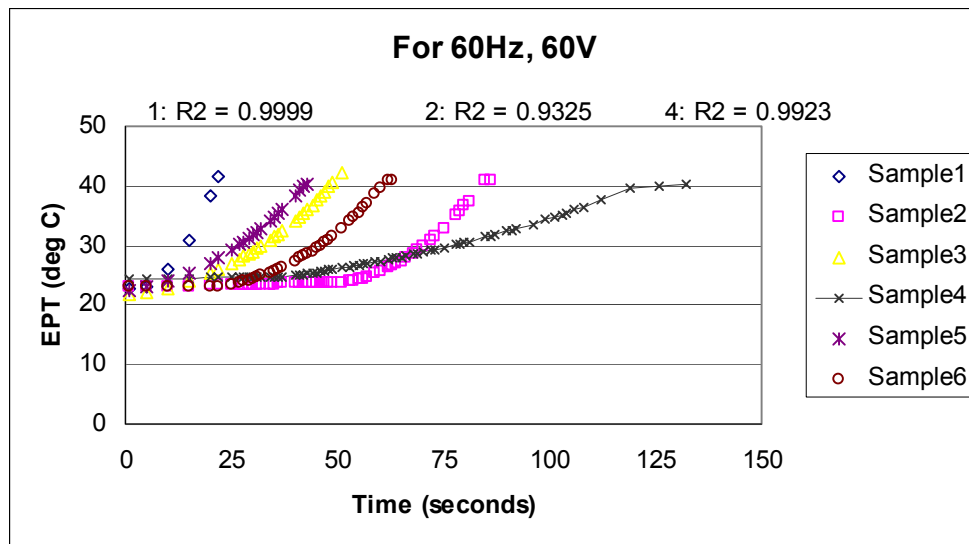


Fig. 31: Temperature profile of sweet potato at 60Hz, 60V, 40°C

For 60Hz, 60V, 40°C

The time taken for the samples to reach the EPT of 40°C varied from 22 sec to 119 sec of which most of the samples took between 50 sec and 90 sec. Only 18 samples

took more than 90 sec. The end-point temperature of the cubes was always with in +3.0°C of the target temperature (Fig. 31).

1Hz, 40V, 40°C

The time taken for the samples to reach the EPT of 40°C varied from 50 sec to 471 sec. From the 146 samples treated only 18 samples took more than 180 sec of which 15 were between 300 sec and 471 sec. The end-point temperature of the cubes was always with in +1.0°C of the target temperature (Fig. 32).

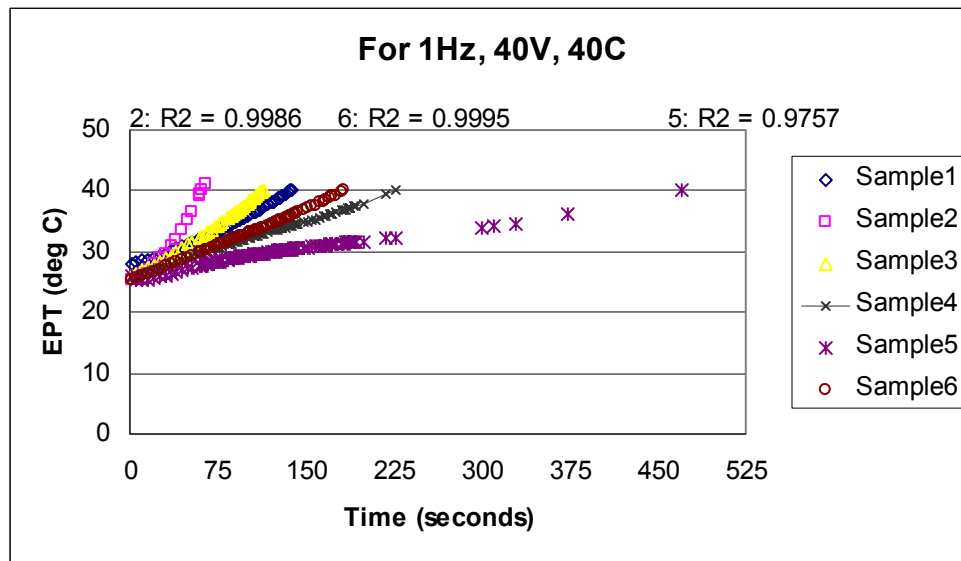


Fig. 32: Temperature profile of sweet potato at 1Hz, 40V, 40°C

To avoid surface moisture loss from the samples all sweet potato cubes were not prepared at one time. They were prepared in the form of batches (around 50) and stored in a covered plastic container before the heating process was carried out. Though care was taken, there might have been loss of moisture from the samples, which resulted in different heating times.

APPENDIX C. DATA SET FOR EXPERIMENTS

a. Data set for Moisture Studies

i. Mean values (S.D) of Moisture Content during storage

1Hz, 40V	1	2	3	4	5	6
11.15%	73.74(3.16)	74.75(1.29)	67.97(0.48)	56.20(0.00)	-	-
32.73%	72.89(1.71)	74.32(3.12)	76.08(0.31)	70.02(2.12)	59.74(5.19)	-
57.70%	73.46(4.37)	79.74(0.61)	75.48(2.94)	69.26(1.64)	70.43(0.04)	-
75.32%	73.55(1.65)	74.81(1.21)	76.57(3.86)	78.40(0.00)	-	-

60Hz, 40V	1	2	3	4	5	6
11.15%	74.88(0.00)	77.51(2.48)	72.17(1.27)	72.25(1.75)	50.54(5.03)	23.45(1.04)
32.73%	74.17(4.56)	75.52(0.63)	72.18(2.21)	74.08(0.04)	61.71(0.04)	54.8(6.70)
57.70%	75.42(7.35)	74.24(5.08)	74.76(4.24)	75.78(1.78)	77.51(3.39)	67.45(3.28)
75.32%	73.61(0.47)	79.01(0.5)	75.81(3.08)	79.17(1.08)	73.54(1.03)	64.27(2.56)

60Hz, 60V	1	2	3	4	5	6
11.15%	74.61(0.33)	74.08(0.81)	71.49(1.62)	69.34(0.96)	61.49(6.28)	32.1(0.43)
32.73%	75.48(1.87)	72.21(2.07)	73.6(1.61)	73.33(1.38)	65.27(3.96)	63.56(6.38)
57.70%	72.97(0.17)	74.14(2.89)	70.44(3.2)	68.67(4.55)	67.25(0.00)	-
75.32%	75.23(2.82)	75.98(1.76)	74.08(4.72)	-	-	-

Raw A	1	2	3	4	5	6
11.15%	72.79(0.5)	76.61(1.48)	68.18(2.08)	65.39(1.22)	54.62(7.61)	47.7(9.88)
32.73%	77.82(2.99)	76.03(1.6)	71.56(1.66)	69.63(5.74)	64.75(2.35)	56.8(1.09)
57.70%	72.93(4.57)	78.36(2.23)	74.65(0.42)	73.68(2.62)	70.90(3.30)	63.81(0.19)
75.32%	77.05(0.38)	74.96(5.05)	75.54(1.85)	71.4(2.73)	69.85(1.61)	68.64(0.28)

Raw B	1	2	3	4	5	6
11.15%	75.48(1.87)	73.63(0.58)	65.81(5.84)	63.42(4.56)	63.96(4.66)	47.7(9.88)
32.73%	73.18(1.16)	77.36(0.44)	67.64(4.45)	66.51(0.72)	69.06(1.45)	56.8(1.09)
57.70%	75.64(0.93)	75.73(2.07)	76.52(0.77)	75.62(0.87)	70.06(1.71)	63.81(0.19)
75.32%	75.79(3.01)	78.65(0.57)	76.1(0.76)	76.09(2.48)	69.87(3.88)	68.64(0.28)

Raw C	1	2	3	4	5	6
11.15%	79.01(1.14)	79.44(0.61)	78.13(1.08)	75.79(1.08)	71.44(1.92)	32.37(1.52)
32.73%	77.44(3.85)	78.55(0.1)	77.46(0.77)	75.21(1.46)	68.61(1.71)	55.71(7.03)
57.70%	82.23(0.14)	76.84(1.12)	75.06(0.3)	76.22(0.04)	76.49(5.96)	72.7(3.82)
75.32%	80.02(0.00)	79.48(0.00)	83.03(0.00)	75.07(0.00)	76.51(0.00)	76.3(0.00)

ii. Mean values (S.D) of Moisture Content after Rehydration

1Hz, 40V	1	2	3	4	5	6
11.15%	79.78(1.82)	76.71(2.35)	78.44(2.62)	66.00(2.98)	-	-
32.73%	77.24(0.37)	76.94(0.07)	77.82(1.3)	73.32(0.09)	71.75(4.23)	-
57.70%	76.54(0.90)	79.89(0.59)	76.87(1.94)	76.38(0.22)	76.53(0.05)	-
75.32%	78.99(2.08)	79.44(0.63)	77.54(1.62)	80.84(0.46)	-	-

60Hz, 40V	1	2	3	4	5	6
11.15%	80.65(1.96)	83.94(0.78)	78.52(3.03)	82.53(0.81)	71.07(0.99)	64.15(1.08)
32.73%	79.37(3.08)	80.89(0.12)	78.04(1.69)	76.86(0.6)	75.45(1.68)	69.8(1.7)
57.70%	81.73(1.71)	79.67(0.16)	80.36(0.23)	79.4(3.04)	79.24(2.98)	75.1(1.92)
75.32%	80.01(0.73)	84.38(8.15)	80.28(1.36)	80.71(1.25)	79.74(0.07)	75.57(1.85)

60Hz, 60V	1	2	3	4	5	6
11.15%	77.06(2.28)	74.97(0.14)	75.29(0.51)	75.65(2.49)	75.38(0.60)	62.31(5.07)
32.73%	76.72(1.60)	76.14(0.99)	77.45(1.31)	74.93(1.27)	70.64(6.20)	63.46(0.41)
57.70%	78.5(0.41)	75.46(1.00)	72.96(1.22)	75.69(1.75)	69.22(0.00)	
75.32%	77.78(3.37)	79.3(1.37)	79.67(5.61)			

Raw A	1	2	3	4	5	6
11.15%	80.85 (1.37)	79.7(3.38)	77.09(4.36)	77.23(1.23)	61.84(2.67)	62.31(5.07)
32.73%	79.82(2.09)	78.72(0.16)	79.87(1.89)	79.07(1.6)	76.91(1.09)	79.49(1.34)
57.70%	78.8(1.02)	78.39(1.26)	77.84(2.98)	77.37(3.59)	79.73(2.17)	72.63(10.52)
75.32%	78.97(1.76)	78.94(1.2)	78.54(2.00)	74.33(1.25)	79.05(2.91)	80.33(0.45)

Raw B	1	2	3	4	5	6
11.15%	76.36(1.09)	76.43(0.44)	78.66(2.58)	77.21(1.87)	78.32(3.71)	62.31(5.07)
32.73%	77(9.38)	79.41(1.00)	79.51(0.64)	78.51(4.35)	77.71(2.03)	79.49(1.34)
57.70%	77.11(2.95)	77.67(1.4)	80.19(0.88)	76.81(2.9)	79.65(1.69)	72.63(10.52)
75.32%	80.71(0.97)	78.51(2.38)	77.44(2.72)	79.13(0.21)	76.36(3.16)	80.33(0.45)

Raw C	1	2	3	4	5	6
11.15%	82.72(2.53)	79.72(1.74)	79.29(0.29)	78.12(0.33)	75.72(1.17)	64.79(10.22)
32.73%	79.36(0.75)	81.57(5.17)	82.42(1.59)	80.67(3.94)	76.45(5.26)	70.03(1.24)
57.70%	80.13(2.39)	78.68(0.16)	81.49(2.49)	80(1.15)	79.56(0.21)	78.72(2.04)
75.32%	81.96(0.00)	81.08(0.15)	83.2(0.00)	80.4(0.55)	80.85(0.00)	80.79(0.00)

iii. Mean values (S.D) of Rehydration Ratio

1Hz, 40V	1	2	3	4	5	6
11.15%	1.15(0.02)	1.10(0.02)	1.06(0.03)	1.30()	-	-
32.73%	1.14(0.18)	1.10(0.04)	1.18(0.01)	1.16(0.05)	1.18(0.06)	-
57.70%	1.04(0.01)	1.17(0.03)	1.11(0.03)	1.15(0.00)	-	-
75.32%	1.08(0.02)	1.14(0.02)	1.11(0.02)	1.15(0.01)	-	-

60Hz, 40V	1	2	3	4	5	6
11.15%	1.19(0.06)	1.19(0.07)	1.19(0.08)	1.19(0.04)	1.63(0.11)	1.76(0.16)
32.73%	1.19(0.08)	1.16(0.06)	1.27(0.03)	1.16(0.02)	1.23(0.06)	1.39(0.03)
57.70%	1.17(0.02)	1.32(0.11)	1.20(0.06)	1.15(0.00)	1.12(0.02)	1.33(0.06)
75.32%	1.31(0.10)	1.21(0.02)	1.27(0.14)	1.15(0.01)	1.38(0.07)	1.18(0.01)

60Hz, 60V	1	2	3	4	5	6
11.15%	1.11(0.02)	1.10(0.02)	1.02(0.01)	1.13(0.05)	1.49(0.05)	1.47(0.05)
32.73%	1.06(0.01)	1.07(0.01)	1.15(0.07)	1.10(0.04)	1.23(0.06)	1.27(0.08)
57.70%	1.06(0.00)	1.09(0.00)	1.04(0.02)	1.09(0.00)	1.16()	
75.32%	1.04(0.01)	1.07(0.04)	1.11(0.07)			

Raw A	1	2	3	4	5	6
11.15%	1.12(0.02)	1.16(0.00)	1.19(0.03)	1.42(0.08)	1.33(0.03)	
32.73%	1.15(0.01)	1.14(0.04)	1.13(0.02)	1.21(0.01)	1.31(0.13)	
57.70%	1.15(0.02)	1.18(0.00)	1.12(0.03)	1.13(0.05)	1.33(0.15)	
75.32%	1.17(0.00)	1.22(0.01)	1.11(0.00)	1.16(0.00)	1.29(0.01)	

Raw B	1	2	3	4	5	6
11.15%	1.13(0.02)	1.11(0.00)	1.17(0.08)	1.26(0.09)	1.61(0.18)	1.35(0.07)
32.73%	1.11(0.33)	1.14(0.01)	1.16(0.06)	1.46(0.11)	1.52(0.00)	1.57(0.16)
57.70%	1.09(0.02)	1.13(0.02)	1.07(0.03)	1.12(0.02)	1.30(0.12)	1.43(0.39)
75.32%	1.12(0.03)	1.10(0.00)	1.09(0.04)	1.16(0.02)	1.27(0.05)	1.42(0.09)

Raw C	1	2	3	4	5	6
11.15%	1.15(0.01)	1.12(0.05)	1.12(0.02)	1.19(0.00)	1.25(0.00)	1.46(0.16)
32.73%	1.15(0.02)	1.13(0.04)	1.16(0.01)	1.14(0.01)	1.24(0.04)	1.24(0.04)
57.70%	1.12(0.02)	1.05(0.03)	1.17(0.05)	1.11(0.04)	1.14(0.03)	1.26(0.09)
75.32%	1.14(0.00)	1.10(0.04)	1.12(0.00)	1.14(0.02)	1.23(0.00)	1.21(0.00)

iv. Mean values (S.D) of Coefficient of Rehydration

1Hz, 40V	1	2	3	4	5	6
11.15%	97.94(17.49)	96.31(6.98)	90.28(9.25)	41.40()	-	-
32.73%	90.50(17.67)	96.96(6.15)	114.10(6.61)	76.11(5.25)	69.52(4.5)	-
57.70%	97.50(19.48)	125.76(8.29)	100.67(0.90)	85.23(6.12)	-	-
75.32%	86.80(4.12)	115.80(2.57)	103.12(8.15)	111.67(5.23)	-	-

60Hz, 40V	1	2	3	4	5	6
11.15%	126.60(2.58)	89.25(12.13)	99.64(1.68)	117.46(5.46)	61.67(4.74)	41.97(3.78)
32.73%	105.68(10.59)	117.20(5.16)	100.17(13.28)	111.93(0.87)	75.32(1.60)	62.51(4.95)
57.70%	104.41(8.55)	118.42(2.70)	111.06(10.24)	124.81(5.17)	130.39(8.67)	88.05(0.38)
75.32%	103.54(7.71)	191.63(17.78)	109.13(6.55)	115.57(6.15)	111.87(16.19)	72.47(3.51)

60Hz, 60V	1	2	3	4	5	6
11.15%	104.71(21.55)	100.90(1.91)	81.95(12.47)	84.67(3.57)	97.93(12.74)	58.61(5.53)
32.73%	96.16(0.44)	92.63(11.39)	97.37(8.43)	127.42(10.22)	81.60(8.34)	61.39(8.50)
57.70%	90.25(1.66)	111.23(15)	73.91(4.18)	105.10(11.07)	73.63(0.00)	
75.32%	88.88(7.92)	95.60(1.84)	94.11(3.98)			

Raw A	1	2	3	4	5	6
11.15%	93.86(0.20)	116.08(3.07)	100.42(6.15)	107.99(8.53)	48.89(4.42)	
32.73%	121.79(0.63)	112.13(12.12)	112.23(0.00)	99.50(2.69)	89.13(13.43)	
57.70%	88.21(3.11)	124.69(5.89)	113.26(4.38)	128.08(2.09)	118.23(0.61)	
75.32%	117.10(0.73)	107.36(4.47)	103.08(0.34)	86.61(3.75)	110.46(2.66)	

Raw B	1	2	3	4	5	6
11.15%	109.90(17.44)	110.59(11.67)	96.91(5.41)	88.62(10.84)	112.49(4.37)	49.68(10.55)
32.73%	100.31(16.33)	133.20(2.43)	86.70(19.81)	95.17(2.18)	118.16(13.44)	82.61(1.00)
57.70%	111.95(5.21)	114.71(9.64)	112.70(5.19)	101.76(3.88)	107.95(4.49)	85.04(26.91)
75.32%	104.22(1.91)	116.68(13.89)	108.07(1.05)	121.40(5.73)	112.21(10.10)	102.74(5.61)

Raw C	1	2	3	4	5	6
11.15%	116.98(3.77)	135.20(19.13)	109.94(1.35)	94.12(0.77)	81.02(1.69)	53.43(0.00)
32.73%	121.87(7.81)	117.20(0.60)	104.46(11.64)	130.10(0.75)	93.01(8.07)	65.14(65.14)
57.70%	154.63(5.08)	110.59(3.17)	125.52(19.42)	93.43(5.45)	103.52(9.57)	115.66(6.14)
75.32%	147.04(0.00)	126.44(1.89)	145.42(0.00)	116.38(0.94)	128.69(0.00)	133.94(0.00)

b. Data set for Color Studies

i. Mean values (S.D) of Coefficient of DL1 during storage

1Hz, 40V	1	2	3	4	5	6
11.15%	-1.47(0.42)	-0.22(3.06)	-6.28(2.94)	2.11(2.28)	-	-
32.73%		-2.37(2.61)	-3.42(3.03)	-4.82(0.95)	-0.30(3.64)	
57.70%	-0.86(2.19)	-3.90(3.73)	-6.03(2.40)	-0.87(4.35)	-	-
75.32%	1.56(5.32)	-2.58(0.89)	-6.44(4.37)	-2.90(1.82)	-	-

60Hz, 40V	1	2	3	4	5	6
11.15%	2.64(1.01)	2.41(0.98)	0.51(0.70)	-0.54(1.62)	1.14(3.01)	-5.91(5.40)
32.73%	4.53(3.16)	1.39(1.62)	-3.49(2.76)	0.16(0.37)	3.01(1.69)	1.22(2.85)
57.70%	1.95(1.07)	0.48(0.77)	-6.57(2.66)	-4.49(1.52)	-0.55(0.87)	-6.56(1.56)
75.32%	2.05(0.83)	-3.53(1.71)	-7.35(0.83)	-6.43(2.38)	-4.70(0.49)	-1.56(0.88)

60Hz, 60V	1	2	3	4	5	6
11.15%	-3.01(6.05)	-4.03(3.96)	-1.47(3.43)	-5.40(1.45)	-3.55(2.37)	-5.31(2.91)
32.73%	-1.78(3.89)	-3.81(3.96)	-5.18(3.05)	-5.49(4.23)	-5.95(0.98)	-4.67(3.77)
57.70%	-0.45(2.10)	-2.59(5.46)	3.46(4.41)	-5.38(1.79)	-4.96(2.24)	
75.32%	-0.95(2.16)	7.22(15.69)	-1.36(2.02)			

Raw A	1	2	3	4	5	6
11.15%	-3.83(3.52)	-3.95(1.52)	-4.62(0.54)	0.58(0.31)	0.85(3.23)	0.65(2.53)
32.73%	-3.35(0.72)	-4.17(1.04)	-5.64(2.03)	-0.91(1.07)	1.27(0.49)	-4.83(1.40)
57.70%	-4.22(0.99)	-5.69(1.74)	-4.54(0.29)	-1.52(1.13)	-1.09(1.46)	-2.81 (2.51)
75.32%	-4.22(0.99)	-3.99(1.35)	-6.23(0.26)	-3.37(3.89)	-1.01(0.27)	-2.90(1.52)

Raw B	1	2	3	4	5	6
11.15%	-7.79(2.13)	-4.77(3.24)	-2.49(2.01)	-4.61(1.58)	-5.53(2.06)	-2.92(2.61)
32.73%	-8.36(1.58)	-8.78(0.09)	-6.31(1.53)	-4.66(2.59)	-4.07(1.75)	-7.63(1.59)
57.70%	-10.29(3.14)	-6.06(0.60)	-6.40(2.20)	-7.63(0.77)	-5.05(0.90)	-6.57(1.53)
75.32%	-13.46(1.86)	-8.71(2.04)	-8.94(1.76)	-11.11(1.45)	-9.22(1.06)	-11.26(3.37)

ii. Mean values (S.D) of Coefficient of Da1 during storage

1Hz, 40V	1	2	3	4	5	6
11.15%	5.64(1.97)	8.64(1.96)	13.27(2.48)	7.80(1.08)	-	-
32.73%		10.74(2.81)	11.25(1.97)	14.17(2.35)	11.91(1.60)	
57.70%	6.33(0.82)	11.73(2.85)	13.67(1.86)	10.82(3.83)	-	-
75.32%	8.09(1.31)	9.02(1.39)	11.77(5.04)	15.75(1.09)	-	-

60Hz, 40V	1	2	3	4	5	6
11.15%	2.30(0.95)	2.38(2.86)	1.93(5.03)	7.27(2.19)	20.14(5.50)	20.99(2.96)

32.73%	2.57(1.63)	4.11(0.82)	8.31(1.82)	6.40(1.13)	9.68(0.70)	24.23(1.19)
57.70%	1.96(1.99)	2.12(0.33)	9.99(2.42)	11.08(1.33)	5.13(0.29)	10.22(1.94)
75.32%	2.78(0.72)	6.99(1.03)	12.31(0.43)	12.27(2.28)	11.13(1.52)	7.64(2.01)

60Hz, 60V	1	2	3	4	5	6
11.15%	6.28(2.62)	8.00(2.82)	7.58(3.80)	11.48(1.77)	12.91(3.18)	17.45(2.21)
32.73%	4.02(3.06)	7.19(4.01)	11.43(1.64)	12.80(1.48)	13.02(2.70)	15.63(0.61)
57.70%	1.98(1.18)	9.72(2.51)	9.71(2.58)	14.26(2.74)	12.61(1.16)	
75.32%	2.11(1.64)	3.13(1.73)	7.25(2.54)			

Raw A	1	2	3	4	5	6
11.15%	-3.83(3.52)	-3.95(1.52)	-4.62(0.54)	0.58(0.31)	0.85(3.23)	0.65(2.53)
32.73%	-3.35(0.72)	-4.17(1.04)	-5.64(2.03)	-0.91(1.07)	1.27(0.49)	-4.83(1.40)
57.70%	-4.22(0.99)	-5.69(1.74)	-4.54(0.29)	-1.52(1.13)	-1.09(1.46)	-2.81 (2.51)
75.32%	-4.22(0.99)	-3.99(1.35)	-6.23(0.26)	-3.37(3.89)	-1.01(0.27)	-2.90(1.52)

Raw B	1	2	3	4	5	6
11.15%	5.50(2.17)	5.64(2.46)	3.23(3.25)	7.08(2.21)	7.71(2.54)	12.56(7.13)
32.73%	6.31(1.96)	9.08(1.18)	7.19(1.44)	7.17(2.19)	7.15(2.13)	9.19(2.08)
57.70%	8.20(2.60)	8.25(2.47)	7.05(0.46)	8.59(1.58)	7.62(0.85)	10.29(3.56)
75.32%	10.87(1.32)	10.46(2.23)	9.40(1.80)	11.89(1.64)	11.25(1.59)	11.17(4.13)

iii. Mean values (S.D) of Coefficient of Db1 during storage

1Hz, 40V	1	2	3	4	5	6
11.15%	9.67(1.61)	11.94(2.05)	17.30(2.46)	8.23(1.40)	-	-
32.73%		14.68(2.26)	14.13(2.91)	14.19(2.84)	13.12(1.37)	
57.70%	10.08(0.37)	15(3.35)	16.57(2.73)	10.91(4.04)	-	-
75.32%	10.16(1.75)	13.81(1.56)	15.29(4.61)	15.15(1.11)	-	-

60Hz, 40V	1	2	3	4	5	6
11.15%	1.94(0.93)	1.33(1.70)	3.17(1.38)	8.67(1.69)	21.68(6.18)	24.67(3.45)
32.73%	2.50(1.30)	2.37(0.14)	9.86(3.32)	8.16(2.25)	9.27(0.80)	28.37(2.24)
57.70%	2.91(1.52)	0.93(0.52)	13.28(3.98)	13.74(2.13)	4.36(0.68)	12.59(5.37)
75.32%	3.10(1.47)	9.06(1.71)	17.04(0.61)	14.08(3.16)	15.85(1.52)	5.05(3.78)

60Hz, 60V	1	2	3	4	5	6
11.15%	14.23(3.41)	11.29(2.18)	14.13(3.87)	17.41(2.88)	16.98(4.75)	23.65(1.76)
32.73%	13.42(4.69)	12.98(3.94)	17.12(3.00)	19.00(2.93)	20.66(1.84)	21.43(1.71)
57.70%	10.40(2.01)	15.45(2.45)	11.00(2.71)	20.04(2.22)	19.58(2.36)	
75.32%	8.05(1.23)	6.39(2.48)	9.27(2.99)			

Raw A	1	2	3	4	5	6
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11.15%	7.10(1.60)	9.83(2.10)	8.32(0.90)	5.39(0.92)	11.35(2.70)	13.05(2.00)
32.73%	6.31(0.49)	8.83(1.22)	8.82(1.44)	4.95(0.75)	4.57(0.85)	9.54(2.16)
57.70%	6.28(1.75)	14.31(2.79)	8.99(0.43)	6.76(3.07)	9.48(2.82)	7.14(1.56)
75.32%	6.28(1.75)	9.82(2.11)	14.35(0.60)	9.24(3.84)	9.86(1.37)	5.68(1.37)

Raw B	1	2	3	4	5	6
11.15%	14.58(3.55)	10.12(3.63)	8.07(4.42)	12.91(3.72)	13.96(3.36)	16.49(6.19)
32.73%	15.28(4.31)	14.97(0.74)	13.52(2.59)	12.04(4.34)	14.59(3.39)	14.87(2.23)
57.70%	16.25(3.78)	11.53(2.16)	15.95(9.50)	13.77(1.24)	11.56(0.02)	15.63(2.43)
75.32%	20.03(1.61)	15.09(2.49)	13.56(2.33)	16.50(0.61)	17.06(1.85)	15.63(1.85)

iv. Mean values (S.D) of Coefficient of Dc1 during storage

1Hz, 40V	1	2	3	4	5	6
11.15%	10.15(2.25)	12.90(3.76)	21.66(3.41)	12.11(2.98)	-	-
32.73%		18.10(3.09)	18.01(3.47)	21.86(1.87)	18.27(5.91)	
57.70%	14.17(5.94)	18.94(4.35)	20.15(2.73)	15.19(5.58)	-	-
75.32%	13.19(2.35)	16.19(3.33)	19.21(6.74)	20.82(3.30)	-	-

60Hz, 40V	1	2	3	4	5	6
11.15%	2.36(1.40)	3.22(1.72)	6.13(0.28)	11.32(2.63)	26.61(6.48)	32.36(4.43)
32.73%	3.78(1.02)	4.54(0.95)	12.87(3.61)	10.27(2.14)	14.10(2.72)	22.87(14.71)
57.70%	-0.96(5.05)	2.83(1.08)	16.58(4.53)	17.29(2.81)	6.55(0.92)	16.46(4.97)
75.32%	4.27(1.55)	11.41(1.87)	14.66(7.16)	18.64(3.76)	15.08(6.45)	12.58(2.85)

60Hz, 60V	1	2	3	4	5	6
11.15%	14.28(4.16)	13.66(3.39)	14.51(4.17)	20.97(3.60)	22.15(2.72)	33.36(6.92)
32.73%	15.48(6.89)	19.29(1.97)	20.31(3.25)	22.61(2.91)	23.99(3.25)	28.71(6.01)
57.70%	4.55(6.10)	17.9(3.45)	12.50(2.79)	24.42(3.49)	22.15(2.43)	
75.32%	7.23(1.93)	10.10(6.50)	11.73(3.87)			

Raw A	1	2	3	4	5	6
11.15%	7.64(2.19)	11.24(2.54)	8.64(0.91)	4.79(0.66)	11.84(3.94)	21.43(7.88)
32.73%	7.19(0.47)	9.14(0.76)	10.06(2.55)	9.79(0.69)	4.61(0.68)	9.42(2.82)
57.70%	8.53(2.12)	12.61(5.30)	9.12(0.77)	6.76(3.07)	8.91(5.35)	5.46(2.86)
75.32%	9.64(4.44)	10.63(2.90)	13.95(3.42)	9.55(3.73)	5.63(10.14)	7.15(2.16)

Raw B	1	2	3	4	5	6
11.15%	15.69(3.59)	11.15(4.32)	7.87 (5.51)	15.05(5.15)	17.41(3.83)	14.15(2.56)
32.73%	14.83(4.46)	17.05(1.21)	16.55(3.58)	16.01(6.42)	15.79(4.18)	16.98(2.87)
57.70%	14.99(5.69)	13.54(1.99)	13.28(1.09)	17.11(2.48)	19.80(2.01)	17.65(3.59)
75.32%	21.21(2.34)	20.12(4.32)	15.62(1.31)	19.27(2.13)	16.45(3.44)	18.47(1.30)

v. Mean values (S.D) of Coefficient of Dh1 during storage

1Hz, 40V	1	2	3	4	5	6
11.15%	3.62(0.76)	3.90(0.72)	4.78(1.71)	-0.71(1.07)	-	-
32.73%		3.42(1.14)	2.65(0.76)	-2.16(1.97)	0.18(2.16)	
57.70%	3.18(1.41)	3.43(1.40)	2.72(1.55)	-1.38(1.88)	-	-
75.32%	1.65(0.79)	4.79(0.48)	3.53(1.67)	-6.11(3.63)	-	-

60Hz, 40V	1	2	3	4	5	6
11.15%	-1.20(1.60)	-1.58(2.22)	-1.53(1.64)	3.35(0.48)	-5.29(3.55)	3.92(6.79)
32.73%	-0.07(1.41)	-2.71(1.65)	0.87(2.00)	10.82(13.44)	-0.75(2.74)	2.04(13.20)
57.70%	1.15(1.71)	-1.75(0.87)	3.21(1.96)	1.64(2.36)	-1.28(0.83)	4.26(1.08)
75.32%	0.26(0.95)	1.53(1.05)	4.24(1.63)	0.67(1.59)	4.61(1.03)	-3.06(4.22)

60Hz, 60V	1	2	3	4	5	6
11.15%	10.18(2.54)	3.34(1.38)	6.29(0.62)	5.13(1.69)	5.23(2.25)	7.51(1.25)
32.73%	10.04(2.69)	5.12(0.28)	5.29(2.01)	6.49(2.89)	7.49(1.53)	5.23(3.49)
57.70%	7.30(2.13)	5.37(0.62)	1.27(0.67)	4.76(1.66)	7.48(1.32)	
75.32%	6.21(0.94)	2.88(0.57)	1.31(0.99)			

Raw A	1	2	3	4	5	6
11.15%	4.54(1.28)	6.06(1.11)	6.56(0.99)	3.95(1.93)	3.61(1.63)	6.13(3.66)
32.73%	3.22(0.55)	6.47(0.55)	4.83(1.70)	2.38(0.20)	3.54(1.62)	8.00(1.33)
57.70%	0.72 (1.56)	5.52(3.01)	6.94(1.62)	3.43(1.19)	-7.21(13.46)	7.16(0.94)
75.32%	0.72(1.56)	6.12(0.36)	8.62(1.49)	4.23(0.49)	-13.69(1.52)	10.55(14.01)

Raw B	1	2	3	4	5	6
11.15%	22.84(3.39)	5.27(1.04)	6.04(0.98)	6.93(0.95)	7.17(2.92)	5.44(2.24)
32.73%	13.50(2.08)	6.48(0.64)	7.04(1.01)	6.27(2.54)	8.84(1.78)	7.33(1.39)
57.70%	12.31(2.61)	4.24(0.83)	5.44(1.12)	6.22(1.67)	5.09(1.08)	6.82(0.79)
75.32%	14.40(2.47)	12.28(14.65)	4.76(1.02)	5.88(1.58)	7.09(1.20)	4.67(3.61)

vi. Mean values (S.D) of Coefficient of DL2 during storage

1Hz, 40V	1	2	3	4	5	6
11.15%	-0.48(0.89)	1.69(2.52)	-4.79(0.64)	5.63(1.95)	-	-
32.73%		0.01(2.79)	-3.70(1.53)	-1.90(2.20)	3.12(3.32)	
57.70%	-0.71(1.87)	-5.24(2.00)	-5.39(2.97)	-1.70(2.22)	-	-
75.32%	1.02(4.74)	-1.68(1.69)	-4.64(2.29)	0.53(3.55)	-	-

60Hz, 40V	1	2	3	4	5	6
11.15%	9.70(2.04)	8.08(2.41)	5.24(3.19)	7.23(5.26)	22.99(2.74)	15.30(7.93)
32.73%	7.16(4.92)	6.67(3.93)	2.15(2.12)	10.67(0.89)	17.91(4.82)	18.40(3.76)

57.70%	5.18(1.79)	3.19(0.31)	3.39(0.51)	-3.48(2.67)	7.92(4.54)	10.48(4.44)
75.32%	8.04(1.59)	0.02(3.53)	-2.88(3.90)	-2.72(1.23)	3.09(2.72)	12.11(4.26)

60Hz, 60V	1	2	3	4	5	6
11.15%	-0.63(4.05)	-2.14(3.65)	-1.21(2.54)	-2.24(1.25)	5.68(1.31)	9.55(4.43)
32.73%	-1.76(2.63)	-2.75(3.77)	-2.46(3.98)	-4.22(4.53)	-3.93(3.55)	5.10(4.11)
57.70%	-0.65(2.30)	-5.27(1.01)	2.91(2.74)	-3.46(3.75)	-3.90(4.04)	
75.32%	-1.87(2.08)	-0.36(0.53)	-0.46(2.68)			

Raw A	1	2	3	4	5	6
11.15%	-2.14(2.70)	1.22(1.23)	1.06(1.70)	3.87(2.80)	18.83(5.38)	26.66(4.84)
32.73%	-0.07(1.06)	-0.73(2.57)	-3.75(1.87)	1.84(3.13)	5.45(3.01)	10.57(3.67)
57.70%	-1.84(1.50)	-1.86(2.69)	-1.06(0.91)	-2.82(0.39)	3.91(1.96)	4.55(2.86)
75.32%	-1.84(1.50)	1.75(0.37)	-3.03(1.22)	-1.08(2.54)	6.82(2.53)	6.92(3.98)

Raw B	1	2	3	4	5	6
11.15%	-3.21(2.78)	-1.50(2.75)	-0.67(1.59)	-0.04(2.22)	3.66(2.88)	11.79(3.72)
32.73%	-7.17(3.39)	-4.59(2.96)	-2.55(4.02)	2.82(3.22)	2.38(1.31)	3.87(1.94)
57.70%	-8.90(3.42)	-1.33(1.22)	-4.47(2.73)	-3.54(2.70)	-1.70(0.44)	3.96(2.70)
75.32%	-7.75(2.11)	-4.41(1.62)	-5.16(2.42)	-4.78(0.95)	-0.92(1.64)	-4.95(2.00)

vii. Mean values (S.D) of Coefficient of Da2 during storage

1Hz, 40V	1	2	3	4	5	6
11.15%	6.14(2.25)	7.50(1.88)	12.63(2.31)	5.31(3.29)	-	-
32.73%		9.13(1.20)	11.31(0.73)	13.08(1.54)	8.44(2.04)	
57.70%	6.98(1.16)	12.73(1.72)	13.33(2.16)	10.46(2.42)	-	-
75.32%	7.45(0.95)	9.40(2.25)	9.57(2.67)	9.89(3.49)	-2.01(0.87)	-

60Hz, 40V	1	2	3	4	5	6
11.15%	-2.01(0.87)	1.94(1.75)	6.00(2.53)	7.29(0.18)	21.43(3.87)	18.95(4.15)
32.73%	1.45(1.56)	1.99(2.25)	8.98(2.71)	12.75(1.88)	16.64(1.08)	24.14(2.85)
57.70%	1.48(1.14)	0.00(1.53)	14.71(1.36)	14.98(1.15)	8.88(2.17)	14.21(0.36)
75.32%	-3.42(1.50)	6.33(1.64)	12.19(2.04)	12.69(2.04)	11.49(1.57)	9.93(1.97)

60Hz, 60V	1	2	3	4	5	6
11.15%	3.98(1.44)	6.73(1.59)	7.79(2.82)	12.84(10.76)	10.27(1.23)	11.64(2.31)
32.73%	4.10(2.14)	6.06(3.22)	8.45(2.46)	12.05(0.85)	12.09(0.85)	11.65(0.61)
57.70%	2.85(1.31)	9.89(2.80)	8.58(1.91)	13.24(2.56)	11.91(2.71)	
75.32%	2.07(0.99)	3.99(1.51)	6.96(3.04)			

Raw A	1	2	3	4	5	6
11.15%	2.84(0.74)	1.95(1.20)	0.18(0.71)	-0.98(3.15)	8.10(8.09)	11.88(0.93)

32.73%	1.85(0.92)	1.82(2.28)	5.30(2.66)	0.74(2.40)	-1.35(2.64)	5.90(2.77)
57.70%	3.45(1.57)	7.56(1.57)	0.19(1.62)	0.44(1.45)	1.10(2.41)	-0.41(1.13)
75.32%	3.45(1.57)	1.34(1.58)	4.20(1.61)	2.92(3.21)	-0.99(1.82)	-1.79(3.96)

Raw B	1	2	3	4	5	6
11.15%	-0.17(3.14)	2.35(2.09)	1.47(1.20)	4.40(4.54)	6.34(2.74)	8.16(5.35)
32.73%	4.52(4.16)	4.58(2.34)	4.05(3.08)	2.17(2.51)	3.04(1.37)	6.83(1.48)
57.70%	6.82(2.90)	2.70(1.90)	6.53(1.47)	6.23(1.41)	2.96(0.75)	8.97(3.50)
75.32%	5.07(0.67)	5.85(1.21)	6.85(3.33)	6.77(1.42)	5.36(1.96)	4.45(1.55)

viii. Mean values (S.D) of Coefficient of Db2 during storage

1Hz, 40V	1	2	3	4	5	6
11.15%	10.55(2.02)	10.42(1.82)	15.73(1.28)	5.40(3.66)	-	-
32.73%		12.69(1.74)	12.97(1.13)	12.57(2.13)	8.08(2.14)	
57.70%	10.86(0.66)	16.02(1.34)	15.77(2.64)	10.07(2.89)	-	-
75.32%	9.55(1.68)	13.19(1.97)	12.63(1.87)	8.78(1.93)	-	-

60Hz, 40V	1	2	3	4	5	6
11.15%	-4.11(1.38)	-0.33(1.47)	3.84(3.87)	7.98(3.49)	27.44(4.46)	25.06(5.82)
32.73%	0.63(2.04)	0.00(3.23)	9.17(3.98)	11.73(2.28)	16.40(2.95)	30.63(1.57)
57.70%	1.24(2.13)	-0.15(0.88)	15.93(3.24)	16.74(0.83)	7.40(1.19)	16.59(4.78)
75.32%	-5.66(1.46)	8.30(2.09)	15.26(1.08)	15.48(3.06)	15.29(1.85)	7.52(6.02)

60Hz, 60V	1	2	3	4	5	6
11.15%	11.20(2.31)	9.60(2.24)	13.72(2.37)	13.95(2.74)	13.00(3.08)	17.03(2.81)
32.73%	13.20(3.59)	11.29(3.08)	13.21(3.50)	18.20(3.02)	18.96(2.23)	18.02(2.29)
57.70%	11.36(2.08)	15.21(2.66)	10.28(2.78)	19.14(1.55)	17.96(4.27)	
75.32%	8.89(0.60)	7.23(2.20)	9.87(3.36)			

Raw A	1	2	3	4	5	6
11.15%	6.39(1.16)	5.82(2.68)	3.28(0.64)	0.58(3.10)	5.86(4.45)	19.34(3.69)
32.73%	3.31(1.69)	5.29(2.60)	7.99(2.09)	1.47(2.95)	-1.18(3.10)	9.52(3.57)
57.70%	3.37(1.84)	11.98(2.93)	5.11(1.05)	3.52(1.87)	2.72(3.33)	2.79(1.19)
75.32%	3.37(1.84)	5.43(1.95)	10.74(1.03)	6.08(3.32)	2.40(1.77)	-0.50(5.86)

Raw B	1	2	3	4	5	6
11.15%	7.01(4.70)	6.19(3.24)	5.39(1.57)	9.83(5.78)	11.09(3.74)	12.92(2.79)
32.73%	11.79(6.84)	9.39(3.50)	8.83(4.47)	5.88(4.48)	7.80(1.88)	14.87(3.37)
57.70%	13.74(4.11)	5.33(2.19)	10.08(2.65)	10.73(0.77)	5.94(2.19)	16.20(0.31)
75.32%	12.03(0.78)	9.57(1.67)	9.79(4.44)	10.67(1.70)	9.73(2.09)	16.44(0.48)

ix. Mean values (S.D) of Coefficient of Dc2 during storage

1Hz, 40V	1	2	3	4	5	6
11.15%	11.92(2.97)	12.72(2.63)	20.01(2.06)	7.56(4.92)	-	-
32.73%		15.55(1.99)	17.21(0.56)	17.69(2.07)	11.66(2.76)	
57.70%	12.73(1.22)	20.38(2.14)	20.63(3.36)	14.47(3.69)	-	-
75.32%	12.07(1.78)	16.03(2.90)	15.78(3.05)	13.09(4.65)	-	-

60Hz, 40V	1	2	3	4	5	6
11.15%	-4.33(1.50)	1.07(1.66)	6.90(4.56)	12.53(5.88)	34.12(5.75)	8.28(0.75)
32.73%	1.47(2.46)	1.39(3.89)	12.13(3.57)	17.37(2.92)	23.02(3.14)	9.52(1.34)
57.70%	1.92(2.29)	-0.11(1.09)	15.27(4.57)	22.16(1.25)	11.54(2.29)	7.53(2.68)
75.32%	-6.49(1.14)	10.40(2.66)	19.51(1.29)	22.99(1.24)	19.05(2.42)	-3.68(2.29)

60Hz, 60V	1	2	3	4	5	6
11.15%	10.61(2.64)	11.56(2.08)	15.38(3.59)	15.94(3.22)	16.49(2.88)	20.41(3.62)
32.73%	12.23(3.87)	12.44(4.41)	15.45(4.20)	21.51(2.67)	22.14(2.88)	21.14(1.97)
57.70%	5.84(5.87)	17.90(3.82)	13.37(3.28)	23.04(2.86)	20.47(5.71)	
75.32%	7.76(0.80)	8.01(2.64)	11.97(4.46)			

Raw A	1	2	3	4	5	6
11.15%	6.64(1.24)	-6.45(23.76)	2.45(0.86)	0.58(3.10)	7.88(6.06)	21.71(2.32)
32.73%	3.83(1.67)	5.04(3.46)	9.39(3.27)	1.47(2.95)	-1.81(3.95)	10.93(4.38)
57.70%	4.82(2.25)	13.86(3.20)	3.81(1.90)	3.52(1.87)	0.58(5.20)	1.72(1.30)
75.32%	8.58(6.01)	4.83(2.53)	10.70(1.80)	6.08(3.32)	1.15(2.43)	-1.61(6.83)

Raw B	1	2	3	4	5	6
11.15%	4.79(5.64)	6.07(3.80)	4.85(2.03)	10.07(7.36)	12.44(4.48)	12.90(8.10)
32.73%	11.32(7.73)	9.95(4.22)	9.20(5.39)	5.72(4.78)	7.73(2.34)	12.04(2.22)
57.70%	14.40(4.82)	5.72(2.86)	11.79(2.88)	12.01(1.50)	10.71(2.73)	15.01(4.43)
75.32%	12.01(0.90)	10.99(2.02)	11.81(5.50)	12.33(2.12)	3.30(0.59)	12.46(1.50)

x. Mean values (S.D) of Coefficient of Dh2 during storage

1Hz, 40V	1	2	3	4	5	6
11.15%	4.11(0.82)	3.11(1.03)	4.39(3.73)	-0.70(0.56)	-	-
32.73%		2.92(1.39)	0.60(2.09)	-2.47(1.82)	-1.76(1.77)	
57.70%	3.33(0.92)	3.38(0.89)	1.87(0.90)	-1.90(1.85)	-	-
75.32%	1.76(1.35)	3.63(0.60)	2.82(2.00)	-3.37(1.50)	-	-

60Hz, 40V	1	2	3	4	5	6
11.15%	-3.55(1.16)	-3.24(2.92)	-3.39(2.59)	-4.49(5.52)	29.97(10.35)	12.49(12.40)
32.73%	-1.20(1.64)	-2.79(1.22)	-1.96(0.82)	-3.02(3.12)	2.13(13.61)	12.60(12.04)

57.70%	-0.39(1.40)	-0.25(2.68)	-4.01(1.34)	-0.61(1.24)	-3.16(1.96)	4.41(2.76)
75.32%	-2.48(1.67)	1.46(0.26)	1.19(3.58)	2.81(1.22)	3.00(1.17)	-2.65(3.96)

60Hz, 60V	1	2	3	4	5	6
11.15%	8.18(1.48)	2.84(2.75)	5.39(1.09)	4.77(1.11)	2.69(2.75)	5.16(1.05)
32.73%	9.53(2.19)	4.41(0.42)	4.04(1.32)	6.22(3.06)	6.34(1.82)	6.05(3.05)
57.70%	7.54(1.75)	4.76(0.54)	1.20(1.29)	4.96(2.54)	5.74(1.94)	
75.32%	7.14(1.35)	2.84(0.54)	2.44(1.24)			

Raw A	1	2	3	4	5	6
11.15%	4.08(1.04)	9.37(9.45)	3.98(0.67)	1.24(1.36)	-0.38(2.41)	20.59(14.46)
32.73%	2.15(0.61)	4.44(0.87)	3.66(1.87)	0.92(2.59)	0.29(1.59)	4.90(2.30)
57.70%	-0.11(1.68)	4.86(1.44)	6.09(1.27)	1.78(1.92)	-11.12(14.01)	4.07(1.82)
75.32%	-0.11(1.68)	4.90(0.31)	6.99(1.26)	3.46(0.62)	-16.22(1.20)	1.98(3.47)

Raw B	1	2	3	4	5	6
11.15%	7.87(1.75)	4.06(0.92)	4.46(0.33)	5.93(1.33)	4.68(1.89)	1.82(1.92)
32.73%	9.72(3.33)	4.62(1.42)	4.66(1.32)	3.89(2.62)	4.65(0.37)	3.28(1.66)
57.70%	9.77(2.54)	2.71(0.86)	3.85(1.77)	4.90(1.32)	2.59(0.47)	3.22(1.34)
75.32%	7.93(0.82)	3.30(0.43)	2.83(1.21)	4.13(1.41)	4.25(1.06)	3.90(1.13)

c. Data set for Texture Studies

i. Mean values (S.D) of Coefficient of Hardness

1Hz, 40V	1	2	3	4	5	6
11.15%	23710.7 3757.73	21818.1 3095.68	22252.66 3888.61)	21147.06 3078.71	.	.
32.73%	27847.48 1513.76	23009.52 193.26	26627.49 5682.72	24955.44 1375.42	25974.10 3408.21	
57.70%	24972.74 3981.05	30284.28 2593.53	24217.52 2955.64	25773.73 1115.39		
75.32%	23981.24 4900.7	26221.28 4230.79	18289.59 691.47	23982.88 .		

60Hz, 40V	1	2	3	4	5	6
11.15%	22988.06 375.8	21201.48 3902.78	18902.01 10389.65	24309.9 4679.41	28290.05 1485.44	22926.85 3909.53
32.73%	22897.65 3255.83	16141.69 3212.01	19796 4129.97	17768.32 727.45	27666.96 2380.7	29842.78 1689.52
57.70%	26075.63 2461.7	26676.11 160.33	18772.25 7442.09	19761.6 1447.18	26388.76 184.87	15168.43 .
75.32%	24637.65 2585.21	25472.68 1895.43	22888.4 922.37	21104.5 4863.96	23809.73 .	19621.67 813.74

60Hz, 60V	1	2	3	4	5	6
11.15%	31442.33 159.64	29804.63 4621.4	28820.31 1537.56	34850.65 673.91	25449.12 1319.36	20313.94 .
32.73%	27053.24 .	30539.3 6986.71	29845.35 448.8	34850.65 673.91	25449.12 1319.36	20313.94 .
57.70%	31187.55 3117.8	33385.7 2961.19	22805.77 6965.38	30984.31 4929.72	25211.63 5695.74	
75.32%	26857.84 .	34533.7 571.95	23045.39 11.73			

Raw A	1	2	3	4	5	6
11.15%	30388.31 1136.02	28811.41 716.6	24667.56 1898.55	25788.09 986.7	27652.27 759.68	25.01 1.16
32.73%	26030.44 241.76	26068.67 0	25695.61 313.5	29014.4 6673.28	24276.93 3842.27	22543.87 0
57.70%	28402.88 933.11	27476.91 3611.94	32111.76 4760.81	28453.11 4743.06	34813.9 930.7	24058.27 5385.88
75.32%	26456.55 2247.53	25973.73 2965.44	27618.69 0	28623.02 1657.16	30441.77 2340.81	27077.68 3545.91

Raw B	1	2	3	4	5	6
11.15%	29213.05 113.36	29496.47 8461.2	28205.77 3311.2	31401.49 5638.32	23452.32 2900.85	34863.82 868.56
32.73%	32725.19 3725.05	28723.65 4428.45	29171.61 305.48	28434.9 1346.8	29232.88 5483.11	34010.89 2074.68
57.70%	33850.37 2301.57	29485.31 1544.28	32852.86 3448.4	30861.16 4360.82	27801.58 5291.23	29211.33 3325.39
75.32%	26790.06 366.01	30772.07 2117.15	29943.12 2242.43	32095.55 2559.35	23407.19 836.24	24131.41 620.75

Raw C	1	2	3	4	5	6
11.15%	23820.68 4316.78	28943.9 8439.77	25065.55 1699.25	23289.09 66.41	28290.05 1485.44	30046.84 4455.77
32.73%	22236.73 361.32	30928.92 6438.69	27341.07 631.45	23338.12 2199.43	27666.96 2380.7	28839.4 1902.97
57.70%	28047.24 1902.19	28625.33 5739	28093.77 3985.35	23400.17 4124.98	26388.76 184.87	24058.27 5385.88
75.32%	32035.63 4181.73	28015.97 0	25521.19 392.64	. .	23809.73 0	21900.13 0

ii. Mean values (S.D) of Coefficient of Adhesiveness

1Hz, 40V	1	2	3	4	5	6
11.15%	-5.23 0.38	-2.37 1.3	-4.24 4.29	-1.68 0.40	. .	
32.73%	-3.58 .	-12.93 15.94	-1.10 0.57	-2.16 .	-1.66 1.72	
57.70%	-13.14 1.88	-3.54 0.03	-2.55 1.18	-1.55 0.58		
75.32%	-12.97 9.24	-9.05 8.66	-1.26 .	-2.16 .		

60Hz, 40V	1	2	3	4	5	6
11.15%	-2.71 0.67	-3.7 1.63	-5.31 0.07	-0.96 0.31	-1.13 0.15	-1.49 .
32.73%	-2.36 1.15	-3.01 1.08	-0.53 0.24	-0.47 0.27	-2.71 0.81	-5.45 0.85
57.70%	-1.33 .	-2 1.67	-4.72 0.15	-1.64 0.12	-12.54 11.91	-1.42 .
75.32%	-2.13 .	-3.48 1.69	-3.49 2.51	-0.35 .	-7.41 .	-1.31 .

60Hz, 60V	1	2	3	4	5	6
11.15%	-97.35	-13.87	-5.04	-16.88	-1.25	-8.37

	31.74	16.35	0.51	14.86	.	.
32.73%	-18.66	-1.98	-3.44	-16.88	-1.25	-8.37
	.	0.87	0.88	14.86	.	.
57.70%	-13.54	-720.72	-22.28	-0.73	-2.98	
	7.36	1010.58	26.11	0.11	0.28	
75.32%	-47.3	-22.34	-31.9			
	.	.	23.78			

Raw A	1	2	3	4	5	6
11.15%	-8.63	-3.39	-20.34	-4.74	-13.77	-10.6
	6.14	0.09	12.44	1.58	16.58	9.82
32.73%	-5.69	-0.05	-8.80	-4.02	-1.79	-4.86
	0.87	0	5.91	0.67	1.05	0
57.70%	-2.94	-2.1	-1.70	-15.38	-12.1	-47.46
	2.18	0.05	0.39	.	8.18	0.99
75.32%	-7.56	-9.66	-11.8	-15.54	-3.38	-16.67
	9.02	9.08	0	16.94	1.79	5.22

Raw B	1	2	3	4	5	6
11.15%	-37.49	-3.54	-4.83	-17.12	-4.79	-4.57
	48.81	2.1	4.29	21.01	2.62	2.88
32.73%	-19.69	-1.48	-20.16	-9.3	-7.16	-12.22
	12.05	1.39	22.63	3.91	0.68	10.41
57.70%	-26.86	-8.08	-2.55	-4.01	-22.55	-13.43
	22.17	7.44	0.23	1.52	17.32	12.84
75.32%	-18.07	-2.93	-6.06	-17.32	-13.65	-24.36
	17.58	1.54	5.12	20.02	16.05	5.65

Raw C	1	2	3	4	5	6
11.15%	.	-2.63	-5.53	-0.12	-1.13	-1.08
	.	1.28	4.86	.	0.15	0.45
32.73%	-2.27	-2.28	-15.44	-1.62	-2.71	-35.17
	1.1	1.58	19.94	0.77	0.81	38.12
57.70%	-0.9	-2.36	-19.88	-3.64	-12.54	-4763.96
	.	1.47	24.49	0.74	11.91	114.83
75.32%	-0.59	-1.35	-12.85	.	-7.41	-1067.33
	.	0	10.18	.	0	0

iii. Mean values (S.D) of Coefficient of Springiness

1Hz, 40V	1	2	3	4	5	6
11.15%	0.38	0.63	0.55	0.57	.	
	0.07	0.01	0.03	0.01	.	
32.73%	0.54	0.56	0.60	0.53	0.50	

	0.05	0.03	0.01	0	0.04	
57.70%	0.41 0.07	0.58 0.02	0.58 0.01	0.54 0.02		
75.32%	0.53 0.13	0.57 0.01	0.53 0.04	0.53 .		

60Hz, 40V	1	2	3	4	5	6
11.15%	0.53 0.02	0.49 0.04	0.58 0.07	0.54 0.11	0.48 0.05	0.36 0.08
32.73%	0.5 0	0.51 0.04	0.58 0.07	0.49 0.1	0.48 0.05	0.47 0.08
57.70%	0.53 0.02	0.48 0.07	0.44 0.11	0.45 0.01	0.53 0.02	0.39 .
75.32%	0.53 0.02	0.58 0.01	0.54 0.01	0.48 0.05	0.50 .	0.42 0.02

60Hz, 60V	1	2	3	4	5	6
11.15%	0.44 0.03	0.51 0.02	0.51 0.02	0.54 0.02	0.53 0.13	0.4 .
32.73%	0.46 .	0.53 0.02	0.5 0.08	0.54 0.02	0.53 0.13	0.4 .
57.70%	0.56 0.08	0.44 0.12	0.33 0.07	0.56 0.04	0.42 0.02	
75.32%	0.45 .	0.43 0.13	0.38 0.01			

Raw A	1	2	3	4	5	6
11.15%	0.47 0.02	0.57 0	0.5 0.02	0.52 0.05	0.51 0.03	0.52 0
32.73%	0.5 0	0.42 0	0.53 0.06	0.49 0.05	0.55 0.12	0.54 0
57.70%	0.45 0.03	0.5 0.02	0.59 0.05	0.56 0.13	0.47 0.06	0.28 0.02
75.32%	0.73 0.36	0.5 0.01	0.60 0	0.5 0.05	0.49 0.06	0.54 0.09

Raw B	1	2	3	4	5	6
11.15%	0.6 0.03	0.57 0.01	0.52 0.05	0.57 0.04	0.53 1:26	0.43 0.04
32.73%	0.69 0.1	0.5 0.05	0.53 0.03	0.66 0.14	0.56 0.03	0.48 0.09
57.70%	0.64 0	0.48 0.08	0.57 0	0.6 0.01	0.58 0.01	0.45 0.01

75.32%	0.46 0.01	0.5 0.03	0.5 0.06	0.51 0.09	0.54 0.03	0.59 0.01
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Raw C	1	2	3	4	5	6
11.15%	0.53 0.01	0.46 0.06	0.48 0.05	0.49 0.02	0.48 0.05	0.42 0.07
32.73%	0.41 0.05	0.43 0.02	0.48 0.07	0.4 0.08	0.48 0.05	0.34 0.03
57.70%	0.5 0.01	0.54 0.03	0.51 0.05	0.52 0.1	0.53 0.02	0.28 0.02
75.32%	0.61 0.09	0.49 0	0.73 0.27	. .	0.5 0	0.3 0

iv. Mean values (S.D) of Coefficient of Cohesiveness

Hardness	1	2	3	4	5	6
11.15%	0.21 0.01	0.2 0.02	0.22 0.04	0.17 0	. .	
32.73%	0.24 0.01	0.2 0.03	0.23 0.03	0.22 0	0.19 0.02	
57.70%	0.19 0.01	0.26 0.01	0.21 0	0.21 0.02		
75.32%	0.21 0.03	0.22 0.02	0.17 0.01	0.22 .		

60Hz, 40V	1	2	3	4	5	6
11.15%	0.16 0	0.17 0.01	0.13 0	0.22 0.01	0.2 0.04	0.59 0.03
32.73%	0.14 0.02	0.14 0.01	0.13 0.03	0.17 0.02	0.2 0	0.17 0
57.70%	0.15 0	0.16 0.08	0.14 0.02	0.16 0.01	0.13 0.02	0.12 .
75.32%	0.16 0.06	0.18 0	0.16 0.01	0.17 0.04	0.20 .	0.17 0.02

60Hz, 60V	1	2	3	4	5	6
11.15%	0.19 0.03	0.24 0.04	0.23 0.02	0.24 0.03	0.27 0.01	0.48 .
32.73%	0.27 .	0.21 0.01	0.22 0.04	0.24 0.03	0.27 0.01	0.48 .
57.70%	0.26 0.1	0.21 0.02	0.23 0.04	0.22 0.02	0.24 0.03	
75.32%	0.28 .	0.3 0.05	0.2 0.04			

Raw A	1	2	3	4	5	6
11.15%	0.16 0.01	0.15 0	0.17 0.06	0.18 0	0.17 0.03	0.18 0
32.73%	0.15 0.02	0.18 0	0.15 0	0.17 0.01	0.16 0.04	0.19 0
57.70%	0.15 0.02	0.11 0	0.2 0.02	0.17 0.03	0.38 0.2	0.19 0.01
75.32%	0.19 0.02	0.15 0.01	0.17 0	0.17 0.01	0.19 0.03	0.18 0.02

Raw B	1	2	3	4	5	6
11.15%	0.2 0.12	0.18 0.03	0.17 0.04	0.18 0	0.18 0.03	0.46 0.04
32.73%	0.21 0.1	0.15 0.02	0.19 0	0.19 0.01	0.2 0.01	0.2 0.02
57.70%	0.2 0.04	0.11 0	0.2 0.02	0.19 0.03	0.18 0.03	0.21 0.02
75.32%	0.18 0.01	0.2 0.06	0.17 0.04	0.17 0.03	0.16 0.03	0.19 0.01

Raw C	1	2	3	4	5	6
11.15%	0.16 0.02	0.16 0.03	0.14 0	0.21 0.02	0.2 0.04	0.55 0.07
32.73%	0.13 0.02	0.14 0.03	0.19 0.01	0.16 0	0.2 0	0.36 0.17
57.70%	0.17 0.02	0.15 0.03	0.15 0.05	0.18 0.01	0.13 0.02	0.19 0.01
75.32%	0.19 0.01	0.13 0	0.12 0.04	. .	0.2 0	0.15 0

v. Mean values (S.D) of Coefficient of Gumminess

1Hz, 40V	1	2	3	4	5	6
11.15%	4986.37 631.61	4294.32 941.45	4924.41 1724.43	3644.81 591.65	. .	
32.73%	6812.67 712.06	4647.86 754.42	6292.51 2138.17	5550.33 353.08	4829.19 1031.52	
57.70%	4886.01 1128.61	7930.66 1076.06	5057.95 638.61	5501.87 692.55		
75.32%	5195.96 1694.58	5791.72 1382.39	3162.22 15.96	5300.66 .		

60Hz, 40V	1	2	3	4	5	6
11.15%	3744.82	3605.89	2423.79	5435.58	5688.36	13671.36

	47.17	948.7	1360.83	761.58	754.62	3004.71
32.73%	3251.74 94.51	2272.75 346.11	2613.61 1130.89	2948.1 155.44	5385.92 332.5	5055.32 402.46
57.70%	3991.26 246.76	4371.89 2178.51	2639.07 1423.03	3174.39 492.41	3445.09 501.54	1750.03 .
75.32%	4004.05 1833.03	4546.33 338.53	3750.87 58.68	3760.79 1635.8	4684.6 .	3266.61 433.01

60Hz, 60V	1	2	3	4	5	6
11.15%	5950.21 927.5	7219.06 2282.35	6554 852.5	8299.98 998.74	6788.34 557.87	9780.29 .
32.73%	7331.51 .	6315.66 1637.85	6519.91 1199.59	8299.98 998.74	6788.34 557.87	9780.29 .
57.70%	8354.76 3952.81	7139.26 1379.79	5356.46 2481.58	6880.73 1738.33	6061.77 2172.44	
75.32%	7518.61 .	10435.5 1727.62	4647.48 839.09			

Raw A	1	2	3	4	5	6
11.15%	4986.82 436.22	4390.11 137.95	4199.12 1135.27	4666.29 233.23	4806.94 559.75	5307.86 0
32.73%	3785.69 617.28	4668.13 0	3908.07 79.99	4913.3 829.81	3944.72 1473.44	4243.91 0
57.70%	4397.09 784.86	3124.2 327.6	6314.35 314.26	4717.03 82.08	13013.98 6618.91	4701.02 1389.63
75.32%	4962.93 1032.7	3993.1 666.17	4681.71 0	4747.97 532.49	5667.88 504.73	4700.55 31.38

Raw B	1	2	3	4	5	6
11.15%	5868.6 3490.52	5368.08 2336.12	4897.84 1696.15	5547.66 936.09	4226.05 1212.46	16199.47 1695.23
32.73%	7105.48 3988.2	4386.9 19.29	5661.77 61.48	5470.28 638.25	5965.51 1431.15	6911.41 943.99
57.70%	6821.52 1884.2	3124.09 217.72	6672.44 91.89	5837.32 1603.25	4822.16 86.28	6072.01 1387.01
75.32%	5589.88 1078.98	6096.83 2380.07	5204.52 1547.17	5357.99 1406.11	3623.64 596.51	4473.07 353.09

Raw C	1	2	3	4	5	6
11.15%	3786.01 1051.1	4528.55 547.43	3611.99 320.08	4895.26 413.87	5688.36 754.62	16276.23 302.47
32.73%	2796.6 442.15	4202.73 118.3	5129.98 260.73	3662.5 387.03	5385.92 332.5	10451.43 5657.51
57.70%	4730.16 991.59	4438.62 1654.58	4030.3 814.59	4252.45 553.6	3445.09 501.54	4701.02 1389.63

75.32%	6045.75 474.67	3676.17 0	3164.35 1078.38	.	4684.6 0	3250.48 0
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vi. Mean values (S.D) of Coefficient of Chewiness

1Hz, 40V	1	2	3	4	5	6
11.15%	1870.75 134.52	2712.13 655.08	2733.45 1081.73	2081.73 390.81	.	.
32.73%	3674.7 750.51	2603.44 577.98	3767.95 2:24	2933.5 210.6	2458.65 720.68	.
57.70%	2052.79 797.96	4583.74 428.74	2938.26 342.67	2952.28 484.75	.	.
75.32%	2614.23 192.08	3293.03 704.69	1685.26 128.19	2784.58 .	.	.

60Hz, 40V	1	2	3	4	5	6
11.15%	2000.42 60.64	1776.92 619.61	1353.52 610.87	2893.61 202.05	2759.73 651.63	5030.16 2201.89
32.73%	1616.52 37.74	1162.52 259.68	1465.55 478.82	1450.21 356	2572.55 131.98	2412.32 603.09
57.70%	2094.62 38.46	2029.58 741.01	1232.19 913.33	1418.68 262.1	1818.03 198.84	676.91 .
75.32%	2145.98 1047.77	2650.99 163.08	2027.48 21.86	1825.98 953.8	2344.92 .	1386.58 254.04

60Hz, 60V	1	2	3	4	5	6
11.15%	2619.72 253.3	3683.82 1310.42	3354.28 557.95	4511.26 694.43	3629.43 1163.42	3893.78 .
32.73%	3397.43 .	3344.45 988.37	3231.62 106.21	4511.26 694.43	3629.43 1163.42	3893.78 .
57.70%	4856.99 2926.96	3214.42 1477.28	1702.02 443.43	3872.04 1224.85	2509.16 794.79	.
75.32%	3359.28 .	4619.07 2065.47	1775.94 381.72	.	.	.

Raw A	1	2	3	4	5	6
11.15%	2320.82 112.67	2504.24 67.26	2094.97 491.55	2430.97 102.97	2447.48 148.68	3452.68 0
32.73%	1877.8 287.36	1941.94 0	2077.9 261.28	2386.83 165.87	2239.31 1260.78	3396.75 0
57.70%	1976.98 234.33	1568.86 240.36	3712.59 121.47	2658.1 562.79	5961.55 2401.55	1317.84 464.35
75.32%	3811.82 2527.12	1981.05 305.91	2822 0	2376.26 46.82	2767.64 562.04	2538.49 420.51

Raw B	1	2	3	4	5	6
11.15%	3574.82 2275.62	3101.05 1414.34	2567.56 1128.64	3166.75 738.01	2258.09 903.73	6913.22 1384.31
32.73%	4692.22 2005.12	2176.18 221.32	2993.7 141.73	3569.07 358.74	3373.96 969.68	3301.26 135.04
57.70%	4368.64 1237.01	1504.03 356.3	3812.5 57.02	3494.94 995.86	2795.58 110.57	2725.6 671.95
75.32%	3425.67 1651.93	3110.27 1382.37	2652.98 1081.15	2781.82 1177.94	1958.54 221	2661.23 246.93

Raw C	1	2	3	4	5	6
11.15%	1990.42 (501.8)	2116.18 (513.72)	1727.18 (326.65)	2420.87 (305.4)	2759.73 (651.63)	6847.08 (1194.36)
32.73%	1152.26 (323.19)	1811.7 (19.03)	2443.63 (471.22)	1441.15 (130.02)	2572.55 (131.98)	3678.25 (2237.47)
57.70%	2387.15 (539.48)	2376.69 (773)	2051.5 (210.04)	2222.54 (711.44)	1818.03 (198.84)	1317.84 (464.35)
75.32%	3713.26 (811.06)	1795.47 (0)	2450.99 (1633.54)	.	2344.92 (0)	972.41 (0)

d. Data set for Correlation Coefficients

For 1HZ, 40V

11.15%	Moist1	Moist2	Hard	Adhe	Spring	Cohes	Gummi	Chewi
Moist1	1	0.8772	0.34776	-0.39288	-0.26247	0.53746	0.48431	0.18328
Moist2	0.8772	1	0.39498	-0.67075	-0.39434	0.78733	0.66615	0.25626
Hard	0.34776	0.39498	1	-0.62395	-0.343	0.57357	0.87991	0.45637
Adhe	-0.39288	-0.67075	-0.62395	1	0.42181	-0.91912	-0.87641	-0.43065
Spring	-0.26247	-0.39434	-0.343	0.42181	1	-0.20664	-0.29867	0.56068
Cohes	0.53746	0.78733	0.57357	-0.91912	-0.20664	1	0.89172	0.62394
Gummi	0.48431	0.66615	0.87991	-0.87641	-0.29867	0.89172	1	0.61867
Chewi	0.18328	0.25626	0.45637	-0.43065	0.56068	0.62394	0.61867	1

32.73%	Moist1	Moist2	Hard	Adhe	Spring	Cohes	Gummi	Chewi
Moist1	1	0.87955	0.11416	-0.32901	0.70811	0.55404	0.39466	0.51811
Moist2	0.87955	1	0.36235	-0.152	0.72422	0.61486	0.55251	0.65782
Hard	0.11416	0.36235	1	0.3705	0.16391	0.63959	0.89369	0.82027
Adhe	-0.32901	-0.152	0.3705	1	0.17618	0.47974	0.45733	0.43909
Spring	0.70811	0.72422	0.16391	0.17618	1	0.50587	0.38654	0.60768
Cohes	0.55404	0.61486	0.63959	0.47974	0.50587	1	0.91365	0.91252
Gummi	0.39466	0.55251	0.89369	0.45733	0.38654	0.91365	1	0.9652
Chewi	0.51811	0.65782	0.82027	0.43909	0.60768	0.91252	0.9652	1

57.70%	Moist1	Moist2	Hard	Adhe	Spring	Cohes	Gummi	Chewi
Moist1	1	0.53629	0.19081	-0.01761	0.22962	0.53211	0.416	0.44548
Moist2	0.53629	1	0.82094	0.18068	0.4685	0.81127	0.84459	0.83784
Hard	0.19081	0.82094	1	0.205	0.38293	0.85061	0.95276	0.8645
Adhe	-0.01761	0.18068	0.205	1	0.89683	0.46405	0.32979	0.56166
Spring	0.22962	0.4685	0.38293	0.89683	1	0.6224	0.50053	0.73155
Cohes	0.53211	0.81127	0.85061	0.46405	0.6224	1	0.96689	0.97735
Gummi	0.416	0.84459	0.95276	0.32979	0.50053	0.96689	1	0.95394
Chewi	0.44548	0.83784	0.8645	0.56166	0.73155	0.97735	0.95394	1

75.32%	Moist1	Moist2	Hard	Adhe	Spring	Cohes	Gummi	Chewi
Moist1	1	-0.13892	-0.15206	0.28209	-0.10596	-0.19609	-0.17193	-0.22416
Moist2	-0.13892	1	0.23379	0.46209	0.36566	0.40913	0.27827	0.48057
Hard	-0.15206	0.23379	1	-0.79264	-0.30329	0.95486	0.99562	0.91891
Adhe	0.28209	0.46209	-0.79264	1	0.45114	-0.73307	-0.79419	-0.5664
Spring	-0.10596	0.36566	-0.30329	0.45114	1	-0.34735	-0.34472	0.07679
Cohes	-0.19609	0.40913	0.95486	-0.73307	-0.34735	1	0.97645	0.87619
Gummi	-0.17193	0.27827	0.99562	-0.79419	-0.34472	0.97645	1	0.90531
Chewi	-0.22416	0.48057	0.91891	-0.5664	0.07679	0.87619	0.90531	1

60Hz, 40V

11.15%	Moist1	Moist2	Hard	Adhe	Spring	Cohes	Gummi	Chewi
Moist1	1	0.9574	-0.22654	-0.45888	0.71646	-0.89435	-0.89081	-0.76727
Moist2	0.9574	1	-0.16444	-0.34754	0.5917	-0.7881	-0.79344	-0.6818
Hard	-0.22654	-0.16444	1	0.53205	-0.31764	0.08485	0.29813	0.39352
Adhe	-0.45888	-0.34754	0.53205	1	-0.26791	0.45153	0.62909	0.85273
Spring	0.71646	0.5917	-0.31764	-0.26791	1	-0.69906	-0.68593	-0.46136
Cohes	-0.89435	-0.7881	0.08485	0.45153	-0.69906	1	0.96733	0.86096
Gummi	-0.89081	-0.79344	0.29813	0.62909	-0.68593	0.96733	1	0.94597
Chewi	-0.76727	-0.6818	0.39352	0.85273	-0.46136	0.86096	0.94597	1

32.73%	Moist1	Moist2	Hard	Adhe	Spring	Cohes	Gummi	Chewi
Moist1	1	0.89696	-0.79581	0.59425	0.14036	-0.56769	-0.82841	-0.83694
Moist2	0.89696	1	-0.70179	0.46522	0.23155	-0.58023	-0.74296	-0.73804
Hard	-0.79581	-0.70179	1	-0.6102	-0.33773	0.54351	0.92898	0.88424
Adhe	0.59425	0.46522	-0.6102	1	0.45522	-0.27854	-0.54464	-0.43445
Spring	0.14036	0.23155	-0.33773	0.45522	1	-0.42184	-0.39615	-0.11864
Cohes	-0.56769	-0.58023	0.54351	-0.27854	-0.42184	1	0.80704	0.76254
Gummi	-0.82841	-0.74296	0.92898	-0.54464	-0.39615	0.80704	1	0.95143
Chewi	-0.83694	-0.73804	0.88424	-0.43445	-0.11864	0.76254	0.95143	1

57.70%	Moist1	Moist2	Hard	Adhe	Spring	Cohes	Gummi	Chewi
Moist1	1	0.53947	0.18377	-0.6012	0.1964	-0.42279	-0.2145	-0.12273

Moist2	0.53947	1	0.23184	-0.26156	0.38291	0.0475	0.13969	0.24603
Hard	0.18377	0.23184	1	-0.26804	0.84261	0.28743	0.73775	0.87787
Adhe	-0.6012	-0.26156	-0.26804	1	-0.39201	0.38324	0.13497	-0.00463
Spring	0.1964	0.38291	0.84261	-0.39201	1	-0.07262	0.37905	0.63363
Cohes	-0.42279	0.0475	0.28743	0.38324	-0.07262	1	0.8536	0.68769
Gummi	-0.2145	0.13969	0.73775	0.13497	0.37905	0.8536	1	0.95323
Chewi	-0.12273	0.24603	0.87787	-0.00463	0.63363	0.68769	0.95323	1

75.32%	Moist1	Moist2	Hard	Adhe	Spring	Cohes	Gummi	Chewi
Moist1	1	0.65105	0.46213	-0.12115	0.6747	0.2019	0.37647	0.51959
Moist2	0.65105	1	0.61681	0.10061	0.58153	0.17494	0.44315	0.55458
Hard	0.46213	0.61681	1	-0.0709	0.84279	0.52581	0.84398	0.92623
Adhe	-0.12115	0.10061	-0.0709	1	-0.20487	-0.31115	-0.23866	-0.24329
Spring	0.6747	0.58153	0.84279	-0.20487	1	0.24473	0.58211	0.78299
Cohes	0.2019	0.17494	0.52581	-0.31115	0.24473	1	0.89777	0.76592
Gummi	0.37647	0.44315	0.84398	-0.23866	0.58211	0.89777	1	0.95941
Chewi	0.51959	0.55458	0.92623	-0.24329	0.78299	0.76592	0.95941	1

60Hz, 60V

11.15%	Moist1	Moist2	Hard	Adhe	Spring	Cohes	Gummi	Chewi
Moist1	1	0.90148	0.75246	-0.32778	0.44279	-0.92249	-0.53394	-0.12239
Moist2	0.90148	1	0.62738	-0.33375	0.39573	-0.84381	-0.50094	-0.11144
Hard	0.75246	0.62738	1	-0.32889	0.40618	-0.63828	-0.00641	0.28374
Adhe	-0.32778	-0.33375	-0.32889	1	0.25011	0.37577	0.31925	0.34902
Spring	0.44279	0.39573	0.40618	0.25011	1	-0.28772	0.07088	0.62431
Cohes	-0.92249	-0.84381	-0.63828	0.37577	-0.28772	1	0.75863	0.3878
Gummi	-0.53394	-0.50094	-0.00641	0.31925	0.07088	0.75863	1	0.81907
Chewi	-0.12239	-0.11144	0.28374	0.34902	0.62431	0.3878	0.81907	1

32.73%	Moist1	Moist2	Hard	Adhe	Spring	Cohes	Gummi	Chewi
Moist1	1	0.84004	0.53259	-0.29138	-0.14458	-0.39458	-0.0974	-0.16423
Moist2	0.84004	1	0.57378	0.08499	0.02729	-0.78191	-0.51444	-0.38393
Hard	0.53259	0.57378	1	-0.20818	0.54181	-0.64849	0.00544	0.44097
Adhe	-0.29138	0.08499	-0.20818	1	-0.14408	-0.21554	-0.57857	-0.70306
Spring	-0.14458	0.02729	0.54181	-0.14408	1	-0.5777	-0.27007	0.46145
Cohes	-0.39458	-0.78191	-0.64849	-0.21554	-0.5777	1	0.74343	0.2241
Gummi	-0.0974	-0.51444	0.00544	-0.57857	-0.27007	0.74343	1	0.72215
Chewi	-0.16423	-0.38393	0.44097	-0.70306	0.46145	0.2241	0.72215	1

57.70%	Moist1	Moist2	Hard	Adhe	Spring	Cohes	Gummi	Chewi
Moist1	1	0.48162	0.04395	-0.56393	-0.00861	-0.2094	-0.08469	-0.0261
Moist2	0.48162	1	0.54875	-0.04127	0.65619	0.14917	0.435	0.61515
Hard	0.04395	0.54875	1	-0.16348	0.4989	0.39962	0.80865	0.72585
Adhe	-0.56393	-0.04127	-0.16348	1	0.36877	0.278	0.08869	0.22377

Spring	-0.00861	0.65619	0.4989	0.36877	1	0.33297	0.52063	0.82167
Cohes	-0.2094	0.14917	0.39962	0.278	0.33297	1	0.86034	0.75617
Gummi	-0.08469	0.435	0.80865	0.08869	0.52063	0.86034	1	0.90534
Chewi	-0.0261	0.61515	0.72585	0.22377	0.82167	0.75617	0.90534	1

75.32%	Moist1	Moist2	Hard	Adhe	Spring	Cohes	Gummi	Chewi
Moist1	1	0.31563	0.2912	0.61049	0.4043	0.22093	0.28759	0.37123
Moist2	0.31563	1	0.01561	0.90642	-0.41177	-0.48468	-0.21878	-0.27057
Hard	0.2912	0.01561	1	0.26876	0.36723	0.82375	0.95198	0.81648
Adhe	0.61049	0.90642	0.26876	1	0.08959	-0.14008	0.10013	0.15477
Spring	0.4043	-0.41177	0.36723	0.08959	1	0.73203	0.61143	0.83423
Cohes	0.22093	-0.48468	0.82375	-0.14008	0.73203	1	0.95276	0.94457
Gummi	0.28759	-0.21878	0.95198	0.10013	0.61143	0.95276	1	0.94284
Chewi	0.37123	-0.27057	0.81648	0.15477	0.83423	0.94457	0.94284	1

Raw A

11.15%	Moist1	Moist2	Hard	Adhe	Spring	Cohes	Gummi	Chewi
Moist1	1	0.82984	0.70943	0.22598	-0.01857	-0.25999	-0.31801	-0.59173
Moist2	0.82984	1	0.58339	0.34412	-0.10318	-0.13993	-0.25724	-0.52652
Hard	0.70943	0.58339	1	0.04771	-0.12259	-0.35433	-0.4436	-0.86852
Adhe	0.22598	0.34412	0.04771	1	0.06522	0.42283	0.53652	0.3283
Spring	-0.01857	-0.10318	-0.12259	0.06522	1	-0.33968	-0.41137	0.1789
Cohes	-0.25999	-0.13993	-0.35433	0.42283	-0.33968	1	0.77283	0.49201
Gummi	-0.31801	-0.25724	-0.4436	0.53652	-0.41137	0.77283	1	0.71784
Chewi	-0.59173	-0.52652	-0.86852	0.3283	0.1789	0.49201	0.71784	1

32.73%	Moist1	Moist2	Hard	Adhe	Spring	Cohes	Gummi	Chewi
Moist1	1	0.13117	0.21761	0.03614	-0.46245	-0.51308	-0.17603	-0.78062
Moist2	0.13117	1	0.35548	-0.14221	0.10363	-0.1016	0.1324	0.17675
Hard	0.21761	0.35548	1	0.09125	-0.18852	-0.06916	0.70243	-0.02592
Adhe	0.03614	-0.14221	0.09125	1	-0.16505	0.31935	0.33329	0.05307
Spring	-0.46245	0.10363	-0.18852	-0.16505	1	0.22681	0.00223	0.62636
Cohes	-0.51308	-0.1016	-0.06916	0.31935	0.22681	1	0.65618	0.78977
Gummi	-0.17603	0.1324	0.70243	0.33329	0.00223	0.65618	1	0.50451
Chewi	-0.78062	0.17675	-0.02592	0.05307	0.62636	0.78977	0.50451	1

57.70%	Moist1	Moist2	Hard	Adhe	Spring	Cohes	Gummi	Chewi
Moist1	1	0.37648	0.14375	0.84112	0.78532	-0.38391	-0.28711	-0.03867
Moist2	0.37648	1	0.42625	0.4609	0.47055	0.26648	0.33837	0.43226
Hard	0.14375	0.42625	1	0.46768	0.31677	0.39764	0.56773	0.65055
Adhe	0.84112	0.4609	0.46768	1	0.75564	-0.18658	-0.04808	0.19318
Spring	0.78532	0.47055	0.31677	0.75564	1	-0.10664	-0.02835	0.29158
Cohes	-0.38391	0.26648	0.39764	-0.18658	-0.10664	1	0.97969	0.90048
Gummi	-0.28711	0.33837	0.56773	-0.04808	-0.02835	0.97969	1	0.94479

Chewi	-0.03867	0.43226	0.65055	0.19318	0.29158	0.90048	0.94479	1
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75.32%	Moist1	Moist2	Hard	Adhe	Spring	Cohes	Gummi	Chewi
Moist1	1	-0.12302	-0.41599	0.38472	0.31615	-0.16774	-0.35973	0.13884
Moist2	-0.12302	1	-0.13783	0.28001	0.31753	0.498	0.29834	0.36271
Hard	-0.41599	-0.13783	1	0.29867	-0.11437	0.05601	0.63518	0.13741
Adhe	0.38472	0.28001	0.29867	1	0.20834	0.31443	0.44872	0.34832
Spring	0.31615	0.31753	-0.11437	0.20834	1	0.57541	0.37472	0.9431
Cohes	-0.16774	0.498	0.05601	0.31443	0.57541	1	0.80509	0.74624
Gummi	-0.35973	0.29834	0.63518	0.44872	0.37472	0.80509	1	0.65811
Chewi	0.13884	0.36271	0.13741	0.34832	0.9431	0.74624	0.65811	1

Raw B

11.15%	Moist1	Moist2	Hard	Adhe	Spring	Cohes	Gummi	Chewi
Moist1	1	0.60351	-0.43842	-0.28749	0.69983	-0.72634	-0.72444	-0.5885
Moist2	0.60351	1	-0.50039	-0.14932	0.58802	-0.91288	-0.91328	-0.84106
Hard	-0.43842	-0.50039	1	-0.14165	-0.05719	0.56413	0.68219	0.74297
Adhe	-0.28749	-0.14932	-0.14165	1	-0.2878	0.32892	0.24665	0.23833
Spring	0.69983	0.58802	-0.05719	-0.2878	1	-0.57264	-0.54443	-0.31262
Cohes	-0.72634	-0.91288	0.56413	0.32892	-0.57264	1	0.98675	0.94252
Gummi	-0.72444	-0.91328	0.68219	0.24665	-0.54443	0.98675	1	0.96313
Chewi	-0.5885	-0.84106	0.74297	0.23833	-0.31262	0.94252	0.96313	1

32.73%	Moist1	Moist2	Hard	Adhe	Spring	Cohes	Gummi	Chewi
Moist1	1	-0.1278	-0.34283	0.30803	0.22971	-0.2999	-0.33371	-0.10765
Moist2	-0.1278	1	0.28068	-0.34731	-0.28345	0.59212	0.55763	0.3998
Hard	-0.34283	0.28068	1	-0.32601	-0.22633	0.46122	0.75036	0.53973
Adhe	0.30803	-0.34731	-0.32601	1	-0.11552	-0.5073	-0.51825	-0.52037
Spring	0.22971	-0.28345	-0.22633	-0.11552	1	-0.09758	-0.14682	0.39578
Cohes	-0.2999	0.59212	0.46122	-0.5073	-0.09758	1	0.93104	0.81891
Gummi	-0.33371	0.55763	0.75036	-0.51825	-0.14682	0.93104	1	0.84133
Chewi	-0.10765	0.3998	0.53973	-0.52037	0.39578	0.81891	0.84133	1

57.70%	Moist1	Moist2	Hard	Adhe	Spring	Cohes	Gummi	Chewi
Moist1	1	0.38004	0.47187	0.18675	0.59465	-0.28669	-0.02185	0.24727
Moist2	0.38004	1	-0.24492	-0.22626	0.24614	-0.3448	-0.3918	-0.1887
Hard	0.47187	-0.24492	1	0.3606	0.43782	0.26647	0.64342	0.68985
Adhe	0.18675	-0.22626	0.3606	1	-0.22978	0.02202	0.19104	0.08626
Spring	0.59465	0.24614	0.43782	-0.22978	1	0.30922	0.42312	0.69936
Cohes	-0.28669	-0.3448	0.26647	0.02202	0.30922	1	0.9079	0.80192
Gummi	-0.02185	-0.3918	0.64342	0.19104	0.42312	0.9079	1	0.93522
Chewi	0.24727	-0.1887	0.68985	0.08626	0.69936	0.80192	0.93522	1

75.32%	Moist1	Moist2	Hard	Adhe	Spring	Cohes	Gummi	Chewi
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Moist1	1	0.18835	0.77477	0.2998	-0.54739	0.30065	0.56327	0.27065
Moist2	0.18835	1	0.122	-0.14235	0.08558	0.69554	0.54301	0.51977
Hard	0.77477	0.122	1	0.18646	-0.20806	0.33064	0.68192	0.419
Adhe	0.2998	-0.14235	0.18646	1	-0.49132	0.08769	0.20405	0.12343
Spring	-0.54739	0.08558	-0.20806	-0.49132	1	0.30009	-0.00031	0.09162
Cohes	0.30065	0.69554	0.33064	0.08769	0.30009	1	0.85694	0.77366
Gummi	0.56327	0.54301	0.68192	0.20405	-0.00031	0.85694	1	0.90413
Chewi	0.27065	0.51977	0.419	0.12343	0.09162	0.77366	0.90413	1

Raw C

11.15%	Moist1	Moist2	Hard	Adhe	Spring	Cohes	Gummi	Chewi
Moist1	1	0.83987	-0.39911	-0.30083	0.54214	-0.98362	-0.99351	-0.96427
Moist2	0.83987	1	-0.53354	-0.33631	0.29936	-0.76179	-0.85231	-0.90831
Hard	-0.39911	-0.53354	1	-0.03398	-0.04975	0.29201	0.45975	0.52252
Adhe	-0.30083	-0.33631	-0.03398	1	-0.39608	0.33882	0.32008	0.30781
Spring	0.54214	0.29936	-0.04975	-0.39608	1	-0.58445	-0.52235	-0.37722
Cohes	-0.98362	-0.76179	0.29201	0.33882	-0.58445	1	0.97776	0.9297
Gummi	-0.99351	-0.85231	0.45975	0.32008	-0.52235	0.97776	1	0.9808
Chewi	-0.96427	-0.90831	0.52252	0.30781	-0.37722	0.9297	0.9808	1

32.73%	Moist1	Moist2	Hard	Adhe	Spring	Cohes	Gummi	Chewi
Moist1	1	0.77468	-0.25781	0.39147	0.34806	-0.89818	-0.88043	-0.80204
Moist2	0.77468	1	-0.3775	0.52657	0.53772	-0.55889	-0.59012	-0.458
Hard	-0.25781	-0.3775	1	-0.10965	0.01904	0.28952	0.43492	0.46255
Adhe	0.39147	0.52657	-0.10965	1	0.26985	-0.22033	-0.20556	-0.13488
Spring	0.34806	0.53772	0.01904	0.26985	1	-0.25375	-0.24811	0.03434
Cohes	-0.89818	-0.55889	0.28952	-0.22033	-0.25375	1	0.98697	0.94145
Gummi	-0.88043	-0.59012	0.43492	-0.20556	-0.24811	0.98697	1	0.95815
Chewi	-0.80204	-0.458	0.46255	-0.13488	0.03434	0.94145	0.95815	1

57.70%	Moist1	Moist2	Hard	Adhe	Spring	Cohes	Gummi	Chewi
Moist1	1	0.18298	0.31046	0.48557	0.46448	-0.17991	0.09065	0.41122
Moist2	0.18298	1	0.39301	0.34133	0.27201	-0.18596	0.05959	0.21023
Hard	0.31046	0.39301	1	0.2922	0.42742	-0.24029	0.47494	0.67399
Adhe	0.48557	0.34133	0.2922	1	0.92867	-0.48347	-0.2195	0.60472
Spring	0.46448	0.27201	0.42742	0.92867	1	-0.61109	-0.2345	0.62769
Cohes	-0.17991	-0.18596	-0.24029	-0.48347	-0.61109	1	0.73524	0.1164
Gummi	0.09065	0.05959	0.47494	-0.2195	-0.2345	0.73524	1	0.59059
Chewi	0.41122	0.21023	0.67399	0.60472	0.62769	0.1164	0.59059	1

75.32%	Moist1	Moist2	Hard	Adhe	Spring	Cohes	Gummi	Chewi
Moist1	1	0.93222	0.46142	0.54397	0.74625	-0.4528	-0.08258	0.39858
Moist2	0.93222	1	0.31076	0.40826	0.74993	-0.32799	-0.06114	0.41919

Hard	0.46142	0.31076	1	0.72534	0.45906	0.12041	0.65968	0.7081
Adhe	0.54397	0.40826	0.72534	1	0.65425	0.11295	0.38718	0.64465
Spring	0.74625	0.74993	0.45906	0.65425	1	0.1323	0.34675	0.80611
Cohes	-0.4528	-0.32799	0.12041	0.11295	0.1323	1	0.82261	0.56507
Gummi	-0.08258	-0.06114	0.65968	0.38718	0.34675	0.82261	1	0.82758
Chewi	0.39858	0.41919	0.7081	0.64465	0.80611	0.56507	0.82758	1

VITA

Sireesha Bhattiprolu was born in April 6, 1979, in Machilipatnam. She graduated from Osmania University College of Technology, Hyderabad, with a Bachelor of Science degree in food processing and preservation technology. She held the position of food technologist in Sun-Sip Beverage Company. She joined the graduate school at Louisiana State University Agricultural and Mechanical College in the department of Biological and Agricultural Engineering. She is a candidate for the Master of Science in Biological and Agricultural Engineering degree in spring 2004.