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EFFECT OF OHMIC PRETREATMENT ON OIL UPTAKE AND SOME PHYSICAL PROPERTIES OF FRIED CARROTS

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APPROVAL OF THE THESIS

"Effect of ohmic pretreatment on oil uptake and some physical properties of fried carrots" submitted by **Mohammed Muayad Ismail Ismail** in partial fulfillment of the requirements for the degree of **Master of Science in Department of Food Engineering**, Graduate School of Natural and Applied Sciences, Süleyman Demirel University by,

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COMMITMENT

I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

Mohammed ISMAIL

TABLE OF CONTENTS

Page

ABSTRACT

M.Sc. Thesis

EFFECT OF OHMIC PRETREATMENT ON OIL UPTAKE AND SOME PHYSICAL PROPERTIES OF FRIED CARROTS

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In the present study, the effect of ohmic heating on some physical and quality properties of carrots was evaluated. Carrots were cut into cubes (1 cm^3) and were pre-treated with two different voltages (95 V and 150 V) for 10 seconds. Then, carrot cubes were fried in sunflower oil for 60 seconds at 180°C, another group of samples was frozen and stored at -20 for three months, samples were taken monthly and analyses were done on these samples. Moisture content, oil content (%, db), textural properties, β-carotene and colour (L^*, a^*, b^*) of the samples were determined. Ohmic heating decreased almost all values of samples and the same thing was found for frozen samples, such as moisture content, texture, β-Carotene, and colour, except the oil content which increased after the ohmic pretreatment and freezing. The effect of freezing was obvious after the first month, but for the second and third months, the values were almost stable. The possibility of decreasing oil uptake after frying also was evaluated by pre-treating samples with deferent voltages (95V and 150V) for deferent time (10 to 60 sec) and after every 10 sec of frying samples was taken and analyses were done for samples to see which sample has the nearest properties to the fried control samples. 150V fried for 10 sec was the nearest properties to the control, for this reason, it had chosen to go ahead with the other analyses and freezing. With 150V fried for 10 seconds, the oil content decreased from (6.07±0.32g/100g) in fried control to (4.23±0,14 g/100g) in 150V fried for 10 sec. These results indicated that ohmic treatment significantly affects the physical properties and some chemical properties such as oil uptake β-carotene content, colour, moisture content and texture of carrots. Also, this study showed the possibility of reducing the amount of absorbed oil during the frying by using 150V as pretreatment and 10 seconds of frying for the carrot samples.

Keywords: Ohmic heating, high voltage, carrot, frying, freezing, oil uptake

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ÖZET

Yüksek Lisans Tezi

OHMİC ÖN İŞLEM UYGULAMASININ KIZARMIŞ HAVUÇLARIN YAĞ EMİLİMİ VE BAZI FİZİKSEL ÖZELLİKLERİ ÜZERİNE ETKİSİ

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Bu tez çalışmasında, ohmik ısıtmanın havuçların bazı fiziksel ve kalite özellikleri üzerine etkisi değerlendirilmiştir. Havuçlar küpler ($1cm^3$) halinde doğranmış ve iki faklı voltaj (gerilim) değerinde (95 V ve 150 V) 10 saniyeliğine ön işleme tabi tutulmuştur. Sonrasında, havuç küpleri 180°C'de 60 saniye süreyle ayçiçeği yağında kızartılmıştır, örneklerin diğer bir kısmı dondurularak -20°C'de üç ay boyunca depolanmıştır. Dondurularak saklanan bu havuç örnekleri aylık analizlere tabi tutulmuşlardır. Örneklerin nem içeriği, yağ içeriği (%, db), dokusal özellikleri, toplam β-karoten miktarı ve renkleri (L*, a*, b*) belirlenmiştir. Ohmik ısıtma örneklerin analiz edilen neredeyse tüm değerlerini, örneğin nem içeriği, doku, β-karoten ve renk değerlerini düşürdü. Benzer durum dondurulmuş örneklerde de aynı şekilde tespit edilmiştir. Dondurulmuş havuç örneklerinde depolamanın ilk ayında dondurmanın etkisi gözlemlendi. Ancak Ohmik ısıtma ön işlemi uygulaması ve dondurma işlemi sonrasında yağ içeriğindeki kısmi artış hariç, depolamanın ikinci ve üçüncü aylarında tüm değerler neredeyse sabit kalmıştır. Farklı voltaj değerlerinde ön işlem uygulanan (95V ve 150V) , farklı sürelerde (10s ve 60s) ve her 10 saniye kızartma işlemi uygulandıktan sonra havuç örnekleri alınıp yağ emilimin deki düşüş tespit edilmeye çalışılmıştır. Yapılan analizlerin sonuçları kontrol örneklerine yakın çıkmıştır. Özellikle 150V gerilimde 10s süreyle kızartılan, kontrol grubuna en yakın muhteviyattaydı. Bu nedenle dondurulmuş örneklerde daha ileri diğer analizler gerçekleştirildi. 150V gerilimde 10s süreyle kızartılandaki yağ oranı , kızartılmış kontrol grubunun yağ oranı (6.07±0.32g/100g) değerinden 150V gerilimde 10s kızartılanın değerine (4.23±0,14 g/100g) düşmüştür. Çalışmada elde edilen sonuçlar gösteriyor ki ohmik ısıtma anlamlı bir biçimde havucun fiziksel özellikleri ve yağ emilimini, β-karoten, renk, nem içeriği ve doku gibi bazı kimyasal özelliklerini etkilemektedir. Ayrıca bu çalışma, havuç örneklerinin 150V gerilim kullanılarak ön işleme tabi tutulmasına ve 10s süreyle kızartılmasına bakılarak kızartma işlemi sırasında absorbe edilen yağ miktarının düşürülmesinin mümkün olduğunu göstermiştir.

Anahtar kelimeler: Ohmik ısıtma, yüksek gerilim, havuç, kızartma, dondurma, yağ emilimi

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LIST OF FIGURES

Page

LIST OF TABLES

Page

LIST OF SYMBOLS AND ABBREVIATIONS

AACC American Association of Cereal Chemists

a* Red-green color value in the CIE colour system

b* Yellow-blue color value in the CIE colour system

cm Centimeter

min Minute

g Gram

L* Brightness value in the CIE color system

mL Milliliter

°C Degrees Celsius

S Second

T Temperature

V Volt

- $^{a-c}$ means in the same column with different superscripts are significantly different ($p \leq 0.05$)

1. INTRODUCTION

Food process engineering is a broad field that involves many processes, both simple and complex. Many processes fall within this field, such as manufacturing processes, evaporation, preservation, extraction, etc., and these processes have more than one method to do.

Electrical heating is an alternative method in food processing, and this electrical heating influences some of the food properties. Electrical heating influences the mass transfer properties of food. This phenomenon has important implications for food process engineering in heat and mass transfer. This explains the use of ohmic heating in a lot of processing such as blanching, evaporation, dehydration, fermentation, and other food processing operations. Heat processing by electricity can also be termed as aseptic processing; and the sole purpose of it is to obtain a sterile product with a sterile packaging in order to preserve the perishable food material for a long duration of time (Bhale, 2004). As is known, this heat is transmitted by convection, radiation, and conduction.

The characteristics of foods are greatly influenced by thermodynamic processes, especially texture, color, and moisture content, so these factors affect the quality of the final product. The processing of foods is helpful in retaining the nutritional quality and preserving the product for long-term use. It is very helpful in case of perishable foods with the added advantage of quality retention.

Ohmic heating is a thermal electrical heating method, is also termed as resistance heating; this uses electrical resistance of the foods and converts it into heat. Ohmic Heating is a direct heating method where food is in contact with the electrodes, it has been extensively used in the past for commercial processing as reported by Palaniappan et al., in 1990 for the pasteurization of milk.

The emphasis on the ohmic heating research slowed down during the 1930s to 1960s, due to the electricity cost constraints. Ohmic heating is very often used in pasteurization/sterilization of food products resulting in excellent quality. It is also used in the rapid cooking of potatoes and vegetables blanching. Past

research as done by Lima and Sastry (1999) also underlines the role of ohmic heating technique enhancing the air-drying rate. But more research is needed for the acceptance of ohmic heating method for use in particulate foods (Bhale, 2004).

Thermal processing has a huge impact on the textural attribute of the final food product, and texture is a major factor contributing to the overall quality of fruits and vegetables. In general, consumers prefer processed vegetables with firmer structure than that of conventionally processed products, as food is consumed not only for its nutritional value but for pleasure. Due to the increasing consumer demand for crisp, firm, succulent textured fruits and vegetables, the research has been concentrated on modifying processing techniques in order to retain textural qualities of fresh products.

Past research has proven that the texture of fruits and vegetables is greatly influenced by the temperature and the thermal processing of the product (Bhale, 2004). With the knowledge of fracture, toughness, and fracture energy, it is possible to relate texture to the structure of food as it happens in the biting/chewing/mastication processes. The work was done by Tetsuya et al. (1995) on white radish confirmed that heating of the sample at low frequency resulted in the same breaking strength as that of the raw samples.

1.1. Carrot

Carrot (*Daucus carota*) is widely produced and consumed in Turkey and around the world. Turkey's production of carrots in 2017 was about 569.533 tones (Ministry of Agriculture and Forestry, 2017). It is one of the popular root vegetables grown throughout the world and is one of the world's most traded vegetables as both fresh and processed (Block, 1994; Karacabey, et al., 2016). Carrot name comes from the Latin word *carota*. Carrot varieties come with different colors, but the most common type is an orange carrot. Carrot is a good source of vitamins and minerals, especially carotene, or provitamin A.

β-Carotene is an orange pigment found in carrots and other fruits and vegetables. β-Carotene belongs to a group of compounds called carotenoids, and this group has antioxidant properties that may reduce the incidence of

cardiovascular diseases and certain types of cancer. Carrot is also an important source of vitamin A, which is necessary for health, for bone growth and tooth development, gene expression, embryonic development, immune function and for normal vision. High intakes of dietary β-Carotene have been investigated as a means to inhibit lipid oxidation and to prevent certain types of cancer in humans and other health benefits as it's shown in Figure 1 (Fan et al., 2005; Sharma et al., 2012).

Carrots have the highest β-Carotene content among most of the human foods (Bao and Chang, 1994). This property has increased the importance of dried carrot slices as an excellent source for developing an oil-free, healthy snack food provided the nutritional quality could be retained. The other use of minimally processed carrots is in carrot juice, which is becoming popular due to its high vitamin A contents. The vegetable juice available in the stores has a portion of carrot juice as a major constituent (Bhale, 2004).

A study conducted by Palaniappan and Sastry in 1991 on carrots demonstrated that the electrical conductivity of carrots increases with higher temperatures and also with the voltage gradient and has a linear relationship most of the times. The changes in the electrical conductivity values may be due to the high-temperature heating which there is the dissolution of cell wall components and dissolution of protopectin (expulsion of non-conductive bubbles, softening) increase in ionic mobility and affecting the electrical conductivity values (Bean et al., 1960).

Gopalan et al. (1989), have detailed the constituents of carrot as moisture (86%), protein (0.9%), fat (0.2%), carbohydrate (10.6%), crude fiber (1.2%), total ash (1.1%), Ca (80 mg/100 g), Fe (2.2 mg/100 g) and p (53 mg/100 g). Kaur et al. (1976), have reported 1.67–3.35% reducing sugars, 1.02–1.18% non-reducing sugars and 2.71–4.53% total sugars in 6 cultivars of carrot. The crude fiber in carrot roots consists of 71.7%, 13.0% and 15.2% cellulose, hemicellulose, and lignin, respectively and the normal nitrate and nitrite contents in crisp carrot had been 40 mg/100 g and 0.41 mg/100 g, respectively, also small amounts of succinic acid, α-ketoglutaric acid, lactic acid, and glycolic acid have also been reported. The special taste of carrot is due to the glutamic acid and the buffering

action of free amino acids which present in carrots. (Sharma et al., 2012). Also, the other components of carrot tissue and nutritional composition can be seen in Table 1 and 2 (Bhale, 2004).

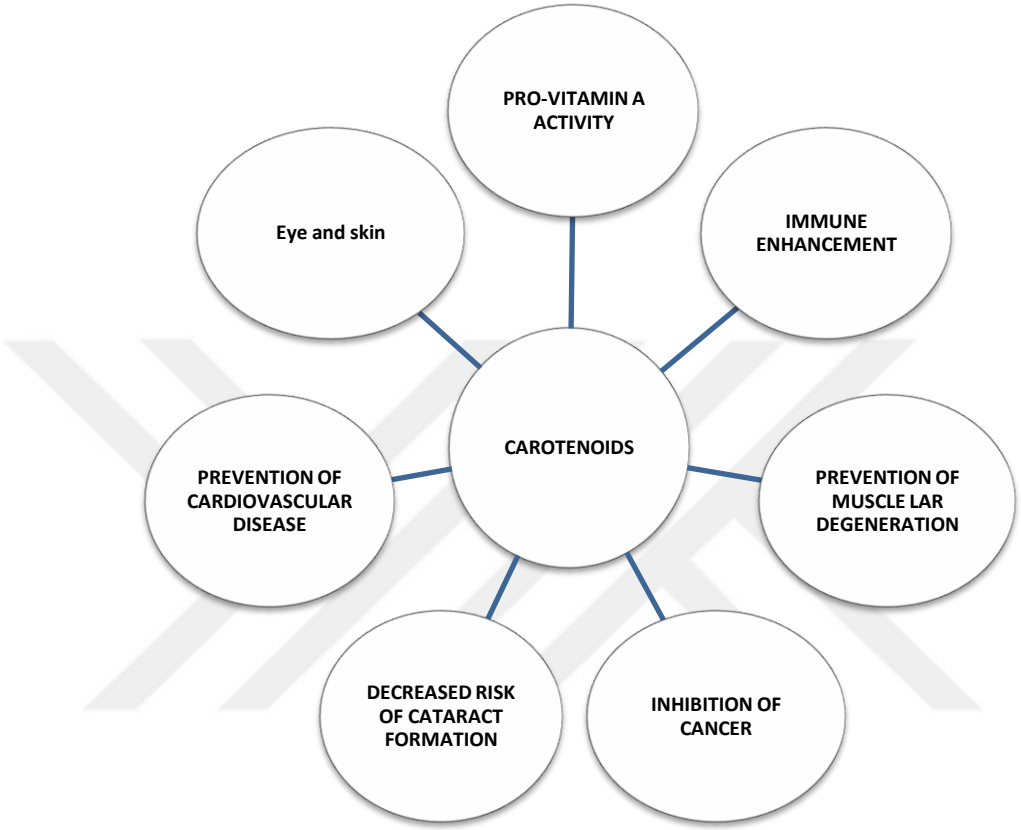

Figure 1.1. Health promoting functions of carotenoids (Sharma et al,. 2012)

Table 1.1. Composition of carrot tissue (Bhale, 2004)

Water (%)	88	Na (mg)	35
Energy (Kcal)	43	K (mg)	323
Protein (g)	1.0	Vitamin A (IU)	28.12
Fat (g)	0.2	Thiamine (mg)	0.10
Carbohydrate (g)	10.1	Riboflavin (mg)	0.06
Fiber (g)	1.0	Niacin (mg)	0.93
Ca (mg)	27	Ascorbic Acid (mg)	9.3
P (mg)	44	Vitamin B6	0.15
Fe (mg)	0.5	Cellulose %	71.7
Hemicellulose %	13.0	lignin	15.2
Nitrate mg/100	40	Nitrite mg/100	0.41
reducing sugars %	1.18	non-reducing sugars	4.53

Table 1.2. Nutritional composition of carrots (Bhale, 2004)

	Nutrient	**Mean**	**±**			**Nutrient**	**Mean**	**±**	
Proximate Analysis	Protein	1.03	±	g	Amino Acids	Tryptophan	0.011	±	g
	Total lipid (fat)	0.19	±	g		Threonine	0.038	±	g
	Carbohydrate,	10.14	±	g		Isoleucine	0.041	±	g
	Ash	0.87	±	g		Leucine	0.043	±	g
	Energy	43.0	±	kcal		Lysine	0.04	±	g
	Water	87.79	±	g		Methionine	0.007	±	g
	Energy	180.0	±	kj		Cystine	0.008	±	g
	Fiber, total dietary	3.0	±	g		Phenylalanine	0.032	±	g
Minerals	Calcium, Ca	27.0	±	mg		Tyrosine	0.02	±	g
	Iron, Fe	0.5	±	mg		Valine	0.044	±	g
	Magnesium, Mg	15.0	±	mg		Arginine	0.043	±	g
	Phosphorus, P	44.0	±	mg		Histidine	0.016	±	g
	Potassium, K	323.0	±	mg		Alanine	0.059	±	g
	Sodium, Na	35.0	±	mg		Aspartic acid	0.137	±	g
	Manganese, Mn	0.142	±	mg		Proline	0.029	±	g
	Selenium, Se	1.1	±	mcg		Serine	0.035	±	g
Fat Soluble Vitamins	Vitamin A, IU	28129.0	±	IU		Alanine	0.059	±	g
	Vitamin A, RE	2813.0	±	mcg_RE	Lipids	Fatty acids, saturated	0.03	±	g
	Vitamin E	0.46	±	mg_		10:0	0.0	±	g
Water Soluble Vitamins	Vitamin C	9.3	±	mg		12:0	0.002	±	g
	Thiamin	0.097	±	mg		14:0	0.001	±	g
	Riboflavin	0.059	±	mg		16:0	0.023	±	g
	Niacin Pantothenic acid	0.928 0.197	± ±	mg mg		18:0	0.001	± ±	g
	Vitamin B-6	0.147	±	mg		18:1	0.006	±	g
	Folate	14.0	±	mcg		18:2	0.067	±	g
						Phytosterols	12.0	±	mg

Values are expressed per 100 g edible portion by USDA

1.2. Carrot products

Carrots are processed, cooked and used in a wide variety of food products, such as fried carrot, chips, carrot juice, soup mixes, and also in oil and other skin care products. Carrot juice has been very useful in the treatment of severe illnesses, especially cancer. Raw carrots are high in β-carotene, vitamin B-complex, C, D, E, K, iron, calcium, phosphorous, sodium, potassium, magnesium, manganese, sulfur, and copper (all in absorbable, organic forms) (Bhale, 2004).

1.3. Frying

Frying is one of the traditional and popular ways of food cooking and processing used in the food industry (Karizaki et a., 2013; Zhang et al., 2018), and one of the oldest and most popular cooking methods is frying, and deep-fat-frying is one of the techniques used. Deep-fat fried food is very popular for consumers because of their desirable flavor, color and crispy texture (Boskou et al., 2006). Frying adds unique characteristics to products that cannot be replicated by other cooking or processing methods (Adedeji and Nagadi, 2018).

Simultaneously, physicochemical and structural changes in proteins, carbohydrates, fats, and some microbiological changes occurred during frying , these changes include protein denaturation, Maillard reaction, starch gelatinization, caramelization reaction, etc, resulting in a unique flavor and taste for fried food (Renaud et al., 2002; Mellema, 2003; Adedeji et al., 2011).

In this technique, an edible fat is heated above the boiling point of water, so food material is partially or totally dried. Fat also migrates into the food, which accompanies water movement, but in the opposite direction (Fan et al., 2005; Karacabey et al., 2016). Frying is also a complex process which consists of heat and mass transfer by using frying oil as a heat exchange medium, where the inner moisture of the food submerged in hot oil is escaped so that the food has a loose and porous structure (Adedeji et al., 2009; Dehghan et al., 2011; Karizaki et al., 2013; Zhang et al., 2018).

Frying leads to high heat transfer rates, color (browning), rapid cooking, texture, and flavor development. Therefore, deep-fat-frying is widely used in an industrial as well as institutional preparation of foods to obtain unique flavors, colors, and textures in processed foods (Song et al., 2007). Frying time, food surface area, the moisture content of the food, types of breading or battering materials, and frying oil influence the amount of absorbed oil by foods (Choe and Min, 2007; Capar and Yalcin, 2017).

1.4 Freezing

Freezing is one of the most important ways of keeping food for long periods. Freezing provides a significantly extended shelf life and it successfully employes for long-term preservation of many foods. Freezing is still one of the most widely used ways of food preservation although several new technologies, such as high pressure, infrared irradiation, pulsed electric field, and ultrasound, are gaining importance. Freezing changes the physical state of a substance by changing water into ice when energy is removed in the form of cooling below freezing temperature. Usually, the temperature is further reduced to storage level (e.g., -18°C) (Rahman and Velez, 2007).

Freezing is used to provide long term preservation by inhibiting the metabolic processes in products and also by slowing down the rate of microbiological changes due to the decrease of temperature below the freezing point of the product. Besides of its desired stabilizing effects, however, irreversible physical changes during storage may compromise the quality characteristics of the product such as flavor, colour, and texture, thus reducing the market potential (Neri et al., 2014). Freezing causes severe damage to cell membranes and may cause excessive softening, it causes softening of vegetable texture due to the expansion of cellular volume as a result of the formation of ice crystals and consequent breaking of the cell walls (Fuchigami et al., 1994).

Bulut et al., (2018) studied the effect of freezing rate and storage on the texture and quality parameters of strawberry and green bean, and they reported that freezing caused a softening for strawberry and bean due to the structural damage and extracellular ice formation during the freezing. Another study was

done by Van Buggenhout et al., (2006) reported the effect of freezing on the microstructure of frozen carrots, Van reported that freezing (whether slow or fast) leads to tissue damage, and thus texture loss, and then softening but at different levels depending on the type of the freezing.

Xu et al., (2016) reported that freezing temperatures dramatically influenced the viscoelastic and nutritional attributes, and rapid freezing (–196^{o}C) contributed to maintaining the elasticity strength and nutritional qualities of carrots. Intermediate temperature (–70^{o}C) well maintained the cohesiveness and chewiness of carrots, also in this study, also he reported that the loss of carotenoids and soluble sugars could be related to the reduction of hardness during freezing.

1.5. Ohmic heating

Ohmic heating (also called Joule heating, electrical resistance heating, direct electrical resistance heating, electro-heating, or electroconductive heating) is defined as a process wherein electric currents pass through foods to heat them (Figure. 2). In this system, heating is internally generated because of electrical resistance. During ohmic heating, energy is transformed from the supplied electrical power to thermal energy. This transformation happens due to interactions between the moving particles that form the current and the atomic ions (Wen, 2014). Ohmic heating is based on the passage of an electrical current through a food product, which serves as an electrical resistance which leads to the generation of heat instantly inside the food (volumetric heating), and this amount of heat generated is directly related to the current induced by the voltage gradient in the field, and to the electrical conductivity (Bozkurt and İçier, 2010; Gavahian, 2019).

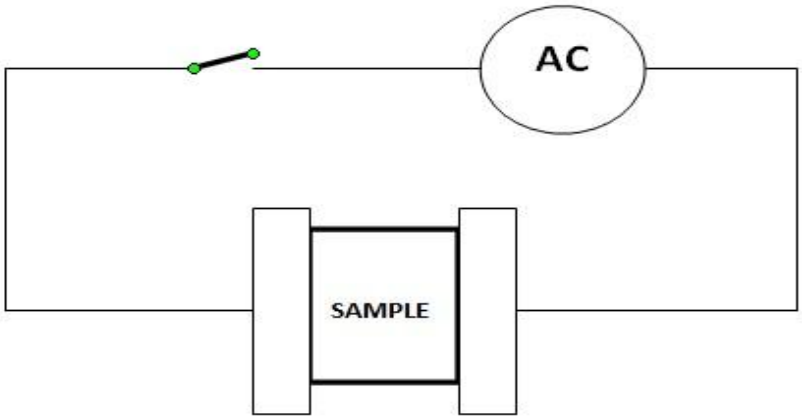

Figure 1.2. The principle of the ohmic heating process.

Ohmic heating has been used for many years and expected to be one of the promising food processing technologies. The first use of this system was in 1987 by the UK Department of Electrical Research and Development, after that in 1989 it became possible for this system to be used in commercial scales (Turgut, 2018). Ohmic heating can be used in a large number of actual and potential future applications, including its use in blanching, evaporation, dehydration, fermentation, extraction, sterilization, pasteurization and heating of foods to serving temperature in the military field or long-duration space missions, also this method is used in aseptic processing of prepared foods in the food industry, pasteurization of fruit and vegetable juices, processing of liquid egg and meat products, pre-heating processes in canned goods (Knirsch et al., 2010; Liu 2014; Turgut, 2018).

The effectiveness of the ohmic heating technique is related to the electrical conductivity of the product. Since the amount of current passing through the system depends on the electrical conductivity coefficient of the product, the most important parameter of the ohmic system is stated as the electrical conductivity coefficient. The electrical conductivity coefficient varies depending

on many factors. Factors such as temperature, food concentration affect the electrical conductivity value. The presence of electrolytes such as salt or acid in the system increases the electrical conductivity and accelerates the temperature rise (Jittanita et al., 2017; Turgut, 2018).

The success of ohmic heating depends on the rate of heat generation in the system, the electrical conductivity of the food, electrical field strength, residence time and the method by which the food flows through the system. Ohmic heating is appropriate for the processing of particulate and protein-rich foods and this heating can be applied in liquid foods, solid foods, and solid-liquid mixture foods. A vast amount of work is still necessary to understand food properties in order to refine system design and maximize the performance of this technology in the field of packaged foods and space food product development (Varghese et al., 2012).

The main advantages of the ohmic system are:

- No theoretical upper-temperature limit: in the ohmic system, there is the generation of internal energy generation and may achieve temperatures far in excess of conventional processing, but in the conventional heat, the medium temperature is the highest temperature can be reached (Ramaswamy et al., 2010).
- High maintenance of the colour, nutritional value, long shelf life and the quality of the food (Varghese et al., 2012; Sengun, 2014).
- The heating rate can be controlled, and this is can be done by controlling the applied voltage (Ramaswamy et al., 2010).
- Shorter processing times and higher yields (Sengun, 2014).
- Rapid and uniform heating: Since ohmic heating depends on the generation of the internal energy, solid pieces within a solid-liquid mixture will be heated at the same rate as the fluid, but in the conventional method, heat is transferred from an external medium through heat exchange walls and a carrier fluid before reaching the solid phase (Ramaswamy et al., 2010).

- It is considered environmentally clean technology, either by improving the overall energy efficiency of the processor by reducing the use of non-renewable resources (Pereira et al., 2016).
- High energy efficiency, nearly all the energy delivered to the food is used, efficiencies of 90% and above are common (Bhale, 2004; Ramaswamy et al., 2010).
- Minimize the need for cleaning: Since the food product does not come into contact with any hot surfaces, there are no problems such as burnt layer, accumulation and coagulation. Therefore, cleaning and maintenance times and costs of equipment are reduced (Kanjanapongkul, 2017).
- No residual heat transfer after shut-off of the current (Rouaud et al., 2016).
- Cost: in the last 10 years, the ohmic heating method has become attractive because of the increase in device manufacturers, cheaper and stronger energy source. Ohmic heating reduces the cost of processing food, improves the product characteristics and increases the added value of the product (Pereira et al., 2016; Turgut, 2018).

Ohmic heating differs from other electrical heating systems by:

- The presence of electrodes, these electrodes contacting the foods directly, but for example in microwave electrodes are absent (Wen, 2014).
- The energy efficiency in the ohmic heating is higher, for example, the energy efficiency of microwave heating is around 50% but in the ohmic heating method, the energy efficiency is 90%, making the ohmic heating method more preferable (Turgut, 2018).
- The unrestricted frequency applied in ohmic heating, but for assigned or microwave there is a range for frequency (Wen, 2014).

Ohmic heating technology originates at the end of the 19th century, and used for pasteurizing milk, but it was with a different name (the electropure process), but at that time, ohmic heating was derelict because of the high costs and the short of inert materials used for the electrodes (Amatore et al., 1998; Wen,

2014). However, research on the ohmic heating method has increased in recent years and this system has become a subject to a lot of researches.

For example, Achir et al., (2016) studied the effect of ohmic heating on the carotenoid profile of two citrus fruit juices: grapefruit and blood orange. In this study, two heat treatments were designed to obtain pasteurization values of 50 and 150 min, with ohmic heating as compared to conventional heating. The results said that the loss in xanthophylls could reach 70% for epoxyxanthophylls and 40% for hydroxyxanthophylls when conventional heating was used, but when ohmic heating was employed, losses were fewer than 30% and 20%, respectively, for these xanthophylls, negative non-thermal effects of ohmic heating were shown. Loss simulations of the studied carotenoids showed that the high temperatures reached with ohmic heating during pasteurization could substantially increase the organoleptic and nutritional quality of acid carotenoid-rich juices.

Another study by Sengun (2014) investigated the effect of ohmic heating on some quality attributes of semi-cooked meatballs. In this study, meatball samples were semi-cooked by 15.26 V/cm voltage gradient and 0 holding time at 75 °C. Results showed that ohmic cooking significantly reduced the numbers of total mesophilic aerobic bacteria, mold- yeast, *Staphylococcus aureus* and completely eliminated *Salmonella spp*. from meatball samples, but at the same time, there was not enough effectiveness to inactivate all *Listeria monocytogenes* cells. Ohmic semi-cooking process resulted in higher cooking yields, which were supported by high fat and moisture retention values in meatball samples. For the sensory evaluation, results showed that the overall acceptance of the semi-cooked meatball samples was good.
Also, the iron, chromium, nickel, and manganese of semi-cooked meatball samples that pretreated with ohmic pre-treatment were found below the upper level of dietary exposure levels (Sengun et al., 2014).

Kanjanapongkul (2017) proposed the ohmic heating as an alternative method to cook rice, and in this study, rice grain's swelling behavior and electrical conductivity, water diffusion, and cooking energy were investigated. Results showed that water diffusion was more effective and the processing time was

shortened and the rice grains expanded faster compared to the traditional electric rice cooker. In addition, the energy used for cooking with ohmic heating was found to be one-fourth of the energy required by electric rice cooking equipment. Also, it was reported that ohmic heating increases the apple juice yields over raw samples or those pretreated with conventional or microwave heating, and it was found that the hot-air drying rate of yam was significantly greater and shorter drying time than the other drying methods (Lima and Sastry, 1999).

The application of the ohmic heating system in meat thawing and its effects on quality was studied. By using ohmic heating, the fastest thawing, the least weight loss and the shortest thawing time were observed in the samples, but at the same time, an increase was determined in pH value and the decrease was determined in a_w and moisture values in consequence of all thawing methods applied on samples with the considering for the frozen storage period (Duygu and Ümit, 2015).

Beef samples were cooked ohmically and conventionally, in ohmic cooking, time was shorter than conventional cooking, and ohmically cooked samples were firmer than those cooked conventionally but yield and fat retention were similar. Also, the reduction in volume during ohmic cooking was significantly smaller than the reduction in volume during the conventional system (Bozkurt and İçier, 2010).

Turkey meat was cooked using both ohmic heating and conventional steam cooking. Ohmic heating gave a significantly lighter, more uniform colour and less color loss than steam cooking. There weren't big differences in textural properties, and ohmic heating has industrially significant potential, shortening the cooking time by 8-15 times with a higher quality product (Zell et al., 2010). Salengke and Sastry, (2005) reported a study about ohmic heating as a pre-treatment for potato slices before frying to investigate its effects on oil absorption. In this study, samples were placed directly between two metal sandwiches. Results indicated that oil uptake during frying and subsequent cooling of potato slices decreased by ohmic pre-treatment using directing sandwiching.

Effects of ohmic heating on the quality of orange juice were investigated and compared to those of heat pasteurization at 90°C for 50s, and ohmic was carried out at 90, 120, and 150°C for 1.13, 0.85, and 0.68s. For the ohmic heating, there was a reduction in pectinesterase activity by 98%, and the reduction in vitamin C was 15%. Also, results showed complete inactivation of bacteria, yeast, and mold during ohmic and conventional treatments, and sensory evaluation results showed no difference between fresh and ohmic heated orange juice because ohmic heated orange juice maintained higher amounts of the five representative flavor compounds than the traditional pasteurization (Leizerson and Shimoni 2005). Extraction of anthocyanins and other bioactive compounds from black rice bran using ohmic heating was investigated, results showed that in ohmic system extraction the yield of bioactive compounds and the concentration of them were high, in addition to their high solubility in water (Loypimai et al., 2015).

Ohmic heating can be used for different purposes. It can be used as an alternative method for cooking, pasteurization, increased extraction, etc. the technique can provide a product with high quality; maintain the nutritional value, decreasing processing time and energy, thus decreasing the costs.

In the present study, the effect of ohmic heating on some physical and quality properties of carrot cubes after and before frying was evaluated. Also, the same properties were determined after freezing the carrots for three months to evaluate the effect of ohmic treatment and freezing on these properties. Moisture content, oil content, textural properties, colour parameters, and β-Carotene were determined. Also, the possibility of decreasing oil uptake after frying was determined by pre-treating samples with deferent voltages and different frying time.

2. MATERIALS AND METHODS

2.1. Sample preparation

Carrots (*Daucus carota* L.) used in the study were obtained from a local market in Isparta, Turkey, and they were stored in a refrigerator at 4°C until processed. Prior to treatments, special care was given in order to select similar samples in colour and size and the ones having any physical damage and microbiological spoilage were removed. Then, carrots were washed with tap water and cut into cubes (1 cm^3) by kitchen cutter.

2.2. Ohmic heating equipment

Carrot cubes (15 cubes, because more or less of this number leads to the burning of the samples due to the high resistance of the samples) were placed between two electrodes (stainless steel) and heating for 10 seconds (more than 10 sec burns the samples) at two different voltages (95 and 150 V), Figure (3).

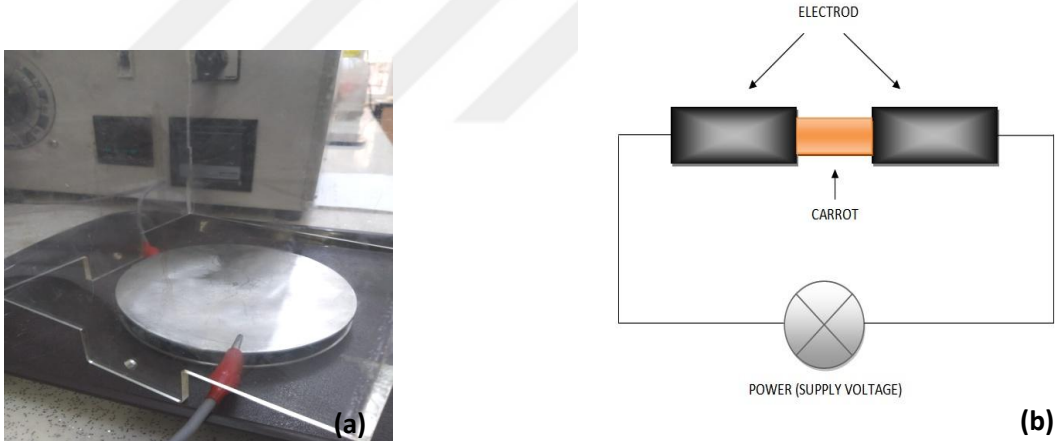

Figure 2.1. Ohmic heating circuit

(a: The stainless steel sandwich, b: scheme for the ohmic heating system)

2. 3. Frying

Samples were immediately fried using an electric fryer (Arnica universal ZG 27A, China) at 180°C for 60 seconds using sunflower oil as a heating medium. Another group of samples was fried after the ohmic treatment (95 and 150V) for different times (10, 20, 30, 40, 50 and 60 seconds), analysis was done for these samples and compared to control samples which just fried for 60 seconds

to check which sample of treated samples has the same or physical properties with control sample to figure out if there is a possibility to decrease the frying time and the oil uptake.

2. 4. Freezing equipment

Raw samples and pretreated ones (95 and 150V) for 10 sec, were frozen at -20 °C in plastic bags for 3 months using a regular household freezer. Monthly samples were taken and analyses were done for these samples.

3. ANALYSES

3.1. Oil content

Reaching a high and constant quality of fried products with appropriate oil content is of considerable interest in the food industry and consumers nowadays. Oil consumption from fried food especially saturated fat is considered the main factor for an increased of health risks such as coronary heart disease (CHD), cancer, diabetes, and hypertension, and even linked to increased causes of deaths. For this, the determination of oil content is an important point for fried food (De and Camp, 2001; Ziaiifar, 2009).

Total lipid content (% db) was determined according to the chloroform-methanol extraction method suggested by Bligh and Dyer (1959) with some modifications presented by Lee, (1996). Briefly, 10 g of sample was mixed and homogenized with 30 mL of extraction solvent (chloroform: methanol, 2:1) for 2 min and the mixture was filtrated through a Whatman no.1 filter paper. This step was repeated for 3 times and all the filtrates were combined. The resulting solution was transferred into a separation funnel, 20 mL 0.5% NaCl solution was added over and the mixture was left for overnight at room temperature. Following, the total volume of chloroform layer was recorded and 10 mL of it was transferred to a pre-weighed aluminum plate and completely evaporated on a hot plate for 30 minutes at 73 °C with the preventing from overheating. After 15 min of cooling the weight of dish was recorded and fat content was calculated as follows:

$$\boldsymbol{Total\ lipid\ content}(\%) = \frac{\boldsymbol{w_L}}{\boldsymbol{w_S}} \times \frac{\boldsymbol{v_C}}{\boldsymbol{10\ ml}} \times \boldsymbol{100}$$

where w_L and w_S were the weight of extracted lipid and sample, and v_C is the total volume of chloroform that was previously recorded.

3.2. Texture analysis

The texture is considered an important quality attribute in food processing, for this texture profile like hardness, cohesiveness, and chewiness were determined in this study. Texture profile analysis (TPA) was defined as follows:

- Hardness: Place sample between molar teeth and bite down evenly, evaluating the force required to compress the food.
- Chewiness: Place the sample in the mouth and masticate at one chew per second at a force equal to that required to penetrate a gumdrop in 0.5 seconds, evaluating the number of chews required to reduce the sample to a state ready for swallowing.
- Gumminess: the product of hardness and cohesiveness and it's the energy required to disintegrate a semisolid food until it is ready to swallow.
- Cohesiveness is defined as the ratio of the positive force area during the second compression to that during the first compression. Cohesiveness may be measured as the rate at which the material disintegrates under mechanical action (Bhale, 2004).

In this study, firmness (F, g-force), hardness (H, g-force), chewiness (C, g-force) and gumminess (G, g-force) of carrots were determined using a texture analyzer (TA.XTPlus; Stable Micro Systems Co. Ltd, Godalming, UK). In order to measure these parameters a Perspex blade (A/LKB) for firmness and a 50mm Cyl. Aluminum (P/50) for hardness were used. Probe movement speed was set as 1×10^{-3} m s^{-1} for both firmness and hardness, and the strain was adjusted to 20% and 70%, respectively (Figure 4). This analysis was done by using special tools according to the method proposed by the AACC (The American Association of Cereal Chemists, 2000).

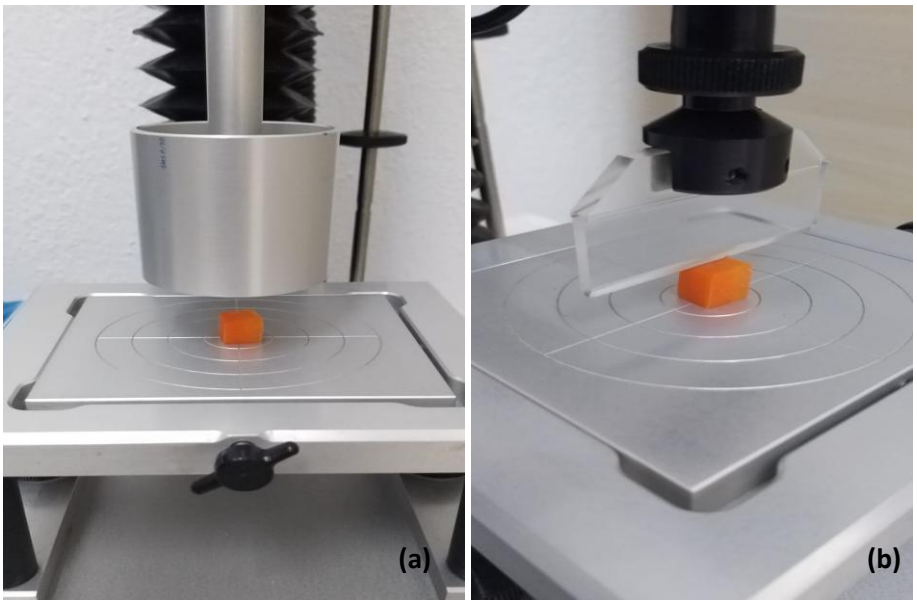

Figure 3.1.Textural analysis, (a) TPA (Texture profile analysis) and (b) LKB (Light knife blade)

3.3. Moisture content

The moisture content of the samples was determined using a bench top moisture analyzer (KERN DBS 60-3, Kern and Sohn GmbH, Balingen-Frommern, Germany) and the results are given in % (db).

3.4. Colour parameters

Colour parameters, CIE scale (L^*, a^*, b^*) of carrot samples were measured using a colorimeter (NH310, 3nh, Shenzhen, China).

L* is the lightness of the colour. This refers to the relation between reflected and absorbed light. A value equals to zero represents black colour and 100 represents white color. Colour values of a* and b*, where a* is the degree of colour depending on the range 0 to 60 represents degree of redness whereas the values between 0 to - 60 represents degree of greenness and b * is the amount of yellowness (0 to 60) or blueness (0 to - 60).

Thus the colour can be defined in terms of L* a* and b* and the individual values represent the colour characteristics of the carrot tissue (Bhale, 2004).

3.5. β-Carotene content

β-Carotene content of fresh and pretreated samples was determined using the method reported by Kotíková et al. (2011) with minor modifications (Turgut et al., 2018). A 1g ground sample was vortexed for 5 min within 10 mL ethyl acetate and centrifuged at 4000×g for 20 min. Supernatants were combined and dried in a rotary evaporator at 40 °C. Before the injection, the residue was dissolved in 5 ml ethanol/acetone (6:4) solution containing 0.2% BHT and filtered through a 0.45-µm membrane filter. In order to analyze the β-Carotene, liquid chromatography-diode array detection analysis was carried out using a liquid chromatography system (Agilent 1260 Infinity series, Agilent Technologies Inc., Palo Alto, CA, USA) equipped with a photodiode array detector, an autosampler, and a control module. Samples of 10 µL were injected into a reversed-phase C18 column (XDB, 5 µm, 250 mm × 4.6 mm, ID, Agilent Technologies Inc., Palo Alto, CA, USA) preceded by a guard column (Eclipse XDB-C18, 5 µm, 4.6 × 12.5 mm, Agilent, USA). β-Carotene (detection at 250 nm) was analyzed qualitatively comparing their retention times and UV spectra with authentic standards (L9879 Lycopene and C9750 β-Carotene, Sigma-Aldrich, St. Louis). The column temperature was set at 25 °C. A gradient solvent system was used with solvent A being methanol, solvent B being acetonitrile, solvent C being tetrahydrofuran, and solvent D being hexane. The elution profile had the following proportions (v/v) of solvent A, B, C, and D: 0 min, 46% A, 54%B; 0–5 min, 46% A, 54% B; 5–35 min, 46% A, 30% B, 12% C, and 12% D; 35–40 min, 46% A and 54% B. The solvent flow rate was 0.8 ml/min. β-carotene concentration was calculated by their peak areas and standard curves. Results were expressed as mg β-carotene/kg dry matter.

3.6. Statistical analysis

All the results were compared by using Minitab Statistical Software (version 17.1) (Minitab Inc., State College, PA, USA). Tukey pairwise comparison test was conducted to determine the significance of mean values during comparison at the level of $p \leq 0.05$. The results were presented as “mean ± standard˝.

4. RESULTS AND DISCUSSION

4.1. Experimental design results

In order to check if there was a possibility to decrease the frying time and/or oil uptake, control samples fried for 60 seconds, pretreated samples with 150V and 95V fried for 60 seconds, but after every 10 seconds samples were taken and sensory analysis, texture, moisture and colour analyses were done for these samples. The sensory analysis was done by a group of 10 semi-educated panelists (Table 3). The samples were randomly coded in a four-digit number and randomly placed on the plates. Samples were presented in a table in the appropriate table layout with water, and panelists evaluated the samples separately. Experimental data were analyzed using Minitab Statistical Package Programme (Minitab 17.1).

From Table 4-6, it can be seen that the sample that pretreated with 150V and fried for 10 seconds is the nearest sample to the control, for this reason, this sample was taken to go under the same analysis with other.

Table 4.1.The form of sensory analysis

1) 2) How did you find the texture of the sample?				
1	2	3	4	5
2) 2) How did you find the oil content of the sample?				
1	2	3	4	5
3) 2) How did you find the taste of the sample?				
1	2	3	4	5
4) 2) How did you find the colour of the sample?				
1	2	3	4	5

Table 4.2. The effect of different voltages and frying time on the textural properties of carrots

Voltage	Frying /second	Hardness (g-force)	Firmness (g-force)	Gumminess (g-force)	Chewiness (g-force)
0V	60	799.76±43.3^{b}	591.25±43.7^{bc}	564.81±14.7^{abc}	375.54±82.1^{bc}
95V	10	1326.49±195^{a}	1696.44±244^{a}	939.23±147^{a}	722.04±114^{a}
95V	20	622.04±159^{bcd}	736.65±482^{b}	757.83±198^{ab}	548.15±60.2^{ab}
95V	30	392.66±77.1^{bcd}	352.60±44.2^{cd}	276.28±55.9^{cd}	217.82±38.3^{c}
95V	40	594.81±83.2^{bcd}	438.37±201^{bcd}	417.94±59.3^{bcd}	325.00±44.6^{bc}
95V	50	389.73±209^{bcd}	192.44±177^{c}	277.54±343^{cd}	143.11±82.1^{c}
95V	60	199.314±46.8^{d}	257.956±266^{cd}	138.94±34.8^{d}	142.26±32.2^{c}
150V	10	656.66±67.3^{bc}	550.50±293^{bc}	490.12±55.3^{bcd}	404.02±57.2^{bc}
150V	20	551.88±54.7^{bcd}	272.96±25.1^{cd}	400.15±46.1^{bcd}	322.59±46.2^{bc}
150V	30	480.44±28.9^{bcd}	491.11±94^{bcd}	333.37±20.6^{cd}	259.10±16.3^{bc}
150V	40	405.54±57.4^{bcd}	361.83±181^{cd}	241.13±38.8^{cd}	221.63±29.3^{c}
150V	50	339.63±32.0^{cd}	300.95±102^{cd}	252.68±19.4^{cd}	229.79±22.5^{c}
150V	60	278.17±17.6^{cd}	284.00±206^{cd}	191.96±11.1^{cd}	151.91±10.3^{c}
- $^{a-c}$ means in the same column with different superscripts are significantly different ($p \leq 0.05$).					

Table 4.3. The effect of different voltages and frying time on the moisture and colour properties of carrots

Voltage	Frying /second	Moisture (% db)	Colour		
			L*	b*	a*
0V	60	77.985 ±0.575^{cd}	58.236± 1.21^{bc}	45.196±0.898^{b}	20.741± 1.44^{b}
95V	10	82.605±0.145^{a}	57.476±0.609^{bcd}	42.80±1.48^{b}	24.938±1.70^{ab}
95V	20	81.780±0.140^{ab}	56.204±0.764^{bcde}	36.480±1.53^{de}	22.057±2.26^{ab}
95V	30	79.480±0.230^{abc}	54.476±0.966^{def}	42.12±1.61^{bc}	22.190±2.63^{ab}
95V	40	79.285±0.425^{abc}	55.244±0.618^{cde}	44.623±0.823^{b}	19.942±0.864^{b}
95V	50	79.300±0.200^{abc}	50.822±1.30^{g}	35.976±0.720^{e}	20.707±1.76^{b}
95V	60	75.815±0.725^{cd}	54.412±0.514^{def}	41.346± 1.28^{bcde}	20.728±1.12^{b}
150V	10	78.085±0.335^{cd}	58.332±0.564^{bc}	45.053±1.21^{b}	23.292±1.02^{ab}
150V	20	76.145±1.05^{cd}	59.478±0.906^{ab}	43.503±0.801^{b}	23.457±1.48^{ab}
150V	30	74.510±0.050^{d}	61.904±0.650^{a}	50.866±0.363^{a}	24.147±0.796^{ab}
150V	40	74.415±0.855^{d}	56.344±0.593^{bcde}	45.83±1.26^{ab}	26.678±0.918^{a}
150V	50	66.130±1.57^{e}	53.494±1.55^{efg}	41.536±0.778^{bcd}	24.757±1.91^{ab}
150V	60	62.365±0.515^{e}	51.866±0.708^{fg}	37.016±1.27^{cde}	22.788±0.841^{ab}

- $^{a-c}$ means in the same column with different superscripts are significantly different ($p \leq 0.05$).

Table 4.4. The effect of different voltages and frying time on the sensory properties of carrots

Voltage	Frying /second	Taste	Oil content	Texture	Colour
0V	60	4 ± 0.373^{a}	3.4 ± 0.306^{b}	3.4 ± 0.213^{b}	4.65 ± 0.153^{a}
95V	10	3.4 ± 0.379^{b}	3.7 ± 0.335^{b}	2.8 ± 0.267^{c}	4.15 ± 0.249^{a}
95V	20	3.4 ± 0.394^{b}	3.9 ± 0.277^{b}	2.8 ± 0.300^{c}	4.05 ± 0.348^{a}
95V	30	3.2 ± 0.407^{b}	3.3 ± 0.213^{b}	3.0 ± 0.306^{b}	3.35 ± 0.249^{b}
95V	40	3.2 ± 0.359^{b}	3.3 ± 0.335^{b}	3.0 ± 0.327^{b}	3.3 ± 0.291^{b}
95V	50	3.2 ± 0.300^{b}	3.2 ± 0.359^{b}	3.3 ± 0.342^{b}	3 ± 0.267^{b}
95V	60	2.7 ± 0.300^{c}	3.5 ± 0.307^{b}	3.0 ± 0.389^{b}	3.65 ± 0.298^{b}
150V	10	4 ± 0.400^{a}	3.3 ± 0.260^{b}	3.4 ± 0.396^{b}	3.55 ± 0.473^{b}
150V	20	2.7 ± 0.348^{c}	3.1 ± 0.233^{b}	2.6 ± 0.333^{c}	3.65 ± 0.389^{b}
150V	30	2.7 ± 0.396^{c}	2.8 ± 0.291^{c}	2.8 ± 0.442^{c}	3.35 ± 0.365^{b}
150V	40	3 ± 0.448^{b}	3.4 ± 0.267^{b}	2.6 ± 0.427^{c}	3.75 ± 0.433^{b}
150V	50	4 ± 348^{a}	3.5 ± 0.269^{b}	2.8 ± 0.340^{c}	3.65 ± 0.342^{b}
150V	60	3.2 ± 0.335^{b}	3.3 ± 0.300^{b}	2.6 ± 0.307^{c}	3.55 ± 0.269^{b}
- $^{a-c}$ means in the same column with different superscripts are significantly different ($p\leq0.05$).					

4.2. Without freezing.

4.2.1. Moisture content

In the present study, the effect of ohmic heating pre-treatment on some quality properties of fried carrots cubes was investigated. Moisture content was presented in Table 7. It is clear that frying and electrical heating caused a decrement in the moisture content of the samples. In deep fat frying, two simultaneous mass transfer phenomena, namely moisture, and oil transfer, take place in opposite directions within the materials, and at the same time heat is transferred from the oil to the food, which forces the evaporation of water from the food and oil is absorbed in it (Bhale, 2004). In ohmic pre-treatment, electrical heating influences the mass transfer properties and makes changes in the texture which leads to the release of part of the water from inside of the plant tissues, also high temperature as a result of high voltage, leads to the partial evaporation of water from sample inside (Fu and Huang, 2014).

For the samples fried for 60 seconds, carrot cubes treated at 150V had the lowest moisture content 67.98±0.82% due to the effect of frying and the pre-treatment of ohmic heating, both of which lead to the loss of moisture. Similar changes were observed for the samples pretreated at 95V, but moisture loss 70.82±0.69% was less than the former one most probably because of the lower voltage level used in ohmic heating compared to 150V treatment. So, the higher the voltage leads to less moisture content (Figure 5).

From the same table, we can see that the sample which pretreated with 150V and fried for 10s has the highest moisture content 75.08±0.33% comparing to other pretreated samples due to the short frying time (10s).

Table 4.5. Effect of different voltage as a pretreatment before and after frying on the moisture content of carrots

Voltage	Frying /second	Moisture content (% db)
0V	-	88.72±0.03[a]
0V	60	73.26±0.21[b]
95V	-	87.54±0.33[a]
95V	60	70.82±0.69[b]
150V	-	85.47±0.40[a]
150V	60	67.98±0.82[c]
150V	10	75.08±0.33[b]
- [a-c] means in the same column with different superscripts are significantly different (p≤0.05).		

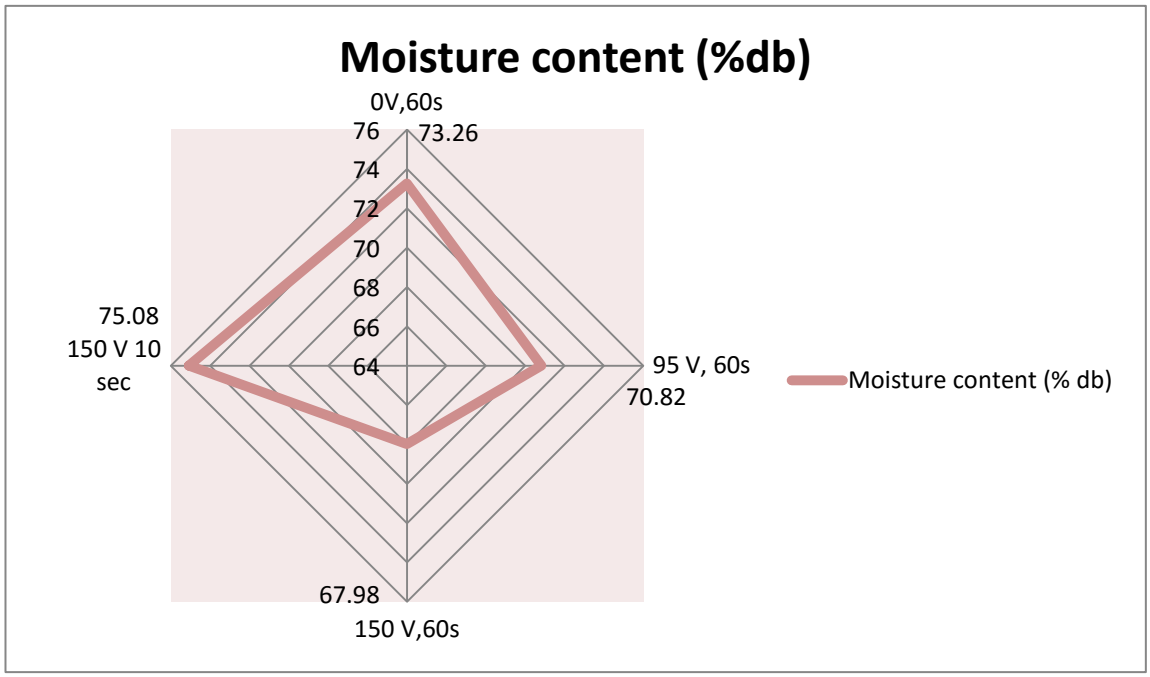

Figure 4.1. The relation between voltage and moisture content, the increasing in the voltage leads to the reduction in moisture content

4.2.2. Oil Content

Table 8 presented the oil content of the samples. From this table and with 60s frying time shows that the lowest oil content 6.07±0.32 g/100g was found for the fried control sample, and the highest one 8.15±0.90 g/100g was for the sample heated at 150V. During frying, heat is transferred from the oil to the food, water is evaporated from the food and oil is absorbed by the material. During this mass transfer cycle, the inner moisture content plays a critical role, as it is converted to steam, creating a pressure gradient as the surface dries out and causing the oil to adhere to the product's surface at the damaged areas (Fu and Huang, 2014).

Thus, briefly, it means that the higher initial moisture content of samples results in higher inner pressure decelerating oil absorption. From that point of view, since the sample treated at 150V has the least moisture content, it was thought that this sample absorbed more oil during frying. Moreover, ohmic heating leads damages and alterations in cell and tissue structure which help the penetration of oil inside the sample during the frying. The low voltage causes less damage, as a result, less moisture loss. This explains why these fried samples heated at a 95V gradient of ohmic heating absorbed less oil than that treated at 150V. So, the increasing of voltage leads to the increasing of the oil content (Figure 6).

Going back to the sample that pretreated with 150V and fried for 10s, from the table we can see oil content for this sample was decreased to 4.23±0,14 g/100g because 10s was not enough time to oil to penetrate inside the samples, and not enough to evaporate the moisture inside the sample and replaced it with the oil.

Table 4.6. Effect of different voltage as a pretreatment on the oil content of carrots after frying

Voltage	Frying /second	Oil content (g/100g)
0V	60	6.07±0.32[b]
95V	60	6.82±0.15[b]
150V	60	8.15±0.90[a]
150V	10	4.23±0,14[c]
- [a-c] means in the same column with different superscripts are significantly different (p≤0.05).		

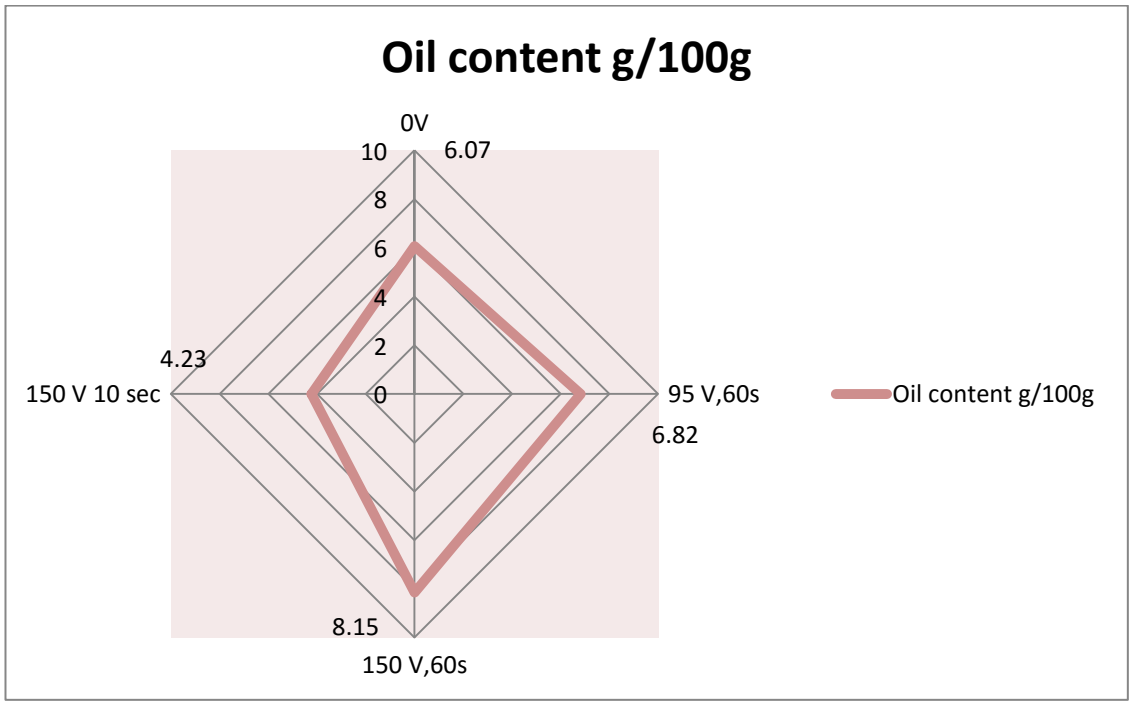

Figure 4.2. The relation between voltage and oil content, the increasing in the voltage leads to the increasing in oil content

4.2.3. Textural results

4.2.3.1. Hardness and Firmness

Textural properties (firmness and hardness) of the processed and raw carrot samples are given in Table 9. For the samples fried for 60s, the frying and pre-treatment processes were found to be significantly effective on textural properties of the carrot cubes ($p \leq 0.05$), and textural properties of all samples irrespective of the application of pretreatment (directly fried and treated by ohmic heating and then fried cubes) significantly decreased compared to fresh carrot cube samples. Based on the above results, in both fried and non-fried carrots, firmness and hardness decreased with the increase of used voltage level. This may be attributed to the deteriorative impacts of electrical current on the plant tissue. Ohmic treatment leads to the breakdown and the rupture of large cells which accelerates the softening (Pereira et al., 2016).

On the other hand, applied high temperature levels as a result of frying and ohmic heating lead to the decreases in firmness and hardness of plant tissues (Figure7,8) due to potential structural modifications which are associated with different phenomena induced by these thermal processes such as changing of inner chemical structure of the cell walls by the hydrolytic degradation reactions, protein insolubilization and the breakdown of the interlamellar layer of cell walls (Ogliano and Ellegrini, 2008).

According to the results, raw control samples had the highest hardness, followed by 95V non-fried and 95V fried which had shown lower strength against deformation than raw control samples due to ohmic heating at 95 V as a pre-treatment. The lowest strength against deformation belonged to the samples labeled as 150V fried due to the high voltage (150 V) use as a pre-treatment. For the samples treated at the processes defined as 95V fried and 150V fried, the low textural values were attributed to the two successive thermal treatments (frying and ohmic heating).

The deteriorative changes such as cell membrane disruption, turgidity loss, and cell wall matrix dissociation at the micro-and ultra-structure levels could be the

underlying reasons (Xu et al., 2016). So, the higher the voltage the lower the strength against deformation.

For the samples with 150V and 10s frying, it was nearer to fried control sample as we mentioned before in the experimental design in Chapter 3, and this is due to the shorter frying time which gave less effect on the texture than the long frying time (60s).

Table 4.7. Effect of different voltage as a pretreatment on firmness and hardness of carrots before and after frying

Voltage	Frying /second	Firmness (g-force)	Hardness (g-force)
0V	-	1720.82±76.29^{a}	6207.90±136.13^{a}
0V	60	492.42±130.22^{c}	429.78±58.92^{c}
95V	-	1481.76±69.39^{a}	4021.17±463.44^{b}
95V	60	1112.32±62.90^{b}	577.22±90.50^{c}
150V	-	736.28±46.23^{c}	927.15±56.06^{bc}
150V	60	466.68±93.59^{cb}	231.03±46.79^{d}
150V	10	520.50±293.00^{c}	510.66±67.3^{c}
- $^{a-c}$ means in the same column with different superscripts are significantly different (p≤0.05).			

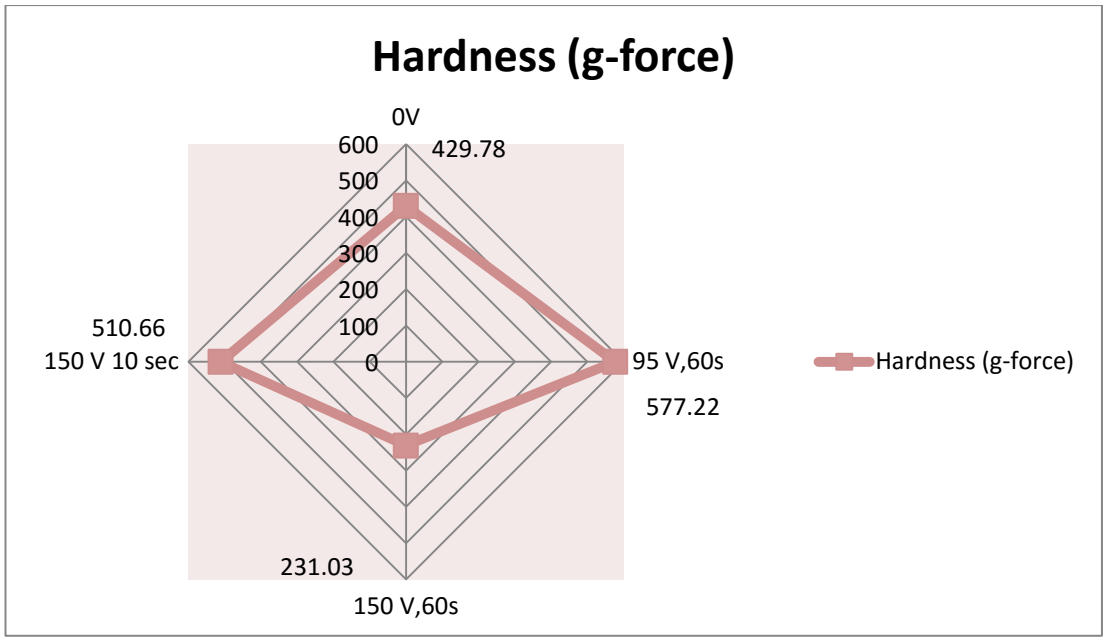

Figure 4.3. The relation between voltage and hardness, the increasing in the voltage leads to the decreasing in the hardness

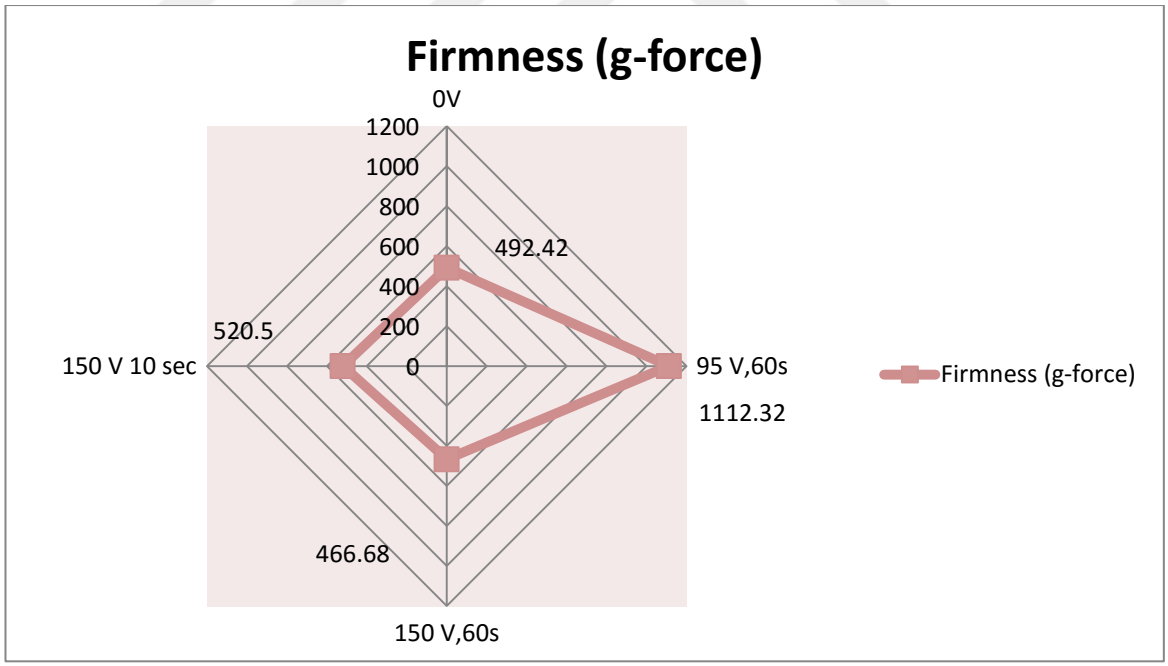

Figure 4.4. The relation between voltage and firmness, the increasing in the voltage leads to the decreasing in the firmness

4.2.3.2. Chewiness and gumminess

The gumminess and chewiness of the processed and raw carrot samples are shown in Table 10. All properties of thermally treated samples significantly decreased compared to control samples. For non-fired samples, the highest gumminess and chewiness values 4864±18, 4163±19 respectively belonged to the raw control. On the other hand, the lowest values 188.7±10.9, 99.8±21.8 were belonging to the samples pretreated with 150V and fried for 60s. With the increasing of voltages, the values of gumminess and chewiness decreased, and both values were found to be significantly different between raw control and pretreated samples with 150V.

Chewiness and gumminess are products of the hardness (Bhale, 2004), so they will be affected like by heating and frying like hardness. Ohmic heating and frying may have affected the microstructure of the carrots and have made a change in the individual cell functionalities which lead to the decreasing of these two values of the samples (Figure9, 10). As we mentioned before, ohmic treatment leads to the breakdown and the rupture of large cells and makes a change in the microstructure which accelerates the softening of the tissues. On the other hand, high temperatures come from frying lead to the decreasing of gumminess and chewiness values due to the several changes happen inside the cells such as the breakdown of the interlamellar layer of cell walls and changing of the inner chemical structure of the cell walls by the hydrolytic degradation reactions.

For the last sample in the table, that pretreated with 150V and fried for 10s, it was found that gumminess and chewiness were 475.6±20.5 and 401.18±1.44 respectively, and this was because of the shorter frying time, which is nearer to the fried control 433.5±54.7 and 355.3±43.7 which means the possibility of decreasing frying time for carrot by using ohmic heating as a pretreatment.

Table 4.8. Effect of different voltage as a pretreatment before and after frying on gumminess and chewiness of carrots

Voltage	Frying /second	Gumminess (g-force)	Chewiness (g-force)
0V	-	4864±18[a]	4163±19[a]
0V	60	433.5±54.7[c]	355.3±43.7[c]
95V	-	3144±495[b]	2582±38[b]
95V	60	483.0±57.2[e]	248.7±71.7[d]
150V	-	773±135[d]	468±11[c]
150V	60	188.7±10.9[f]	99.8±21.8e
150V	10	475.6±20.5[e]	401.18±1.44[c]
- [a-c] means in the same column with different superscripts are significantly different (p≤0.05).			

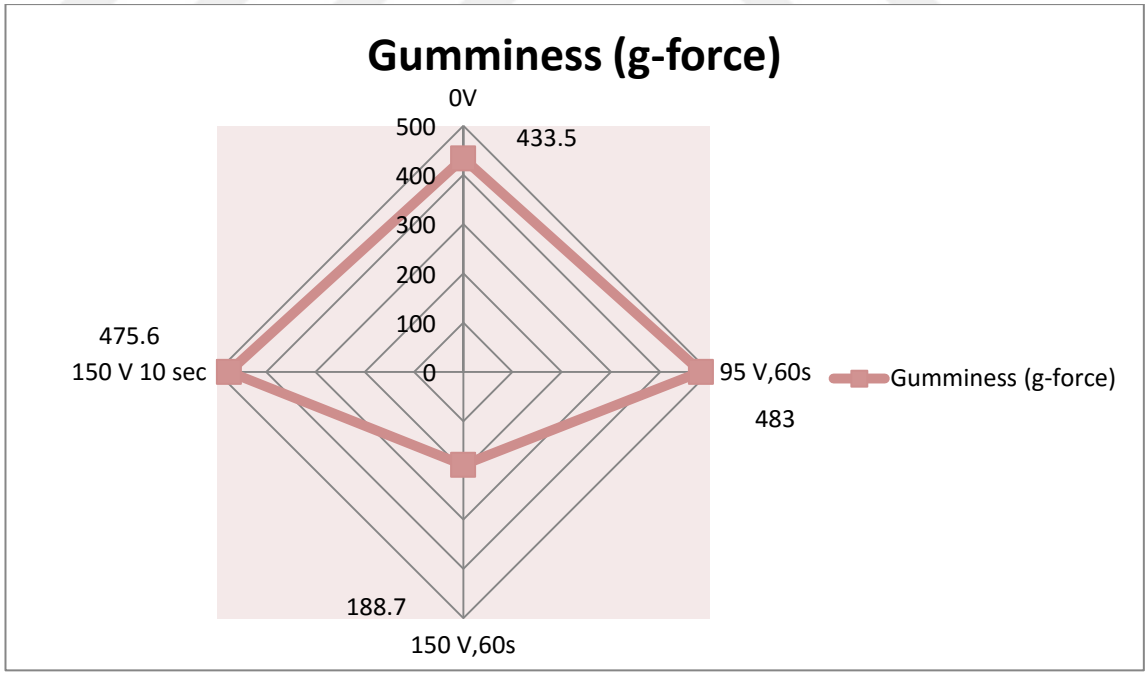

Figure 4.5. The relation between voltage and gumminess, the increasing in the voltage leads to the decreasing in the gumminess

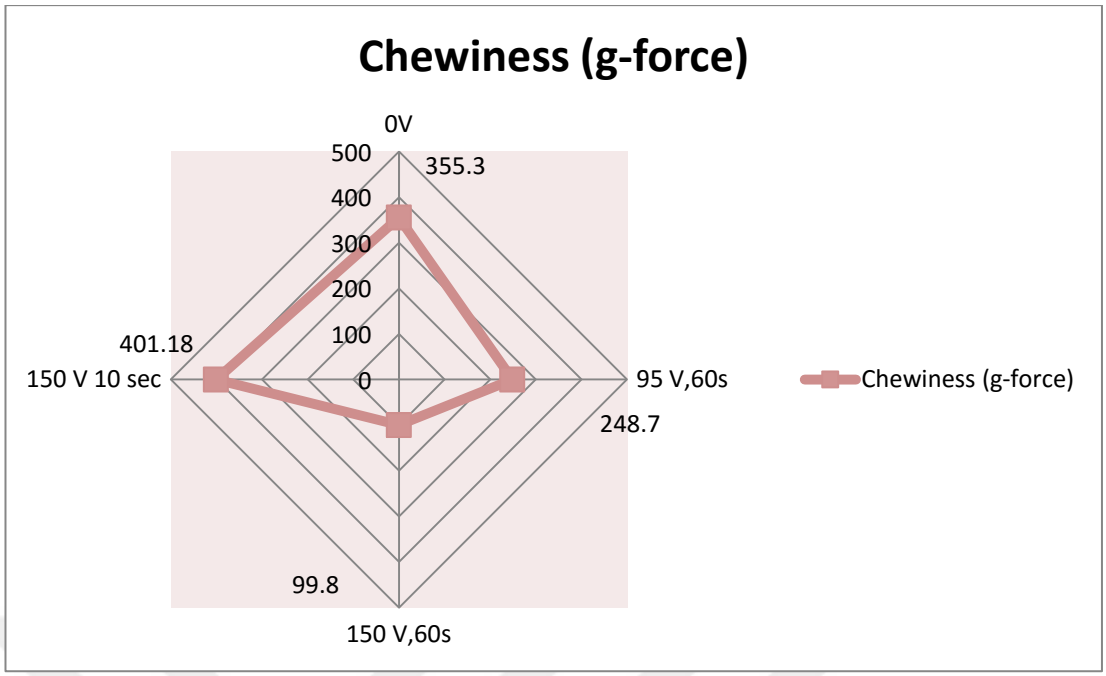

Figure 4.6. The relation between voltage and chewiness, the increasing of voltage leads to the decreasing of chewiness

4.2.4. Colour

The effect of ohmic heating on the colour properties of samples is presented in Table 11. There were significant differences between colour values for raw carrot and pretreated (150 V) fried samples ($p \leq 0.05$). All colour properties were reduced under the thermal stress, and this reduction may be related to the α- and β-carotene decrease and their isomerization during thermal processes (Lebovka et al., 2004). Moreover, a study by Sulaeman et al., (2001) indicated that there is a high negative correlation between the colour parameter and the carotene content of thermally pretreated carrots especially deep fried carrots.

L^* (lightness) (which is a critical colour parameter of fried foods, is usually used as a quality control determinant and so its adequate control is of utmost importance (Mariscal and Bouchon 2008), was between 50.49±1.0 in fried 150V and 61.04±1.03 in raw control, the lowest L^* was found in fried 150V due to more severe pre-treatment which decreased the lightness of the surface of the sample.

This phenomenon most probably arose from that the only fried samples (no pre-treatment) were exposed to high temperatures less than others, as in others that have additional heat which comes from the ohmic pre-treatment causes colour loss (Figure 11).

Heating and rehydration lead to the drying of the surface that resulted in decreases in the lightness (L^*) values, also the reduction in lightness may be attributed to intense browning reaction due to exposure to high temperature and to carotene content as noted above. Another colour parameter is the a* value, (which represents the degree of redness of the surface colour if the value lies between 0 to 60 or greeness if the value lies between 0 to -60) was between 18.95±1.43 in fried control and 31.22±1.52 in raw control.

A similar result for the b^* value (which indicates the yellowness of surface colour if the value lies between 0 to 60 or blueness if the value lies between 0 to -60) was observed and it was between 38.10±1.35 in fried control and 42.71±0.81 in raw control. The a^* value and b^* value were low in fried control which underwent one time thermal treatment (only frying) meaning fried control samples had more familiar visual characteristics compared to the other pretreated samples, but for the samples fried pre-treated with ohmic heating (fried 95V and fried 150V), a^* and b^* values increased due to the ohmic heating which gives darker red and yellow colours (Bhale,2004).

Table 4.9. Effect of different voltage as a pretreatment before and after frying on colour properties of carrot

Voltage	Frying /second	L*	a*	b*
0V	-	61.04±1.03^{a}	31.22±1.52^{a}	42.71±0.81^{a}
0V	60	53.66±0.61^{d}	18.95±1.43^{f}	38.10±1.45^{d}
95V	-	59.99±1.80^{b}	28.45±2.35^{b}	39.10±1.47^{c}
95V	60	52.53±0.77^{e}	25.27±1.22^{c}	39.35±0.82^{e}
150V	-	57.57±2.6^{c}	23.69±1.95^{d}	40.60±2.94^{b}
150V	60	50.49±1.03^{e}	21.83±1.37^{e}	43.38±1.75^{f}
150V	10	53.33±0.56^{d}	20.29±1.02^{e}	40.00±1.21^{b}
- $^{a-c}$ means in the same column with different superscripts are significantly different ($p \leq 0.05$).				

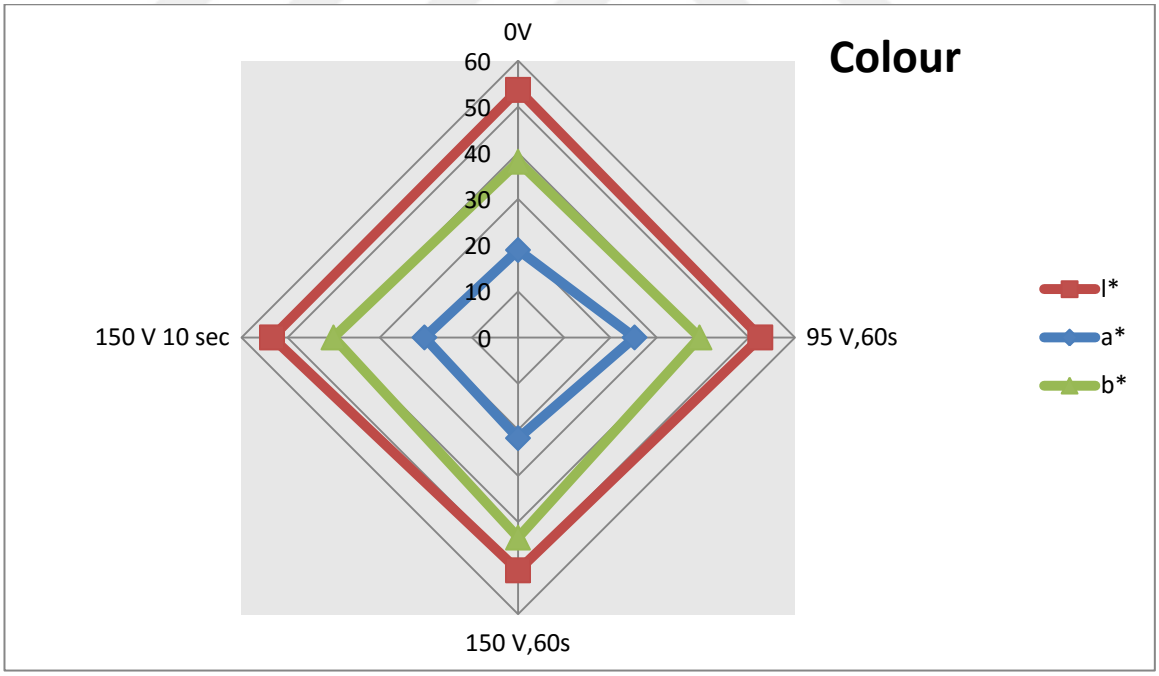

Figure 4.7. The relation between voltage and colour, the increasing of voltage leads to the decreasing of colour properties

4.2.5. β-Carotene content

From Table 12 below, we can observe the effect of the ohmic heating and frying on the β-Carotene content on carrot models. β-Carotene content ranges from 54.62±0.45 mg/kg in raw carrot samples to 40.91±6.91 mg/kg in 150V fried 60s samples. As we see from the results, the effect of the ohmic pretreatment and frying is very clear, especially in the fried models. Note also that the higher the voltage the lower the β- carotene in the models, hence the greatest effect is with the 150V fried model, with less effect with model 150V- 10s fried due to short frying time.

The decrease in β-Carotene content is due to the effect of frying and the ohmic pretreatment. Gomes, 2013 reported, that thermal processes reduce the proportion of β-Carotene due to the occurrence of isomerization of β-Carotene resulting from high heat generated by thermal processes during frying or ohmic treatment, as well as a reference to the transfer of part of β-Carotene to frying oil during frying as well as part of β-Carotene loses during the ohmic pretreatment (Figure 12). High heat also converts β-Carotene into free form and also leads to β-Carotene degradation, this effect increases with increasing heat and time (Karacabey et al., 2016). For this, with 95V non-fried sample β-Carotene content was 47.82±0.92 mg/kg and with 150V non-fried was 44.67±1.01 mg/kg, the content decreased with the increase of voltage that used.

We can observe the great effect by comparing the β-Carotene content for the raw samples 54.62±0.45 mg/kg and the 150V fried samples 40.91±6.91 mg/kg. For the 150V fried for 10s, we can see that the β- Carotene content was higher from 150V fried for 60s, due to the shorter frying time which reduced the frying effect on the content.

Table 4.10. Effect of different voltage as a pretreatment before and after frying on carotene content of carrot

Voltage	Frying/second	β-Carotene content (mg/kg)
0V	-	54.62±0.45[a]
0V	60	51.29±5.08[ba]
95V	-	47.82±0.92[c]
95V	60	46.44±0.63[c]
150V	-	44.67±1.01[cd]
150V	60	40.91±6.91[e]
150V	10	43.90±3.50[cd]
- [a-c] means in the same column with different superscripts are significantly different (p≤0.05).		

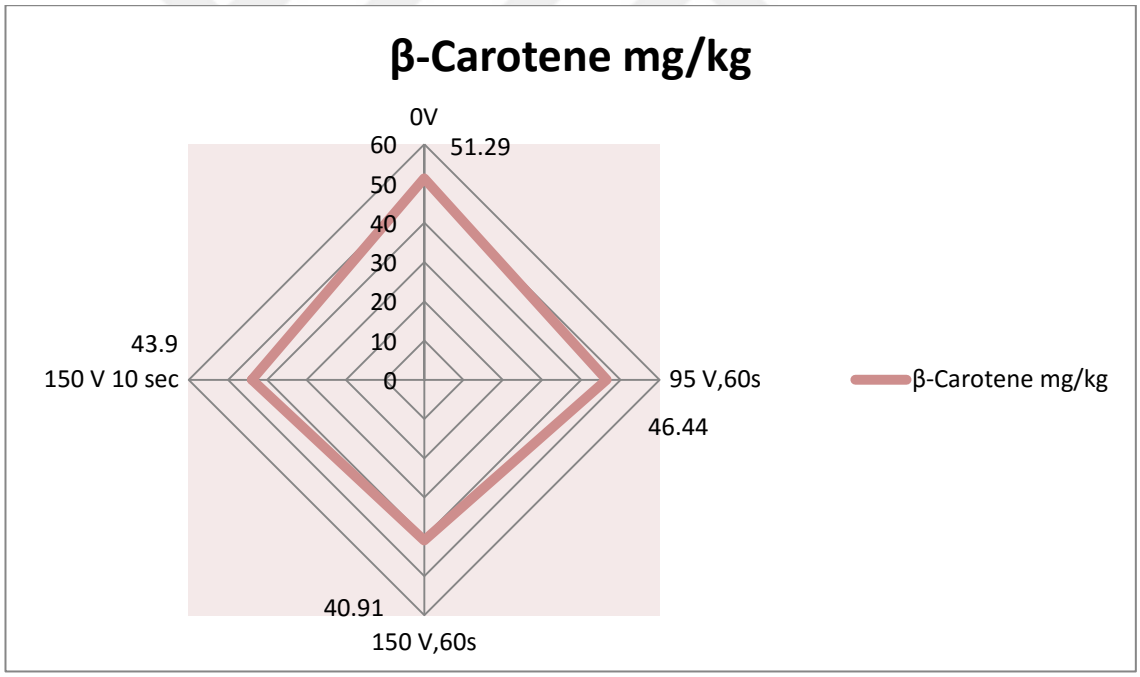

Figure 4.8. The relation between voltage and carotene, the increasing of voltage leads to the decreasing of β-content

4.3. After freezing

4.3.1. Moisture content

Moisture content is presented in Table 13. The value was ranging between 87.81±1.12 % in raw control and 64.65±0.22 % in the third month 150V fried 60s samples. From the table below, there is no significant difference between the results of the models during the three months, even in some results it is found that there is no difference in moisture content, and this is maybe due to the effect of ohmic pre-treatment which already let to the decreasing of moisture content before the freezing.

We can see that the effect of the freeze was so light after the first month only, and then the second and third month of the week there was no clear effect on the moisture content. For example, in 150V fried sample (without feezing) moisture content was 67.98±0.82 %, after freezing for one month it decreased and became 65.01±1.22 %, after that for the second and third months there was a slight decrease in the moisture content.

But if we compare the results of the models without freezing (Table 7) and the results of the models after freezing, we will notice a small difference between the two cases. The comparison shows that there is a small decrease in moisture content in the fried samples. This difference is due to the effect of frying and freezing together. Freezing leads to damage in the cells of the walls of the tissues, which facilitates the process of penetrating of oil during frying and get rid of the most possible amount of moisture content. (Van Buggenhout et al., 2006).

Table 4.11.. Effect of freezing and ohmic pretreatment on moisture content after and before frying of carrots

Samples	Frying/second	Freezing/month	Moisture content (%db)
0V	-	1	87.81±1.12^{a}
0V	60	1	69.32±2.11^{c}
0V	-	2	87.59±0.43^{a}
0V	60	2	70.33±0.25^{bc}
0V	-	3	86.01±1.99^{a}
0V	60	3	67.68±0.04^{c}
95 V	-	1	86.69±1.86^{a}
95 V	60	1	68.09±1.77^{c}
95 V	-	2	86.30±1.04a
95 V	60	2	70.55±2.10^{bc}
95 V	-	3	87.15±0.23^{a}
95 V	60	3	69.66±0.17^{c}
150 V	-	1	84.57±0.65^{ab}
150 V	60	1	65.01±1.22^{c}
150 V	-	2	84.37±0.13^{ab}
150 V	60	2	64.28±1.87^{cd}
150 V	-	3	84.75±2.01^{ab}
150 V	60	3	64.65±0.22^{cd}
150 V	10	1	75.54±0.88^{b}
150 V	10	2	76.04±2.1^{b}
150 V	10	3	75.55±.06^{b}
- $^{a-c}$ means in the same column with different superscripts are significantly different ($p \leq 0.05$).			

4.3.2. Oil content

Table 14 shows the oil content of the samples, and values were ranging between 10.88±1.01 g/100g in the second month 150V 60s fried samples and 4.11±1.66 g/100g in the first month 150V 10s fried samples. As shown in the table below, there are no obvious differences in the oil content of the models during storage. The great difference is when comparing non-frozen models (Table 8) and frozen models, for example, fried control not frozen; the oil content was 6.07±0.32 g/100g and for fried control frozen for 1 month was 8.91±1.23 g/100g, the same thing to the 150V fried non-frozen samples, oil content was 8.15±0.90 g/100g and 10.76±2.47 g/100g, and this is due to the extra effect that comes from freezing for the last samples.

Freezing leads to the breakage to the cell membrane resulting in cell wall collapse and tissue breakage due to the formation of the crystals inside the tissues and are usually large in cases of slow freezing (Van Buggenhout et al., 2006; Chassagne et al., 2009), and this facilitates the absorption of larger amounts of oil during frying. For these reasons, pretreated frozen samples, especially after one-month freezing, absorbed extra oil during frying than the pretreated non-frozen samples as it clear from the results in Table 14.

But after the second and third freezing month, there weren't differences in oil content, because the majority of the wall collapse and tissue breakage were done in the first month of freezing, because the formation of crystals had become stable during the first month and almost there is no formation for new crystals that led to the breakdown of tissues and cell wall.

Table 4.12. Effect of freezing and ohmic pretreatment on the oil content after frying for carrots

Voltage	Frying / second	Freezing / month	Oil content gm/100gm
0V	60	1	8.91 ± 1.23^{bc}
0V	60	2	9.17 ± 2.43^{b}
0V	60	3	9.50 ± 0.11^{abc}
95 V	60	1	9.69 ± 1.76^{ab}
95 V	60	2	10.02 ± 1.25^{a}
95 V	60	3	10.22 ± 0.44^{a}
150 V	60	1	10.76 ± 2.47^{a}
150 V	60	2	10.88 ± 1.01^{a}
150 V	60	3	10.56 ± 0.22^{a}
150 V	10	1	4.11 ± 1.66^{e}
150 V	10	2	4.25 ± 90^{e}
150 V	10	3	4.48 ± 1.09^{e}
- $^{a-c}$ means in the same column with different superscripts are significantly different ($p\leq0.05$).			

4.3.3. Texture

Textural properties of the carrot samples are given in Table 15 and 16. The freezing was found to be significantly effective on textural properties of the carrot cubes ($p\leq0.05$), and textural properties of all samples irrespective of the application of pretreatment were significantly decreased compared to the non-frozen samples (Tables 9 and 10), especially after the first month of freezing for all texture properties.

For example, hardness, firmness, gumminess, and chewiness for the 150V fried samples were 231.03±46.79, 466.68±93.59, 188.7±10.9 and 99.8±21.8 respectively, while in the 1st month- frozen 150V fried samples values were 88.4±10.2, 398.7±76.5, 60.81±7.54 and 55.76±6.90 respectively, and the big difference between the two cases is due to the effect of the slow freeze on texture of the carrot samples which makes the frozen samples softer. Also for

non-fried samples, the effect of freezing was so clear especially after the first month of freezing, for example, row carrot in the Table (9) non-frozen samples, the hardness was 6207.90±136, and after one month freezing this value decreased to 525.7±27.3, with the 150V the effect was from 927.15±56 in Table (9) to 349.0±41.8 after one month freezing, and this is due to the effect of freezing on cell wall and tissues.

During freezing, structure degradation happens, severe tissue damage occurred during freezing leads to the damage of tissue, and thus texture loss (Van Buggenhout et al., 2006). The main reason for this is due to the formation of crystals within the tissues, which varies in size according to the speed of freezing, the lower the speed of freezing led to the formation of large crystals (Chassagne et al., 2009; Hajji et al., 2018). Carrot is holding high freezable water content, which induces ice crystals formed during freezing which implies physical changes in the structure of foods. In most cases, these changes are perceived as important cellular damage and losses in the thawed product (James et al., 2015; Hajji et al., 2018).

All values were almost stable after the first month of freezing, for second and third months of freezing there weren't differences between the values for all models, and this is due to the stabilization of the formation of crystals inside the tissues which decreases the degradation of the texture of the cell wall. The same thing was for the non-fried gumminess and chewiness, the big effect was after the first month of freezing, gumminess and chewiness were 4864±18 and 4163±19 respectively but after one month of freezing they became 319±18.5 and 303±17.9 respectively due to the effect of freezing, and also for the fried samples, gumminess and chewiness were 433.5±54 and 355±43 respectively, and after one month freezing they became 60.81±7.54 and 55.76±6.9 respectively.

Table 4.13. Effect of freezing and ohmic pretreatment on hardness and firmness after and before frying of carrots

Voltage	Frying/second	Freezing/month	Hardness (g-force)	Firmness (g-force)
0V	-	1	525.7±27.3^{a}	1551.3±62.9^{a}
0V	60	1	101.53±9.84^{e}	619±12^{e}
0V	-	2	518.2±47.3^{a}	1546±14^{a}
0V	60	2	96.26±9.55^{f}	581.6±99.5^{f}
0V	-	3	520.2±45.5^{a}	1365±31^{c}
0V	60	3	97.54±7.59^{f}	576.1±35.3^{f}
95 V	-	1	401.6±58.2^{b}	1403±253^{b}
95 V	60	1	90.7±10.7^{f}	554±13^{f}
95 V	-	2	411.3±35.8^{b}	1236±30^{d}
95 V	60	2	90.30±6.82^{f}	563±18^{f}
95 V	-	3	417.5±37.8^{b}	1235.7±28.8^{d}
95 V	60	3	91.94±4.00^{f}	551±15^{f}
150 V	-	1	349.0±41.8^{c}	512.5±91.9^{f}
150 V	60	1	88.4±10.2^{g}	398.7±76.5
150 V	-	2	340.4±52.7^{c}	511.2±47.7^{f}
150 V	60	2	87.5±10.7^{g}	395.8±32.3
150 V	-	3	323.4±25.8^{c}	577.4±45.2^{f}
150 V	60	3	87.75±1.69^{g}	299±14^{g}
150 V	10	1	290.5±23.1^{d}	867±22^{d}
150 V	10	2	293.7±15.9^{d}	865.1±29.7^{d}
150 V	10	3	299.2±23.0^{d}	858.2±54.8^{d}
- $^{a-c}$ means in the same column with different superscripts are significantly different ($p \leq 0.05$).				

Table 4.14. Effect of freezing and ohmic pretreatment after and before frying on gumminess and chewiness of carrots

Voltage	Frying/second	Freezing/month	Gumminess (g-force)	Chewiness (g-force)
0V	-	1	319±18.5^{a}	303±17.9^{a}
0V	60	1	72.68±7.34^{e}	69.69±8.02^{e}
0V	-	2	316.6±35.4^{a}	300.1±34.3^{a}
0V	60	2	70.84±7.43^{e}	68.12±8.20^{e}
0V	-	3	313.1±16.2^{a}	301.3±11.1^{a}
0V	60	3	70.93±4.64^{e}	63.25±3.75^{e}
95 V	-	1	246.9±45.4^{b}	265.4±33.7^{b}
95 V	60	1	65.07±6.55^{f}	59.4±15.5^{f}
95 V	-	2	240.±23.8^{b}	258.9±17^{b}
95 V	60	2	65.15±4.85^{f}	56.73±4.85^{f}
95 V	-	3	227.1±33.8^{b}	266.5±33.4^{b}
95 V	60	3	65.24±2.29^{f}	58.11±2.63^{f}
150 V	-	1	204.1±22.8^{bc}	201.4±17.9^{ba}
150 V	60	1	60.81±7.54^{f}	55.76±6.90^{f}
150 V	-	2	201±37^{bc}	203±36.1^{ba}
150 V	60	2	60.10±7.75^{f}	52.88±7.02^{f}
150 V	-	3	210.7±18.8^{bc}	200.3±20.4^{ba}
150 V	60	3	60±1.62^{f}	54.02±0.99^{f}
150 V	10	1	144±17.3^{d}	133.4±16.7^{cd}
150 V	10	2	143.7±11.8^{d}	131.1±11.3^{cd}
150 V	10	3	130±17.6^{d}	129.3±17.5^{cd}
- $^{a-c}$ means in the same column with different superscripts are significantly different ($p \leq 0.05$).				

4.3.4. Colour

The effect of ohmic heating on colour properties (*L*, a*, b**) of samples is presented in Table 17. There are no significant differences between the properties of colour between the samples during the storage period, meaning there are no significant differences between the properties of the first month and the second month and the third, just in the raw samples because they weren't pretreated with any thermal processes. In a previous study, Lee and Coates reported that the diminishing of the redness, increasing of the yellow character and a lighter colour, were the characteristic colour changes in carotenoid foods during frozen storage in some high-carotenoid foods including tomato products and carrot (Lee and Coates, 2002), and this is only for raw control samples as we said above. This might be attributed to pigment diffusion from the center of the fruit to the outmost cell layers because of disrupted cell walls, as previously reported (Holzwarth et al., 2012).

There were significant differences between colour values for non-frozen samples (Table 11) and 1st-month frozen samples for (*L*, a*, b**) properties of samples ($p \leq 0.05$). All colour properties were reduced after the freezing stress, and this reduction may be related to the α- and β-Carotene changes during freezing processes and before this the thermal processes (Lebovka et al., 2004). Also, this rejection of colour properties might be a result of small ice crystal formation on the surface of the sample (Holzwarth et al., 2012).

Orun et al. (1997) studied the effect of freezing on the pigment contents, and he reported that β-Carotene decreased markedly during the first 2 months and then stabilized which affected the colour properties of the sample during the freezing. Since slow freezing brought about severe damage to the cell which caused degradation of the chloroplast. As a result, pigments may move to the inner parenchymama which causes a reduction in pigments concentration in the outer epidermis, hypodermis, and outer parenchyma.

Table 4.15. Effect of freezing and ohmic pretreatment on the colour properties after and before frying of carrots

Voltage	Frying/ second	Freezing/ month	L*	a*	b*
0V	-	1	54.38±0.66^{abcd}	26.11±0.90^{a}	35.62±1.47^{def}
0V	60	1	52.83±0.65^{bcde}	23.73±0.75^{abcd}	42.52±2.09^{ab}
0V	-	2	56.37±0.60^{ab}	25.12±1.25^{ab}	36.48±1.44^{cdef}
0V	60	2	52.18±1.0^{bcdef}	23.28±0.75^{abcd}	42.76±1.48^{ab}
0V	-	3	56.85±0.50^{a}	24.65±1.03^{abc}	37.41±2.21^{bcde}
0V	60	3	53.67±0.24^{abcd}	23.79±0.83^{abcd}	43.61±1.58^{a}
95 V	-	1	52.03±1.14^{bcdef}	22.74±0.91^{abcd}	32.80±2.71^{ef}
95 V	60	1	50.70±0.54^{de}	21.42±0.99^{abcd}	40.26±2.10^{abc}
95 V	-	2	50.36±0.61^{de}	22.92±0.75^{abcd}	31.40±0.96^{f}
95 V	60	2	50.25±0.53^{de}	21.52±0.32^{bc}	39.43±1.57^{bcd}
95 V	-	3	49.98±0.54^{efg}	23.01±0.70^{abcd}	31.73±0.97^{f}
95 V	60	3	50.11±0.66^{de}	21.39±0.80^{c}	37.90±2.09^{bcde}
150 V	-	1	49.63±0.77^{efg}	22.92±1.47^{abcd}	33.63±1.14^{ef}
150 V	60	1	50.67±0.86^{de}	22.47±1.14^{bc}	38.97±1.96^{bcd}
150 V	-	2	49.72±1.13^{efg}	23.04±1.06^{abcd}	32.87±1.87^{ef}
150 V	60	2	49.40±0.74^{efg}	21.11±0.48^{c}	36.70±0.91^{cdef}
150 V	-	3	48.50±0.40^{fg}	22.27±0.46^{bc}	33.04±2.68^{ef}
150 V	60	3	47.30±1.07^{g}	21.11±0.70^{c}	35.51±0.98^{def}
150 V	10	1	57.57±1.61^{a}	25.39±1.14^{ab}	38.04±1.31^{bcd}
150 V	10	2	55.12±0.35^{abc}	24.86±0.54^{abc}	38.49±2.71^{bcd}
150 V	10	3	54.74±0.75^{abcd}	22.36±0.79^{bc}	37.39±2.09^{bcde}
- $^{a-c}$ means in the same column with different superscripts are significantly different ($p \leq 0.05$).					

4.3.5. β-Carotene content

From Table 18, we observe the effect of freezing after the ohmic pretreatment on the β-Carotene content before and after frying. As is evident from the table, the freezing had a negative effect on the content of β-Carotene after freezing. For example, with a raw control sample after freezing for one-month, β-Carotene content was 50.54±1.12 mg/kg and this content decreased to 45.54±1.99 mg/kg after the third month of freezing. Also with the other thermally treated models the loss of β-Carotene content due to thermal coefficients plus the effect of freezing. For example, fried control 1st month was 33.60±2.11 mg/kg and for the 1st month, 95 fried was 30.49±1.77 mg/kg due to the additional thermal process of ohmic treatment with 95V which leads to loss additional β-Carotene.

On the other hand, if we go back to the results in Table 12 for samples that were not frozen and after comparison with the current results in Table 18, we can see the obvious effect of freezing on the content of β-Carotene, for instance, for raw control non-frozen samples,the β-Carotene content was 54.62±045 mg/kg after freezing for one month this value decreased to 50.54±0.02 mg/kg and it was the same for the other models, same thing for the ohmic pretreated samples, for example with non-frozen/fried 95V, β-Carotene content was 47.82 mg/kg and it decreased to 34.14 mg/kg after one month freezing. For the second and third freezing months, there wasn't decreasing of β-Carotene content and the content was stable due to the stability of the tissue and cell wall.

This loss of β-Carotene during freezing could be due to non-oxidative changes (cis-trans isomerization, epoxide formation or heat degradation of tissues) or to tissues damages which causes the β-Carotene to ooze out with water during the thawing. The freezing process apparently caused the disruption of the carrot parenchyma tissues; in some cases, the cells were clearly disrupted and the parenchyma appeared fissured and the structure damages were increased during freezing, particularly in the inner parenchyma, near the vascular tissue and this leads to the loosing of β-Carotene especially during thawing and also during frying and the ohmic pretreatment (Paciulli et al., 2016).

Table 4.16. Effect of freezing and ohmic pretreatment before and after frying on the β-Carotene content of carrots

Voltage	Frying/second	Freezing/month	β-Carotene (mg/kg)
0V	-	1	50.54±1.12[a]
0V	60	1	33.60±2.11[c]
0V	-	2	45.53±0.43[b]
0V	60	2	32.46±0.25[c]
0V	-	3	45.54±1.99[b]
0V	60	3	32.26±0.04[c]
95 V	-	1	34.14±1.86[c]
95 V	60	1	30.49±1.77[cd]
95 V	-	2	34.12±1.04[c]
95 V	60	2	30.71±2.10[cd]
95 V	-	3	34.30±0.23[c]
95 V	60	3	30.21±0.17[cd]
150 V	-	1	33.54±0.65[c]
150 V	60	1	30.26±1.22[cd]
150 V	-	2	33.97±0.13[c]
150 V	60	2	31.37±1.87[c]
150 V	-	3	33.77±2.01[c]
150 V	60	3	29.26±0.22[d]
150 V	10	1	33.50±0.88[c]
150 V	10	2	33.44±2.1[c]
150 V	10	3	33.11±.06[c]
- [a-c] means in the same column with different superscripts are significantly different (p≤0.05).			

CONCLUSION

In the present study, the effects of ohmic heating on some quality characteristics (moisture, oil content, texture, and colour) of pre-treated, pretreated\fried, frozen, pre-treated/frozen and pre-treated/frozen/fried carrot samples were evaluated. Two voltages were used as pre-treatments (95 and 150 V) for 10 seconds. Deep-fat frying was carried at 180°C using sunflower oil for 60 seconds. For all samples, values decreased after the pretreatment of ohmic heating before and after frying. The lowest values were to the 150V frozen/fried samples almost for all properties. The undesirable result of increased voltages was increased oil absorption during frying and also decreasing moisture content.

Other samples were pretreated with (95V and 150V), and every sample of these two treatments were fried for 60 sec, after every 10 sec the samples were taken for the analysis and check the results with result of control fried to check if there is a possibility for decrease the oil uptake for the fried carrot. For this purpose, texture, colour and moisture content analyses were done to complete this comparison in addition to sensory analysis which done with 10 persons. 150V fried for 10 sec was the nearest sample to the fried control, which means the possibility to decrease the oil uptake and time during frying by using ohmic heating as a pre-treatment before the frying. The same was with β-carotene content, ohmic pretreatment, frying and freezing decrease the carotene content.

Results showed that ohmic pretreatment significantly affects the physical properties and some chemical properties of carrots after and before frying. Also, this study showed that by using 150V as pretreatment and frying for 10 seconds it is enough to minimize the amount of absorbed oil with obtaining almost same properties of control samples (without pretreatment and fried for 60 seconds).

According to this study, the need for a new procedure to evaluate the effect of ohmic heating as a pretreatment, and find a new way to decrease the negative effects of this pretreatment such as decreasing of β-carotene amount especially with high voltage are an important point for the next studies.

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