EFFECTS OF DIFFERENT BATTER FORMULATIONS ON QUALITY OF DEEP-FAT FRIED CARROT SLICES

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ABSTRACT

EFFECTS OF DIFFERENT BATTER FORMULATIONS ON QUALITY OF DEEP-FAT FRIED CARROT SLICES

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The main objective of the study was to evaluate the effects of starch and gum types on product quality of deep-fat fried carrot slices. It was also aimed to evaluate the applicability of image processing for determination of oil uptake.

In the first part of the study, carrot slices were dipped into batters containing three different concentrations of dextrin or pre-gelatinized tapioca starch and fried for 2, 3, and 4 minutes at 170±2 ^{o}C. Coating pick-up of batter formulations and moisture content, oil content, frying yield, bulk density, porosity, texture and color of fried slices were evaluated. In the second part of the study, the effects of different gum types (HPMC, xanthan gum, guar gum, guar-xanthan gum combination) on quality attributes were studied. No starch or gum added coating formulation was used as the control. Finally, images of carrot and batter sections of the fried samples were obtained using digital camera and area fractions of oil droplets were determined using image processing.

Acceptable product quality was obtained at higher concentrations of pre-gelatinized tapioca starch. On the other hand, increasing dextrin concentrations had an adverse affect on the product quality.

As a result of the study, guar-xanthan gum combination has been found as the most effective additive on the batter performance. This additive provided the highest moisture content, lowest oil content, highest volume and lightest color to the product after frying. The porous and crunchy structure obtained using this combination was at the acceptable level for deep-fat fried products.

Determination of area fraction of oil droplets on carrot and batter surfaces of fried samples using image processing was correlated with the oil content of fried product at initial stages of frying.

The correlation coefficient between moisture content and frying yield was found as 0.90. A correlation was also determined between oil content and moisture content (r= -0.88).

Keywords: Batter, Carrot, Frying, Gums, Physical properties, Starches.

ÖZ

DEĞİŞİK KAPLAMA FORMÜLASYONLARININ KIZARTILMIŞ HAVUÇ DİLİMLERİNİN KALİTESİ ÜZERİNE ETKİSİ

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Bu çalışmanın temel amacı, nişasta ve sakız çeşitlerinin kızartılmış havuç dilimlerinin kalitesi üzerine etkisinin değerlendirilmesidir. Ayrıca görüntü işleminin yağ emiliminin belirlenmesinde uygulanabilirliğinin tespiti amaçlanmaktadır.

İlk bölümde, havuç dilimleri önceden jelatinize edilmiş tapioka nişastası veya dekstrinin üç farklı konsantrasyonunu (1%, 3% , 5%) içeren hamurlara batırılmış ve 170±2^{o}C'de 2, 3, 4 dakika kızartılmıştır. Kızarmış dilimlerin kaplama tutması, nem miktarı, yağ miktarı, kızartma verimi, yoğunluğu, gözenekliliği, tekstürü ve rengi değerlendirilmiştir. İkinci kısımda, değişik zamk çeşitlerinin (HPMC, guar zamkı, ksantan zamkı ve guar-ksantan zamk kombinasyonunun kalite niteliklerine olan etkileri çalışılmıştır. Nişasta veya zamk eklenmemiş kaplama formülasyon kontrol olarak kullanılmıştır. Son olarak, kızartılmış numunenin havuç ve kaplama kısımlarının görüntüleri dijital kamera ile elde edilmiş ve yağ damlacıklarının kapladıkları alan fraksiyonları görüntü işlemi ile tespit edilmiştir.

Nişastanın nispeten yüksek oranlarda kullanımı arzu edilen ürünlerin elde edilmesini sağlamıştır. Diğer yandan, dekstrin konsantrasyonundaki artışın ürün kalitesi üzerine olumsuz etkide bulunduğu gözlenmiştir.

Çalışmanın sonucunda, guar-ksantan zamk kombinasyonu hamur performansında en etkili katkı olarak bulunmuştur. Bu katkı ürüne kızartma sonrasında en yüksek nem oranını, en düşük yağ içeriğini, en büyük hacmi ve en açık rengi sağlamıştır. Bu kombinasyonun kullanımı sırasında elde edilen gözenekli ve çıtır yapı derin yağda kızartılmış ürünler için kabul edilebilir düzeydedir.

Kızartılmış numunelerin havuç ve kaplama kısımlarındaki yağ damlacıklarının kapladıkları alanın fraksiyonunun görüntü işlemi ile tespiti kızartmanın başlangıç aşamasındaki yağ içeriği hakkında fikir vermektedir.

Nem içeriğiyle kızartma verimi arasındaki korelasyon katsayısı 0.90 olarak bulunmuştur. Yağ içeriğiyle nem içeriği arasında da korelasyon tespit edilmiştir (r= -0.88).

Anahtar sözcükler: Havuç, Fiziksel özellikler, Kaplama hamuru, Kızartma, Nişasta, Zamk.

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INTRODUCTION

1.1 Carrot

Yellow types carrots were selected and cultured in Syria and Turkey in the 9 or 10th century; then spread to China in the late 13th century and to Europe in the 14th century (www.uga.edu/vegetable/carrot.html).

Today, carrot (*Daucus carota*) is one of the most popular vegetables consumed in the world whatever the season is. In addition, consumption of carrot has been increasing regularly, particularly for cooked carrots.

Carrots have moisture content of 80-90% (wb) at the time of harvest and they are highly susceptible to moisture loss. Carrot is one of the root vegetable rich in fibers and carotenoids, which are associated respectively to cholesterol metabolism and antioxidant protection (Nicolle et al., 2003). It contains 12 % dietary fiber, 5 % sugar, 1 % protein and 5.6 mg carotenoids/100 g besides being rich in B vitamins, vitamin C, potassium, sodium and magnesium (http://www.nutritiondata.com).

1.2 Deep-Fat Frying Mechanism

Deep-fat frying is a dry cooking process, which consists basically the immersion of food slices in hot vegetable oil (Moyano et al., 2002). It is a widely used method for preparing tasty foods that have soft and moist interior together with the crispy crust (Garcia et al., 2001). Throughout frying process, physical, chemical and sensory characteristics of the food are modified. The main purpose of deep-fat frying is to retain of all the flavors and juices inside a crisp crust by immersing the food in the hot oil (Moyano et al., 2002).

During frying, simultaneous heat and mass transfer occur. Upon addition of the food to the hot oil, the surface temperature of the food rises and the water at the surface immediately starts boiling. Due to the evaporation, surface drying is seen. The evaporation also leads to shrinkage and crust formation (Mellema, 2003). Heat transferred from the oil to the food causes conversion of inner moisture to steam, which creates a pressure gradient as the surface dries out. By the help of capillaries and channels in the cellular structure this pressure gradient within the product gently 'pumps' the water from the core of the food to the crust, which will remove during frying. At the same time, oil adheres to product's surface at the damaged areas and enters the voids left by the water vapor (Debnath et al., 2003). The fact that the vapor leaves voids for the oil to enter later, is the reason why the moisture content of the food largely determines oil uptake (Gamble et al., 1987a; Lamberg et al., 1990; Mehta and Swinburn, 2001;Saguy and Pinthus, 1995; Southern et al, 2000).

Especially at high moisture content, vapor protects the food from oil absorption by creating an overpressure inside the pores. This barrier property of vapor probably continues until a few seconds after removal of the food from the oil. After taking the food out of the fryer the temperature drops and the vapor in the pores condensates (Mellema, 2003). This condensation mechanism creates vacuum effect, which causes the adhering oil being pulled into the product (Debnath et al., 2003). For tortilla chips while 80% of the oil remains at the surface of the product only 20% is present internally at the end of frying. During cooling about 64% of this surface oil is later absorbed into the interior (Moreira et al., 1997).

Water plays a number of roles during frying process. Firstly, it takes away thermal energy from the hot frying oil surrounding the frying food. This removal of energy by conversion of liquid water to steam prevents burning caused by excessive dehydration at the surface of the product. Therefore, despite the fact that the oil may be at 170°C, the frying food is only about 100°C, which represents phase change temperature. Another function of water is to cook the interior of frying food. As known water is a better conductor than the fat, protein, and carbohydrate portions of food, which facilitates to conduct heat energy from the surfaces contacted by hot frying oil to the interior. On the other hand, migration of water from the central portion radially outward to the walls and edges causes to the movement of water-soluble materials to the exterior and leaching liquified food components from the food (Blumenthal, 1991).

1.3 Quality Parameters in Fried Foods

In general, the four principal quality factors in foods are: (1) appearance, including color, shape, etc.; (2) flavor, including taste and odor; (3) texture; and (4) nutrition (Bourne, 1982).

In fried foods the most important product properties that are measured to determine related quality characteristics are discussed in this part of the study. These properties are: moisture content, oil content, color, texture and porosity.

1.3.1 Oil and Moisture Contents

Oil content is one of the most important quality attributes of a deep fat fried product. The texture of a low-oil-content product can be hard and unpleasant. However, the high oil content is costly to the processor and results in an oily and tasteless product (Moreira et al, 1999). Also, with the growing healthy consciousness of the consumer, demand for lower oil-content fried foods has increased. Therefore, oil contents of products have to be taken into consideration.

Foods with more moisture loss also show more oil uptake (Gamble et al, 1987b). Some even argue that the total volume of oil will equal the total volume of water removed (Pinthus et al., 1993).

Oil uptake during deep-fat frying of products is affected by many factors, including oil quality, frying temperature and duration, its composition (e.g. moisture, solids), porosity, pre-frying treatments (e.g., drying, blanching) and coating (Pinthus et al., 1995b; Selman and Hopkins, 1989; Stier and Blumenthal, 1990). All these factors affecting oil uptake of product during frying are summarized in Table 1.1.

Since most of the fat is taken up after removal of the food from the oil so, the habits of the consumer during removal of the food from the oil can play large role. Proper shaking and draining of the food are important for reducing oil content of the food (Mellema, 2003).

Excess oil absorption may result from low frying temperatures or over-loading the fryer beyond its capacity. At low temperatures, there is a tendency to cook food longer to obtain the desired color of the food. Therefore, oil absorption increases (Orthoefer et al., 1996). In contrast, Moreira et al. (1999) argued that higher oil temperatures lead to a faster crust formation and so favoring the conditions for oil absorption.

It is well known that oil uptake is a function of the surface area of the food, thus it is obvious that the shape of the food will affect total oil uptake. For instance, samples can be sliced in larger chunks or surface roughness can be reduced by control of the quality of the slicing blades (Mellema, 2003).

As previously mentioned, one of the most often mentioned parameters to reduce oil uptake at the level of the food composition is the moisture content. Pre-drying of foods like potatoes is a common way to reduce oil uptake (Krokida et al., 2001).

Since the properties of the surface of the food are most important for oil uptake, the application of a coating is a promising route. Often mentioned properties of coatings in relation to oil uptake are low moisture content, low moisture permeability, thermo-gelling or cross-linked (Mellema, 2003).

Table 1.1 Typical factors affecting oil uptake

Factor	Reference
Increasing	
Surface roughness	Rubnov and Saguy (1994)
Thinner product	Krokida et al. (2000)
Increased area	Keller et al. (1990)
Porosity	Pinthus et al. (1995b)
Decreasing	
Pre-drying	Krokida et al. (2001)
Lower initial moisture content	Krokida et al. (2000)
Coating	Khalil (1999); Rayner et al. (2000); Shih et al. (2001)

There are abundant methods to determine oil content of products. Soxhlet extraction is a simple gravimetric method, in which the oil is extracted from the product using organic solvents. In DSC method, the melting enthalpy is taken as a measure of oil. MRI (magnetic Resonance imaging) method relies on the difference in relaxation between solids and liquids (Mellema, 2003). Ufheil and Escher (1996) followed the uptake of oil during deep-fat frying of potato slices by frying slices for an equal length of time, introducing oil soluble and heat stable dye into the oil at different times. Gamble et al. (1987b) investigated the distribution of oil taken up during frying. Samples were fried in red-stained oil and after frying products were photographed.

1.3.2 Texture

The term texture is still not well defined in food technology; but it is a very important quality characteristic of the fried product. An important texture characteristic for fried products is crispness without being very hard. Crispness indicates freshness and high quality (Szczesniak, 1988). A lack of crispness can be defined as either a chewy toughness or a mushy softness (Fizsman and Salvador, 2003).

The crispness is a phenomenon with two components: oral and aural. The tactile sensation of the teeth biting through the food and the sound produced inside the head as the teeth cause the crushing and collapse of a multitude of small cells within the product. Ideally, the crust should exhibit a structure that sufficiently resists the initial bite but then disappears quickly in the mouth (Loewe, 1993).

The crisp final texture of the fried product can be investigated by means of instrumental or sensory techniques. Parameters such as crispness or crunchiness, fragility, tenderness, etc., are hard to quantify using instrumental techniques because what is perceived in the mouth is a complex of sensations (Fizsman and Salvador, 2003).

Puncture with a plunger is the most used technique for the measurements of texture parameters (Fan et al., 1997; Mohammed et al., 1998). Other parameters such as greasiness, juiciness, oiliness and mealiness of products can be assessed with trained panelist (Prakash and Rajalakshimi, 1999).

The overall texture of a fried product is partially influenced by the composition of a food material. Interactions between proteins, starch, and its components (amylose and amylopectin) are of importance for the final quality of the product (Rovedo et al., 1999).

Olewnick and Kulp (1993) studied how some characteristics of wheat flour affect the behavior of tempura type-batters during frying, when applied on chicken drumsticks. In this study, the crispness of products was evaluated organoleptically. Salvador et al. (2002) tried effects of corn flour, salt and leavening on the texture of fried, battered squid rings. It was reported that the ingredient having the greatest effect on the final texture of the coating layer of the fried product is the leavening agent. Leavening agent contributes to the crispness and tenderness required for the fried outer crust of this product type.

1.3.3 Color

Color is an important factor influencing consumer acceptability of a fried product. It can indicate high-quality products such as the golden yellow of a potato. Color also influences flavor recognition. Panel evaluation and comparison to standards are the most common approaches for determining color of fried foods. Colorimeters can also be used to determine the color of products objectively. Hunter L, a and b color scale to express color differences among samples is commonly used. The L dimension defines the lightness, the a refers to the redness or greenness and the b dimension refers to the blueness or yellowness.

The consumer generally uses the color of a product in order to determine the end of the frying process. The final color of the fried product depends on the absorption of oil and the chemical reactions of browning of reducing sugars and protein sources (Baixauli et al., 2002). Caramelization, involving thermal degradation of sugars without amine participation also takes place during frying process (Baik and Mittal, 2003). Frying temperature and duration are directly effective on color development. Ling et al. (1998) found onion rings fried at 190^{o}C had lower L values (decreased lightness), higher a values (increased redness) and lower b values (decreased yellowness) than onion rings fried at 170°C. Furthermore, similar color changes for coated chicken parts with increasing frying times were reported (Waimaleongora-Ek and Chen, 1983). Fried foods are also affected by the type and age of the frying oil (Loewe, 1990). Lee and Dawson (1973) showed that the adsorption of reused corn oil by chicken pieces would undoubtedly affect product quality.

Applied coating formulation and the colorant that may be included in it are effective in determining color of the final product. Corn flour and colorants (e.g.,riboflavin, tartrazine) added to the coating give a more yellow or orange color to the product, which otherwise would look pale (Baixauli et al., 2002).

Hanson and Fletcher (1963) studied the effects of flour type on color of deep-fat fried chicken parts. They reported wheat flour produced a grayish-brown color and yellow corn flour provided a greenish yellow color.

1.3.4 Porosity

Porosity is generally used for leavened batters and describes the open cellular network found in products. The porosity of the product formed during frying plays an important role in the oil uptake. When a crust begins to form at the surface of the sample, there is an excessive pressure buildup and the product expands and puffs. Low leavening level or low batter viscosity may cause decreased tempura puff (Loewe, 1990).

Frying process can change the product's porous structure by the phenomenon of shrinkage or puffing (Yamsaengsung and Moreira, 2002). Moreira, et al. (1995) reported that bulk density decreases and porosity and oil uptake increase with frying time during frying of tortilla chips. Llorca et al. (2001) showed that the CO_2 that forms during frying process because of the leavening agent in the batter formulation is responsible, together with the released water vapor, for producing the pores and channels.

1.4 Batter Systems

The properties of the surface of the food are very important for oil uptake so the application of a coating is a promising route. Coatings can be thin and invisible or thick like a batter. The main difference is that batters may be more easily applied by the consumer and also they have less of the puncturing problems associated with thin coatings (Mellema, 2003).

A batter can be defined as liquid dough, basically consisting of flour and water, into which a product is dipped before frying whereas breading is a dry mixture and applied to the moistened or battered foods prior to cooking. Batter systems are classified into two categories: interface/adhesion and puff/tempura. The interface/adhesion batters are typically used with a supplement breading or breadcrumb. The batter serves, as an adhesive layer between the food surface and the breading and chemical leavening is not normally used. In puff/tempura batter systems both wheat and corn flours play an important role. They are chemically leavened and used as an outside coating for the food. The batter uniformity and thickness, which is related to the batter viscosity, determine acceptability of the finished product (Loewe, 1990).

The mode of action of batter in retarding oil absorption appears to be due to the rapid formation of a hard crust as a result of water loss, the crust being relatively impervious to the movement of water and oil (Love and Goodwin, 1974). The ability of batter to form a crust is enhanced by the higher initial amount of coating adhering.

Tempura-type batters form crisp and uniform layer over the food, constituting its final outer coating. Batters enhance the texture, flavor and appearance of foods. They act as a barrier against loss of moisture by protecting the natural juices of foods, thereby ensuring a final product that is tender and juicy on the inside and at the same time crisp on the outside (Fiszman and Salvador, 2003).

In practice, the list of ingredients in batter systems is quite long (starch, salt, leavening agent, gums and many other items) and batters have therefore become highly sophisticated, complex systems in which the nature of ingredients is very wide-ranging and their interaction determines the final performance of the product (Table 1.2). The most important ingredients were explained below in more detail.

Table 1.2 Concentrations and functionality of ingredients used in batter formulations (Fiszman and Salvador, 2003).

Ingredient	Addition range (%)	Functionality or effect on quality
Wheat flour	> 40	Body structure, viscosity
Corn flour	> 30	Crispness, golden brown color
Starches	≤ 5	Changes in tenderness and crunchiness
Leavening agents	< 3	Porous structure
Gums	≤ 1	Viscosity control, ability to participate in gel/film formation
Salt, sugars, dextrins	At different concentrations	Product quality improvement

1.4.1 Starches

The theoretical explanation of how wheat and corn flours affect the structure of batter coatings focuses upon the complementary actions of the protein and starch components.

Starch occurs widely in the nature and is the most commonly used food hydrocolloid. This is because of the wide range of functional properties it can provide in its natural and modified forms. It is a mixture of a linear polymer (amylose) and a branched-chain polymer (amylopectin). Amylose, usually the minor component of starch, is a long linear polymer containing 250 to 2000 D-glucose units connected by α-1,4-linkages, with a corresponding molecular weight of approximately 4000-340000 (Glicksman, 1969).

Amylopectin is a highly branched, treelike configuration composed of linear chains similar to those of amylose, but at branch points connected by α-1,6-linkages. These branch points are believed to occur at intervals of about 20-30 glucose units. The total amylopectin molecule is composed of several hundred branches and molecular weight of amylopectin is considered to be in the millions. Amylopectin has a globular shape that shows enhanced dilation and higher viscosities in the solution (Glicksman, 1969).

A number of modified starches can be used with a wide range of hydration and film-forming characteristics. Pre-gelatinization is the simplest modification. Until gelatinization is achieved the starch is heated in water and then dried to a power to obtain pre-gelatinized starch. Extensive modifications including changes in the degree of branching (variations in amylose and amylopectin content) can be accomplished (Loewe, 1990).

Gelatinization is the phenomenon shown by starches when they are heated in aqueous dispersion. When an aqueous suspension of starch is heated, a temperature is reached at which the hydrogen-bonding forces are weakened so that water can be absorbed by the granules. As the temperature of the aqueous suspension of starch is raised hydrogen bonds continue to be disrupted, water molecules become attached to the hydroxyl groups and the granules continue to swell. With continued swelling of the granules, starch molecules that have become fully hydrated separate from the intricate network and diffuse into the surrounding aqueous medium (Glicksman, 1969). Amylose is considered primarily responsible for gel formation. It is the chief material that forms gel network, which binds and entraps unabsorbed water. It also links together intact starch granules or fragments thus providing additional structure in the network (Ott and Hester, 1965).

Corn starch, for example, is different from wheat starch in terms of the size and shape of their granules, so that their gelatinization properties, water absorption rate and swelling capacity are not the same (Fiszman and Salvador, 2003). In addition, the amount of leached amylose from the granules, responsible for the network formation, is higher for corn starch (Rovedo et al., 1999).

In general terms, starches can be divided into three types: those from roots (e.g., tapioca starch), those from tubers (e.g., potato starch) and those from cereals (e.g., wheat starch, corn starch, rice starch) (Sanderson, 1981).

Starches contain both the amylose and amylopectin polymers, the relative proportions of which are constant in any particular species of starch. The amylose and amylopectin content of different starches were given in Table 1.3.

Table1.3 Amylose and amylopectin content of starches (Zallie, 1988).

Starch	Source	Amylose (%)	Amylopectin (%)
Wheat	cereal	23-27%	73-77%
Corn	cereal	24-28%	72-76%
Tapioca	root	17-20%	80-83%

Increasing the amylose content would increase the polysaccharide-polysaccharide interaction, which gives a more crunchy batter and reduced oil uptake. However, too much amylose causes a fried product that is too hard/though to chew. It was reported that crispness is positively correlated with amylose content, while oil absorption is negatively correlated with amylose content (Mohammed et al., 1998). Amylose is known to form coherent and relatively strong in contrast to amylopectin films, which are brittle and non-continuous (Gennadios et al., 1997). Therefore, the amylose/amylopectin ratio in the batter formulation is important to determine product quality.

Dextrin has the same general formula as starch but a smaller and less complex molecule than any one of a number of carbohydrates. They are polysaccharides and are produced as intermediate products in the hydrolysis of starch by heat, by acids, and by enzymes. Their nature and their chemical behavior depend to a great extent on the kind of starch from which they are derived. For commercial use dextrin is prepared by heating dry starch or starch treated with acids to produce a colorless or yellowish, tasteless, odorless powder (http://www.infoplease.com/ce6/sci/A0815381.html).

Dextrins generally have a medium-high viscosity and help to the formation of a continuous, uniform batter (Fiszman and Salvador, 2003). The use of dextrins in batter formulations is related to an improvement in the crispness of the fried product (Shinsato et al., 1999).

1.4.2 Proteins

Formation of films from plant proteins such as wheat gluten and corn zein is important in affecting product quality. Film formation from corn zein, the prolamin fraction of corn proteins, and from wheat gluten, a mixture of the prolamin and glutenin fractions of wheat proteins play important role (Gennadios et al., 1997).

The amount and type of protein in flour affects the final product. In wheat flour, the proteins responsible for developing batter's characteristic structure are gliadin and glutenin. When water is added to the flour, these hydrate to form gluten. This is a strong elastic substance, which forms a network throughout the dough. The network traps carbon dioxide, produced by the added yeast and allows the dough to rise. The process of kneading dough helps develop the gluten network (http://www.nutrition.org.uk/information/foodandingredients/cereal.html).

Hard wheat flours, because of their higher protein content, require more water than soft wheat flours to yield comparable viscosities when used in a batter. This is due to the efficient water-binding capacity of the gluten protein (Loewe, 1990). Gnanasambandam and Zayas (1992) reported that batters containing wheat germ flour and corn germ protein flour improved batter characteristics by increasing water binding capacity and decreasing cooking loss.

1.4.3 Gums

Many of hydrocolloid substances used as ingredients in batters known as gums. They control viscosity and water holding capacity of batters. Some gums have the ability to participate in a gel or film formation in conjunction with other ingredients (Loewe, 1990).

1.4.3.1 Cellulose Derivatives

Cellulose chemically differs from starch simply by having β-1,4-linked rather than α-1,4-linked glucose units (Sanderson, 1981).

One of the most widely used of all gums, cellulose gums are a family of products made by chemically modifying cellulose. By this way cellulose, the long chain polymer found in most land plants, becomes water-soluble. Compounds such as carboxymethylcellulose (CMC), methylcellulose (MC) and hydroxypropylmethylcellulose (HPMC) are examples of modified celluloses (Dziezak, 1991). Treating cellulose with alkali to swell the structure, followed by reaction with propylene oxide and methyl chloride yields HPMC (Kester and Fennema, 1986).

MC and HPMC are the only gums that gel when heated and return to their original viscosities when they are cooled. This unusual property makes these gums suitable for use in fried foods in where they create a barrier to oil absorption by the product. They retard the loss of natural product moisture and improve the adhesion of batter to the product (Dziezak, 1991). In addition, these derivatives can function as emulsifiers and their acid stability is good since they do not contain negatively charged groups (Sanderson, 1981). The number of substituent groups on the ring determines properties of the product.

The use of HPMC in fried foods has been studied by a number of authors. Chicken balls coated with an HPMC edible film showed a reduction in oil absorption in the surface layer and the core, as well as an increase in moisture retention (Balasubramaniam et al., 1997). Meyers and Conklin (1990) reported that the effectiveness of HPMC to reduce oil absorption in fried battered products such as chicken pieces, fish and vegetables.

1.4.3.2 Xanthan Gum

Xanthan gum is the only microbial polysaccharide permitted in food. Culturing on a carbohydrate medium the bacterium *Xanthomonas campestris* produces this high molecular weight polysaccharide. The gum has a cellulosic backbone with trisaccharide branches attached to every second glucose unit. Xanthan gum is completely soluble in cold or hot water by the presence of these short side chains (Sanderson, 1981).

Xanthan gum has found use in many products for its thickening, suspending and stabilizing properties (Dziezak, 1991). Its water binding capacity is important for the batter systems to yield enhanced moisture retention within the product. Xanthan gum is an example of gum that is nonionic and is not affected by the presence of salt in the coating material (Loewe, 1990). Altunakar (2003) reported 1% xanthan gum addition to the tempura type batter provided significant decrease in oil uptake of chicken nuggets while affecting volume development within the fried product.

1.4.3.3 Guar Gum

Guar gum is obtained from the ground endosperm of the guar plant, *Cyamopsis tetragonolobus*. The backbone of the gum is a linear chain of mannose units. One galactose unit is attached as side chains per every two-mannose units of guar gum. Mannan backbone can be solubilized by the presence of single unit galactose side chains. The fact that guar gum can be dissolved in cold water while another galactomannan locust beam gum requires hot water is due to the more substituent structure of guar gum (Sanderson, 1981).

Guar gum is non-gelling but gives highly viscous solutions at low concentrations. Therefore, it is chiefly used as viscosity builder, stabilizer and water binder. In addition, since it is nonionic, it is not adversely affected by the presence of salt in the batter formulation (Dziezak, 1991). Patil et al. (2001) used guar gum (0.25- 1%) in batter formulations and showed that 9.7 – 22% oil content reduction over the control during frying.

1.4.3.4 Synergistic Interactions

Starches and gums are often used together in food systems to provide proper texture, to control moisture, to improve overall product quality and to reduce costs (Shi and BeMiller, 2002).

Xanthan gum interacts synergistically with galactomannas, such as guar gum. The content of galactose and the distribution of galactose residues in the galactomannan can have a significant influence on the interaction with xanthan gum molecules (Tako, 1991). Mixtures of guar gum and xanthan gum do not normally gel but show significantly higher viscosities compared to the viscosities of sole components (Katzbauer, 1998).

Synergistic interactions also take place between starch and xanthan gum or guar gum. It is shown to be advantageous in order to obtain increased moisture retention (Katzbauer, 1998). Carlson et al. (1962) have reported that the viscosity of a combination of guar and wheat starch cooked at high temperature is higher than the total thickening capacity of individual ingredients. It is supposed that the wheat starch is tied to the guar gum by means of hydrogen bonding (Glicksman, 1969).

1.5 Objectives of the Study

Battered foods such as fish and poultry are very popular in the market. Very little technical literature exists on the application of batters and breadings to vegetable products. Onions are the most commonly coated vegetable. Other battered or breaded vegetable products are bell peppers, cauliflower, eggplant, mushrooms, okra, and zucchini. Nevertheless, research on carrots has not yet been reported.

The objectives of the study were to evaluate the effect of starch or gum added batter coatings on product quality during deep-fat frying of carrot slices. In the first part of the study, dextrin and pre-gelatinized tapioca starch at different concentrations (1%, 3% and 5%) were included in the batter formulation and effects of these ingredients on quality of fried carrot slices were investigated. Subsequently, the effects of HPMC, guar gum, xanthan gum and a combination of guar and xanthan gum in deep-fat frying of battered carrots were studied. In addition, contributions of gums and starches to the coating formulation in terms of fried product quality were compared and optimum frying time was reported. It was also aimed to analyze oil content of samples using Image processing.

CHAPTER 2

MATERIALS AND METHODS

2.1.Materials

Fresh good quality carrots (*Daucus carota* L.) were procured from a local super market. They were stored at 4^{o}C prior the experimental runs. Initial moisture content of carrots was determined using AOAC Method 14.003 (AOAC 1980).

The hydrocolloids used in the study and their sources were dextrin (acid hydrolyzed, Başar Trade Company, Turkey), pre-gelatinized tapioca starch (Ultra-Tex ^{TM} 3, National Starch and Chemical Company, USA), hydroxypropylmethylcellulose (HPMC) (Methocel K, The Dow Chemical Company, USA), xanthan gum (Aldrich Chemical Company, USA) and guar gum (Aldrich Chemical Company, USA). Detailed information about HPMC can be obtained from www.dow.com/methocel/resource/chem.htm for Methocel K.

The other ingredients used in batter preparation and their sources were wheat flour (Pınar Un, Turkey), corn flour (Bünsa Trade Company, Turkey), salt (Billur Tuz, Turkey) and leavening agent (Kenton, Turkey).

The carrot slices were deep-fried in refined sunflower oil (Bizim Ayçiçek, Turkey), in an electric fryer (HAD, Turkey).

2.2. Batter Preparation

Dry solid content of control batter formulation was composed of equal amount of wheat and corn flour (49.25% each), 1% salt and 0.5% leavening agent.

The effects of dextrin and pre-gelatinized tapioca starch at different concentrations (1%, 3% or 5%) were studied by replacing wheat and corn flour mixture.

In the case of gums, 1% of wheat and corn flour mix was replaced with gums to study their effects on product quality. The gums used were hydroxypropylmethylcellulose (HPMC), xanthan gum, guar gum or the combination of guar and xanthan gums (0.5% each).

The pre-blended powders were mixed with water (15 ^{o}C) in a mixer (Arçelik ARK55 MS, Turkey) at speed 1 for 15 seconds for batter preparation. The proportion of dry mix / water was always 3 / 4.5.

2.3.Sample Preparation and Frying Conditions

Carrots were peeled and cut into slices of 60 mm x 30 mm x 2.7 mm by means of a manual peeler and slicer. They were immediately dipped in the coating suspensions for 5 s and then fried in a controlled temperature deep-fat fryer filled with 2.5 L of sunflower oil. Frying temperature was set at 170 ± 2 ^{o}C and temperature was monitored by a copper constantan thermocouple. This temperature was decided to be suitable according to the preliminary experiments. Batches of four battered slices were fried for 2, 3 or 4 minutes. The fried carrots were removed from the fryer, drained and allowed to cool to room temperature.

After each frying, the oil level was checked and replenished; the oil was changed after 6 h of frying time.

2.4. Analysis of Sample

2.4.1. Coating Pick-Up Calculations

Batter pick-up was calculated from the difference between battered weight and non-coated weight of raw carrot sample. It can be formulated as in equation 2.1 (Parinyasiri et al., 1991);

$$\% \text{ Coating Pick-Up} = (C - I) / I * 100 \qquad (2.1)$$

Where; C: weight of raw coated carrot slices (g)
I: initial weight of raw non-coated carrot slices (g)

2.4.2. Moisture Analysis

Moisture content was determined by measuring weight loss of fried products, upon drying in an oven at 105 ^{o}C until constant weight (AOAC, 1980). It was expressed as percentage of original sample.

2.4.3. Oil Analysis

Soxhlet extraction of the sample previously dried for moisture analysis was utilized to measure oil content. Extraction was performed with n-hexane for 6 hours and the oil content of sample was expressed as percentage of original sample (AOAC, 1984).

2.4.4.Frying Yield Calculations

Percentage of frying yield was obtained by considering the weights of the fried carrot slices and the raw carrot slices after coating. It can be formulated as equation 2.2 (Parinyasiri et al., 1991);

$$\% \text{ Frying Yield} = (CW / C) * 100 \qquad (2.2)$$

Where; CW: cooked weight of coated carrot slices (g)
C: weight of non-cooked coated carrot slices (g)

2.4.5.Colorimetric Measurements

The color parameters (Hunter L, a, b) were measured with a Minolta color reader (CR-10, Japan). The three color coordinates ranged from L=0 (black) to L=100 (white), -a (greenness) to +a (redness), and –b (blueness) to +b (yellowness) (Clydesdale 1984). Total color difference (ΔE) was calculated from Equation 2.3 (Ling et al., 1998);

$$\Delta E = [\, (L - L_{standard})^2 + (a - a_{standard})^2 + (b - b_{standard})^2 \,]^{1/2} \qquad (2.3)$$

Where; standard values referred to the $BaCl_2$ plate (L=96.9, a=0 and b=7.2) used for calibrating the colorimeter.

Triplicate readings were carried out at room temperature on three different locations of each slice: the center point and both ends, and the mean values were recorded.

2.4.6.True and Bulk Volume Measurements

True volume was measured by a stereopycnometer (Quantacrome, USA) using nitrogen. A tank pressure of 1.406 kgf/cm^2 was used. True volume was calculated from equation 2.4.

$$V_t = V_2 + V_1 \, [(P_2 - P_1) / P_2] \qquad (2.4)$$

Where; V_t: true volume of carrot slices (cm^3)

V_1: volume of the first chamber (cm^3)

V_2: volume of the second chamber (cm^3)

P_1: equilibrium pressure when the second chamber is closed (kgf/ cm^2)

P_2: equilibrium pressure when the second chamber is opened (kgf/ cm^2)

Bulk volume of sample was measured by immersing the samples in a graduated cylinder filled with paraffin. Bulk volume was calculated from equation 2.5.

$$V_b = [(W_{pf} - W_p) - (W_{pfs} - W_{ps})] / \rho_f \qquad (2.5)$$

Where; V_b: bulk volume of carrot slices (cm^3)

W_{pf}: weight of the pycnometer filled with paraffin (g)

W_p: weight of empty pycnometer (g)

W_{pfs}: weight of the pycnometer containing the sample and filled with paraffin (g).

W_{ps}: weight of the pycnometer containing sample with no paraffin (g)

ρ_f: density of the paraffin at 25 ^{o}C (g/ cm^3)

2.4.7.True and Bulk Density Calculations

True and bulk densities of the sample were determined by dividing weight of the sample by true and bulk volume, respectively.

The main reason to calculate density may be expressed by the fact that density serves as the first estimate to porosity (Marousis and Saravacos, 1990).

2.4.8.Porosity Calculations

Porosity (ε) defined as the volume fraction of air or void fraction in the sample and was determined from equation 2.6 (Pinthus et al., 1995a);

$$\varepsilon = 1-(\rho_b / \rho_t) \qquad (2.6)$$

Where; ρ_b: bulk density (g/cm^3)

ρ_t: true density (g/cm^3)

2.4.9.Textural Measurements

A standard texture analyzer (Lloyd Instruments, TA Plus, U.K.) was used to evaluate the fracturability of products. Penetrometry tests were performed at 15 minutes after frying. Three carrot slices were put on top of each other and the thickness of fried carrot slices were detected with a micrometer (Mitutoyo, Japan). A conic plunger (D=1.6 cm, H=1.5 cm) was utilized to measure the force required to penetrate 25% thickness of products. A load cell of 50 N was used.

2.4.10.Image Processing

The fried samples were cut into rectangular shapes 1.20 x 2.30 cm in size and the batter separated from the carrot portion with a scalpel. Special care was taken not to remove oil droplets, which were also visible with the naked eye. After separation, the carrot and batter sections were placed on to the slides and observations were carried out with a digital camera (Kodak DX4530 5 megapixel CCD sensor, 5.2 megapixel CCD resolution and 5 megapixel image resolution). Images were enlarged 10 times of their original size and image analysis was performed using Image J software.

2.4.11. Statistical Analysis

All measurements were performed at least in triplicate and mean values were reported. Analysis of variance (ANOVA) was performed to study differences in quality parameters of deep-fat fried carrot slices coated with different formulated tempura batters. When significant differences were found the Duncan's Multiple Comparison test was applied to determine the difference among means ($p \leq 0.05$) (SAS, 1988).

Correlations were obtained to relate moisture content to oil content and moisture content to frying yield.

CHAPTER 3

RESULTS AND DISCUSSION

3.1.Effects of Tapioca Starch and Dextrin on the Quality Parameters of Deep-fat Fried Carrot Slices

Initial moisture contents of the carrots were determined to be 90±1 %. The effects of adding pre-gelatinized tapioca starch or dextrin to the batter formulation at different concentrations (1, 3, 5%) on coating pick-up and on major quality parameters of fried carrot slices; moisture and oil contents, frying yield, crispness, porosity and color were investigated. No starch or dextrin added batter was used as control batter formulation.

3.1.1.Coating Pick-up

Coating pick-up is an important physical property since it affects quality parameters of fried products. Coating pick-up for the batters containing different concentrations of pre-gelatinized tapioca starch or dextrin is shown in Figure 3.1.

The increasing concentrations of pre-gelatinized tapioca starch gave higher coating pick-up values (Figure 3.1). Concentration of 3% and 5% tapioca starch gave significantly higher batter pick-up values as compared to control and dextrin containing batters (Table B.1). This may be explained by high water binding capacity of pre-gelatinized tapioca starch (Appendix C). Batter viscosity is the key factor to control the amount of batter pick-up. A good correlation between batter viscosity and pick-up was previously reported (Altunakar, 2003; Dogan, 2004). Pre-gelatinized starch increased batter pick-up by its viscosity enhancing property.

The addition of dextrin at different concentrations (1, 3, 5%) didn't affect coating pick-up in the studied concentration range (Table B.1). Similar result was observed for dextrin at the concentrations of 1.5, 4.5 and 7.5 % by Baixauli et al. (2003).

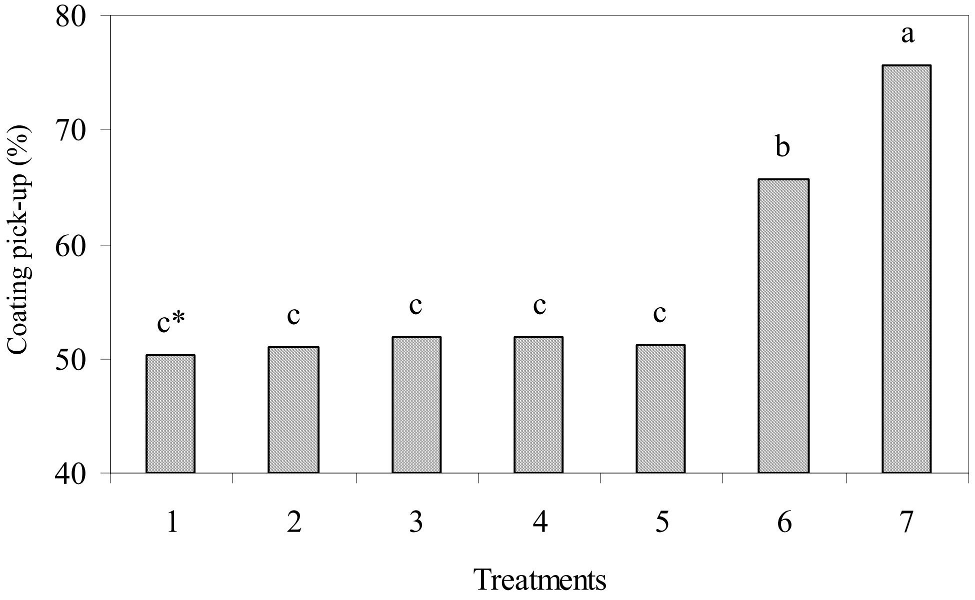


Figure 3.1 Effects of pre-gelatinized tapioca starch and dextrin at different concentrations on coating pick-up of fried carrot slices.
(1) control, (2) dextrin 1%, (3) dextrin 3%, (4) dextrin 5%, (5) tapioca starch 1%, (6) tapioca starch 3%. (7) tapioca starch 5%.
* means bars with different letters are significantly different (p≤0.05).

3.1.2. Moisture Content

The moisture content of the fried carrot slices was affected by different formulations. As expected, moisture content of products decreased with frying time (Figure 3.2).

The role of pre-gelatinized tapioca starch addition is to complement or improve the properties of the natural starches in the flour fraction of batter (Davis, 1983). Data indicated that samples coated with pre-gelatinized tapioca starch added batter enabled high moisture retention within the product (Figure 3.2). It is related with high coating pick-up values of this type of batter (Figure 3.1).

In Figure 3.2 it is seen that increasing dextrin concentrations has an adverse effect on moisture retention. Addition of 3% or less dextrin to the batter formulation improved moisture retention (Table B.2). At higher concentrations, especially at 3 and 4 minutes of frying, dextrin addition to the batter mix had no advantage in terms of controlling moisture loss. This may be due to the dilution of gluten in batter formulation.

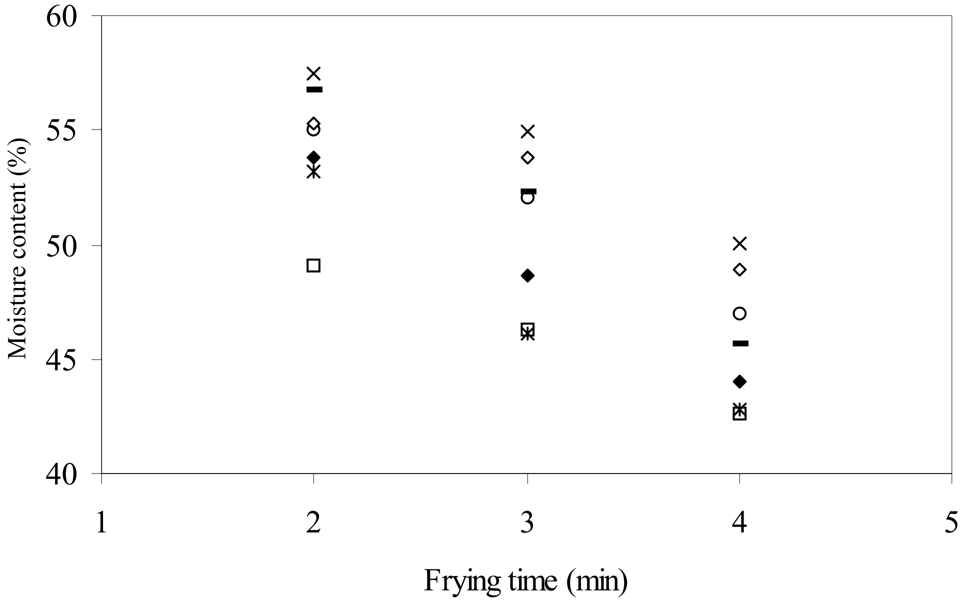


Figure 3.2 Effects of pre-gelatinized tapioca starch and dextrin at different concentrations on moisture content of deep-fat fried carrot slices.
(□) control^{d} , (-) dextrin 1%^{b} , (◆) dextrin 3%^{c} , (*)dextrin 5%^{cd},
(o) tapioca starch 1%^{b} , (◊) tapioca starch 3 %^{ab} , (x) tapioca starch 5%^{a} .

3.1.3. Oil Content

Oil contents of carrot slices during frying were represented in Figure 3.3. Oil absorption of products increased as the retention time of slices in frying medium increased. An inverse relationship was seen between the oil uptake and moisture content of fried carrots (Figure 3.2 and Figure 3.3). Since the samples had the same initial water content, an increase in final moisture content means a reduction in moisture loss during frying, which is normally correlated with oil uptake for the fried product. A correlation was determined between oil content and moisture content (r= -0.88). It was known that batter coating functions to reduce water loss which, in turn, lessens oil absorption during frying (Mohammed et al., 1998).

The water binding capacity of pre-gelatinized tapioca starch affected simultaneously water loss and oil uptake. The increase in concentrations of pre-gelatinized tapioca starch decreased oil uptake values (Figure 3.3). Usage of starch was suitable for reducing oil uptake since it was hydrophilic and in readily gelatinized form. The lowest oil uptake was determined at 5% pre-gelatinized tapioca starch concentration, which was related with its high moisture retention capability (Table B.3). A high concentration of starch is necessary to yield desirable product quality in means of high moisture and low oil uptake.

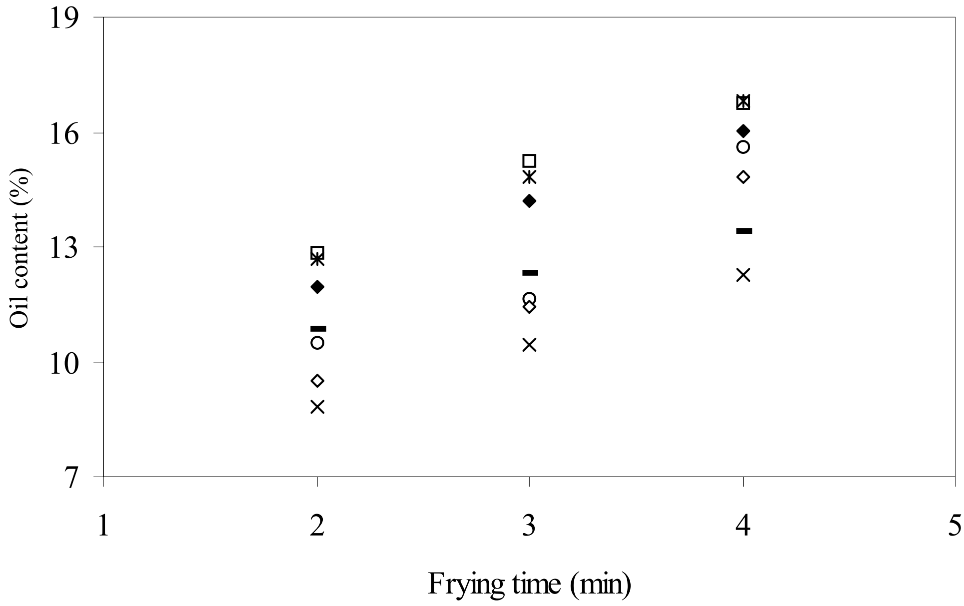


Figure 3.3 Effects of pre-gelatinized tapioca starch and dextrin at different concentrations on oil uptake of deep-fat fried carrot slices.
(□) control[a], (-) dextrin 1%[b], (◆) dextrin 3%[a], (*)dextrin 5%[a],
(o) tapioca starch 1%[b], (◊) tapioca starch 3 %[b], (x) tapioca starch 5%[c].

Addition of 1% dextrin enabled resistance to transport of water vapor and so decreased oil uptake. On the other hand, higher concentrations of dextrin addition levels dilute protein content of coating material. Therefore, the moisture retention capacity of batter decreased and more oil absorption by the product was observed. The dilution problem of proteins might not be compensated by addition of dextrin, a low molecular weight polysaccharide.

3.1.4. Frying Yield

Percentage frying yield is related with the weight change of coated samples during frying (Parinyarisi, 1991). It also indicates adhesion during frying which is important in terms of economic feasibility. It might be evaluated with simultaneous moisture loss and oil uptake mechanism of deep fat frying, which causes respectively weight loss and gain during frying. The decrease in frying yield with time show that the rate of moisture loss is higher than that of oil uptake. The observed high frying yield (Figure 3.4 and Table B.4) with addition of 3% and 5 % pre-gelatinized tapioca starch could be due to increased amount of moisture retention within the product. Frying yield was found to be related with moisture content and correlation coefficient was determined to be 0.90.

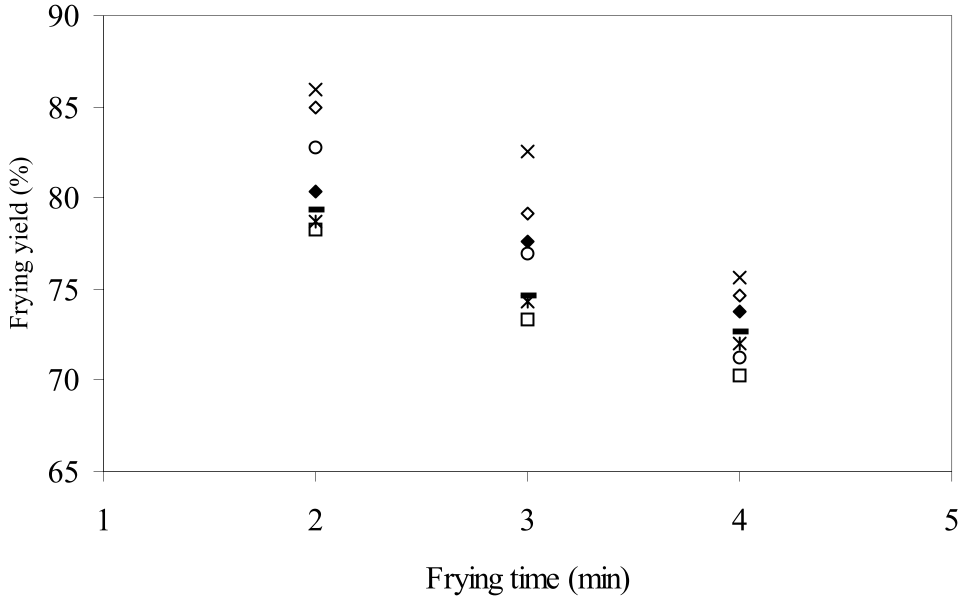


Figure 3.4 Effects of pre-gelatinized tapioca starch and dextrin at different concentrations on frying yield of deep-fat fried carrot slices.
(□) control^{c} , (-) dextrin 1%^{bc} , (◆) dextrin 3%^{b} , (*)dextrin 5%^{bc},
(o) tapioca starch 1%^{b} , (◊) tapioca starch 3 %^{a} , (x) tapioca starch 5%^{a}.

3.1.5.Crispness

One of the most appreciated characteristics in battered and fried products is an external crispy crust without being very hard (Salvador et al., 2002). Therefore, the textural performance of the product was associated with the fracturability data analysis, which is a good indicator of crispness. The typical texture profile analysis (TPA) curve can be seen in Appendix A.

Adding 5% pre-gelatinized tapioca starch to the formulation increased crispness of samples significantly (Figure 3.5 and Table B.5). Texture of the fried batters is influenced by the degree of polysaccharide-polysaccharide, polysaccharide-protein, polysaccharide-water and polysaccharide-oil interaction. The ability of the branched amylopectin structure to hold and interact strongly with water resulted in a soft soggy batter (Mohammed et al., 1998). The amylose content of starches enhanced the polysaccharide-polysaccharide interactions and gave crispness to the crust of products. The usage of increasing concentrations of pre-gelatinized tapioca starch provided higher fracturability values (Figure 3.5). These values also enhanced with frying time. During frying process the swelling of starch granules releases the amylose fraction and provides a film barrier. Gelatinization and the film formation play an important role in crispy structure of the finished product (Arenson, 1969).

Replacing part of the wheat and corn flour with dextrin also changed sample's fracturability (Figure 3.5 and Table B.5). An increase in fracturability was obtained when high concentrations of dextrin were added to the batter formulation. This is probably because of the reduction in protein content and so the water binding capacity. Similar findings about the effect of dextrin on the crispness of the coated fried foods have been reported in the literature (Shinsato et al., 1999). The addition of dextrin to the coating batter of squid rings produced crisp texture and the texture was retained longer after frying (Baixauli et al., 2003).

Considering the later stages of frying, 5% pre-gelatinized tapioca starch or 5% dextrin addition to the batter formulation provided high crispness since the acceptable product can be obtained between 3 and 4 minutes.

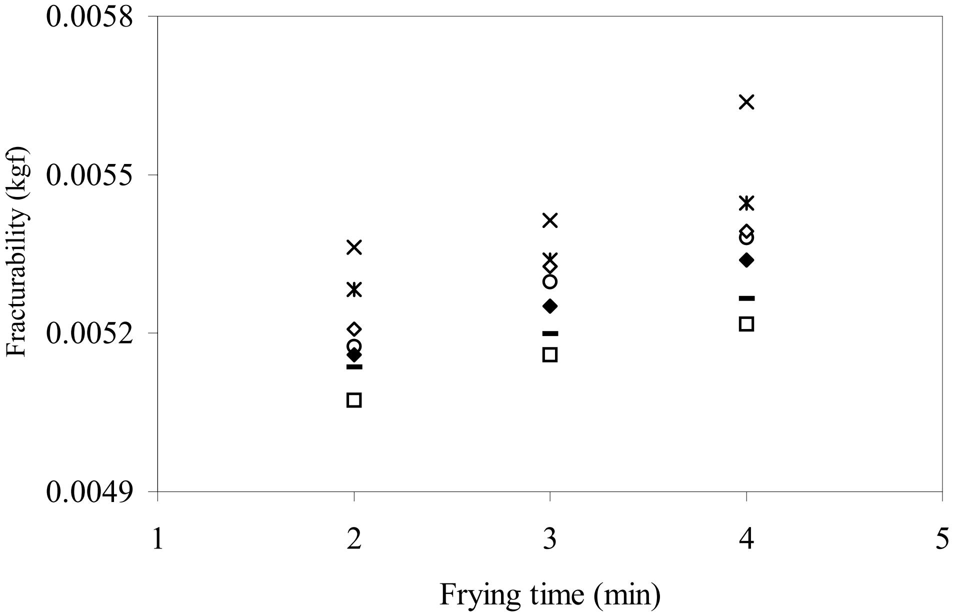


Figure 3.5 Effects of pre-gelatinized tapioca starch and dextrin at different concentrations on fracturability of deep-fat fried carrot slices.
(□) control^{e}, (-) dextrin 1%^{de}, (◆) dextrin 3%^{cd}, (*)dextrin 5%^{b},
(o) tapioca starch 1%^{c}, (◊) tapioca starch 3 %^{bc}, (x) tapioca starch 5%^{a}.

3.1.6. Bulk Density

In Figure 3.6 the bulk densities of the fried products coated with batter containing pre-gelatinized tapioca starch or dextrin at different concentrations were given. The bulk densities of fried products with pre-gelatinized tapioca starch or dextrin added batters were markedly lower than the control batter coated products (Table B.6). As mentioned before with increasing pre-gelatinized tapioca starch concentration, batter pick-up increased, which enhanced the formation of a hard crust during frying (Figure 3.1 and 3.5). The crust serves as a barrier to prevent water loss and, as a result, contributes to reduction in oil absorption (Shih and Daigle, 1999). The crust is also responsible for gas retention within the product. This explains the lower bulk density or higher specific bulk volume of fried carrot slices coated with batter containing pre-gelatinized tapioca starch.

Dextrin addition to the batter formulation also reduced bulk density of the fried product significantly but its effect was lower as compared to that of pre-gelatinized tapioca starch added formulations (Table B. 6).

The decrease in the bulk density with respect to time was the result of expansion of carrot slices during deep-fat frying process. As can be seen in Figure 3.6, the rate of decrease in bulk density during frying was higher in carrot slices coated with control and dextrin added batter formulations. This was presumably the result of expansion caused by sudden loss of moisture from slices.

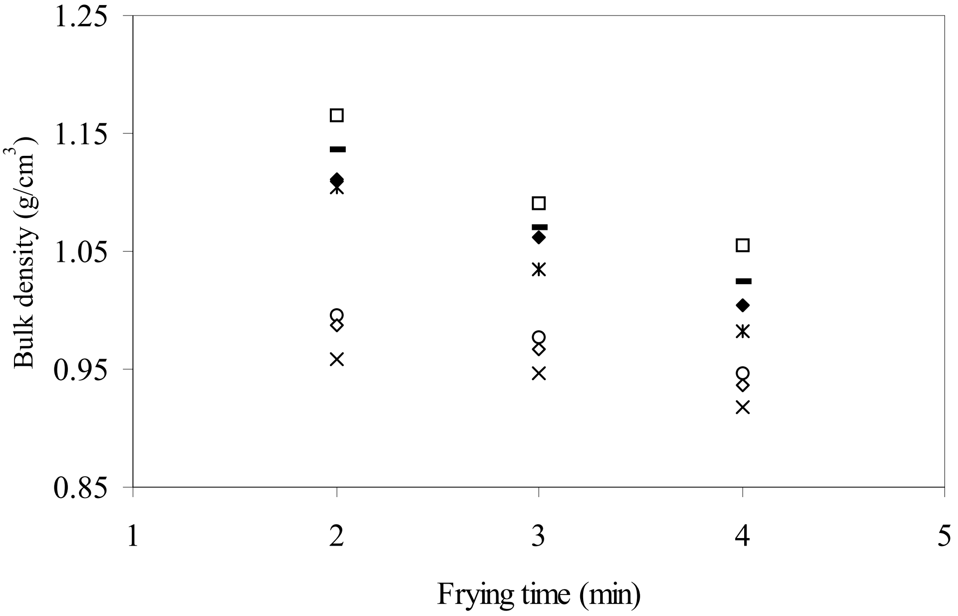


Figure 3.6 Effects of pre-gelatinized tapioca starch and dextrin at different concentrations on bulk density of deep-fat fried carrot slices.
(□) control[a], (-) dextrin 1%[ab], (◆) dextrin 3%[bc], (*)dextrin 5%[c],
(o) tapioca starch 1%[d], (◊) tapioca starch 3 %[d], (x) tapioca starch 5%[d].

3.1.7. Porosity

Crust porosity enhanced linearly with frying time and positively affected by adding pre-gelatinized starch or dextrin to the coating material (Figure 3.7).

Duncan's multiple range test also showed that using pre-gelatinized tapioca starch or dextrin enabled more porous products than control batter (Table B.7). Addition of 5% pre-gelatinized tapioca starch provided the most porous structure. This observation can be evaluated by less oil uptake into pores of slices during frying process since the pores of the crust were not filled with frying oil.

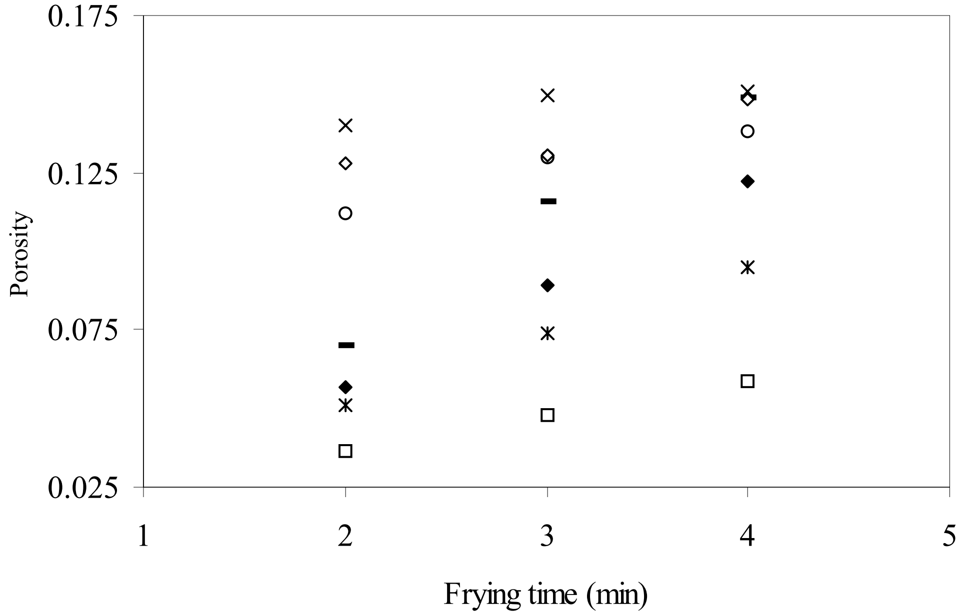


Figure 3.7 Effects of pre-gelatinized tapioca starch and dextrin at different concentrations on porosity of deep-fat fried carrot slices.
(□) control^{e}, (-) dextrin 1%^{bc}, (◆) dextrin 3%^{cd}, (*)dextrin 5%^{d},
(o) tapioca starch 1%^{ab}, (◊) tapioca starch 3 %^{ab}, (x) tapioca starch 5%^{a}.

3.1.8. Color

The final color of the fried product depends on the frying time, the absorption of oil and the chemical browning reactions of reducing sugars and protein sources (Baixauli et al., 2002). Lightness value decreased while Hunter a value increased during frying (Figure 3.8 and Figure 3.9). There was no definite trend in variation of Hunter b value during frying (Figure 3.10). Significantly higher Hunter L values were obtained when pre-gelatinized tapioca starch was added to the formulation. It is probably related with the reduced amount of oil uptake during frying process (Loewe, 1990).

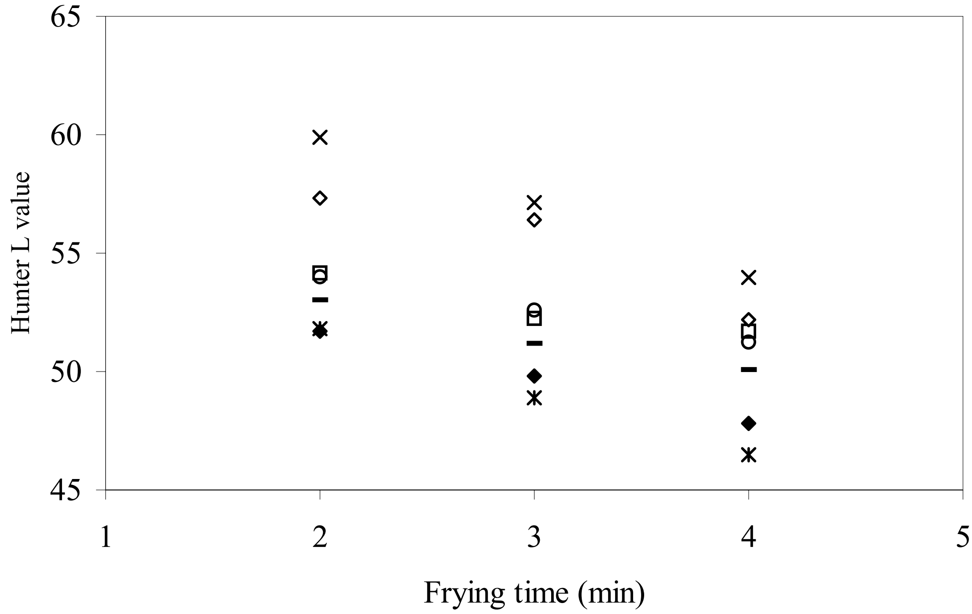


Figure 3.8 Effects of pre-gelatinized tapioca starch and dextrin at different concentrations on Hunter L value of deep-fat fried carrot slices.

(□) control^{a}, (-) dextrin 1%^{ab}, (◆) dextrin 3%^{bc}, (*)dextrin 5%^{c},
(o) tapioca starch 1%^{d}, (◊) tapioca starch 3 %^{d}, (x) tapioca starch 5%^{d}.

Increased amount of dextrin concentration resulted in lower lightness values (darker color) within the product, which is due to the increase in the rate of Maillard and caramelization reactions (Table B.8).

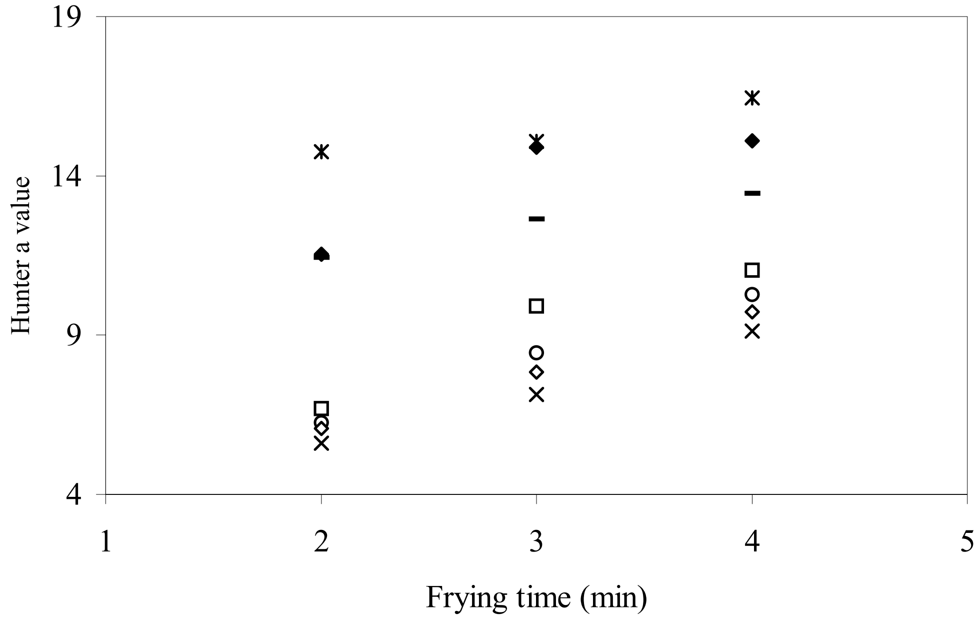


Figure 3.9 Effects of pre-gelatinized tapioca starch and dextrin at different concentrations on Hunter a value of deep-fat fried carrot slices.
(□) control[d], (-) dextrin 1%[c], (◆) dextrin 3%[b], (*)dextrin 5%[a],
(o) tapioca starch 1%[de], (◊) tapioca starch 3 %[e], (x) tapioca starch 5%[e].

In Figure 3.9 Hunter a values of fried carrot slices were represented. Positive Hunter a values represented redness of products. No significant difference was observed between pre-gelatinized tapioca starch concentrations (Table B.9). However significant differences were reported between dextrin concentrations (Table B.9). Addition of 5% dextrin concentration provided the highest a value (highest redness) due to the contribution of dextrin in non-enzymatic browning reactions.

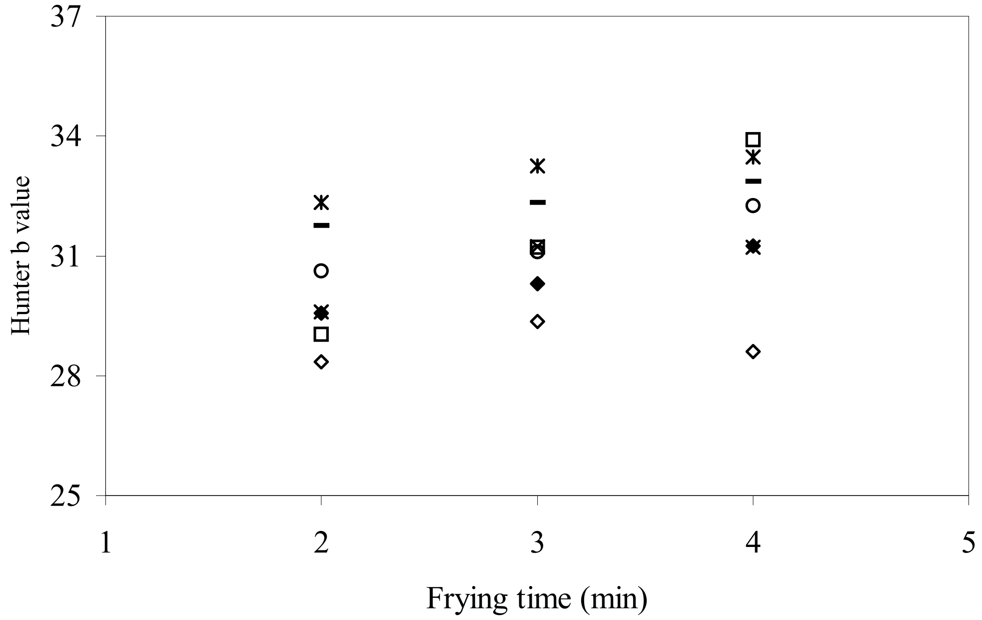


Figure 3.10 Effects of pre-gelatinized tapioca starch and dextrin at different concentrations on Hunter b values of deep-fat fried carrot slices.

(□) control , (-) dextrin 1% , (◆) dextrin 3% , (*)dextrin 5%,
(o) tapioca starch 1% , (◊) tapioca starch 3 % , (x) tapioca starch 5%.

In Figure 3.10, Hunter b values of fried carrot slices were represented. Positive b value represented yellowness of products. As mentioned before, a definite trend could not obtained for b values of deep-fat fried carrot slices.

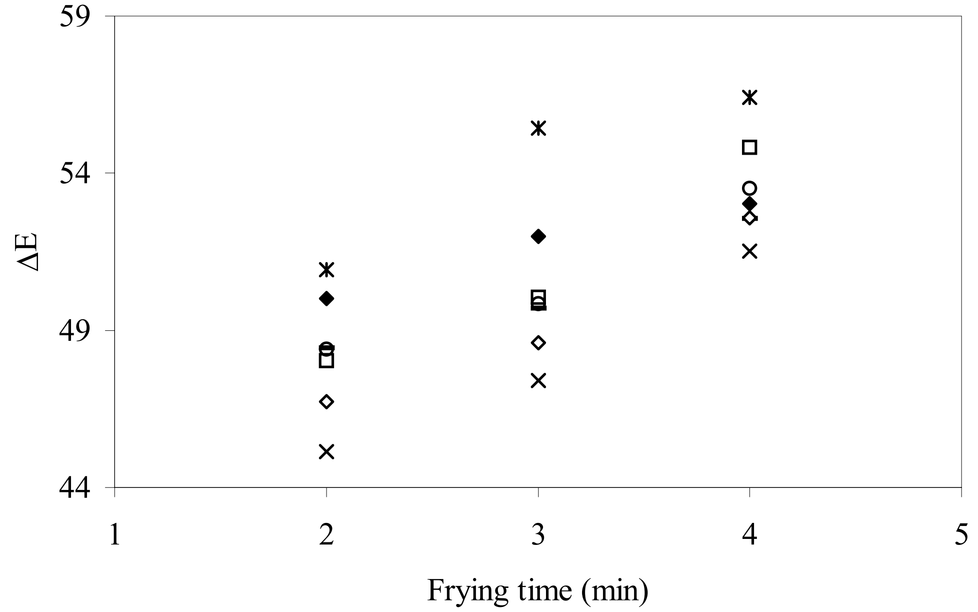


Figure 3.11 Effects of pre-gelatinized tapioca starch and dextrin at different concentrations on ΔE of deep-fat fried carrot slices.
(□) control[bc] , (-) dextrin 1%[bc] , (◆) dextrin 3%[b] , (*)dextrin 5%[a],
(o) tapioca starch 1%[bc] , (◊) tapioca starch 3 %[cd] , (x) tapioca starch 5%[d].

Color change (ΔE) of carrot slices was also given in Figure 3.11. Duncan's multiple range test showed that 5% dextrin addition to the formulation provided higher ΔE value during frying (Table B.10).

3.2.Effects of Different Gum Types on the Quality Parameters of Deep-fat Fried Carrot Slices

The effects of different gum types (HPMC, guar gum, xanthan gum and guar-xanthan gum combination) on coating pick-up and on major quality parameters of fried products; moisture and oil contents, crispness, porosity, color and frying yield were evaluated in this part of the study. To determine the effectiveness of gums no gum added coating was used as the control batter formulation.

3.2.1. Coating Pick-up

Batter pick-up is generally directly correlated with batter viscosity: that is, as viscosity increases, more batter remains on the sample (Cunningham and Tiede, 1981; Altunakar, 2003; Dogan, 2004). Gums are able to provide high viscosity to their dispersions even at low concentrations. Therefore, gum addition to the batter formulation resulted in higher batter pick-up values (Figure 3.12). No significant differences were detected between gum types but the combination of guar and xanthan gum yielded higher coating pick-up due to the high degree of synergism, which led them to suggest interactions between molecules as a possible cause of the increase in the viscosity (Table B.11). It is very well known that synergistic interaction of xanthan gum with guar gum gives a synergistic increase in viscosity (Sanderson, 1981).

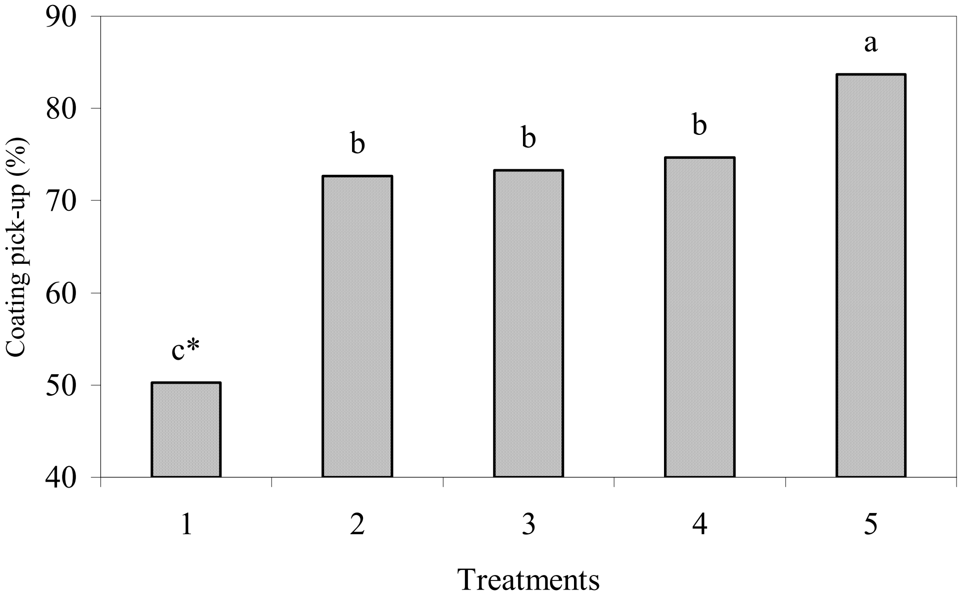


Figure 3.12 Effects of gum types on coating pick-up of deep-fat fried carrot slices.
(1) control, (2) HPMC, (3) xanthan gum, (4) guar gum,
(5) guar-xanthan gum combination.
* means bars with different letters are significantly different ($p \leq 0.05$).

3.2.2. Moisture Content

Moisture contents of fried carrot slices coated with batters containing different gum types and with the control formulation were represented in Figure 3.13. Duncan's multiple range test showed that all types of gums were significantly effective in controlling moisture loss (Table B.12).

Film formation and thermal gelation abilities are critical functions of gums for both barrier properties; moisture retention and oil uptake reduction (Loewe, 1990). The higher moisture retention was reported when guar gum or the combination of guar and xanthan gum was used. This may be due to high water binding capacities of these gums (Table C.1). Synergistic interaction of guar gum with xanthan gum is important to increase viscosity (Dziezak, 1991). Mixtures of guar gum-xanthan gum do not usually help gelatinization but show enhanced batter pick-up values compared to values of individual components, which resulted in decreased moisture loss within the product (Figure 3.12 and Figure 3.13). A homogenous film formation provides efficient and effective coverage of the product in order to decrease moisture loss (Loewe, 1990).

Thermal gelation property of HPMC above its incipient gelation temperature is important in controlling moisture loss. The methyl groups in HPMC molecules undergo intermolecular association with adjacent molecules above gelation temperature. As a result, viscosity increases dramatically with increase in temperature (Mallikarjunan et al., 1997).

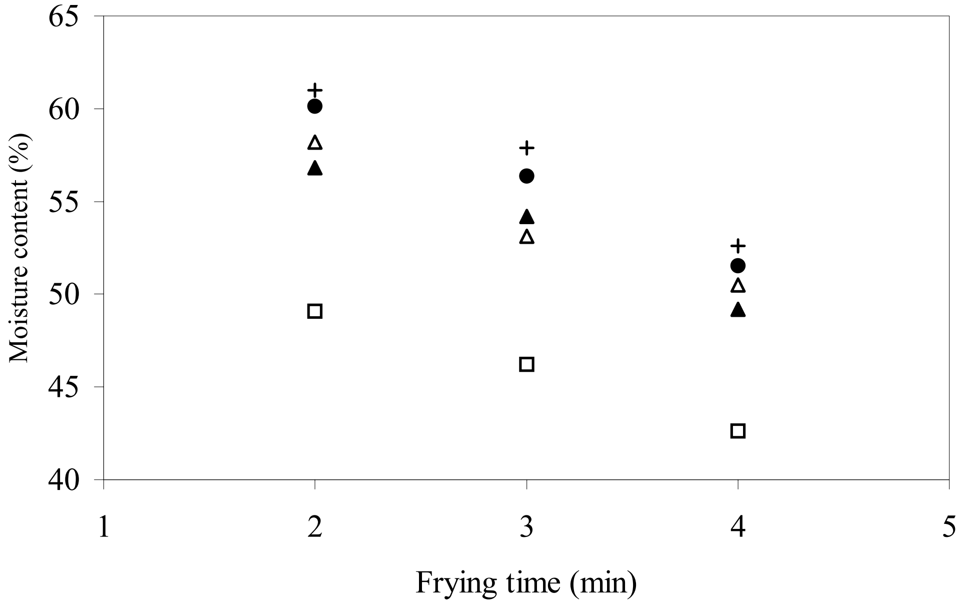


Figure 3.13 Effects of gum types on moisture content of deep-fat fried carrot slices.
(□) control[c], (▲) HPMC[b], (Δ) xanthan gum[b], (●)guar gum[a],
(+) guar-xanthan gum combination[a].

3.2.3. Oil Content

The gelling ability of gums together with their usual hydrophilic nature and film forming ability makes them useful for reducing oil uptake during frying in battered products (Annapure et al., 1999). Oil contents of products provided with coatings containing different gum types and with the control formulation were shown in Figure 3.14.

The trend of oil uptake of carrot slices during frying was the reverse of that shown by moisture content. Using gums in batter formulations resulted in lower oil uptake by enhancing moisture retention as a result of a strong interaction due to hydrogen bonding between water molecules in the batter and gums. The displacement of water by oil during frying is restricted.

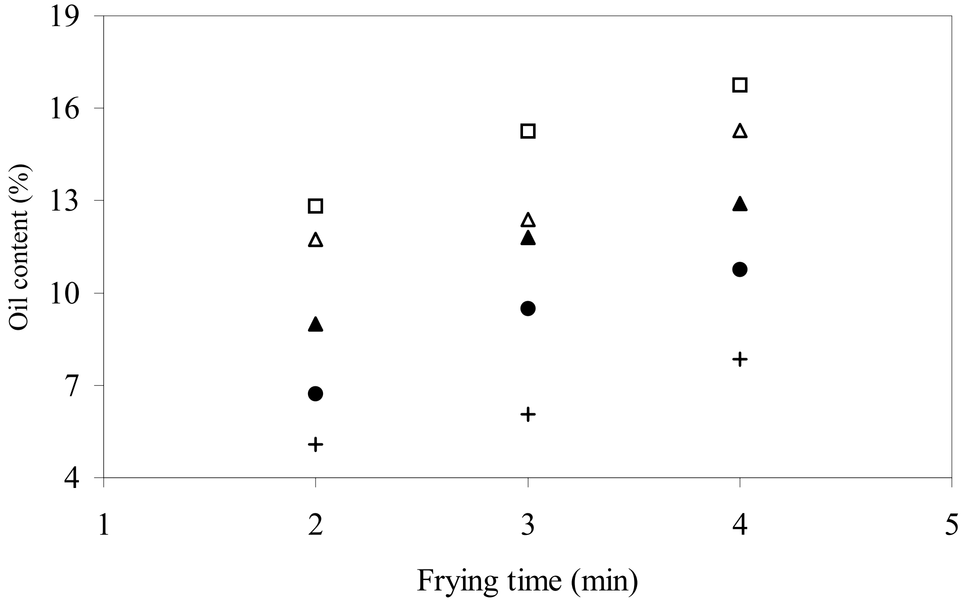


Figure 3.14 Effects of gum types on oil content of deep-fat fried carrot slices.
(□) control[a], (▲) HPMC[c], (Δ) xanthan gum[b], (●)guar gum[d],
(+) guar-xanthan gum combination[e].

Guar-xanthan gum added coating reduced oil uptake significantly as compared to other coatings (Table B.13). This can be explained by the synergistic effect, which led to more batter pick-up, resulting in high moisture retention and low oil content.

Thermo-gelling property of HPMC promotes the formation of a small amount of wide punctures with low capillary pressures (Mellema, 2003). Less oil uptake was observed in HPMC added batters as compared to the products coated with control batter. It is probably due to the low capillary pressure, which resulted in less oil entrance to the pores of slices. In literature, it was also reported that HPMC reinforces the natural barrier properties of starch and proteins especially when they are added in dry form (Myers, 1990).

3.2.4.Frying Yield

Percent frying yield is an indicator of batter adhesion during frying process (Hsia et al., 1992). All gum containing batters supplied yields greater than the control (Figure 3.15 and Table B.14). The higher frying yield values obtained for guar and xanthan gum combination added batter is probably because of high moisture retention. Besides batter adhesion, in calculating percent frying yield, both moisture loss and oil absorption plays role.

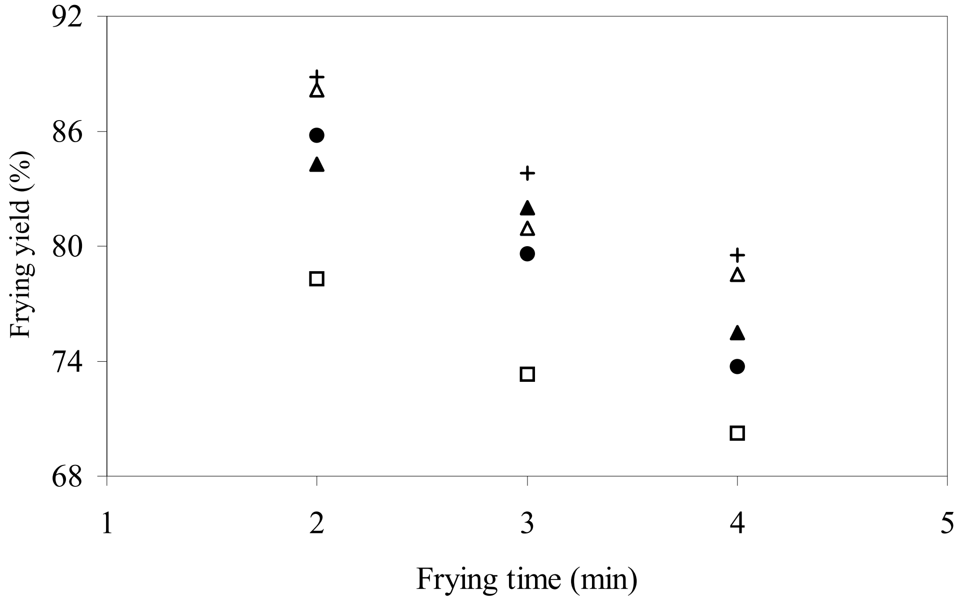


Figure 3.15 Effects of gum types on frying yield of deep-fat fried carrot slices. (□) control[d] , (▲) HPMC[bc] , (Δ) xanthan gum[ab] , (●)guar gum[c], (+) guar-xanthan gum combination[a].

3.2.5.Crispness

Fracturability values of all gums were found to be significantly different from control batter (Figure 3.16 and Table B.15). It may be explained by thermo-gelling and cross-linking properties of gums.

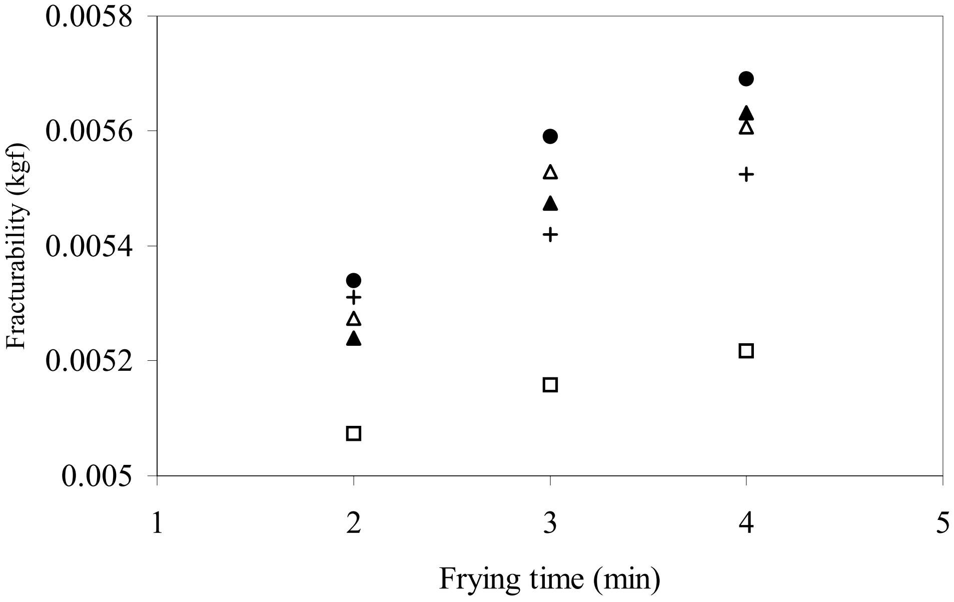


Figure 3.16 Effects of gum types on fracturability of deep-fat fried carrot slices. (□) control[c], (▲) HPMC[ab], (Δ) xanthan gum[ab], (●)guar gum[a], (+) guar-xanthan gum combination[b].

3.2.6. Bulk Density

The variation of bulk densities of carrot slices coated with different batter formulations during frying were shown in Figure 3.17. The densities of carrot slices decreased during frying. Bulk densities of carrot slices were significantly reduced when gums were used in batter formulations (Table B.16). This is mainly due to better film forming and gas holding ability of gum added batters

Usage of xanthan and guar gum combination had no advantage over usage of xanthan gum only with respect to bulk density (Figure 3.17 and Table B. 16). However the combination may be preferred since xanthan gum is higher in price.

The sharp decrease in bulk density within the initial period of frying in the case of control formulation was most probably due to the expansion caused by sudden moisture loss from the slices.

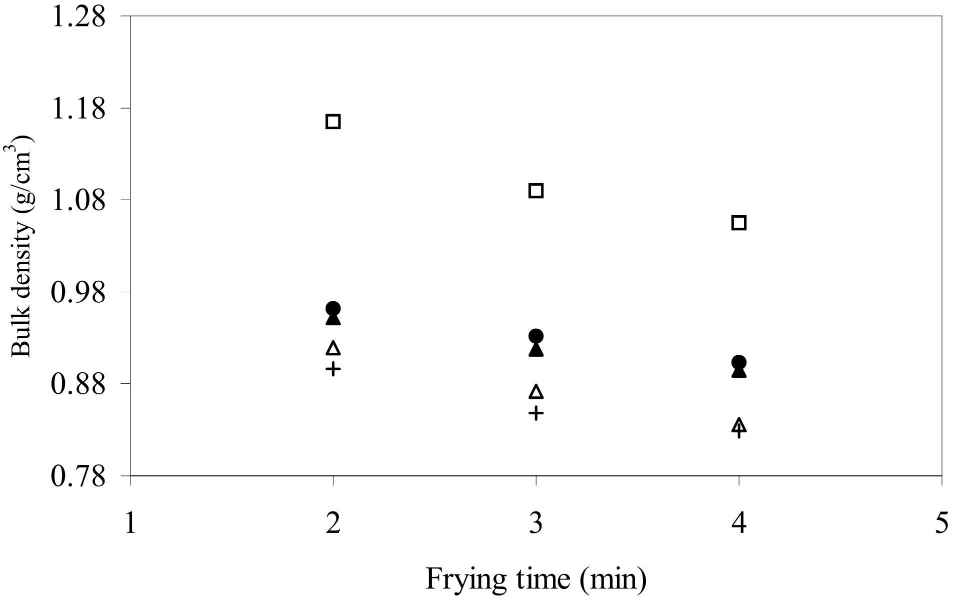


Figure 3.17 Effects of gum types on bulk density of deep-fat fried carrot slices.
(□) control[a] , (▲) HPMC[b] , (Δ) xanthan gum[c] , (●)guar gum[b],
(+) guar-xanthan gum combination[c] .

3.2.7. Porosity

The porosity data of experiments were shown in Figure 3.18. It is obviously seen that adding gums to the coating enables more porous products (Table B.17).

The differences between gum types can be explained with the different film forming and gas retention abilities of gums. During frying, oil can be taken up before the food is taken from the frying medium as in the case of small food pieces like thin carrot slices (Mellema, 2003). Therefore, the barrier property to oil uptake may help to prevent filling the voids of the crust enabling more porous product.

When xanthan gum was used in batter formulation highly porous product was obtained as compared to other formulations (Figure 3.14 and Figure 3.18). This may be due to the better film forming and so gas retaining ability of xanthan gum. Lower bulk density of samples coated with xanthan gum added batter formulation also confirms this fact (Figure 3.17).

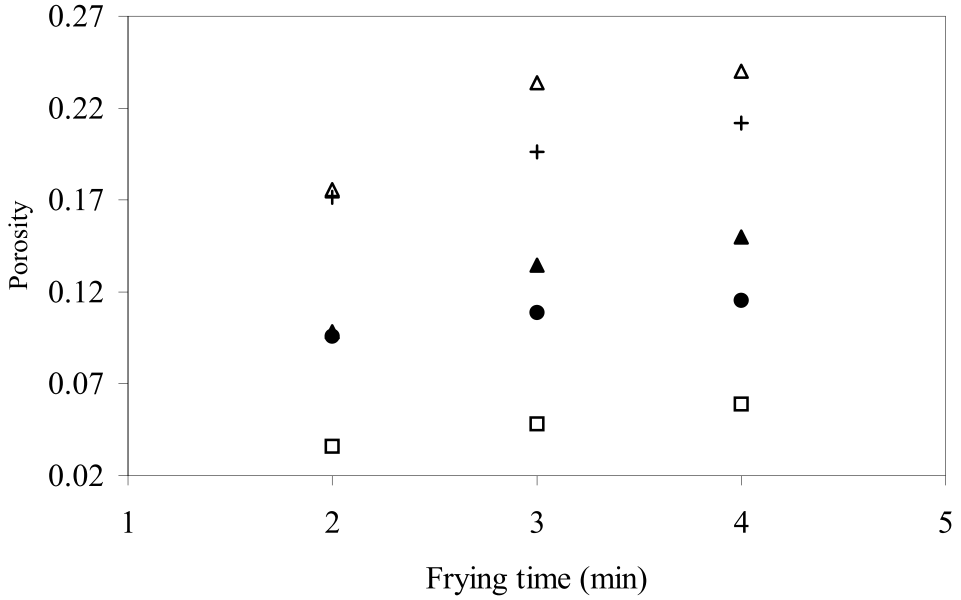


Figure 3.18 Effects of gum types on porosity of deep-fat fried carrot slices.
(□) control[d] , (▲) HPMC[c] , (Δ) xanthan gum[a] , (●)guar gum[c],
(+) guar-xanthan gum combination[b] .

3.2.8. Color

Gum addition resulted in higher L but a lower a value meaning lighter and less red color (Figure 3.19, Figure 3.20, Table B.18 and Table B.19). In literature, it is reported that gum’s ability to bind moisture prevents dehydration and inhibits the Maillard browning reaction. The lighter color can also indicate that the product absorbed less frying oil (Loewe, 1990). Therefore, it was not surprising that gum types provided significantly lighter colors to products.

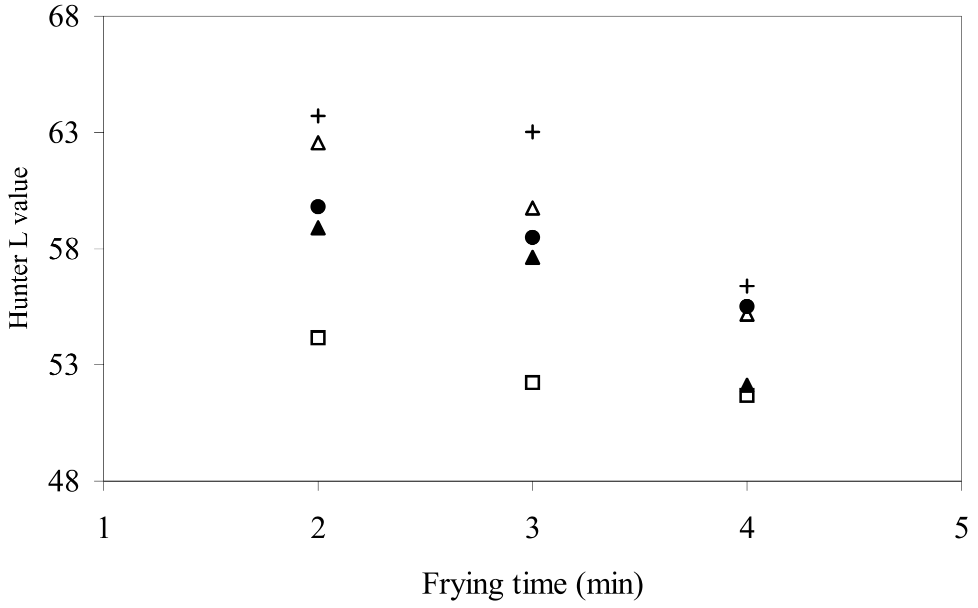


Figure 3.19 Effects of gum types on Hunter L value of deep-fat fried carrot slices.
(□) control[d] , (▲) HPMC[c] , (Δ) xanthan gum[ab] , (●)guar gum[bc],
(+) guar-xanthan gum combination[a].

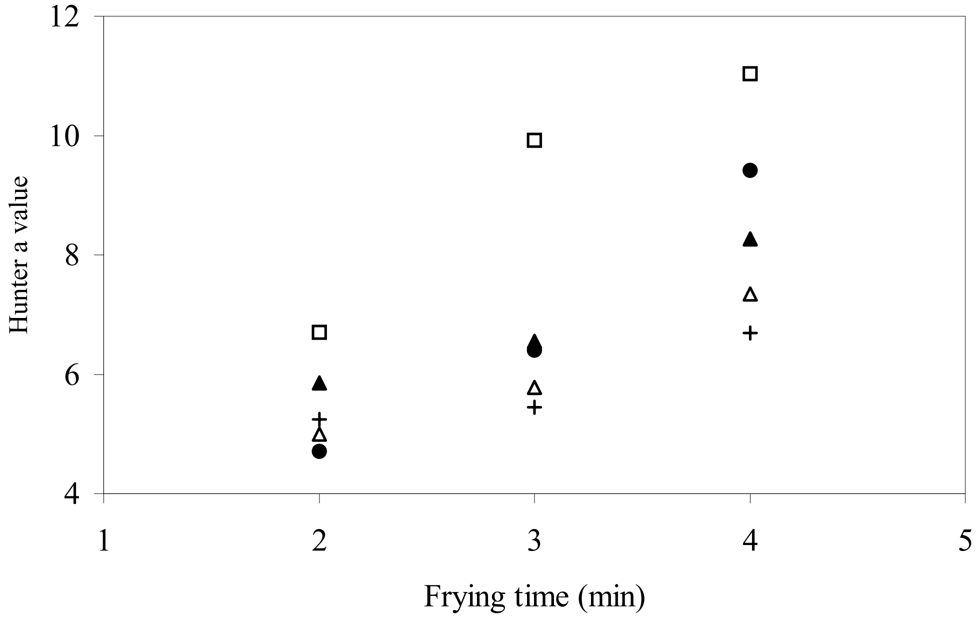


Figure 3.20 Effects of gum types on Hunter a value of deep-fat fried carrot slices. (□) control[a] , (▲) HPMC[b] , (Δ) xanthan gum[b] , (●)guar gum[b],
(+) guar-xanthan gum combination[b].

Gum types enabled significantly lower Hunter a values in comparison with control batter (Figure 3.20). No significant difference was seen between gum types in terms of redness given to the product during frying process (Table B.19).

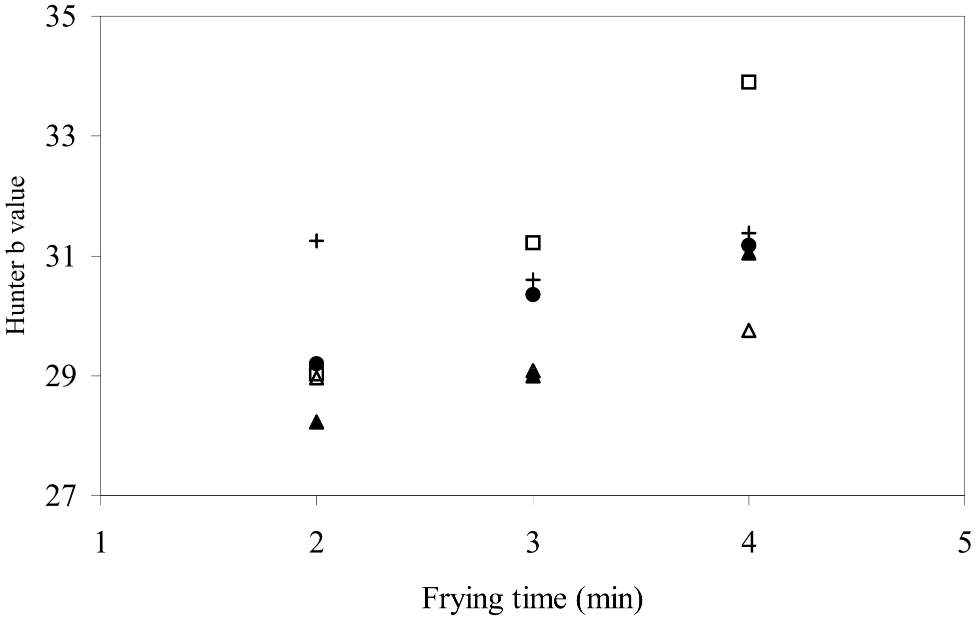


Figure 3.21 Effects of gum types on Hunter b value of deep-fat fried carrot slices. (□) control , (▲) HPMC , (Δ) xanthan gum , (●)guar gum, (+) guar-xanthan gum combination.

A definite trend was not observed for variation of Hunter b values of coated carrot slices with different gum types during frying (Figure 3.21). Color changes (ΔE values) during frying of carrots coated with different gums were significantly less than the ones coated with control batter (Figure 3.22).

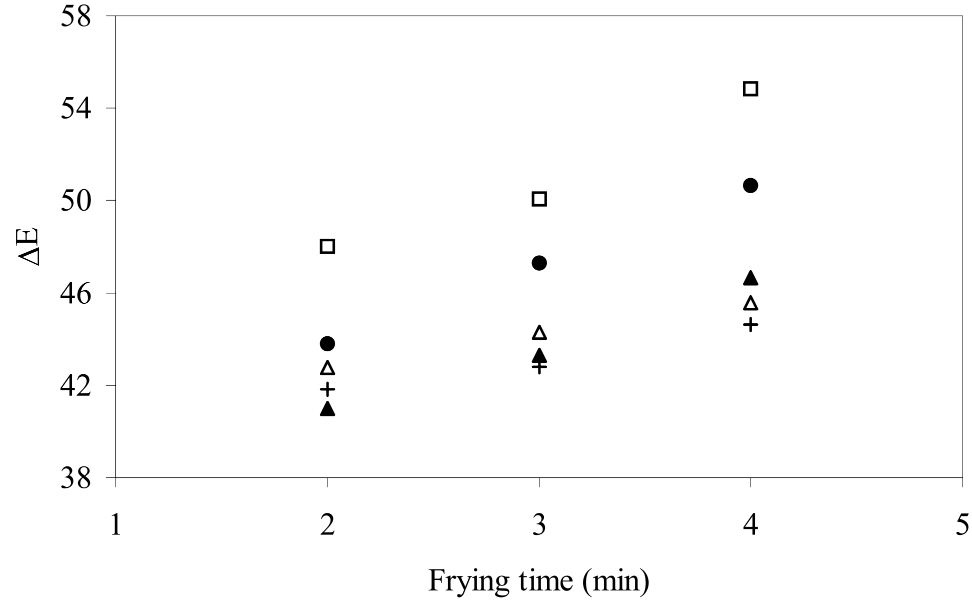


Figure 3.22 Effects of gum types on ΔE of deep-fat fried carrot slices.
(□) control[a] , (▲) HPMC[c] , (Δ) xanthan gum[c] , (●)guar gum[b],
(+) guar-xanthan gum combination[c].

3.3. Comparison of the Effects of Pre-gelatinized Tapioca Starch, Dextrin and Gums on Deep-Fat Fried Carrot Slices

The effects of pre-gelatinized tapioca starch & dextrin at concentrations of 1,3, 5% and different gums (HPMC, guar gum, xanthan gum and guar-xanthan gum combination) on some quality parameters of fried carrot slices were compared in this section. Frying time of 3 minutes was chosen to make this evaluation, since at this time acceptable products were obtained.

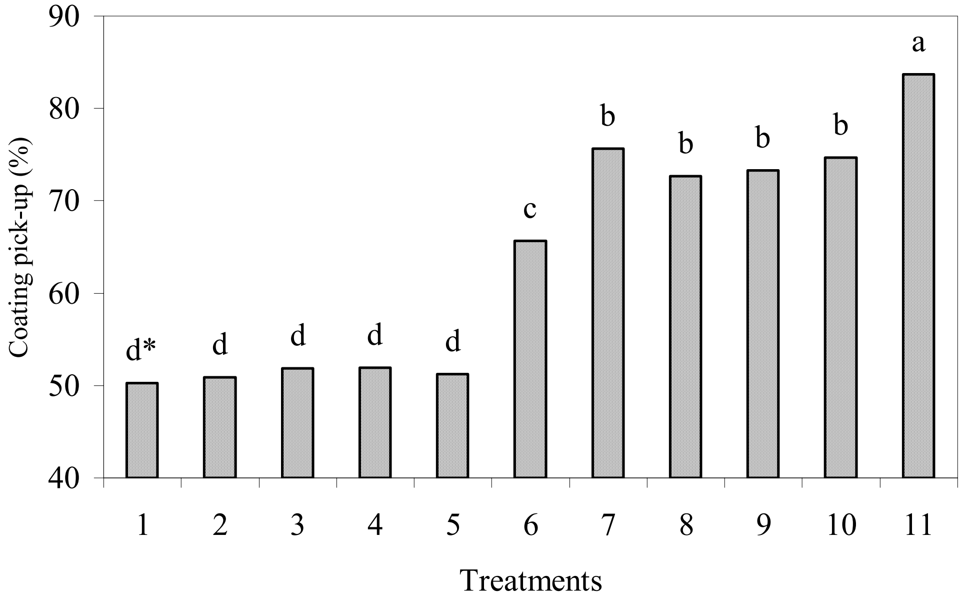


Figure 3.23 Effects of different hydrocolloids on coating pick-up of deep-fat fried carrot slices.

(1) control, (2) 1% dextrin, (3) 3% dextrin, (4) 5% dextrin, (5) 1% pre-gelatinized tapioca starch, (6) 3% pre-gelatinized tapioca starch, (7) 5% pre-gelatinized tapioca starch, (8) 1% HPMC, (9) 1% xanthan gum, (10) 1% guar gum, (11) 1% guar-xanthan gum combination.
* means bars with different letters are significantly different ($p \leq 0.05$).

The coating pick-up data for different batter formulations were given in Figure 3.23. Usage of dextrin at all concentrations and pre-gelatinized tapioca starch at 1% concentration do not have any significant improvement on coating pick-up of batter (Table B.21). Significantly higher pick-up values were obtained for pre-gelatinized tapioca starch at concentrations higher than 1% and for all gum types especially for guar-xanthan gum combination (Table B.21). It is known that coating pick-up is positively correlated with batter viscosity. Therefore, the differences among pick-up values were most probably due to the difference in their viscosities. Gums are commonly used for cold-batter viscosity adjustment (Davis, 1983). As well as gums, starches provide viscosity and so coating pick-up, but gums are effective at much lower concentration levels. This lower concentration provides gums to be more cost effective than starches (Davis, 1983).

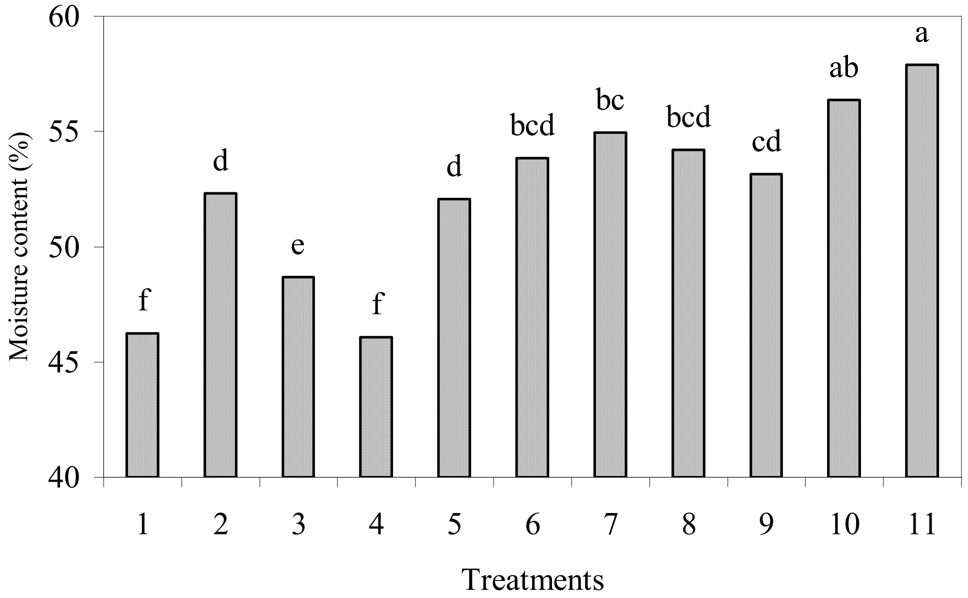


Figure 3.24 Effects of different hydrocolloids on moisture content of deep-fat fried carrot slices.

(1) control, (2) 1% dextrin, (3) 3% dextrin, (4) 5% dextrin, (5) 1% pre-gelatinized tapioca starch, (6) 3% pre-gelatinized tapioca starch, (7) 5% pre-gelatinized tapioca starch, (8) 1% HPMC, (9) 1% xanthan gum, (10) 1% guar gum, (11) 1% guar-xanthan gum combination.

Moisture and oil contents of carrot slices fried for 3 minutes were shown in Figure 3.24 and Figure 3.25, respectively. Usage of hydrocolloids strengthens the coating and provides more moisture retention enabling low oil uptake during deep-fat frying by means of their better film forming and water binding abilities. The most effective ingredient for reducing moisture loss and so oil uptake was guar and xanthan gum combination (Table B.22 and Table B.23).

All of the hydrocolloids used in this study can be recommended for lower oil uptake except dextrin at higher concentrations.

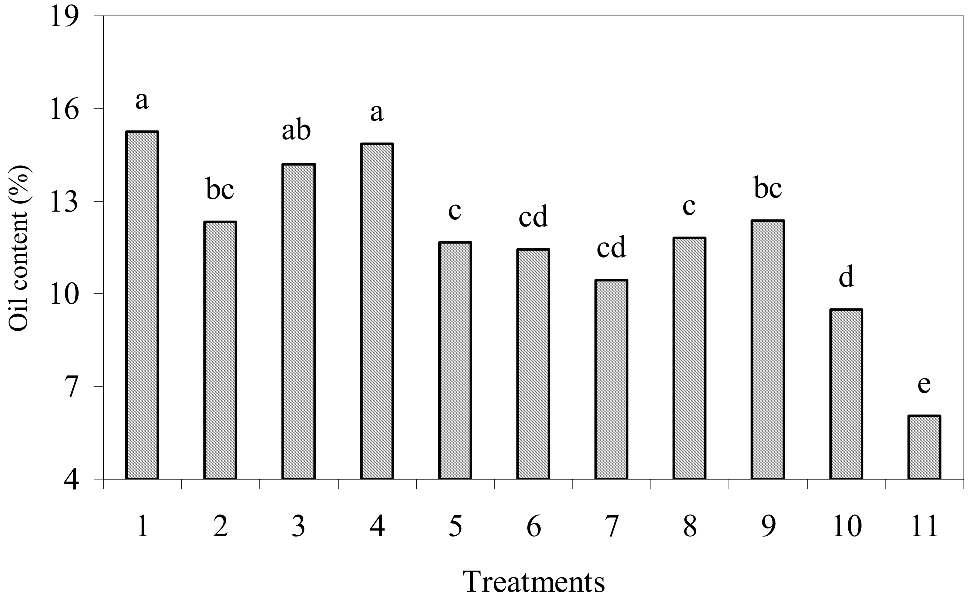


Figure 3.25 Effects of different hydrocolloids on oil content of deep-fat fried carrot slices.

(1) control, (2) 1% dextrin, (3) 3% dextrin, (4) 5% dextrin, (5) 1% pre-gelatinized tapioca starch, (6) 3% pre-gelatinized tapioca starch, (7) 5% pre-gelatinized tapioca starch, (8) 1% HPMC, (9) 1% xanthan gum, (10) 1% guar gum, (11) 1% guar-xanthan gum combination.

One of the most appreciated characteristics in fried products is crispness that can be associated with fracturability data. Crispness data of fried samples were given in Figure 3.26. Slight differences were obtained among different formulations (Table B. 24). Crispness increased with the use of gums since they provide structural integrity to the batter coating during frying. The high crispness value for guar gum may be due to the synergistic interaction of guar gum with wheat starch (Carlson et al., 1962).

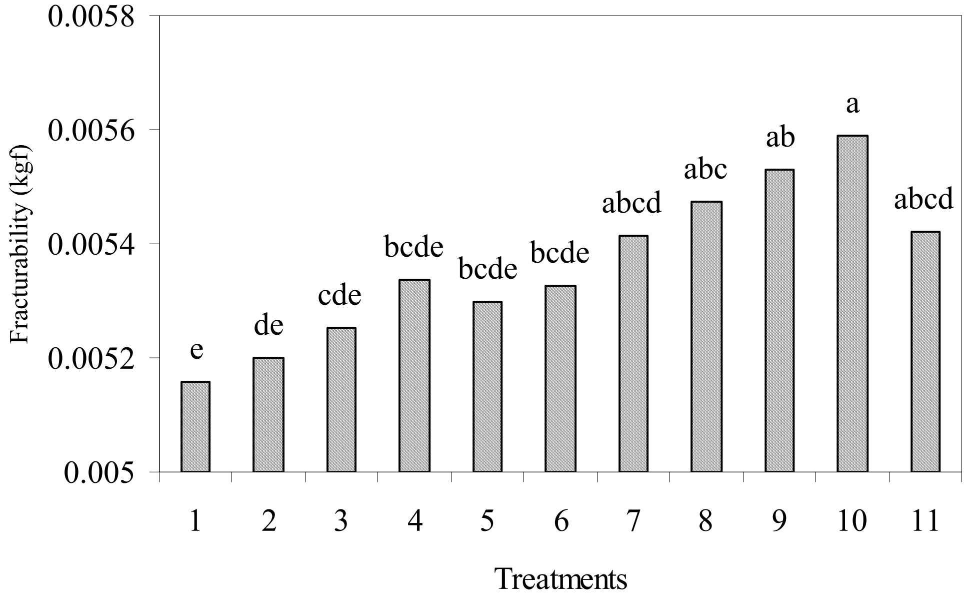


Figure 3.26 Effects of different hydrocolloids on fracturability of deep-fat fried carrot slices.

(1) control, (2) 1% dextrin, (3) 3% dextrin, (4) 5% dextrin, (5) 1% pre-gelatinized tapioca starch, (6) 3% pre-gelatinized tapioca starch, (7) 5% pre-gelatinized tapioca starch, (8) 1% HPMC, (9) 1% xanthan gum, (10) 1% guar gum, (11) 1% guar-xanthan gum combination.

Bulk densities of coated products were compared in Figure 3.27. It is obviously seen that dextrins and control batter provided higher density, which means lower volume (Table B.25). The gas may not be kept within the system due to lower pick-up values of these formulations. Addition of pre-gelatinized tapioca starch or gums to the batter formulation improved film-forming ability, which is important for gas retention during leavening. As a result more aerated and porous structure is obtained. The low level of gum addition may not be significant in dilution of gluten in batter formulation. Therefore, gums especially HPMC and guar and xanthan gums in combination were much more effective in obtaining higher bulk volume.

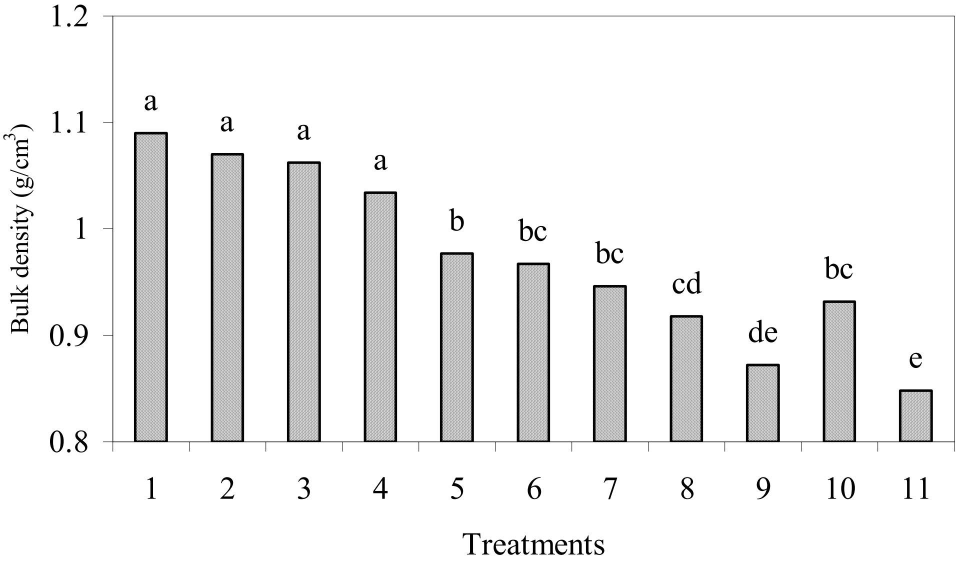


Figure 3.27 Effects of different hydrocolloids on bulk density of deep-fat fried carrot slices.

(1) control, (2) 1% dextrin, (3) 3% dextrin, (4) 5% dextrin, (5) 1% pre-gelatinized tapioca starch, (6) 3% pre-gelatinized tapioca starch, (7) 5% pre-gelatinized tapioca starch, (8) 1% HPMC, (9) 1% xanthan gum, (10) 1% guar gum, (11) 1% guar-xanthan gum combination.

Lightness data of fried products were shown in Figure 3.28. Gums and pre-gelatinized tapioca starch at high concentrations have the ability to bind more water, which inhibits Maillard reaction (Figure3.24). Significantly lighter color that provided by gums and high concentrations of pre-gelatinized tapioca starch can also be due to less oil absorption within the product (Table B.26, Figure 3.25 and Figure 3.26).

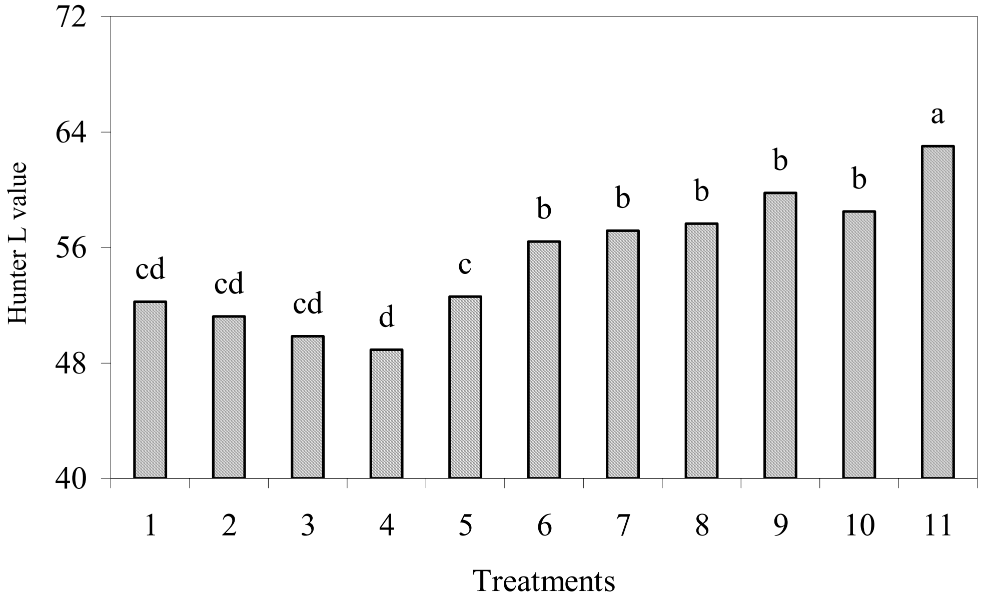


Figure 3.28 Effects of different hydrocolloids on Hunter L value of deep-fat fried carrot slices.

(1) control, (2) 1% dextrin, (3) 3% dextrin, (4) 5% dextrin, (5) 1% pre-gelatinized tapioca starch, (6) 3% pre-gelatinized tapioca starch, (7) 5% pre-gelatinized tapioca starch, (8) 1% HPMC, (9) 1% xanthan gum, (10) 1% guar gum, (11) 1% guar-xanthan gum combination.

Hunter a values of deep-fat fried carrot slices were represented in Figure 3.29. Dextrin addition to batter formulation significantly changed the redness of fried products (Table 3.27).

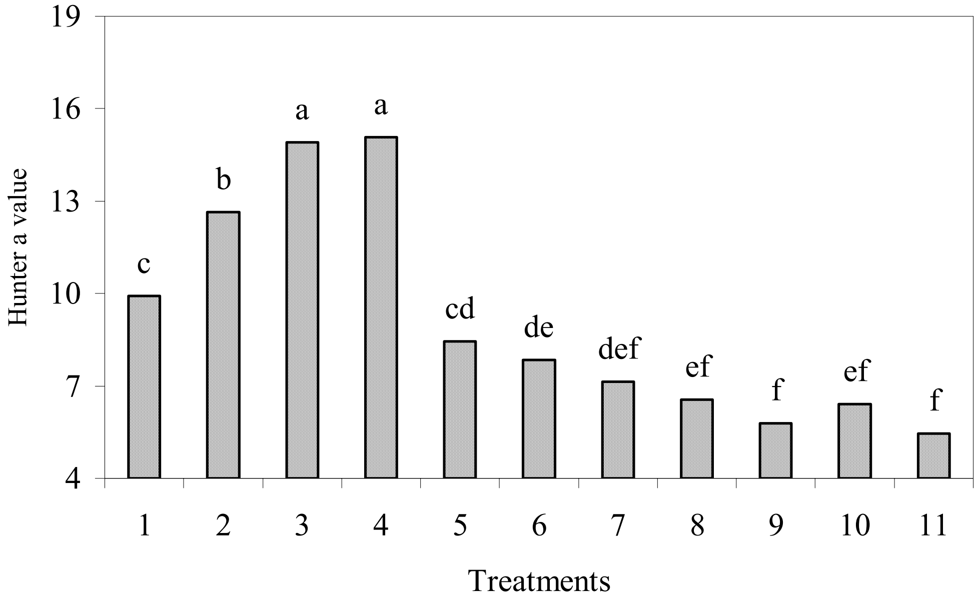


Figure 3.29 Effects of different hydrocolloids on Hunter a value of deep-fat fried carrot slices.

(1) control, (2) 1% dextrin, (3) 3% dextrin, (4) 5% dextrin, (5) 1% pre-gelatinized tapioca starch, (6) 3% pre-gelatinized tapioca starch, (7) 5% pre-gelatinized tapioca starch, (8) 1% HPMC, (9) 1% xanthan gum, (10) 1% guar gum, (11) 1% guar-xanthan gum combination.

3.4. Image Analysis

Images of fried products coated with different batter formulations were discussed in this part of the study. After frying, oil droplets seen on the carrot and crust surface were detected by photographing and analyzed by the help of Image processing. The images were given in Appendix D. In Appendix E surface plots of images for control formulation and guar-xanthan gum combination were given as sample graphs. Lighter areas (oil droplets) in the source image represent lower elevations (valleys) while darker areas in the source image represent higher elevations (peaks).

There is abundant proof that oil hardly penetrates in the cooked core (Pinthus et al., 1995a). Bouchon, et al. (2001) using infrared microspectroscopy showed that the oil penetration depth in potato is very close to the evaporation front. Therefore, so as to determine oil uptake of slices, oil droplets at the surface of the carrot and batter portion of the sample were detected with enlarging the surfaces.

For 3 and 4 minute-frying times no correlation was noticed between total oil fraction given by image process and gravimetrically obtained oil content data of products represented in Figure 3.3 and Figure 3.14. This might be due to the oil absorption to the inner parts of thin pieces for longer frying times. Hence to detect oil droplets only at the surface didn't represent the actual oil contents for later stages of frying.

On the other hand, image analysis results of 2 minutes fried carrot slices were positively correlated with oil content data of samples (Figure 3.3, Figure 3.14 and Table 3.1). The difference in different formulations on affecting oil uptake was batter reflected by the area fraction of oil droplets on carrot surface as compared to those on batter surface (Table 3.1). As can be seen in Table 3.1 total area fraction of oil droplets was lower in case of guar-xanthan gum combination added batter formulation. This is confirmed by the lowest oil content carrots coated with batters containing of guar-xanthan gum combination (Figure3.14).

Table 3.1 Area fraction and average size of droplets observed on surfaces of carrot and batter portions of the fried sample.

Additive	Area fraction and average size of oil droplets observed on carrot surface	Area fraction and average size of oil droplets observed on batter surface	Total area fraction
Control	2.4%; 0.000063 cm^2	0.5%; 0.000037 cm^2	2.9%
5% Dextrin	2.1%; 0.000056 cm^2	0.5%; 0.000035 cm^2	2.6%
1% Dextrin	1.9%; 0.000069 cm^2	0.5%; 0.000026 cm^2	2.4%
1% Starch	1.6%; 0.000047 cm^2	0.3%; 0.000026 cm^2	1.9%
Xanthan gum	1.4%; 0.000060 cm^2	0.2%; 0.000026 cm^2	1.6%
HPMC	0.7%; 0.000037 cm^2	0.4%; 0.000036 cm^2	1.1%
5% Starch	0.7%; 0.000034 cm^2	0.3%; 0.000027 cm^2	1.0%
Guar-xanthan gum combination	0.7%; 0.000042 cm^2	0.2%; 0.000026 cm^2	0.9%

CHAPTER 4

CONCLUSION AND RECOMMENDATIONS

Addition of gums to batter formulations increased moisture retention, crispness, frying yield and porosity but decreased oil uptake.

Guar-xanthan combination has been found to be the most effective additive on the batter performance. It provided the highest moisture retention, and lowest oil uptake within the product. In addition, the highest volume and lightest color were obtained when this combination was used. When carrot slices were dipped into guar-xanthan gum added batter formulation, fracturability values were higher than control but lower than the values obtained with other gums. Acceptable porosity values were observed during the usage of this gum combination.

Experimental results indicated that using pre-gelatinized tapioca starch at higher concentrations enhanced efficiency of batter while increasing dextrin concentrations had an adverse affect on the product quality. Usage of starch at relatively high levels, provided to obtain desirable products. Frying time for coated carrot slices can be recommended as 3 minutes.

The oil fraction obtained using image analysis of carrot and batter surfaces was correlated with oil content of samples during the initial frying period since oil hardly penetrates into the inner parts. However, this method of analysis was not useful in later stages of frying.

The correlation coefficient between moisture content and frying yield was obtained as 0.90. Also, oil content was found to be related with moisture content and correlation coefficient was determined to be –0.88.

It was the first research made on deep-fat frying of coated carrot slices. For further research, different coating formulations can be evaluated. As an example, modified high amylose starch, extra wheat gluten or corn zein can be added to coatings of carrots. Different combinations of gums and starches can also be studied to determine their synergistic interactions.

To decrease the initial moisture content of carrots pre-drying or osmotic pre-treatment or pre-dust application can be used to improve product quality in deep- fat frying. Carrots having different shapes and thicker slices can be used. In these conditions optimum frying times have to be determined.

Unfortunately, sensory evaluation and carotene analysis could not be included in this study. Further researches will be helpful to understand deep-fat frying mechanism of coated carrot slices.

REFERENCES

Altunakar, B. 2003. Functionality of different batters in deep-fat fried chicken nuggets. MS. Thesis. The department of Food Engineering, METU.

Annapure, U.S., Singhal, R.S., and Kulkarni, P.R. 1999. Screening of hydrocolloids for reduction in oil uptake of a model deep fat fried product. Fett/lipid, 101, 217-221.

Arenson, S.W. 1969. Predict ingredient performance. II. Starches. Food Eng. 41 (10): 150-151,154.

AOAC. 1980. Official methods of analysis, 13th ed., pp: 132-211. Washington, DC: Association of Offical Analytic Chemists.

AOAC. 1984. Official methods of analysis, 14th ed., Method 28.074. Washington, DC: Association of Offical Analytic Chemists.

Baik, O.D., and Mittal, G.S. 2003. Kinetics of tofu color changes during deep-fat frying. Lebensm.-Wiss. U.-Technol. 36:43-48.

Baixauli, Salvador, A., Fiszman, S. M. and Calvo, C. 2002. Effect of addition of Corn flour and colorants on the color of fried, battered squid rings. http://link.springer.de/link/serv...paper/s00217-002-0605-zch100.html

Baixauli, R., Sanz, T., Salvador, A., Fiszman, S. M. 2003. Effect of addition of dextrin or dried egg on the rheological and textural properties of batters for fried foods. Food Hydrocolloids, 17:305-310.

Balasubramaniam, V.M., Chinnan, M.S., Mallikarjunan, P., and Phillips, R.D. 1997. The effect of edible film on oil uptake and moisture retention of a deep-fat fried poultry product. Journal of Food Process Engineering. 20:17-29.

Blumenthal, M.M. 1991. A new look at the chemistry and physics of deep-fat frying. Food Technology, 45(2): 68-71, 94.

Bouchon, P., Hollins, P., Pearson, M., Pyle, D.L., and Tobin, M.J. 2001. Oil distrubution in fried potatoes monitored by infrared microspectroscopy. Journal of Food Science. 66:918-923.

Bourne, M.C. 1982. Food texture and viscosity. New York: Academic Press.

Carlson, W.A., Ziegenfuss, E.M., and Overton, J.D. 1962. Compatibility and manipulation of guar gum. Food Technol. 16(10), 50-54.

Cunningham, F.E., and Tiede, L.M. 1981. Influence of batter viscosity on breading of chicken drumsticks. Journal of Food Science. 46: 1950-1952.

Davis, A. 1983. Batter and breading Ingredients. pp:15-23 in:Batter and Breading Technology. D.R. Suderman and F.E. Cunningham , ends. AVI Publishing, INC., Westport, CT.

Debnath, S., Bhat, K.K., and Rastogi, N.K. 2003. Effect of pre-drying on kinetics of moisture loss and oil uptake during deep fat frying of chickpea flour-based snack food. Lebensm.-Wiss. U.- Technol. 36:91-98.

Dogan, F. 2004. Effects of different batter formulations on quality of deep-fat fried chicken nuggets. MS. Thesis. The department of Food Engineering, METU.

Dziezak, J.D. 1991. A focus on gums. Food Technology's Special Report.

Fan, J., Singh, R.P., and Pinthus, E.J. 1997. Physicochemical changes in starch during deep-fat frying of a model corn starch patty. Journal of food Processing and Preservation. 21:443-460.

Fiszman, S.M., and Salvador, A. 2003. Recent developments in coating batters. Trends in Food Science and Technology. 14:399-407.

Gamble, M.H., Rice, P., and Selman, J.D. 1987a. Relationship between oil uptake and moisture loss during frying of potato slices from CV record UK tubers. International Journal of Food science and Technology. 22:233-241.

Gamble, M.H., Rice, P., and Selman, J.D. 1987b. Distribution and morphology of oil deposits in some deep fried products. Journal of Food Science, 52, 1742.

Garcia, M.A., Ferrero, C., Bertola, N., Martino, M., and Zaritsky, N. 2001. Effectiveness of edible coatings from cellulose derivatives to reduce fat absorption in deep fat frying.
Available:http://iftconfex.com/ift/2001/techprogram/paper_7480.htm

Gennadios, A., Hanna, M.A., and Kurth, L.B. 1997. Application of Edible coatings on meats, poultry and seafoods: A Review. Lebensm.-Wiss. U.- Technol.
30, 337-350.

Glicksman, M. 1969. Gum Technology in the Food Industry. pp:275-329.
Academic Press, INC. New York.

Gnanasambandam, R., and Zayas, J.F. 1992. Funtionality of wheat germ protein in comminuted meat products as compared with corn germ and soy proteins. Journal of Food Science. Volume 57, No.4. 829-833.

Hanson, H.L., and Fletcher, L.R. 1963. Adhesion of coatings on frozen fried chicken . food Technol. 17: 793-796.

Hsia, H. Y., Smith, D. M., Steffe, J. F. 1992. Rheological properties and adhesion characteristics of flour-based batters for chicken nuggets as affected by three hydrocolloids. J. Food Sci. 57:16-19, 24.

Katzbauer, B. 1998. Properties and applications of xanthan gum. Polymer Degradation and Stability. 59:81-84.

Keller, C., Escher, F., and Solms, J. 1990. Nutrient retention in deep-fat frying case study on chips. Über die Nahrstofferhaltung im Fritierprozess-Untersuchungen am Beispiel der Pommes-frites- Herstellung. Mitteilungen aus dem Gebiete der Lebens-mitteluntersuchung und -hygiene. 81: 168-181.

Kester, J.J., and Fennema, O.R. 1986. Edible films and coatings: a review. Food Technology. December: 47-59.

Khalil, A.H. 1999. Quality of French fried potatoes as influenced by coating with hydrocolloids. Food Chemistry. 66:201- 206.

Krokida, M.K., Oreopoulou, V., Maroulis, Z.B. 2000. Water loss and oil uptake as a function of frying time. Journal of Food Engineering. 44: 39-46.

Krokida, M.K., Oreopoulou, V., Maroulis, Z.B., Marinos-Kouris, D. 2001. Effect of pre-drying on quality of french fries. Journal of Food Engineering. 49, 347-354.

Lamberg, I., Hallstrom, B., and Olsson, H. 1990. Fat uptake in a potato drying frying process. Lebensmittel-Wissenschaft and Technologie. 23:295-300.

Lee, W.T., and Dawson, L.E. 1973. Chicken lipid changes during cooking in fresh and reused cooking oil. Journal of Food Science. 38:1232-1237.

Ling, D., Gennadios, A., Hanna, M.A., and Cuppett, S.L. 1998. Quality evaluation of deep-fat fried onion rings. Journal of Food Quality. 21:95-105.

Llorca, E., Hernando, I., Perez-Munuera, I., Fiszman, S.M., and Lluch, M.A. 2001. Effect of frying on the microstructure of frozen battered squid rings. European Food Research and Technology.
http://link,springer.de/link/service/j,,,01/00382/paper/s002170100382ch110.html

Loewe, R. 1990. Ingredient selection for batter systems. In Kulp, K., Loewe, R., editors. Batters and Breadings in food processing. pp 11-28. St. Paul, Minn. AAAC.

Loewe, R. 1993. Role of ingredients in batter systems. Cereal Foods World, 38(9): 673-677.

Love, B.E., and Goodwin, T.L. 1974. Effects of cooking methods and browning temperatures on yields of poultry parts. Poultry Science. 53: 1391-1398.

Mallikarjunan P., Chinnan, M.S., Balasubramaniam, V.M., and Phillips, R.D. 1997. Edible film Coatings for deep-fat frying of starchy products. Lebensm.-Wiss.u-Technol. 30:709-714.

Marousis, S.N., and Saravacos, G.D. 1990. Density and porosity in drying Starch materials. Journal of Food Science. 55 (5): 1367-1372.

Mehta, U., and Swinburn, B. 2001. A review of factors affecting fat absorbtion in hot chips. Critical Reviews in Food Science and Nutrition. 41:133-154.

Mellema, M. 2003. Mechanism and reduction of fat uptake in deep-fat fried foods. Trends in Food Science and Technology. 14, 364-373.

Meyers, M.A., and Conklin, J.R. 1990. Method of inhibiting oil adsorption in coated fried foods using hydroxypropyl methyl cellulose. US patent 4,900,573.

Mohamed, S., Hamid, N. A., Hamid, M.A. 1998. Food components affecting the oil absorption and crispiness of fried batter. Journal of Food Science and Agriculture, 78:39-45.

Moreira, R.G., Palau, J.E., and Sun, X. 1995. Deep-fat frying of tortilla chips. An Engineering approach. Food Technology. 49(4):146-150.

Moreira, R. G., Sun, X.Z., and Chen, Y. H. 1997. Factors affecting oil uptake in tortilla chips in deep-fat frying. Journal of Food Engineering. 31, 485-498.

Moreira, R. G., Castell-Perez, M. E., Barrufet, M. A. 1999. Deep-Fat Frying fundamentals and applications. pp 75-104. Aspen Publishers, Inc., Gaithersburg, Maryland.

Moyano, P.C., Rioseco, V.K., Gonzalez, P.A. 2002. Kinetics of crust color changes during deep-fat frying of impregnated french fries. Journal of Food Engineering, 54, 249-255.

Myers, M.A. 1990. Functionality of hydrocolloids in batter coating systems. In K.Kulp, &R. Loewe(Eds), Batters and Breadings in food processing. St. Paul, MN: American association of cereal chemists.

Nicolle, C., Cardinault N., Aprikian, O., Busserolles, J., Grolier, P., Rock, E., Demigne, C., Mazur, A., Scalbert, A., Amouroux, P., and Remesy, C. 2003. Effect of carrot intake on cholesterol mechanism and on antioxidant status in cholesterol-fed rat. Eur. J. Nutr. 42:254-261.

Olewnick, M., and Kulp.K. 1993. Factors influencing wheat flour performance in batter systems. Cereal Foods World. 38(9): 679-685.

Orthoefer, F.T., Gurkin, S., Liu, K. 1996. Dynamis of frying. In Perkins, E.D., Erickson, M.D. editors. Deep frying chemistry, nutrition and practical applications, pp:223-245. Champaign, Illinois.

Ott, M., and Hester, E.E. 1965. Gel formation as related to concentration of amylose and degree of starch swelling. Cereal Chem. 42, 476-484.

Parakash, M., and Rajalkshmi, D. 1999. Effect of steamed wheat flour on the sensory quality of batter coated products. Journal of Food quality. 22:523-533.

Parinyasiri, T., Chen, T.C., and Reed, R.J, 1991. Yields and breading dispersion of chicken nuggets during deep-fat frying as affected by protein content of breading flour. Journal of Food Processing and Preservation. 15:369-376.

Patil, S.L., and Singhal, R.S., and Kulkarni, P.R. 2001. Scrrening of different hydrocolloids for improving the quality of fried papad. European Journal of Lipid Science Technology. 103: 722-728.

Pinthus, E.J., Weinberg, P., and Saguy, I.S. 1993. Criterion for oil uptake during deep-fat frying. Journal of Food Science, 58, 204.

Pinthus, E. J., Weinberg, P., Saguy, I. S. 1995a. Deep-fat fried potato product oil uptake as affected by crust physical properties. Journal of Food Science, 60(4)

Pinthus, E.J., Weinberg, P., and Saguy, I.S. 1995b. Oil uptake in deep fat frying as affected by porosity. Journal of Food Science, 60(4): 767-769.

Rayner, M., Ciolfi, V., Maves, B., Stedman, P., and Mittal, G.S. 2000. Development and application of soy protein films to reduce fat intake in deep-fried foods. Journal of the Science of Food and Agriculture. 80:777-782.

Rovedo, C.O., Pedreno-Navarro, M.M., and Singh, R.P. 1999. Mechanical properties of a corn starch product during the post-frying period. Journal of Texture Studies. 30:279-290.

Rubnov, M., Saguy, I.S. 1997. Fractal analysis and crust diffusivity of a restructured potato product during deep-fat frying. Jouranal of Food Science. 62.135,137,154.

Saguy, I.S., and Pinthus, E.J. 1995. Oil uptake during deep-fat frying –factors and mechanism. Food Technology, 49, 142.

Salvador, A., Sanz, T., Fiszman, S. 2002. Effect of corn flour, salt, and leavening on the texture of fried, battered squid rings. Journal of Food Science. Vol.67, Nr.2: 730-733.

Sanderson, G.R. 1981. Polysaccharides in foods. Food Technology. July, 50-58.

SAS.1988. SAS User’s Guide Statistics. SAS Institute, Inc., Raleigh, NC.

Selman, J. D. and Hopkins, M. 1989. Factors affecting oil uptake during the production of fried potato products. Tech. Memorandum. 475. Gloucestershire.UK. Campden Food and Drink Res. Assoc. Chipping. Campden.

Shi, X., and BeMiller, J.N. 2002. Effects of food gums on viscosities of starch suspensions during pasting. Carbohydrate polymers. 50:7-18.

Shinsato, E., Hippleheuser, A.L., and Van Beirendonck, K. 1999. Products for batter and coating systems. The World of Ingredients, January-February, 38-42.

Shih, E.F., Daigle, K. 1999. Oil uptake properties of fried batters from rice flour. Journal of Agriculture and Food Chemistry, 47:1611-1615.

Shih, E.F., Daigle, K.W., Clawson, E.L. 2001. Development of low oil uptake donuts. Journal of Food science. 66(1) :141-144.

Southern, C.R., Chen, X.D., Farid, M.M., Howard, B., and Eyres, L. 2000. Determining internal oil uptake and water content of fried thin potato crisps. Food and Bioproducts Processing. 78:119-125.

Stier, R. F., and Blumenthal, M.M. 1990. Heat transfer in frying. Baking and Snack Systems, 12(9):15-19.

Szczesniak, A.S. 1988. The meaning of crispness as a textural characteristics. J Texture Studies, 19:51-59.

Tako., M. 1991. Carbohydrate polym. 16:239-252.

Ufheil, G., and Escher, F. 1996. Dynamics of oil uptake during deep-fat frying of potato slices. Lebensm.-Wiss. u.-Technol., 29:640-644.

Waimaleongora-Ek, C., and Chen, T.C. 1983. Effect of Shortening color frying temperature and coating ingredients on color of fried chicken parts. Poultry Science. 62:793-797.

Yamsaengsung, R., and Moreira, R.G. 2002. Modelling the transport phenomena and structural changes during deep fat frying Part I: model development. Journal of Food Engineering. 53:1-10.

Zallie, J.P. 1988. The role and function of starches in microwable food formulation. Microwave Foods.

British Nutrition Foundation, BNF information cereals, http://www.nutrition.org.uk/information/foodandingredients/cereal.htlm, 05 August 2004.

Nutrition Data, Vegetabables and Vegetable Products - Raw Carrots, http://www.nutritiondata.com, 10 August 2004.

The Columbia Electronic Encyclopedia 6th edition, Dextrin http://www.infoplease.com/ce6/sci/A0815381.html, 10 August 2004.

The Dow Chemical Company, Typical Chemical Structures of Methocel Products, http:www.dow.com/methocel/resource/chem.htm, 10 August 2004.

The University of Georgia Department of Horticulture, Vegetablable Crops-Carrot, www.uga.edu/vegetable/carrot.html, 20 January 2000.

APPENDIX A

TEXTURE PROFILE ANALYSIS

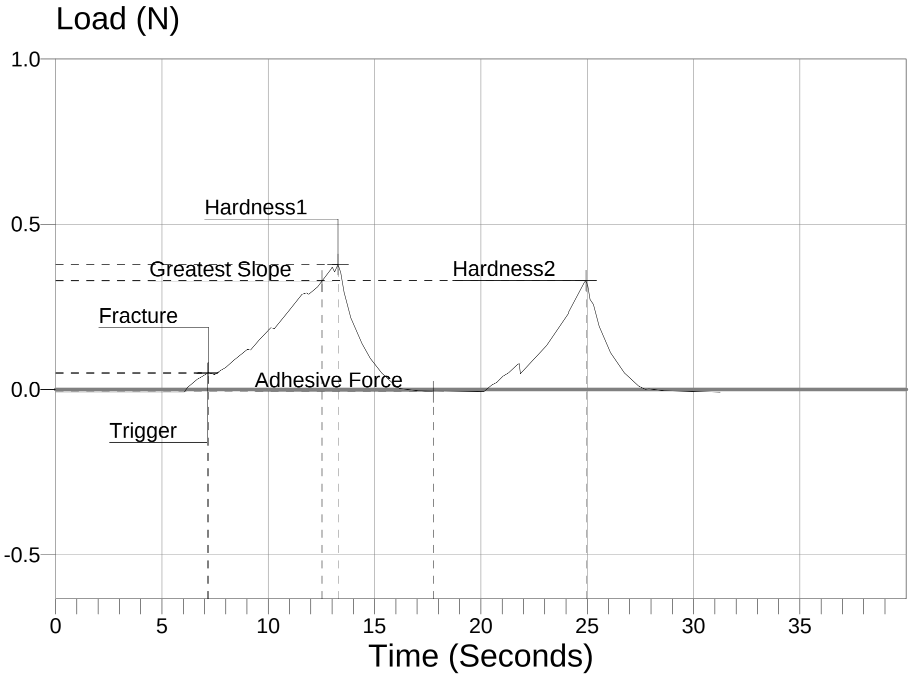


Figure A.1 Typical TPA curve (guar-xanthan gum combination coated carrot slices; 3 minutes fried).

APPENDIX B

ANOVA and DUNCAN TABLES

Table B.1 ANOVA and Duncan's Multiple Range Test Table for coating pick-up of fried samples with different concentrations of dextrin and tapioca starch.

Class	Levels	Values
Formulations	7	control, 1% dextrin, 3% dextrin, 5% dextrin, 1% starch, 3% starch, 5% starch

Number of observations in data set = 21

Source	DF	Sum of Squares	Mean Square	F Value	$P_r > F$
Model	6	1769.33631	294.88938	143.62	0.0001
Error	14	28.74560	2.05325		
Total	20	1798.08191			

Source	DF	Type III SS	Mean Square	F Value	$P_r > F$
Formulations	6	1769,33631	294,88938	143,62	0.0001

Alpha = 0.05

Means with the same letter are not significantly different.

Duncan Grouping	**Mean**	**N**	**Formulations**
A	75.650	3	5% tapioca starch
B	65.640	3	3% tapioca starch
C	51.940	3	5% dextrin
C	51.840	3	3% dextrin
C	51.220	3	1% dextrin
C	50.920	3	1% tapioca starch
C	50.290	3	control

Table B.2 ANOVA and Duncan's Multiple Range Test Table for moisture content of fried samples with different concentrations of dextrin and pre-gelatinized tapioca starch.

Class	Levels	Values
Formulations	7	control, 1% dextrin, 3% dextrin, 5% dextrin, 1% starch, 3% starch, 5% starch
Frying time (min)	3	2, 3, 4

Number of observations in data set = 21

Source	DF	Sum of Squares	Mean Square	F Value	$P_r > F$
Model	8	413.10716	51.63839	36.24	0.0001
Error	12	17.10041	1.42503		
Total	20	430.20758			

Source	DF	Type III SS	Mean Square	F Value	$P_r > F$
Batter Type	6	158.62466	26.43744	18.55	0.0001
Frying time	2	254.48250	127.24125	89.29	0.0001

Duncan Grouping	**Mean**	**N**	**Formulations**
A	54.1550	3	5% tapioca starch
AB	52.7033	3	3% tapioca starch
B	51.6000	3	1% dextrin
B	51.3633	3	1% tapioca starch
C	48.8367	3	3% dextrin
CD	47.3600	3	5% dextrin
D	45.9833	3	control

Table B.3 ANOVA and Duncan's Multiple Range Test Table for oil content of fried samples with different concentrations of dextrin and pre-gelatinized tapioca starch.

Class	Levels	Values
Formulations	7	control, 1% dextrin, 3% dextrin, 5% dextrin, 1% starch, 3% starch, 5% starch
Frying time (min)	3	2, 3, 4

Number of observations in data set = 21

Source	DF	Sum of Squares	Mean Square	F Value	$P_r > F$
Model	8	107.68878	13.46109	36.12	0.0001
Error	12	4.47271	0.37272		
Total	20	112.16149			

Source	DF	Type III SS	Mean Square	F Value	$P_r > F$
Batter Type	6	48.87122	8.14520	21.85	0.0001
Frying time	2	58.81755	29.40877	78.90	0.0001

Duncan Grouping	**Mean**	**N**	**Formulations**
A	14.9400	3	control
A	14.7767	3	5% dextrin
A	14.0667	3	3% dextrin
B	12.5900	3	1% tapioca starch
B	12.2100	3	1% dextrin
B	11.9167	3	3% tapioca starch
C	10.4967	3	5% tapioca starch

Table B.4 ANOVA and Duncan's Multiple Range Test Table for frying yield of samples with different concentrations of dextrin and pre-gelatinized tapioca starch.

Class	Levels	Values
Formulations	7	control, 1% dextrin, 3% dextrin, 5% dextrin, 1% starch, 3% starch, 5% starch
Frying time (min)	3	2, 3, 4

Number of observations in data set = 21

Source	DF	Sum of Squares	Mean Square	F Value	$P_r > F$
Model	8	382.18128	47.77266	31.43	0.0001
Error	12	18.23863	1.51988		
Total	20	400.41992			

Source	DF	Type III SS	Mean Square	F Value	$P_r > F$
Batter Type	6	123.50399	20.58399	13.54	0.0001
Frying time	2	258.67729	129.338	85.10	0.0001

Duncan Grouping	**Mean**	**N**	**Formulations**
A	81.373	3	5% tapioca starch
A	79.600	3	3% tapioca starch
B	77.227	3	3% dextrin
B	77.007	3	1% tapioca starch
BC	75.577	3	1% dextrin
BC	11.9167	3	5% dextrin
C	73.953	3	control

Table B.5 ANOVA and Duncan's Multiple Range Test Table for fracturability of fried samples with different concentrations of dextrin and pre-gelatinized tapioca starch.

Class	Levels	Values
Formulations	7	control, 1% dextrin, 3% dextrin, 5% dextrin, 1% starch, 3% starch, 5% starch
Frying time (min)	3	2, 3, 4

Number of observations in data set = 21

Source	DF	Sum of Squares	Mean Square	F Value	$P_r > F$
Model	8	0.00000032	0.00000004	35.34	0.0001
Error	12	0.00000001	0.0000000008		
Total	20	0.00000033			

Source	DF	Type III SS	Mean Square	F Value	$P_r > F$
Batter Type	6	0.00000020	0.00000003	29.64	0.0001
Frying time	2	0.00000012	0.00000006	52.97	0.0001

Duncan Grouping	**Mean**	**N**	**Formulations**
A	0.00547	3	5% tapioca starch
B	0.00535	3	5% dextrin
BC	0.00530	3	3% tapioca starch
C	0.00527	3	1% tapioca starch
CD	0.00524	3	3% dextrin
DE	0.00520	3	1% dextrin
E	0.00514	3	control

Table B.6 ANOVA and Duncan's Multiple Range Test Table for bulk density of fried samples with different concentrations of dextrin and pre-gelatinized tapioca starch.

Class	Levels	Values
Formulations	7	control, 1% dextrin, 3% dextrin, 5% dextrin, 1% starch, 3% starch, 5% starch
Frying time (min)	3	2, 3, 4

Number of observations in data set = 21

Source	DF	Sum of Squares	Mean Square	F Value	$P_r > F$
Model	8	0.09654	0.01206	35.52	0.0001
Error	12	0.00419	0.00034		
Total	20	0.10074			

Source	DF	Type III SS	Mean Square	F Value	$P_r > F$
Batter Type	6	0.07174	0.01195	34.20	0.0001
Frying time	2	0.02480	0.0124	35.47	0.0001

Duncan Grouping	**Mean**	**N**	**Formulations**
A	1.10333	3	control
AB	1.07700	3	1% dextrin
BC	1.05933	3	3% dextrin
C	1.04033	3	5% dextrin
D	0.97267	3	1% tapioca starch
D	0.96333	3	3% tapioca starch

Table B.7 ANOVA and Duncan's Multiple Range Test Table for porosity of fried samples with different concentrations of dextrin and pre-gelatinized tapioca starch.

Class	Levels	Values
Formulations	7	control, 1% dextrin, 3% dextrin, 5% dextrin, 1% starch, 3% starch, 5% starch
Frying time (min)	3	2, 3, 4

Number of observations in data set = 21

Source	DF	Sum of Squares	Mean Square	F Value	$P_r > F$
Model	8	0.02832	0.00354	20.81	0.0001
Error	12	0.00204	0,00017		
Total	20	0.03036			

Source	DF	Type III SS	Mean Square	F Value	$P_r > F$
Batter Type	6	0.02317	0.00386	22.70	0.0001
Frying time	2	0.00515	0.00257	15.14	0.0005

Duncan Grouping	**Mean**	**N**	**Formulations**
A	0.14675	3	5% tapioca starch
AB	0.13560	3	3% tapioca starch
AB	0.12661	3	1% tapioca starch
BC	0.11150	3	1% dextrin
CD	0.08935	3	3% dextrin
D	0.07323	3	5% dextrin
E	0.04769	3	control

Table B.8 ANOVA and Duncan's Multiple Range Test Table for Hunter L value of fried samples with different concentrations of dextrin and pre-gelatinized tapioca starch.

Class	Levels	Values
Formulations	7	control, 1% dextrin, 3% dextrin, 5% dextrin, 1% starch, 3% starch, 5% starch
Frying time (min)	3	2, 3, 4

Number of observations in data set = 21

Source	DF	Sum of Squares	Mean Square	F Value	$P_r > F$
Model	8	203.34278	25.41784	37.85	0.0001
Error	12	8.05854	0.671545		
Total	20	211.40132			

Source	DF	Type III SS	Mean Square	F Value	$P_r > F$
Batter Type	6	145.73705	24.28950	36.17	0.0001
Frying time	2	57.60572	28.80286	42.89	0.0001

Duncan Grouping	**Mean**	**N**	**Formulations**
A	57.0067	3	5%tapioca starch
B	55.3067	3	3% tapioca starch
C	52.7033	3	control
C	52.6167	3	1% tapioca starch
C	51.4333	3	1% dextrin
D	49.7733	3	3% dextrin
D	49.0667	3	5 % dextrin

Table B.9 ANOVA and Duncan's Multiple Range Test Table for Hunter a value of fried samples with different concentrations of dextrin and pre-gelatinized tapioca starch.

Class	Levels	Values
Formulations	7	control, 1% dextrin, 3% dextrin, 5% dextrin, 1% starch, 3% starch, 5% starch
Frying time (min)	3	2, 3, 4

Number of observations in data set = 21

Source	DF	Sum of Squares	Mean Square	F Value	$P_r > F$
Model	8	226.34373	28.29296	65.29	0.0001
Error	12	5.20029	0.43335		
Total	20	231.54402			

Source	DF	Type III SS	Mean Square	F Value	$P_r > F$
Batter Type	6	188.69036	31.44839	72.57	0.0001
Frying time	2	37.65337	18.82668	43.44	0.0001

Duncan Grouping	**Mean**	**N**	**Formulations**
A	15.4267	3	5 % dextrin
B	13.8467	3	3% dextrin
C	12.5100	3	1% dextrin
D	9.2200	3	control
DE	8.3233	3	1% tapioca starch
E	7.8833	3	3% tapioca starch
E	7.2900	3	5%tapioca starch

Table B.10 ANOVA and Duncan's Multiple Range Test Table for ΔE of fried samples with different concentrations of dextrin and pre-gelatinized tapioca starch.

Class	Levels	Values
Formulations	7	control, 1% dextrin, 3% dextrin, 5% dextrin, 1% starch, 3% starch, 5% starch
Frying time (min)	3	2, 3, 4

Number of observations in data set = 21

Source	DF	Sum of Squares	Mean Square	F Value	$P_r > F$
Model	8	166.30951	20.78868	24.00	0.0001
Error	12	10.39342	0.86611		
Total	20	176.70293			

Source	DF	Type III SS	Mean Square	F Value	$P_r > F$
Batter Type	6	68.99904	11.49984	13.28	0.0001
Frying time	2	97.31047	48.65523	56.18	0.0001

Duncan Grouping	**Mean**	**N**	**Formulations**
A	54.2533	3	5% dextrin
B	51.6700	3	3% dextrin
BC	50.9720	3	control
BC	50.5833	3	1% tapioca starch
BC	50.2367	3	1% dextrin
DC	49.3033	3	3% tapioca starch
D	48.0200	3	5% tapioca starch

Table B.11 ANOVA and Duncan's Multiple Range Test Table for coating pick-up of fried samples with different gum types.

Class	Levels	Values
Formulations	5	control, HPMC, xanthan gum, guar gum, guar-xanthan gum combination
Frying time (min)	3	2, 3, 4

Number of observations in data set = 21

Source	DF	Sum of Squares	Mean Square	F Value	$P_r > F$
Model	4	1835.13420	458.78355	69.49	0.0001
Error	10	66.02300	6.60230		
Total	14	1901.15720			

Source	DF	Type III SS	Mean Square	F Value	$P_r > F$
Formulations	4	1835.13420	458.78355	69.49	0.0001

Duncan Grouping	**Mean**	**N**	**Formulations**
A	83.710	3	guar-xanthan gum combination
B	74.640	3	guar gum
B	73.300	3	xanthan gum
B	72.660	3	HPMC
C	50.290	3	control

Table B.12 ANOVA and Duncan's Multiple Range Test Table for moisture content of fried samples with different gum types.

Class	Levels	Values
Formulations	5	control, HPMC, xanthan gum, guar gum, guar-xanthan gum combination
Frying time (min)	3	2, 3, 4

Number of observations in data set = 15

Source	DF	Sum of Squares	Mean Square	F Value	$P_r > F$
Model	6	379.88572	63.31428	130.48	0.0001
Error	8	3.88206	0.48525		
Total	14	383.76779			

Source	DF	Type III SS	Mean Square	F Value	$P_r > F$
Batter Type	4	228.84585	57.21146	117.90	0.0001
Frying time	2	151.03987	75.51993	155.63	0.0001

Duncan Grouping	**Mean**	**N**	**Formulations**
A	57.1667	3	guar-xanthan gum combination
A	56.0150	3	guar gum
B	53.9450	3	xanthan gum
B	53.4000	3	HPMC
C	45.9833	3	control

Table B.13 ANOVA and Duncan's Multiple Range Test Table for oil content of fried samples with different gum types.

Class	Levels	Values
Formulations	5	control, HPMC, xanthan gum, guar gum, guar-xanthan gum combination
Frying time (min)	3	2, 3, 4

Number of observations in data set = 15

Source	DF	Sum of Squares	Mean Square	F Value	$P_r > F$
Model	6	170.66274	28.44379	92.13	0.0001
Error	8	2.46978	0.30872		
Total	14	173.13253			

Source	DF	Type III SS	Mean Square	F Value	$P_r > F$
Batter Type	4	137.68233	34.42058	111.49	0.0001
Frying time	2	32.98041	16.49020	53.41	0.0001

Duncan Grouping	**Mean**	**N**	**Formulations**
A	14.9400	3	control
B	13.1300	3	xanthan gum
C	11.2367	3	HPMC
D	8.9933	3	guar gum
E	6.3333	3	guar-xanthan gum combination

Table B.14 ANOVA and Duncan’s Multiple Range Test Table for frying yield of samples with different gum types.

Class	Levels	Values
Formulations	5	control, HPMC, xanthan gum, guar gum, guar-xanthan gum combination
Frying time (min)	3	2, 3, 4

Number of observations in data set = 15

Source	DF	Sum of Squares	Mean Square	F Value	$P_r > F$
Model	6	408.53485	68.08914	46.00	0.0001
Error	8	11.84238	1.48029		
Total	14	420.37724			

Source	DF	Type III SS	Mean Square	F Value	$P_r > F$
Batter Type	4	179.13337	44.78334	30.25	0.0001
Frying time	2	229.40148	114.70074	77.48	0.0001

Duncan Grouping	**Mean**	**N**	**Formulations**
A	84.0467	3	guar-xanthan gum combination
AB	82.5433	3	xanthan gum
BC	80.5967	3	HPMC
C	79.7000	3	guar gum
D	73.9533	3	control

Table B.15 ANOVA and Duncan's Multiple Range Test Table for fracturability of fried samples with different gum types.

Class	Levels	Values
Formulations	5	control, HPMC, xanthan gum, guar gum, guar-xanthan gum combination
Frying time (min)	3	2, 3, 4

Number of observations in data set = 15

Source	DF	Sum of Squares	Mean Square	F Value	$P_r > F$
Model	6	0.00000048	0.00000008	25.44	0.0001
Error	8	0.00000003	0.000000003		
Total	14				

Source	DF	Type III SS	Mean Square	F Value	$P_r > F$
Batter Type	4	0.00000027	0.000000067	21.35	0.0001
Frying time	2	0.00000021	0.000000105	33.63	0.0001

Duncan Grouping	**Mean**	**N**	**Formulations**
A	0.00554	3	guar gum
AB	0.00547	3	xanthan gum
AB	0.00544	3	HPMC
B	0.00541	3	guar-xanthan gum combination
C	0.00514	3	control

Table B.16 ANOVA and Duncan's Multiple Range Test Table for bulk density of fried samples with different gum types.

Class	Levels	Values
Formulations	5	control, HPMC, xanthan gum, guar gum, guar-xanthan gum combination
Frying time (min)	3	2, 3, 4

Number of observations in data set = 15

Source	DF	Sum of Squares	Mean Square	F Value	$P_r > F$
Model	6	0.12833	0.02138	151.22	0.0001
Error	8	0.00113	0.00014		
Total	14	0.12946			

Source	DF	Type III SS	Mean Square	F Value	$P_r > F$
Batter Type	4	0.11391	0.02847	210.34	0.0001
Frying time	2	0.01441	0.00720	50.97	0.0001

Duncan Grouping	**Mean**	**N**	**Formulations**
A	1.10333	3	control
B	0.93233	3	guar gum
B	0.92166	3	HPMC
C	0.87566	3	xanthan gum
C	0.85766	3	guar-xanthan gum combination

Table B.17 ANOVA and Duncan's Multiple Range Test Table for porosity of fried samples with different gum types.

Class	Levels	Values
Formulations	5	control, HPMC, xanthan gum, guar gum, guar-xanthan gum combination
Frying time (min)	3	2, 3, 4

Number of observations in data set = 15

Source	DF	Sum of Squares	Mean Square	F Value	$P_r > F$
Model	6	0.05957	0.00992	80.15	0.0001
Error	8	0.00099	0.00012		
Total	14	0.06056			

Source	DF	Type III SS	Mean Square	F Value	$P_r > F$
Batter Type	4	0.05536	0.01384	111.74	0.0001
Frying time	2	0.00420	0.0021	16.98	0.0001

Duncan Grouping	**Mean**	**N**	**Formulations**
A	0.21653	3	xanthan gum
B	0.19320	3	guar-xanthan gum combination
C	0.12765	3	HPMC
C	0.10670	3	guar gum
D	0.04769	3	control

Table B.18 ANOVA and Duncan's Multiple Range Test Table for Hunter L value of fried samples with different gum types.

Class	Levels	Values
Formulations	5	control, HPMC, xanthan gum, guar gum, guar-xanthan gum combination
Frying time (min)	3	2, 3, 4

Number of observations in data set = 15

Source	DF	Sum of Squares	Mean Square	F Value	$P_r > F$
Model	6	205.12676	34.18779	18.71	0.0001
Error	8	14.61981	1.82747		
Total	14	219.74657			

Source	DF	Type III SS	Mean Square	F Value	$P_r > F$
Batter Type	4	120.36730	30.09182	16.47	0.0001
Frying time	2	84.75945	42.37972	23.19	0.0001

Duncan Grouping	**Mean**	**N**	**Formulations**
A	61.043	3	guar-xanthan gum combination
AB	59.163	3	xanthan gum
BC	57.930	3	guar gum
C	56.217	3	HPMC
D	52.703	3	control

Table B.19 ANOVA and Duncan's Multiple Range Test Table for Hunter a value of fried samples with different gum types.

Class	Levels	Values
Formulations	5	control, HPMC, xanthan gum, guar gum, guar-xanthan gum combination
Frying time (min)	3	2, 3, 4

Number of observations in data set = 15

Source	DF	Sum of Squares	Mean Square	F Value	$P_r > F$
Model	6	45.41208	7.56868	11.46	0.0015
Error	8	5.28289	0.66036		
Total	14	50.69497			

Source	DF	Type III SS	Mean Square	F Value	$P_r > F$
Batter Type	4	21.98110	5.49527	8.32	0.0060
Frying time	2	23.43097	11.71548	17.74	0.0011

Duncan Grouping	**Mean**	**N**	**Formulations**
A	9.2200	3	control
B	6.8933	3	HPMC
B	6.8433	3	guar gum
B	6.0433	3	xanthan gum
B	5.7933	3	guar-xanthan gum combination

Table B.20 ANOVA and Duncan's Multiple Range Test Table for ΔE of fried samples with different gum types.

Class	Levels	Values
Formulations	5	control, HPMC, xanthan gum, guar gum, guar-xanthan gum combination
Frying time (min)	3	2, 3, 4

Number of observations in data set = 15

Source	DF	Sum of Squares	Mean Square	F Value	$P_r > F$
Model	6	192.76376	32.12729	27.66	0.0001
Error	8	9.29325	1.16165		
Total	14	202.05702			

Source	DF	Type III SS	Mean Square	F Value	$P_r > F$
Batter Type	4	130.04506	32.51126	27.99	0.0001
Frying time	2	62.71870	31.35935	27.00	0.0001

Duncan Grouping	**Mean**	**N**	**Formulations**
A	50.9720	3	control
B	47.2500	3	guar gum
C	44.2133	3	xanthan gum
C	43.6500	3	HPMC
C	43.0867	3	guar-xanthan gum combination

B.21. ANOVA and Duncan's Multiple Range Test Table for coating pick up of fried samples with different starch or gum types.

Class	Levels	Values
Formulations	11	control, 1% dextrin, 3% dextrin, 5% dextrin, 1% starch, 3% starch, 5% starch HPMC, xanthan gum, guar gum, guar-xanthan gum combination
Frying time (min)	3	2, 3, 4

Number of observations in data set = 33

Source	DF	Sum of Squares	Mean Square	F Value	$P_r > F$
Model	10	4550.64123	455.064123	107.78	0.0001
Error	22	80.22010	3.64636		
Total	32	4630.86133			

Source	DF	Type III SS	Mean Square	F Value	$P_r > F$
Formulations	10	4550.64123	455.064123	107.78	0.0001

Duncan Grouping	**Mean**	**N**	**Formulations**
A	83.710	3	guar-xanthan gum combination
B	75.650	3	5% starch
B	74.645	2	guar gum
B	73.300	3	xanthan gum
B	72.660	3	HPMC
C	64.120	2	3% starch
D	51.940	3	5% dextrin
D	51.840	3	3% dextrin
D	51.505	2	1% starch
D	50.920	3	1% dextrin
D	50.290	3	control

B.22. ANOVA and Duncan's Multiple Range Test Table for moisture content of fried samples with different starch or gum types.

Class	Levels	Values
Formulations	11	control, 1% dextrin, 3% dextrin, 5% dextrin, 1% starch, 3% starch, 5% starch HPMC, xanthan gum, guar gum, guar-xanthan gum combination
Frying time (min)	3	2, 3, 4

Number of observations in data set = 33

Source	DF	Sum of Squares	Mean Square	F Value	$P_r > F$
Model	10	450.14330	45.0143	22.68	0.0001
Error	22	43.66520	1.98478		
Total	32	493.80850			

Source	DF	Type III SS	Mean Square	F Value	$P_r > F$
Formulations	10	450.14330	45.014330	22.68	0.0001

Duncan Grouping	**Mean**	**N**	**Formulations**
A	57.900	3	guar-xanthan gum combination
AB	56.370	3	guar gum
BC	54.955	3	5% starch
BCD	54.190	3	HPMC
BCD	53.840	3	3% starch
CD	53.135	3	xanthan gum
D	52.310	3	1% dextrin
D	52.060	3	1% starch
E	48.680	3	3% dextrin
F	46.250	3	control
F	46.080	3	5% dextrin

B.23. ANOVA and Duncan's Multiple Range Test Table for oil content of fried samples with different starch or gum types.

Class	Levels	Values
Formulations	11	control, 1% dextrin, 3% dextrin, 5% dextrin, 1% starch, 3% starch, 5% starch HPMC, xanthan gum, guar gum, guar-xanthan gum combination
Frying time (min)	3	2, 3, 4

Number of observations in data set = 33

Source	DF	Sum of Squares	Mean Square	F Value	$P_r > F$
Model	10	157.42253	15.742253	17.27	0.0001
Error	22	11.85140	0.5387		
Total	32	169.27393			

Source	DF	Type III SS	Mean Square	F Value	$P_r > F$
Formulations	10	157.42253	15.742253	17.27	0.0001

Duncan Grouping	**Mean**	**N**	**Formulations**
A	15.2500	4	control
A	14.8500	2	5% dextrin
AB	14.2000	2	3% dextrin
BC	12.3800	2	xanthan gum
BC	12.3300	2	1% dextrin
C	11.8100	2	HPMC
C	11.6600	2	1% starch
DC	11.4400	2	3% starch
DC	10.4400	2	5% starch
D	9.4900	2	guar gum
E	6.0600	2	guar-xanthan gum combination

B.24. ANOVA and Duncan's Multiple Range Test Table for fracturability of fried samples with different starch or gum types.

Class	Levels	Values
Formulations	11	control, 1% dextrin, 3% dextrin, 5% dextrin, 1% starch, 3% starch, 5% starch HPMC, xanthan gum, guar gum, guar-xanthan gum combination
Frying time (min)	3	2, 3, 4

Number of observations in data set = 33

Source	DF	Sum of Squares	Mean Square	F Value	$P_r > F$
Model	10	0.00000055	0.000000055	3.55	0.0063
Error	22	0.00000034	0.000000015		
Total	32	0.00000090			

Source	DF	Type III SS	Mean Square	F Value	$P_r > F$
Formulations	10	0.00000055	0.000000055	3.55	0.0063

Duncan Grouping	**Mean**	**N**	**Formulations**
A	0.0055900	3	guar gum
AB	0.0055290	3	xanthan gum
ABC	0.0054750	3	HPMC
ABCD	0.0054200	3	guar-xanthan gum combination
ABCD	0.0054140	3	5% starch
BCDE	0.0053380	3	5% dextrin
BCDE	0.0053270	3	3% starch
BCDE	0.0052970	3	1% starch
CDE	0.0052510	3	3% dextrin
DE	0.0051990	3	1% dextrin
E	0.0051590	3	control

B.25. ANOVA and Duncan's Multiple Range Test Table for bulk density of fried samples with different starch or gum types.

Class	Levels	Values
Formulations	11	control, 1% dextrin, 3% dextrin, 5% dextrin, 1% starch, 3% starch, 5% starch HPMC, xanthan gum, guar gum, guar-xanthan gum combination
Frying time (min)	3	2, 3, 4

Number of observations in data set = 33

Source	DF	Sum of Squares	Mean Square	F Value	$P_r > F$
Model	10	0.19811	0.019811	20.78	0.0001
Error	22	0.02097	0.000953		
Total	32	0.21909			

Source	DF	Type III SS	Mean Square	F Value	$P_r > F$
Formulations	10	0.19811	0.019811	20.78	0.0001

Duncan Grouping	**Mean**	**N**	**Formulations**
A	1.09000	3	control
A	1.07000	3	1% dextrin
A	1.06200	3	3% dextrin
A	1.03400	3	5% dextrin
B	0.97700	3	1% starch
BC	0.96700	3	3% starch
BC	0.94600	3	5% starch
BC	0.93200	3	guar gum
CD	0.91800	3	HPMC
DE	0.87200	3	xanthan gum
E	0.84800	3	guar-xanthan gum combination

B.26. ANOVA and Duncan’s Multiple Range Test Table for Hunter L value of fried samples with different starch or gum types.

Class	Levels	Values
Formulations	11	control, 1% dextrin, 3% dextrin, 5% dextrin, 1% starch, 3% starch, 5% starch HPMC, xanthan gum, guar gum, guar-xanthan gum combination
Frying time (min)	3	2, 3, 4

Number of observations in data set = 33

Source	DF	Sum of Squares	Mean Square	F Value	$P_r > F$
Model	10	814.81985	81.48198	16.93	0.0001
Error	22	158.82800	7.21945		
Total	32	973.64785			

Source	DF	Type III SS	Mean Square	F Value	$P_r > F$
Formulations	10	814.81985	81.481985	16.93	0.0001

Duncan Grouping	**Mean**	**N**	**Formulations**
A	63.010	4	guar-xanthan gum combination
B	59.760	4	xanthan gum
B	58.480	4	guar gum
B	57.620	4	HPMC
B	57.140	4	5% starch
B	56.400	4	3% starch
C	52.600	4	1% starch
CD	52.250	4	control
CD	51.200	4	1% dextrin
CD	49.820	4	3% dextrin
D	48.900	4	5% dextrin

B.27. ANOVA and Duncan's Multiple Range Test Table for Hunter a value of fried samples with different starch or gum types.

Class	Levels	Values
Formulations	11	control, 1% dextrin, 3% dextrin, 5% dextrin, 1% starch, 3% starch, 5% starch HPMC, xanthan gum, guar gum, guar-xanthan gum combination
Frying time (min)	3	2, 3, 4

Number of observations in data set = 33

Source	DF	Sum of Squares	Mean Square	F Value	$P_r > F$
Model	10	506.42581	50.64258	36.09	0.0001
Error	22	46.31120	2.10505		
Total	32	552.73701			

Source	DF	Type III SS	Mean Square	F Value	$P_r > F$
Formulations	10	506.42581	50.64258	36.09	0.0001

Duncan Grouping	**Mean**	**N**	**Formulations**
A	15.0800	4	5% dextrin
A	14.9000	4	3% dextrin
B	12.6400	4	1% dextrin
C	9.9200	4	control
CD	8.4400	4	1% starch
DE	7.8400	4	3% starch
DEF	7.1400	4	5% starch
EF	6.5500	4	HPMC
EF	6.4000	4	guar gum
F	5.7800	4	xanthan gum
F	5.4500	4	guar-xanthan gum combination

APPENDIX C

WATER BINDING CAPACITY

Table C.1 Water binding capacities (WBC) of different starches and gums (Altunakar, 2003).

	WBC (w/w)
Corn and wheat	1.04
Pre-gelatinized tapioca starch	4.80
HPMC	12.10
Xanthan gum	11.49
Guar gum	14.36

APPENDIX D

FIGURES OF DEEP-FAT FRIED CARROT SLICES

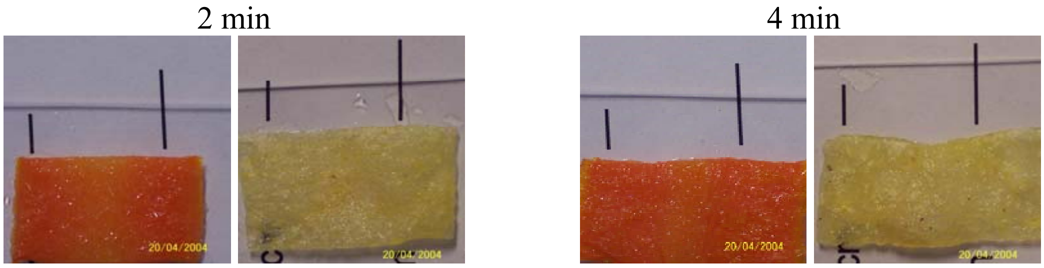


Figure D.1 Carrot and control batter fried for 2 & 4 minutes.

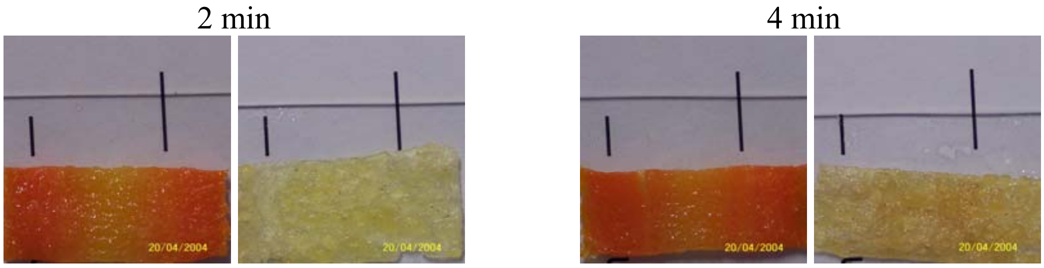


Figure D.2 Carrot and 1% dextrin added batter fried for 2 & 4 minutes.

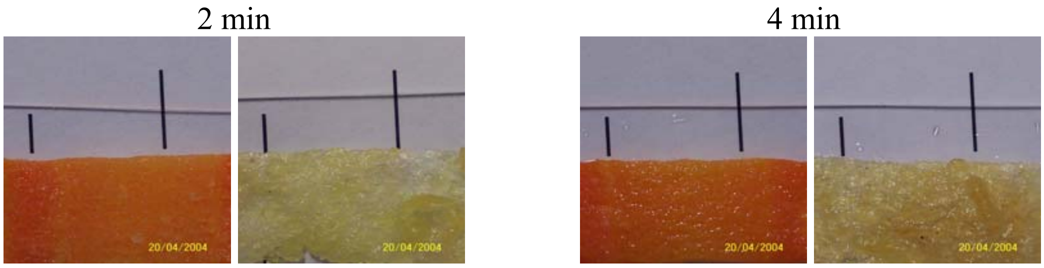
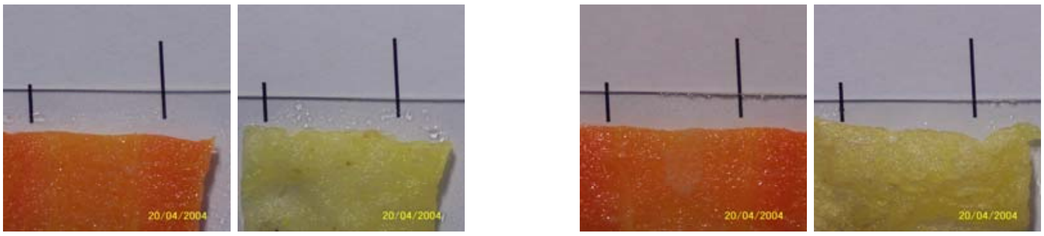


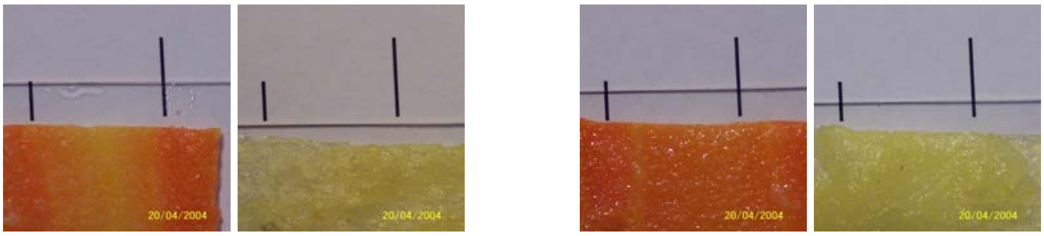
Figure D.3 Carrot and 5% dextrin added batter fried for 2 & 4 minutes.



2 min

4 min

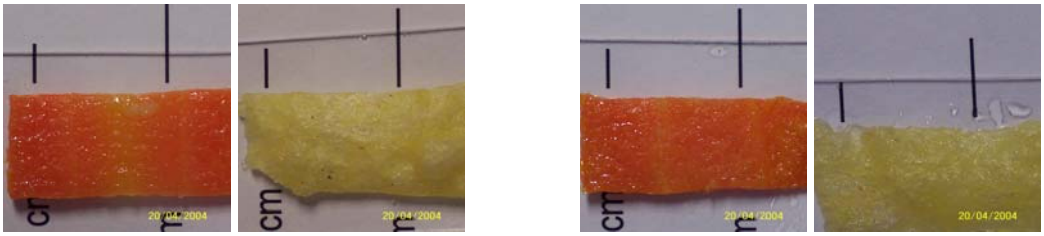
Figure D.4 Carrot and 1% pre-gelatinized tapioca starch added batter fried for 2 & 4 minutes.



2 min

4 min

Figure D.5 Carrot and 5% pre-gelatinized tapioca starch added batter fried for 2 & 4 minutes.



2 min

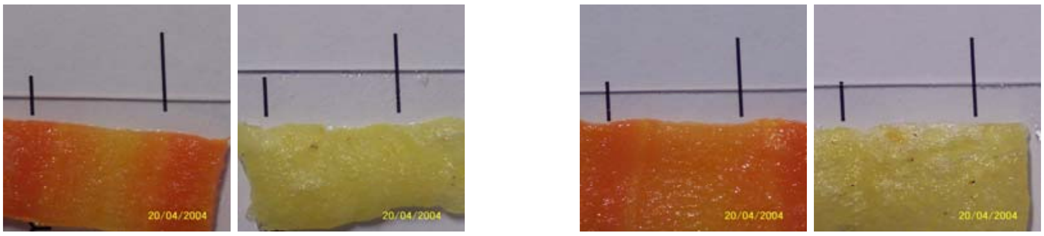
4 min

Figure D.6 Carrot and xanthan gum added batter fried for 2 & 4 minutes.


2 min

4 min

Figure D.7 Carrot and HPMC added batter fried for 2 & 4 minutes.


2 min

4 min

Figure D.8 Carrot and guar-xanthan gum combination added batter fried for 2 & 4 minutes.

APPENDIX E

SURFACE PLOTS OF IMAGE PROCESSING

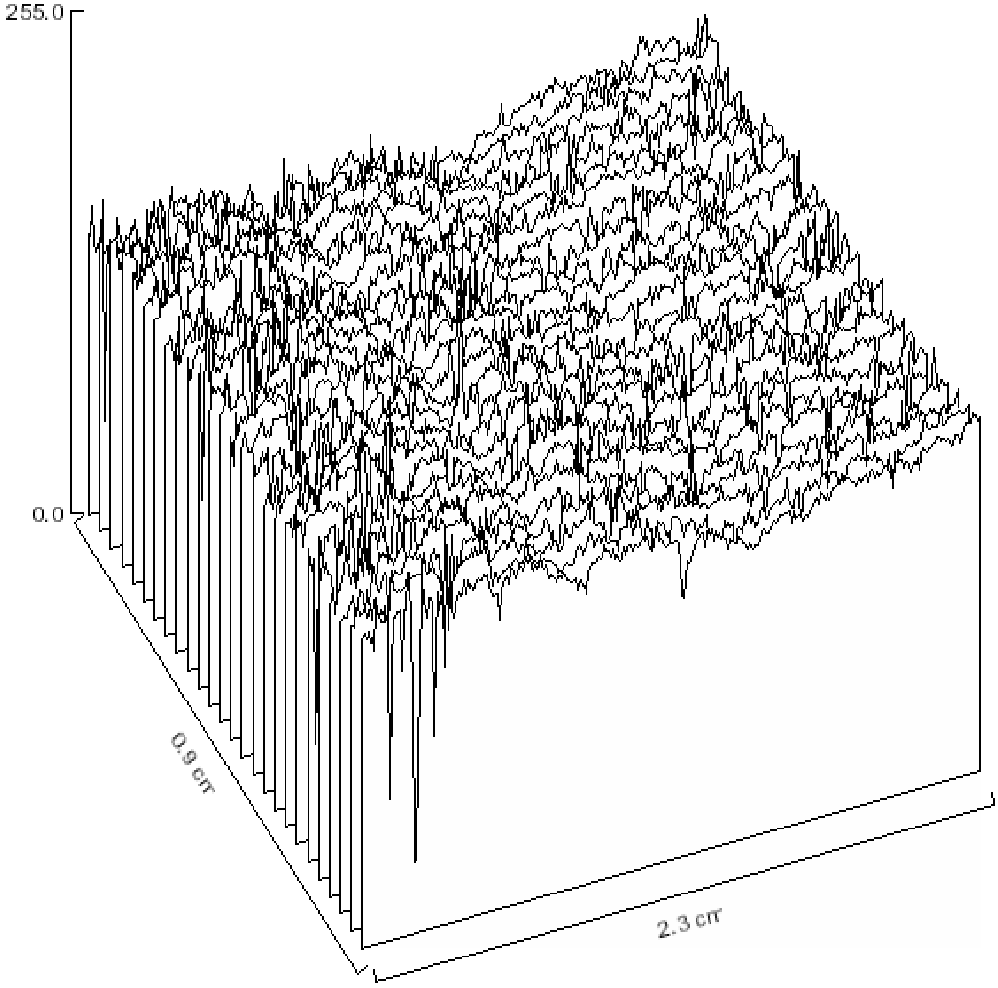


Figure E 1: Surface plot of control coated carrot

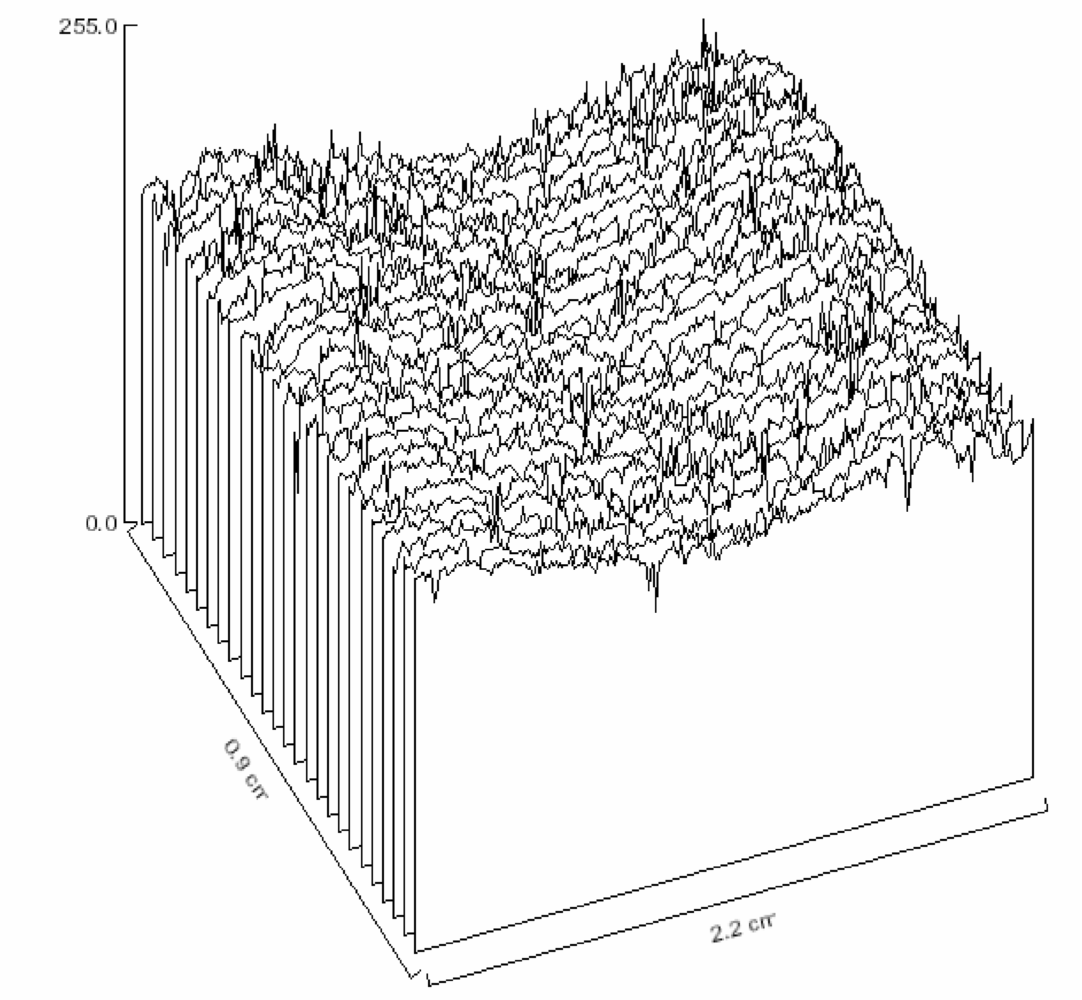


Figure E 2: Surface plot of guar-xanthan gum combination added batter coated carrot.