PONTIFICIA UNIVERSIDAD CATOLICA DE CHILE

ESCUELA DE INGENIERIA

ANALYSIS OF WHEAT GLUTEN AND STARCH MATRIXES DURING DEEP-FAT FRYING

ANA MARIA GAZMURI BARKER

Thesis submitted to the Office of Research and Graduate Studies in partial fulfillment of the requirements for the Degree of Master of Science in Engineering

Advisor:
PEDRO ALEJANDRO BOUCHON AGUIRRE

Santiago de Chile, July, 2008

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To my parents

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GENERAL INDEX

TABLE INDEX

Pág.

FIGURE INDEX

RESUMEN

Los productos formulados están adquiriendo importancia en la industria de los snacks como alternativa al uso de ingredientes tradicionales por las ventajas que tiene la reproducibilidad y ausencia de defectos, lo que los hace especialmente adecuados para satisfacer las exigencias de los consumidores. En productos fritos, pueden representar una opción para la producción de snacks con bajo contenido de aceite y alta calidad.

Se ha planteado que la absorción de aceite durante la fritura es un fenómeno superficial, que resulta del equilibrio entre adhesión y drenaje de aceite cuando se remueve el alimento del aceite. Como consecuencia, la estructura superficial y la permeabilidad de las capas externas son parámetros importantes a controlar para disminuir la absorción de aceite.

El objetivo de este trabajo es estudiar el efecto del contenido de gluten en los principales atributos de calidad en masas de alto y bajo contenido de humedad durante la fritura. Se enfocó el trabajo principalmente en la absorción de aceite, pero también se estudiaron otros atributos de calidad como color y expansión. Se analizaron cuatro formulaciones diferentes usando dos contenidos de gluten (8 y 12% b.s.) y dos contenidos de agua (38 and 44% b.h.). Cada uno de ellos fue laminado en dos grosores (1 y 2 mm) y luego cortados en discos, los cuales fueron freídos inmediatamente o luego de 2 min de secado con aire seco.

El gluten tuvo un rol predominante en el desarrollo de una estructura elástica y poco permeable a la absorción de aceite. Un alto contenido de gluten en productos de baja humedad, resultó en una menor absorción de aceite. En los productos presecados, aun cuando un alto contenido de gluten implicaba un mayor contenido de humedad al momento de freir, también tuvo como resultado una menor cantidad de aceite, demostrando la capacidad del gluten para disminuir la permeabilidad de la superficie, siendo este el atributo más relevante que influencia la absorción de aceite. El secado mostró ser un tratamiento efectivo para disminuir el contenido de aceite a través de cambios estructurales en la superficie del producto, reduciendo su permeabilidad. El gluten también mostró un rol importante en la expansión del producto debido a la formación de una estructura elástica que retiene el vapor generado durante la fritura, generando un producto expandido.

Keywords: Fritura por inmersión, productos formulados, gluten, almidón.

ABSTRACT

Formulated products are getting importance in the snack industry as a good alternative to the use of traditional raw materials because of the advantages of reproducibility, uniformity and lack of defects, which make them suitable to fit consumer demands. In fried products, these may be an option for the production of taylor-made snacks with low oil content and improved quality.

It has been suggested that oil absorption during frying is primarily a surface phenomenon, resulting from the equilibrium between adhesion and drainage of oil upon removal of the piece from the oil, during the cooling period. As a consequence, surface structure and permeability are important parameters to control in order to minimize the oil uptake.

The main objective of this work was to study the effect of gluten content on a low and a high moisture-content dough on most important quality attributes during deep-fat frying. Focus was particularly centered in oil absorption kinetics, but quality attributes such as color development and expansion of the food matrix were also studied. Four different products formulations were analyzed using 2 levels of gluten content (8 and 12% d.b.) and 2 levels of water content (38 and 44% w.b.). Each of them was sheeted into 2 thicknesses (1 and 2 mm) and cut into discs that were either directly fried or fried after a predrying step for 2 min with dry air.

Gluten had a predominant role in the structure making the dough more elastic and less permeable to oil absorption. High gluten content resulted in lower oil uptake in products with low moisture content. In dried products, even though products with high gluten content had a higher moisture content before frying, they absorbed a lower amount of oil, showing that gluten’s film forming capability and its ability to decrease surface permeability are the most relevant attributes influencing the oil uptake. Drying was an effective pretreatment diminishing oil content of fried products through structural changes at the product surface reducing its permeability. Gluten also had an important role in developing expanded products because of the elastic structure formed that traps the vapor that is escaping during frying, producing an expanded product.

Keywords: Deep-fat frying, formulated products, gluten, starch.

1. INTRODUCTION

Creation of food microstructures that respond to new consumers demands is the target of many food product developers. In fact, the processing of foods is facing new challenges to provide in addition to safe and high quality foods, products that contribute to the health and well-being of consumers. This product-driven process engineering approach aims to contribute to the understanding of how food microstructure formation can be controlled during processing. What is central to the food industry is the transformation of ingredients into microstructural elements in processed foods that contribute to texture and quality. This new approach aims to develop foods with particular attributes to contribute to consumer wellness and health, as well as satisfying their needs in relation to specific textures, flavors, colors, among other quality attributes (Aguilera, 2006). The development of new products requires specific knowledge about ingredients functionality, assemblage, effects of processing conditions and microstructural aspects to design the right structures (Bouchon, 2007).

Frying is a unit operation that is especially suited for this purpose because of the unique flavors and textures that are developed during the frying process. Fried products are very important to the food industry because of their popularity among consumers and the huge quantities of fried food and oils that are used at industrial and commercial levels (Bouchon, 2002). A wide variety of food materials can be used to produce fried products, including meats, dairy, grains and vegetables. Formulated products are getting importance in the snack industry as a good alternative to the use of traditional raw materials, because of the advantages of reproducibility, uniformity and lack of defects, which make them very suitable to fit consumer demands. In fried products, these may allow designing controlled structures, minimizing the heterogeneity between products. Products based on wheat flour dough are highly used in frying operations to produce products like doughnuts, battered products and fritters among others, but they may also be sheeted and cut into small pieces to be fried. Formulated sheeted products based on wheat flour could make possible the investigation of the effect of different product formulations and the role of different additives on the oil absorption mechanisms. However, there is little research on this topic.

Most of the articles are based on battered or breaded products, but not on sheeted dough products (Hernando et al., 2007; Fiszman et al., 2005; Mohamedet al., 1998).

One of the most important quality parameters of fried food is the amount of fat absorbed during the process, reaching in some cases 1/3 of the total food product weight (Bouchon and Pyle, 2004; Mellema, 2003). Fat has a strong influence on the palatability of fried foods. The exchange of water for cooking fat and the crusty surface developed during the frying process impart a ‘crunchy’ quality that is highly appreciated by consumers (Ruiz-Roso and Varela, 2001).

On the other hand, the linkage between over consumption of fat and several diseases has been well documented. The high amount of fried products consumption is considered to be one of the key dietary contributors to diseases like obesity, coronary heart diseases and some types of cancer. It is estimated that diet-related diseases cost society over US$250 billion annually in medical expenses and loss of productivity (Anand and Basiotis, 1998). In accordance, it would be desirable to design a low-fat food product with just enough fat to impart the desired quality attributes of deep-fried food (Bouchon, 2007).

An understanding of the complex processes that occur during frying is necessary to control the quality of the final fried product and certainly the knowledge of the mechanisms involved in the frying process is key for this objective. In this context it becomes of interest, to study the effect of product composition and microstructure on a formulated product during frying based on key structural elements such as wheat starch and gluten. Some of the advantages of working with formulated products are the homogeneity that is possible to obtain in the flour and the ease to study the effect of different product formulations.

1.1 Deep-Fat frying

Deep-fat frying can be defined as a process for cooking foods, by immersing them in an edible oil, at a temperature above the boiling point of water (Farkas, 1994). It is one of the oldest and most common unit operations used in the preparation of food. Today, numerous processed foods are prepared by deep-fat frying all over the world, since in addition to cooking frying provides unique flavours and textures (Dobraszczyk et al., 2006).

Deep-fat or immersion frying involves significant microstructural changes both to the surface and the body of the product, and simultaneous heat and mass transfer, resulting in flows in opposite directions of water vapor (bubbles) and oil (Bouchon et al., 2003). The high temperatures of the frying oil lead to the evaporation of water at the surface of the food. Due to evaporation, water in the external layers of the product moves out of the food to the surrounding oil and surface drying occur inducing crust formation. Additionally, oil is absorbed by the food, replacing part of the water lost (Mellema, 2003).

Most of the desirable characteristics of frying foods are derived from the formation of a composite structure: a dry, porous, crispy and oily external layer or crust and a moist cooked interior or core (Bouchon, 2002). This is the result of several alterations that mainly include: starch gelatinization, water vaporization and consequent dehydration of the tissue, protein denaturation, color development and finally oil uptake. Thick products will present this composite structure, whereas a thin product will be completely dehydrated, so it will be just crust.

A schematic presentation of a food product during deep-fat frying is shown in figure 1.1, where the composite structure and some of the changes occurring during the process are shown.

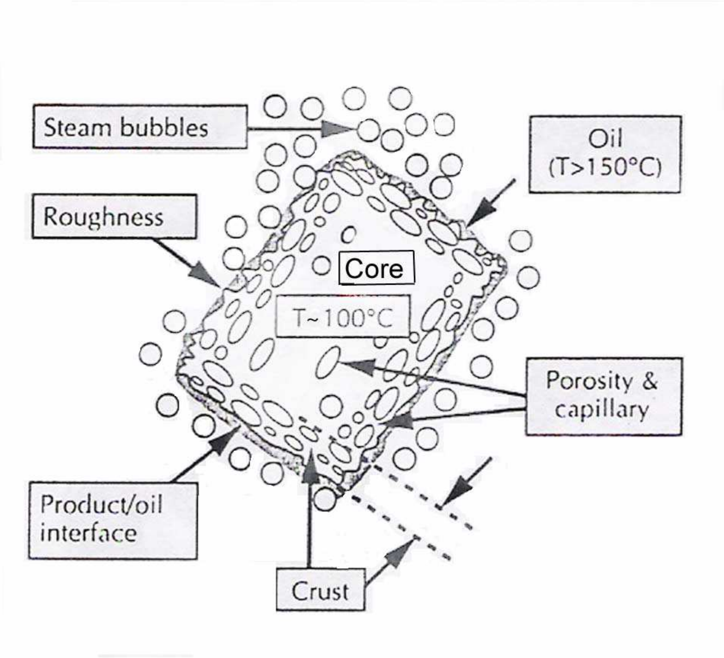


Figure 1.1: Schematic diagram of a food product during deep fat frying (Saguy et al., 1998).

1.1.1 Oil uptake during deep-fat frying

During deep-fat frying heat and mass transfer occur simultaneously. Convective heat is transferred from the frying media to the surface of the product and, thereafter, conductive heat transfer occurs inside the food. Mass transfer is characterized by the loss of water from the food as water vapor and the movement of oil into the food (Singh, 1995; Dobraszczyk et al., 2006).

The temperatures inside a food material, in the core region, where there is still water remaining inside the structure, are restricted to values below the boiling point of the liquid inside the food, which is slightly higher than the boiling point of water. As the frying process proceeds, more water evaporates and consequently, the temperature of the dried regions begins to rise above the boiling point of water, approaching to the oil temperature (Farkas, 1994).

Mass transfer during frying is characterized by the movement of water in the form of vapor from the food into the oil and the movement of oil into the food (Singh, 1995). There is a quantitatively smaller mass-transfer phenomenon from the food into the oil: the small movement of water-soluble food materials as water escape during frying (Blumenthal, 1991).

Frying is a dehydration process and the water escape would leave empty spaces inside the crust structure. In fact, the amount of water removed during the process determines the extent of crust formation and consequently the volume available for oil absorption. The amount of oil uptake has been shown to be directly proportional to the amount of moisture lost. Therefore, the crust microstructure development has a marked effect in oil absorption. There is abundant proof that the microstructure of the crust is the main determining factor in oil uptake (Bouchon et al., 2001; Pinthus et al., 1995).

Most of the oil is limited to the surface region of the fried product. The oil absorption is essentially a surface related phenomena resulting from the competition between drainage and suction into the crust once the food is removed from the oil bath. The final oil intake would depend on the oil layer deposited on the surface of the product after the immersion (Bouchon et al., 2001). The reduction of internal pressure due to water loss and by subsequent cooling creates a vacuum effect which increases the oil uptake (Saguy et al., 1998).

1.1.2 Factors affecting oil uptake

According to the oil absorption mechanisms explained in the previous section, some factors that may be relevant in the amount of oil absorbed have been identified.

a) Moisture content

The amount of oil uptake has been shown to be directly proportional to the amount of moisture lost. Several studies claim that higher initial moisture content results in an increased oil uptake, but the oil absorption seems to be more related to the amount of water lost than to the initial moisture content (Gamble et al., 1987).

As explained in the previous section, it is well established that oil absorption occurs as moisture is removed from the food. The effective water-vapor transport through the crust is, therefore, an important parameter that affects water escape and probably oil uptake. Diffusion rate is markedly affected by the mechanical properties of the product and the crust (Saguy et al., 1998).

b) Microstructure development

The development of microstructure during frying is one of the predominant factors affecting oil absorption and it is closely related to the moisture content. Pore development was found to influence the final oil uptake during frying (Thanatuksorn et al., 2007). As the moisture turns to steam and exits the product, it leaves behind a sponge-like tunnel network. The structure of this network is expected to determine the permeability of the product to oil entrance (Saguy et al., 1998).

In formulated products, the permeability of the outer layer of the product depends on the thickness of the sheeted dough since it determines the structural resistance to vapor escape. A stronger and more elastic network can result in a less permeable outer layer that may act as an effective barrier against oil absorption (Bouchon and Pyle, 2004).

Some natural ingredients are added to reduce oil uptake because of their film forming capability or because they reduce the porosity of the outer layer. Pore size distribution, which develops during frying, was considered as the main cause for oil absorption (Saguy et al., 1998).

c) Product Geometry

The surface area of the fried food plays an important part in oil uptake. As explained previously, the oil absorption is a surface phenomenon involving equilibrium between adhesion and oil drainage as the product is removed from the fryer. Therefore, products with a greater surface area to volume ratio, will absorb more oil (Gillat, 2001).

A linear relationship was found between the surface area and the amount of oil uptake. Surface roughness is another factor that could result in a higher oil uptake, because it increases overall surface area and also it difficults the oil drainage when removing the product from the oil bath (Saguy et al., 1998).

d) Frying oil temperature and frying time

These two process parameters are closely related since products must be fried until reaching a certain final moisture content, so a lower oil temperature implies a longer frying time.

Bouchon et al. (2003) showed that total oil absorption is a temperature-independent process for short frying times (for 1 minute at 155, 170 and 185°C), frying potato cylinders. However, for longer frying times a significant difference was found between 155°C and the other 2 temperatures. The total oil absorbed was significantly lower for the samples fried at 155°C. On the other hand, there was no difference between the 2 higher temperatures (170°C and 185°C).

Krokida et al. (2000) when frying potato strips for 10 different frying times going from 0.3 min to 20 min also concluded that a lower oil temperature result in a lower oil content for long frying times (over 3 min), the difference being higher as frying proceeded. They also found that equilibrium moisture content varied as the oil temperature increased from 150°C to 190°C. In accordance, they concluded that the lower oil content could be explained by the lower moisture loss and not necessarily as an effect of the oil temperature itself. They also determined that oil content increased for increasing frying times, especially for the thinner products.

The effect of the frying time in the amount of oil absorbed may be related to the microstructure developed during frying, as previously explained. Pinthus et al. (1995) concluded that crust porosity increased linearly with frying time and, as the crust structure has been demonstrated to play a significant role in the oil uptake, a thicker porous crust would lead to a higher oil content.

Some conclusions about the effect of the oil temperature in oil uptake may be biased by the way results are expressed. Some researchers have reported oil absorption results as a percentage of the total weight of the product (that is, wet basis) (Gamble et al., 1987; Moreira et al., 1997). Conclusions must be analyzed with care in these situations since when frying at a higher temperature for the same frying time a higher dehydration results, so when results are expressed on wet basis (w.b.) there is a systematic reduction in the basis as the water content diminishes. When oil uptake results are measured as a percentage on a dry-weight basis (d.b.) and the solids remain constant throughout the whole process, it may provide a consistent basis for comparison (Bouchon et al., 2003).

e) Oil deterioration and surfactant content

Food materials leaching into the oil, breakdown of the oil itself and oxygen absorption at the oil-air interface, contribute to change the pure triglyceride oil into a mixture of hundreds of compounds. These materials will affect the heat transfer and reduce the surface tension between the food and the oil (Blumenthal, 1991). These surface active agents have a pronounced effect on fat absorption. By improving the wetting capabilities of oil and reducing the surface tension, these surfactants may lead to a higher oil uptake (Saguy et al., 1998).

Also, oil viscosity increases as a result of dimer and polymer formation in aging oils (Blumenthal, 1991). A higher viscosity would difficult the oil drainage in the product surface, increasing the oil taken up.

f) Pre-frying treatments and edible coatings

Some pre-frying treatments have been shown to be effective in reducing oil uptake. Lowering the moisture content of the food before frying using hot air treatment, microwaves and baking, has resulted in a significant reduction in oil content, whereas other pretreatments such as freeze-drying and osmotic drying increase the oil absorption (Lamberg et al. 1990, Krokida et al., 2001; Bouchon and Pyle, 2004; Moreno and Bouchon, 2008).

The high reduction potential of these pretreatments is not due to a reduction of the moisture content on its own but due to the structural changes occurring at the surface of the piece, which reduce surface permeability. The difference in the effectiveness of the different methods is explained by the crust microstructure developed in each case. For example, Moreno and Bouchon (2008) studied different drying pretreatments when frying potato cilinders: air-dried, freeze dried and osmotic drying. Air-dried samples tended to shrink and case-harden which resulted in a significantly lower oil uptake, whereas in freeze-dried samples, the formation of a dry and fragile outer porous region increased oil absorption. In osmotically dehydrated cylinders, the solids absorbed during the drying process helped to maintain the structure minimizing shrinkage and therefore maintaining the space available for oil penetration.

Reducing surface permeability can also be achieved through edible film coating or direct blend modification in formulated products, using hydrocolloids such as methylcellulose, hydroxypropyl methylcellulose, long fiber cellulose, corn zein, starch, and modified starch, among others (Moreno and Bouchon, 2008). Properties of coatings in relation to oil uptake are low moisture permeability, thermogelling or crosslinking, aimed to reduce moisture loss and/or modification of the surface structure formed upon frying (Mellema, 2003).

1.1.3 Product formulation as a way to develop taylor-made snacks

The need to develop new products with controlled attributes makes product formulation a good alternative for product design. The requirement of specific knowledge about ingredients functionality and the effects of processing conditions makes interesting the use of formulated products to minimize variations and heterogeneity between products.

Many formulated products are based on wheat flour among other components. Wheat popularity is largely determined by the ability of wheat flour to be processed into different foods which is mainly given by the unique properties of wheat flour gluten proteins (Anjum et al., 2007).

Formulated products make possible the study of the effects that different formulations have in the multiple structural changes occurring during frying and consequently help understanding their effect in the final product structure and its role in the absorption mechanisms. Changes occurring during frying are caused mainly by the heat transferred from the oil into the food. Protein denaturation, starch gelatinization, water vaporization, crust formation and color development are typical phenomena of the combined effect of multiple-order chemical reactions (Sahin, 2000; Singh, 1995). Several reactions between various food constituents at elevated temperature take place, including both physical (i.e. phase and volume changes) and chemical (i.e. chemical bonds destruction and formation) changes.

Generally, research about wheat flour fried products is based on battered products, and the focus is centered on the structures formed by gluten and the impact of the batter on the quality parameters of the product. There are also some studies about the effect that different additives have in oil absorption and other quality parameters like crispness and color development (Mohamed et al., 1998; Fiszman et al. 2005).

The effect of protein content in formulated products has been widely studied. Olewnik and Kulp (1993) showed that the addition of proteins speeds up browning of the batter during frying due to the increase in amino clusters involved in non-enzymatic browning reactions. High protein content in flour has been associated with batter-fried food with greater crispness and darker color. The use of proteins is also associated with increasing water-retention capacity, resulting in a lower density and, consequently, a more porous and crunchier final batter texture.

Another research subject in fried products is the use of food hydrocolloids with thermal gelling or thickening properties in batters and other fried products as a mechanism to decrease oil uptake, both as an edible coating or as a constituent ingredient (Funami et al., 1999; Garcia et al. 2002; Mittal and Albert, 2002).

In this context, it becomes interesting to study a formulated product based on a reconstituted blend of wheat gluten and wheat starch instead of commercial wheat flour. In this way, it could be possible to investigate the effect of the different components on the structural changes that occur during frying.

a) Dough formation

Wheat flour, with the addition of water and input of mixing energy, can form a cohesive and viscoelastic dough that posses the ability to trap and retain gases during fermentation. Mature wheat grains are mainly composed by starch (about 60%) and contain between 8 and 20% proteins, from which up to 85% are constitute by gluten proteins. They are the responsible for these unique properties of elasticity and extensibility, essential for the functionality of wheat flours (Shewry et al., 1995).

The main components of wheat flour dough are flour (mainly gluten and starch) and water. To obtain the most suitable dough the appropriate amount of water must be present. There is always competition among flour components for water, which makes water content a critical factor. Water has several important functions in the dough. It is a solvent for some components (e.g. salt, sugar, and some proteins), a medium for enzymatic and redox reactions, and it determines the conformation of the components based on hydrophobic interactions. Water also acts as a “mobility enhancer.” Its low molecular weight greatly increases mobility. As the moisture content is increased from dry solute to a solution, it results in an increased free volume and a decreased viscosity (Mani et al., 1992).

Also, water is one of the most important constituents determining the texture of fried foods. In the process of water vaporization during frying, the molecular volume of water increases rapidly as a result of the phase change from liquid to gas. This increase often leads to volume expansion of the fried object if the vapor does not have a clear passage to the food/oil interface. During this process, volume expansion of water also contributes to the porous structure of the crust, while the rate of dehydration determines the pore size. The volume expansion of the product also depends on the relative ease of migration of water through the surface matrix, which depends on the strength of the structure (Chen et al., 2001).

The moisture content and processing temperature of wheat-flour dough systems determine whether gluten or starch plays a predominant role in the product structure. In high moisture systems, gluten is primarily involved in the formation of a continuous network. On the other hand, it is suspected that starch plays a predominant role in low-moisture content systems (Chanvrier et al., 2007).

b) Gluten as a building block

Wheat gluten is by far the most important cereal protein in terms of usage. It is widely used in baking for structural purposes, but its components find applications in many other foods (Kulp and Ponte, 1990).

Gluten is a protein complex derived from the storage proteins of the wheat grain. When mixed with water, what was merely storage protein forms a dough with unique rheological properties, capable of retaining gas bubbles. It may be defined as the cohesive, visco-elastic proteinaceous material prepared as a by-product of the isolation of starch from wheat flour. These unique properties are the ones that make wheat alone suitable for the preparation of a great diversity of food products like breads, noodles, pasta, cookies, cakes, pastries and many other foods (Day et al., 2006). A scanning electron micrograph of dough rising showing the gluten network can be observed in figure 1.2. Starch granules can be seen randomly amongst the gluten network.

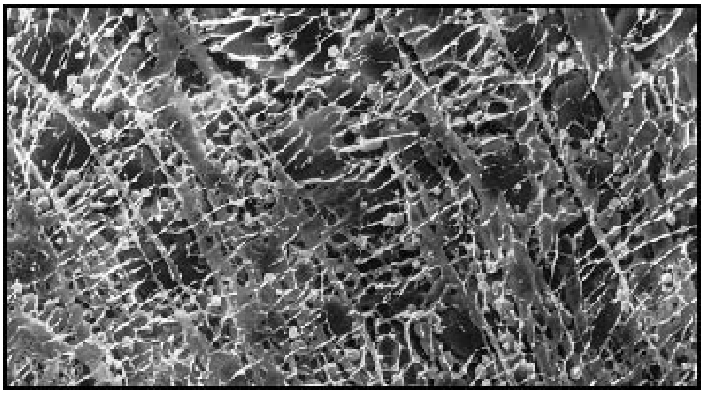


Figure 1.2: Scanning electron micrograph of dough rising, showing gluten network (Baking Industry, n.d.).

In its most familiar form, gluten is traded in the dried state as ‘Vital Wheat Gluten’. In this form, the functional properties of wheat gluten may be regenerated by rehydration. Vital Wheat Gluten’s unique viscoelastic properties improve dough strength, mixing tolerance, and handling properties. Its film-forming ability provides gas retention and controlled expansion for improved volume, uniformity and texture; its thermosetting properties contribute to structural rigidity and its water absorption capacity improves baked product yield, softness, and shelf-life (Day et al., 2006).

The two mayor protein components of gluten that contribute to viscoelasticity are glutenin and gliadin, which differ markedly in their chemical and physical properties. Glutenin proteins are multichained, with very high molecular weights. When isolated from wheat gluten, glutenin exhibits pronounced resiliency but little extensibility and therefore appears to provide the elastic properties of gluten. Gliadin from wheat consists of some 50 single-chained proteins of relatively low molecular weight. Upon isolation form wheat gluten, gliadins are notably extensible and quite sticky and therefore seem to provide the extensibility and cohesive properties of gluten (Kulp and Ponte, 1990). A schematic presentation of glutenin and gliadin structures is presented in figure 1.3.

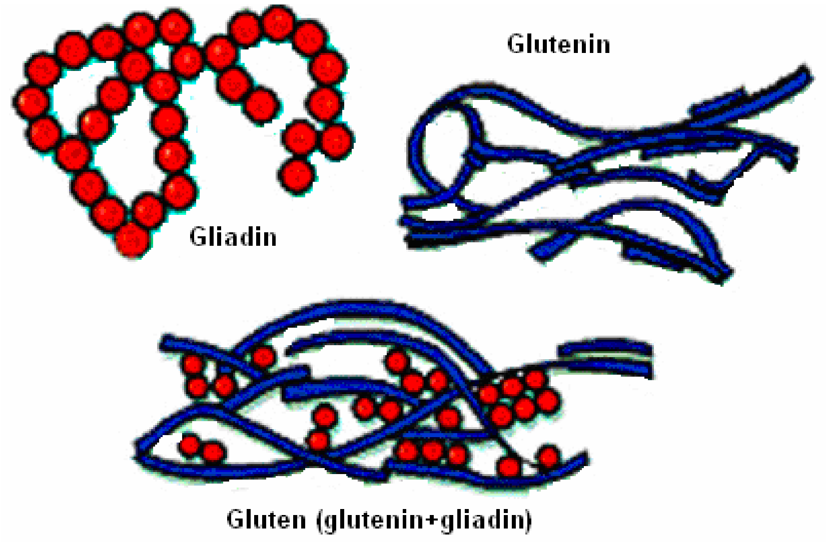


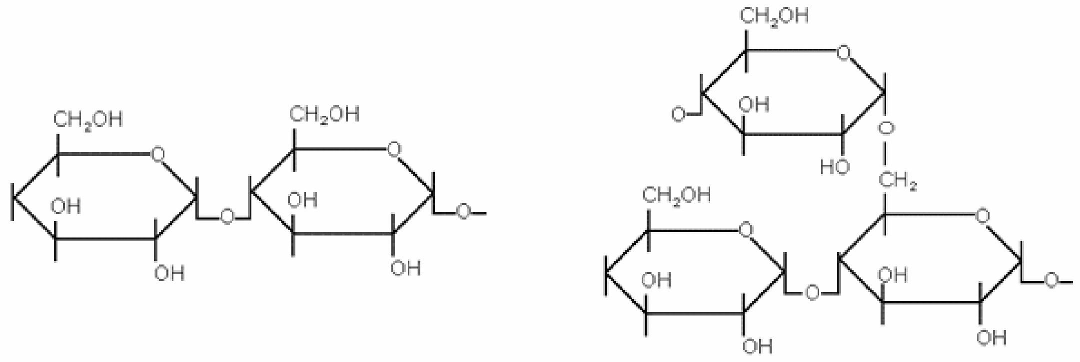
Figure 1.3: Schematic diagram of glutenin and gliadin proteins (Faculty of Land and Food Systems, University of British Columbia, n.d.).

All the individual proteins contribute in some way to the functional properties of whole gluten, but it appears that one group of proteins are of particular importance in determining elasticity, the high molecular weight (HMW) subunits of glutenin. These are minor components in terms of quantity, but they are key factors in determining gluten elasticity (Shewry et al., 1997).

As stated previously, high protein content is associated with darker color and higher water retention. Fizsman et al. (2005), when frying different additives in battered squid rings, showed that the addition of gluten presented relatively lower oil absorption and a significant moisture retention. Rovedo et al. (1998) studied the effects of adding gluten to a potato starch-water dough and concluded that higher gluten content caused an increase in oil uptake and a considerable higher volume. Gluten has also been suggested as an edible coating in fried products for its film forming capability and its barrier properties to oil and water vapor (Mittal and Albert, 2001).

c) Starch as a building block

Starch is the most available and widely distributed food component derived from cereals, representing more than 60% of the composition of cereals. It is an n-glucose polymer occurring as essentially linear (amylose) chains linked with alpha-1,4 bonds and as highly branched (amylopectin) chains with alpha-1,4 and alpha-1,6 bonds. One of the mayor industrial applications of starch in the food industry is to provide characteristic texture, consistency, and mouthfeel (Kulp and Ponte, 1990). The chemical structure and a schematic diagram of amylose and amylopectin are shown in figure 1.4. A micrograph of native starch granules is shown in figure 1.5.



Chemical structure of amylose molecule

Chemical structure of amylopectin molecule

Linear amylose molecule

Branched amylopectin molecule

Figure 1.4: Amylose and amylopectin structure (Baking Industry, n.d.).

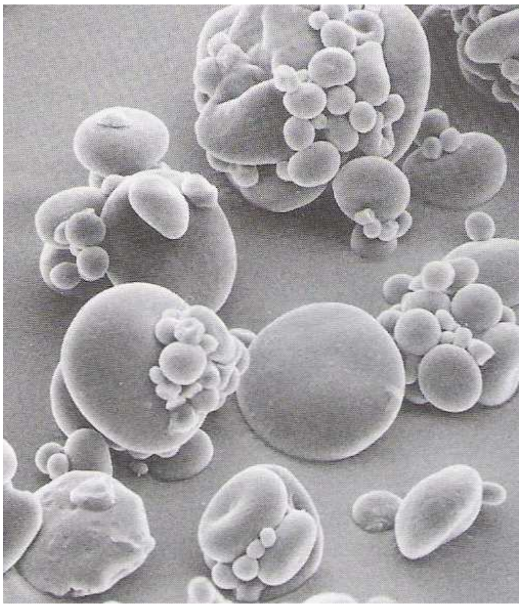


Figure 1.5: Scanning electron micrograph of native wheat starch granules (Aguilera and Stanley, 1999).

Gelatinization of the starch granule is a term used to describe a range of irreversible events occurring when starch is heated in water. When the gelatinization temperature is reached, the hydrogen-bonding forces are weakened so that water can be absorbed by the granules. The disordering of the crystalline domains in the granules is thus the first step. The absorption of water leads to the swelling of the granules which is often measured as an increase in the volume (Gudmundsson, 2006). 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). Starch gelatinization is crucial in frying: it holds water and provides volume expansion (Chen et al., 2001).

Starch is the major component of wheat flour dough and is responsible for the body of the crust in fried products. Starches from varying sources are commonly used in batter mixtures. The main starch sources are corn and wheat; cornstarch production is considerably higher. Native starch is frequently used in combination with flour in batter mixtures. The consistency of the flour can be adjusted through changes in the starch-flour proportions used in the mix. The introduction of various forms of modified starches like oxidation, substitution, dextrinization and pregelatinization, has given rise to a wide range of new applications in the preparation of batter-fried foods.

Bouchon and Pyle (2004) studied the addition of native potato starch and pregelatinized potato starch as complementary ingredients of restructured potato chips made from potato flakes. The effect of the starch content was different between thin and thick products. They concluded that oil uptake was higher when replacing 20% of potato flakes for pregelatinized starch. Pregelatinized starch produced a stronger network, making the dough more elastic which resulted in an expanded structure with rough surface, which traps the oil when removing from the frying bath. This effect was less markedly in thick products. When using native starch instead of pregelatinized starch, the oil content was much higher for the thin chips, but lower for the thick ones compared to the control. This may be explained based on the stronger solid structure in thick products which can withstand higher steam pressures without rupture. In addition, a flat, smooth surface was obtained in these products, which allowed oil to drain easily from the surface.

2. HYPOTHESIS

Formulated products are getting importance in the food industry because of their uniformity and lack of defects that allow designing controlled structures, minimizing the heterogeneity between products, improving product quality.

In fried products, the structure developed during frying, determines most of the product quality attributes. As explained before, the permeability of the food outer layer and the crust microstructure developed during frying is one of the main factors determining oil uptake, which is one of the most important quality parameters of fried food. So, the structure developed in each product will determine the crust permeability and consequently, the oil uptake.

In formulated products based on wheat flour, this structure will be given by the moisture content of the product and the proportion between gluten and starch in the dough. Knowledge about the different ingredients functionality and its role in the product structure and during the frying process, will enable to create the right structures and control the quality of the final product.

Based on the literature review, it can be hypothesized that gluten will have a predominant role in structure development making the dough more elastic and probably less permeable to oil absorption. Crust permeability should be also dependent on water content, since a higher content should lead to explosive vaporization, creating tissue disruption and therefore increasing the volume available for oil absorption. In addition, it could be expected that a predrying treatment should decrease oil uptake because it should reduce the external layers permeability.

3. OBJETIVES

The main objective of this work is to study the effect of gluten content on a low and a high moisture content dough on most important quality attributes during deep-fat frying, particularly focusing on oil uptake.

In particular, the specific aims of this thesis are:

- To define formulations based on maximum and minimum levels of gluten and water content which allow obtaining a sheetable dough.
- To study the effect of gluten content, water content, and product thickness on oil uptake, and associated quality attributes such as color development and product expansion occurring during deep-fat frying.
- To study the effect of a drying pretreatment on the different quality attributes of a deep-fat fried formulated product.

4. MATERIALS AND METHODS

4.1 Materials and sample preparation

4.1.1 Materials

The product being fried is a structured matrix formed with native wheat starch and vital wheat gluten with water, varying in each case, the proportion of these ingredients. There were two types of flour mixed, with 8% and 12% of gluten (%d.b.). The ingredients used were vital wheat gluten, with an approximate water content of 5% and wheat starch, with an approximate water content of 6%, both of them acquired from Asitec S.A. (Santiago, Chile). The technical files of gluten and starch are shown in appendix A. The exact water content of the ingredients was determined experimentally by drying in a forced air oven at 105 °C for 24 h (to constant mass), cooled in a desiccator and then weighted to obtain the dry weight.

The oil used was high oleic sunflower oil (Camilo Ferrón, Chile). It was stored at room temperature before the experiment. The oil type was kept constant in all experiments.

4.1.2 Sample Preparation

The dry ingredients were mixed and sieved with a 40 mesh sieve (W.S.Tyler, USA). To form the dough, distilled water was added until reaching a 38 or a 44% of water content for each of the two different flour composition products. The amount of water added depend on the initial water content of the dry ingredients (starch and gluten) and was adjusted to ensure that the dough contained 38 or 44% of water (%w.b.). For each of the 2 water contents the amount of water was kept constant and only the dry ingredients proportion was varied. Half of the water was added at 15°C while mixing for 1 min. After mixing for 2 min, the rest of the water preheated at 100°C was added during the next min. Mixing was carried out using a household mixer 5K5SS (KitchenAid, USA). Once the ingredients were mixed, the dough was passed between two rollers of a dough sheeter LSB516 (Doyon, Canada) until a final thickness of 1 or 2 mm was obtained. The sheets were cut manually into 3.8 cm diameter discs.

Discs were either directly fried or fried after a pre-drying step. Drying was carried out under controlled conditions using using a Self-Cooking Center Model SCC661 (Rational, Germany), with dry air at 150 °C for 2 min. The drying time was kept constant in all formulations to study the effect of drying as well as the water retention capacity of the different products during frying.

4.1.3 Frying

Frying was carried out in an electrically heated fryer, DF535T (Somela, Santiago, Chile), which was thermostatically controlled to maintain the set frying temperature ± 2°C using an electrical control system, PID+Autotuning configured for PT100 (Veto, Chile). The fryer was filled with 4 l of oil, which was preheated for 2 h prior to frying (Blumenthal, 1991) and discarded after frying for 3 h. The frying temperature was set for all the experiments at 170°C.

Six discs, previously weighted in an analytical balance GR-200(AND, Japan; d=0.1 mg), were placed inside the frying basket and covered with a grid to prevent them from floating. Frying was carried out by immersing the basket in the oil for 1, 2 and 3 min for the 2 mm thickness discs and for 30 s and 1 min for the 1 mm thickness discs, ensuring reaching bubble-end point. Same frying times were used when frying pre-dried discs. After each frying time, the samples were removed from the fryer and were hold in a stainless steel grid for 10 min.

No de-oiling system was used in any experiment in order to determine the total oil content absorbed by the samples. All experiments were run in triplicate, that is three batches were made for each product formulation. Figure 3.2 shows a flow diagram of the whole experiment along with the different analysis made.

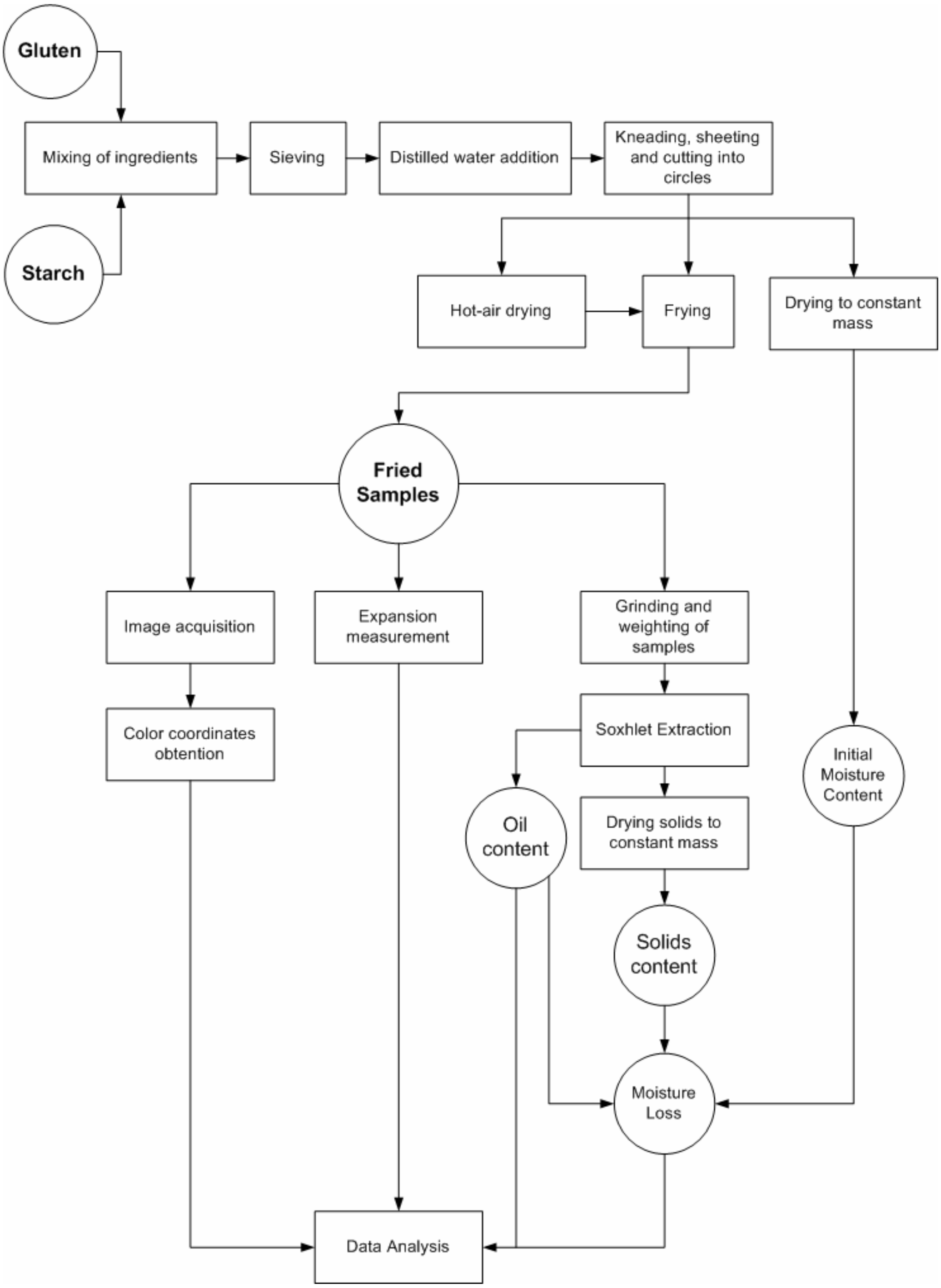


Figure 4.1: Flow diagram of the experiments.

4.2 Analytical methods

4.2.1 Oil Content and Moisture Loss

After frying, the products were ground and weighted. The oil content was determined by solvent extraction using the soxhlet technique (AOAC, 1995). Each extracted group was placed in Petri dishes, dried in a forced air oven at 105 °C for 24 h (to constant mass), cooled in a desiccator and then weighted to obtain the dry solids content. The moisture content was obtained from the difference between the original weight and the dry solids plus the oil content.

Moisture loss was reported on a dry basis and was calculated from the difference between the original moisture content of the product before frying and the moisture content after the frying process.

4.2.2 Color analysis

Color measurement was done using the technique explained by Papadakis et al. (2000). The technique involves setting up a lightning system, using a high resolution camera to capture images and using Photoshop software to obtain color parameters.

The image acquisition system consisted of a color digital camera model PowerShot A70 (Canon,USA) connected to a computer USB interface IFC-300PCU (Canon, USA), mounted on a stand inside a large box impervious to light with internal black surfaces. The lighting system consisted of four CIE source D65 lamps (60 cm length and 18 W; Model TLD/965, Philips, Singapore) placed above the sample at a 45° angle to maximize diffuse reflection responsible for color. The angle between the camera lens axis and the sample was around 90° to reduce gloss. A Kodak gray card with 18% reflectance was used as a white reference to standardize the illumination level before each session (Briones and Aguilera, 2005). The iris was operated in manual mode, with a lens aperture of f = 8 and a speed 1/3 (1/6) (no zoom, no flash) to achieve high uniformity and repeatability. A picture of the system is shown in figure 4.2.

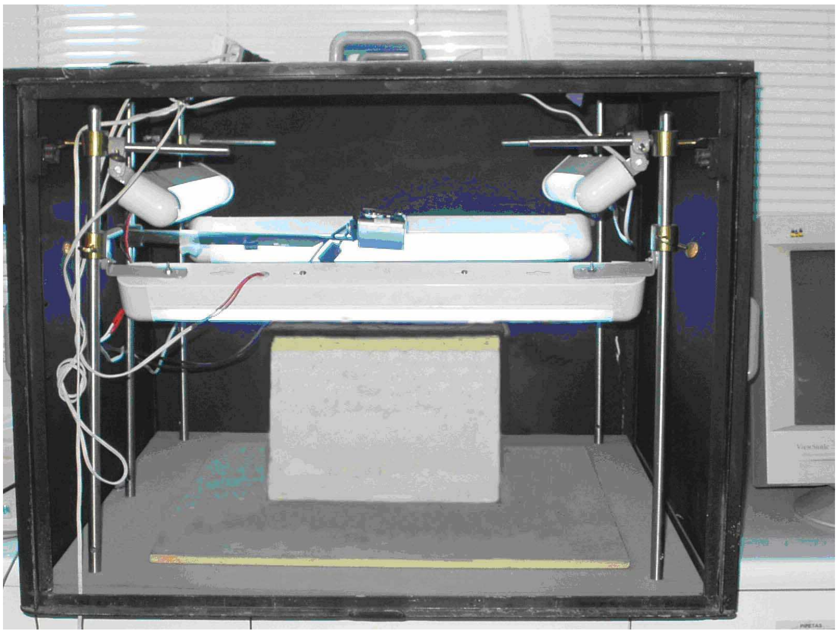


Figure 4.2: Image acquisition system.

Samples were placed in the field of view of the camera and an image of 1600 x 1200 pixels was acquired and stored in JPEG format of high resolution and fine quality, in RGB color coordinates.

L, a, b coordinates were obtained using Adobe Photoshop 6.0 software (Adobe Systems Inc., California, USA.), which were thereafter normalized to L*, a*, b*, according to equations 3.1, 3.2 and 3.3 (Yam and Papadakis, 2004).

$$L^* = \frac{L}{255}100 \tag{4.1}$$

$$a^* = a\frac{240}{255} - 120 \tag{4.2}$$

$$b^* = b\frac{240}{255} - 120 \tag{4.3}$$

Finally, the color difference between raw (Lo*, ao*, bo*) and fried discs (L*, a*, b*) was determined taking the Euclidean distance between them, according to equation 4.4 (Mariscal and Bouchon, 2008).

$$\Delta E^* = \sqrt{(L_o^* - L^*)^2 + (a_o^* - a^*)^2 + (b_o^* - b^*)^2} \qquad (4.4)$$

4.2.3 Expansion measurement

The expansion developed in each product was determined using a Vernier Caliper. Expansion was defined as the maximum height developed during frying (H in figure 3.1). In addition, maximum and minimum diameters were measured (D1 and D2 in figure 3.1). Generally the samples preserved their round shape, so the difference between these two diameters was not statistically significant.

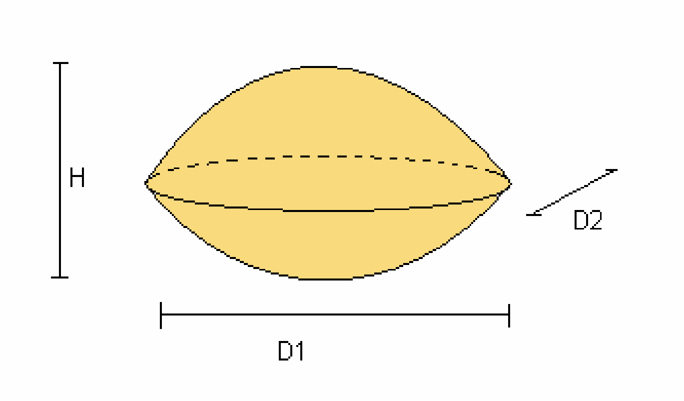


Figure 4.3: Diagram showing the way that expansion and shrinkage was measured

4.2.4 Statistical analysis

Statistical analysis was done using Statgraphics for Windows software, version 5.1 (Manugistic Inc., Rockville, MD, USA). Results were compared using analysis of variance, Duncan’s multiple range contrast and Kruskal-Wallis contrast with 95% confidence level. Details about the statistical comparisons are shown in appendix B.

5. RESULTS AND DISCUSSION

5.1 Moisture Loss

Figures 5.1 and 5.2 show the development of the moisture loss for different frying times for the 1 mm and 2 mm dough thickness, respectively. At the beginning of the frying process there is a rapid fall of water content due to loss of surface water. Then the rate decreases gradually until bubble-end point. The initial rate of water loss is higher for the 1 mm thickness products compared to the 2 mm ones. This may be mainly because in a thinner product water is nearer to the surface so it can escape more easily, but also because of the stronger structure that is developed in the thicker product that helps to retain water for a longer time. Bubble-end point was around 1 min for the thinner products and around 3 min for the thicker ones.

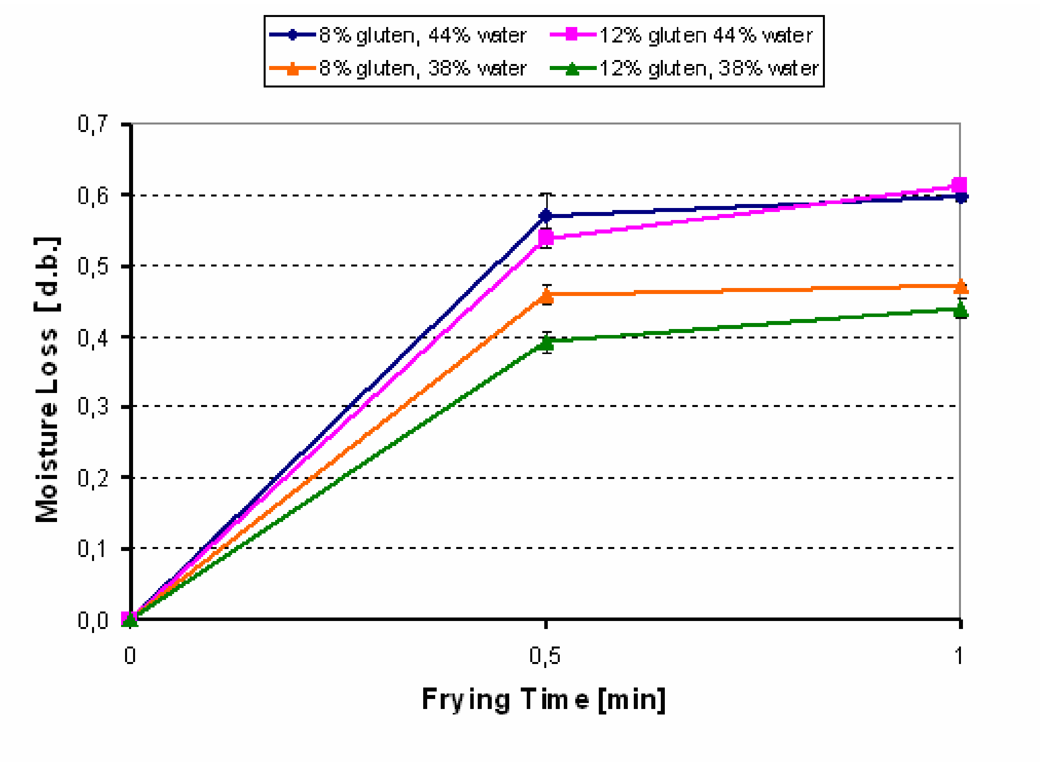


Figure 5.1: Moisture loss when frying 1 mm thickness discs for increasing times. (Points are means ± standard error, n=3).

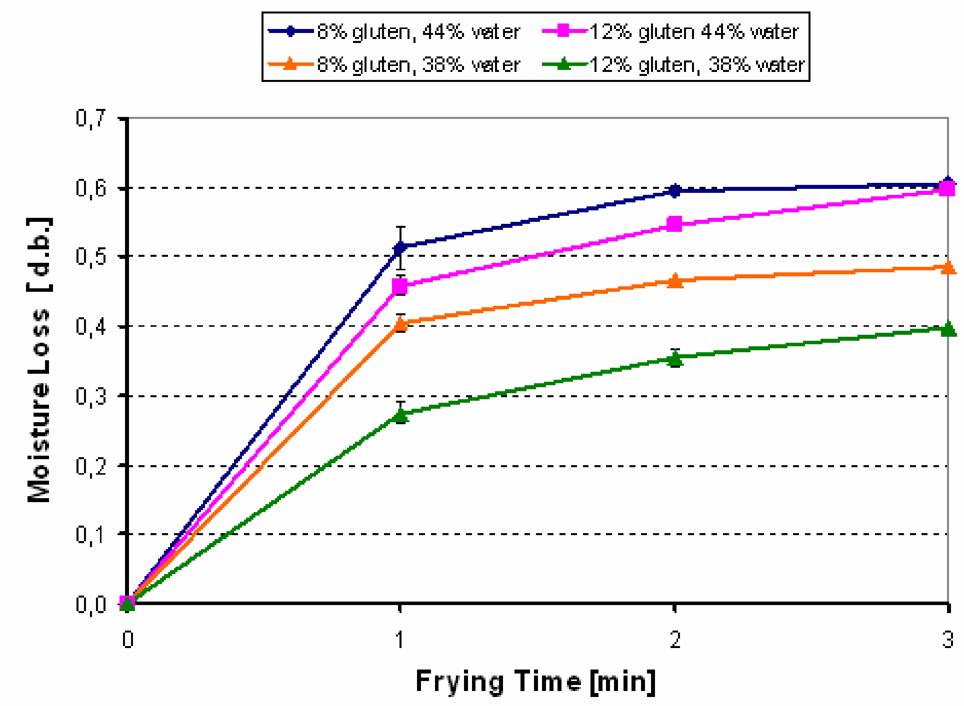


Figure 5.2: Moisture loss when frying 2 mm thickness discs for increasing times. (Points are means ± standard error, n=3).

The statistical analysis showed that the gluten has a significant effect in the moisture loss rate for the 38% water content product (ANOVA p=0.0239). Both figures show that a higher gluten content difficults water escape. The addition of gluten is generally associated with higher water retention (Fizsman et al., 2005). The gluten network retains water in the structure, so moisture loss rate is expected to be lower for the product with 12% gluten content. This difference is more evident in the 2 mm product, probably because the structure formed by the gluten network is stronger than the one in the thinner product. In the products with 44% water content, there is no statistical difference between the products with different gluten content for the whole set of data (ANOVA p=0.1859). This may be because at higher moisture content water vapor escape can not be effectively precluded by the gluten network. Although, there is a clear difference in the thick products for the first 2 frying times between the

8% and 12% gluten products. The products with higher gluten content have higher water retention for frying times previous to bubble-end point.

All the samples were predried for the same period of time, which is 2 min with dry air at 150°C. As a consequence, the moisture content before frying was different in each case. This way it was possible to study the different water retention capacities between the different formulations during drying. Table 5.1 shows the average moisture content (% d.b.) after drying and therefore before frying for each product. As in frying, gluten had an important role retaining water in the structure during drying. For the two levels of moisture content and for the two different thicknesses, the products with 8% gluten lost more water during the drying step compared to the products with 12% gluten.

Table 5.1: Moisture content of predried products after drying with air at 150°C for 2 min.

	Moisture Content before frying (d.b.)			
	44%water dough (79%d.b)		38%water dough (61% d.b.)	
	8% gluten	12% gluten	8% gluten	12% gluten
1 mm thickness	0,34 ± 0,031	0,39 ± 0,005	0,23 ± 0,014	0,32 ± 0,036
2 mm thickness	0,53 ± 0,014	0,56 ± 0,005	0,35 ± 0,029	0,40 ± 0,044

Figure 5.3 shows the moisture loss for the samples that have been dried before frying. As explained before, the products with more gluten had higher moisture content before frying (Table 5.1), so they present a higher moisture loss. This can be appreciated for the thin products, for both levels of initial moisture content. On the other hand, in the thick ones, even though the product with 12% gluten content had a higher initial moisture level prior to frying, they retained water for a longer time. The moisture loss rate was significantly lower for the first frying minute, in products with 12% gluten and 44% moisture content compared with the product with 8% gluten and 44% moisture content (ANOVA $p<0.01$). This may be explained by the stronger structure formed in the thick product and associated surface changes occurring during drying that result in a less permeable surface that difficult water

escape. There is no difference in the moisture loss between the 2 products with 38% water content, probably because the initial moisture content was too low after drying.

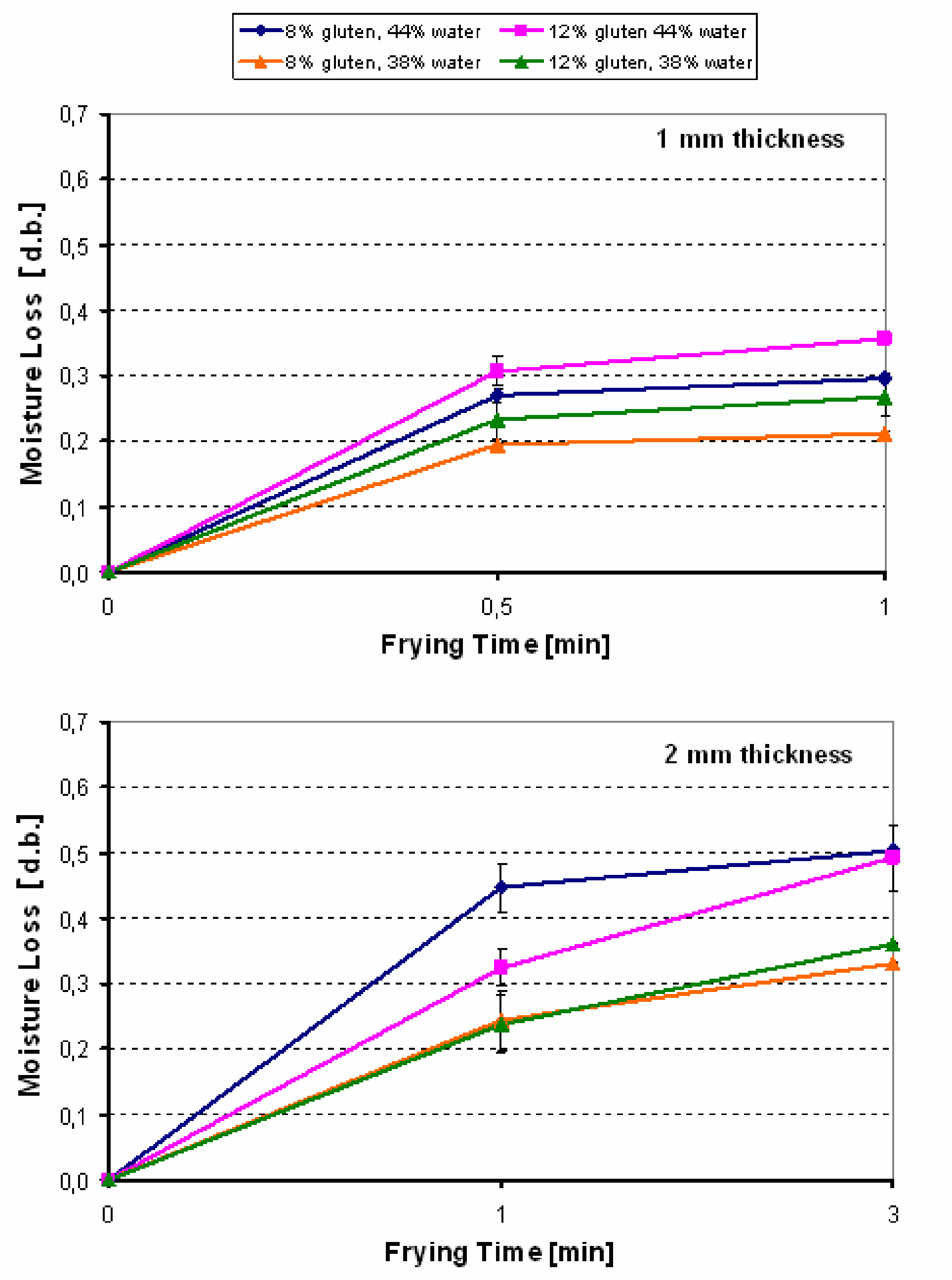


Figure 5.3: Moisture loss when frying 1mm and 2 mm thickness predried discs for increasing times. (Points are means ± standard error, n=3).

5.2 Oil Uptake

Figure 5.4 shows the oil uptake (% d.b.) for the products with 38% water content, for increasing frying times and the two levels of gluten content, for the 1 and 2 mm thickness products. The highest oil absorption corresponds to the product with the lower gluten content. For the thin products, at bubble-end point, the product with 8% gluten content absorbed 32% more oil compared to the 12% gluten product. For the 2 mm thickness product, the effect of gluten content is higher. At bubble-end point, a 44% difference was found in the oil uptake between the 2 gluten contents. Overall the statistical analysis showed that the gluten content has a significant effect in oil uptake ($p < 0.05$).

On the other hand, in the 44% water-content products, the gluten content has no significant effect on the oil uptake, in none of the 2 thicknesses (Figure 5.5). This may be directly related to what was determined in terms of moisture loss reported in the previous section, where no differences were determined between the 2 mixtures when working with a 44% water-content dough. In fact, a higher water content means a higher amount of bubbles escaping from the product, which may rupture the inner structure impairing gluten’s effect.

When comparing the oil uptake of thin and thick products, it may be observed that thinner products absorb more oil. There is a statistically significant difference in the amount of oil absorbed between the 2 thicknesses, for each of the four compositions (ANOVA, $p<0.01$). As it was stated previously, products with a greater surface area per volume are expected to absorb more oil since oil uptake is essentially a surface-related phenomenon. Also, the thinner product structure is weaker and may provide little resistance and therefore more permeability to oil penetration as found in related studies (Bouchon and Pyle, 2004). At bubble-end point, the difference between the oil uptake of the thin and the thick products was 48% on average. The difference was more important for the 12% gluten products than for the 8% ones, probably because the effect of a stronger structure is increased by higher gluten content in a thick product.

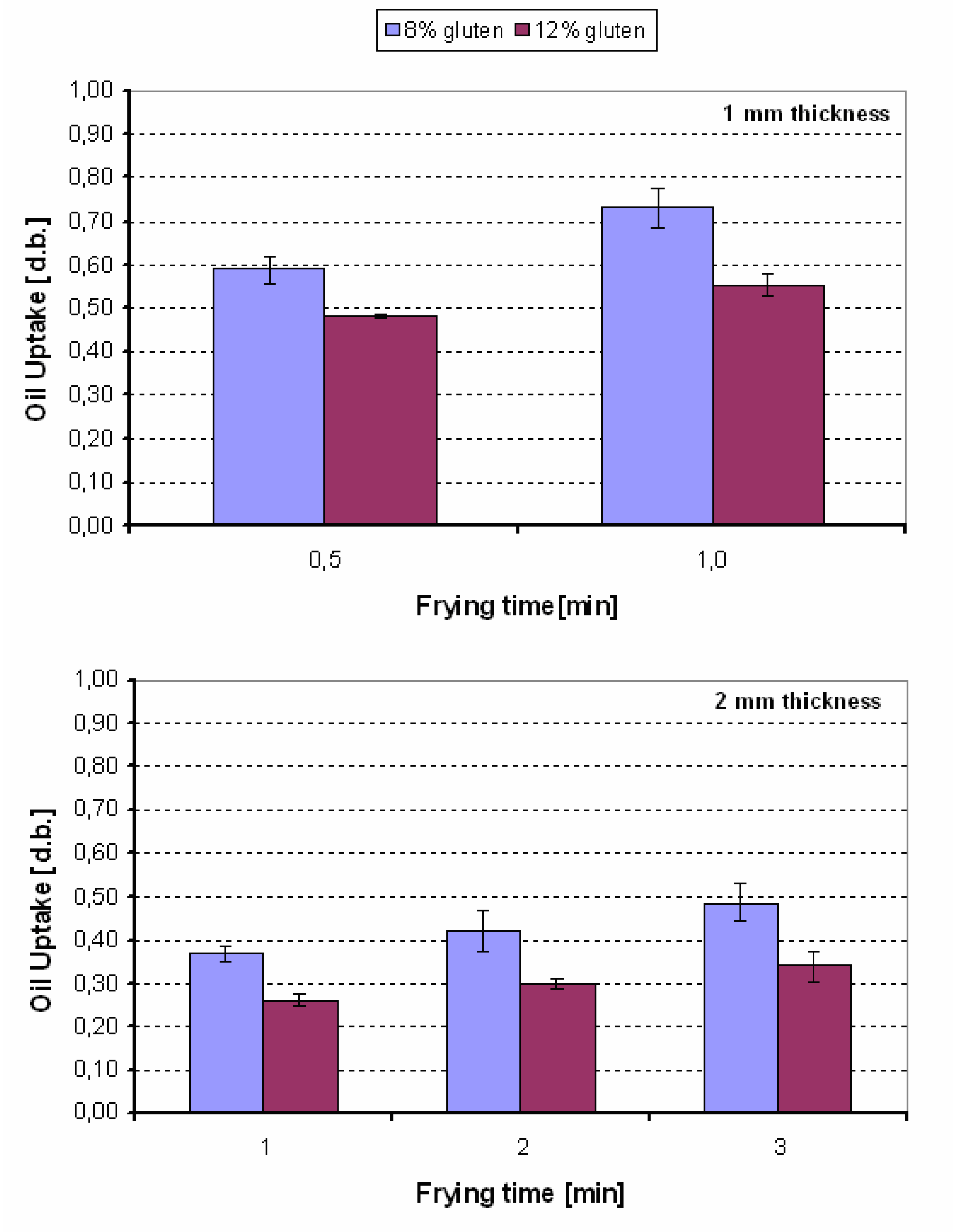


Figure 5.4: Oil uptake for increasing frying times when frying 38% water content discs, with two different gluten contents and thicknesses. (Points are means ± standard error, n=3).

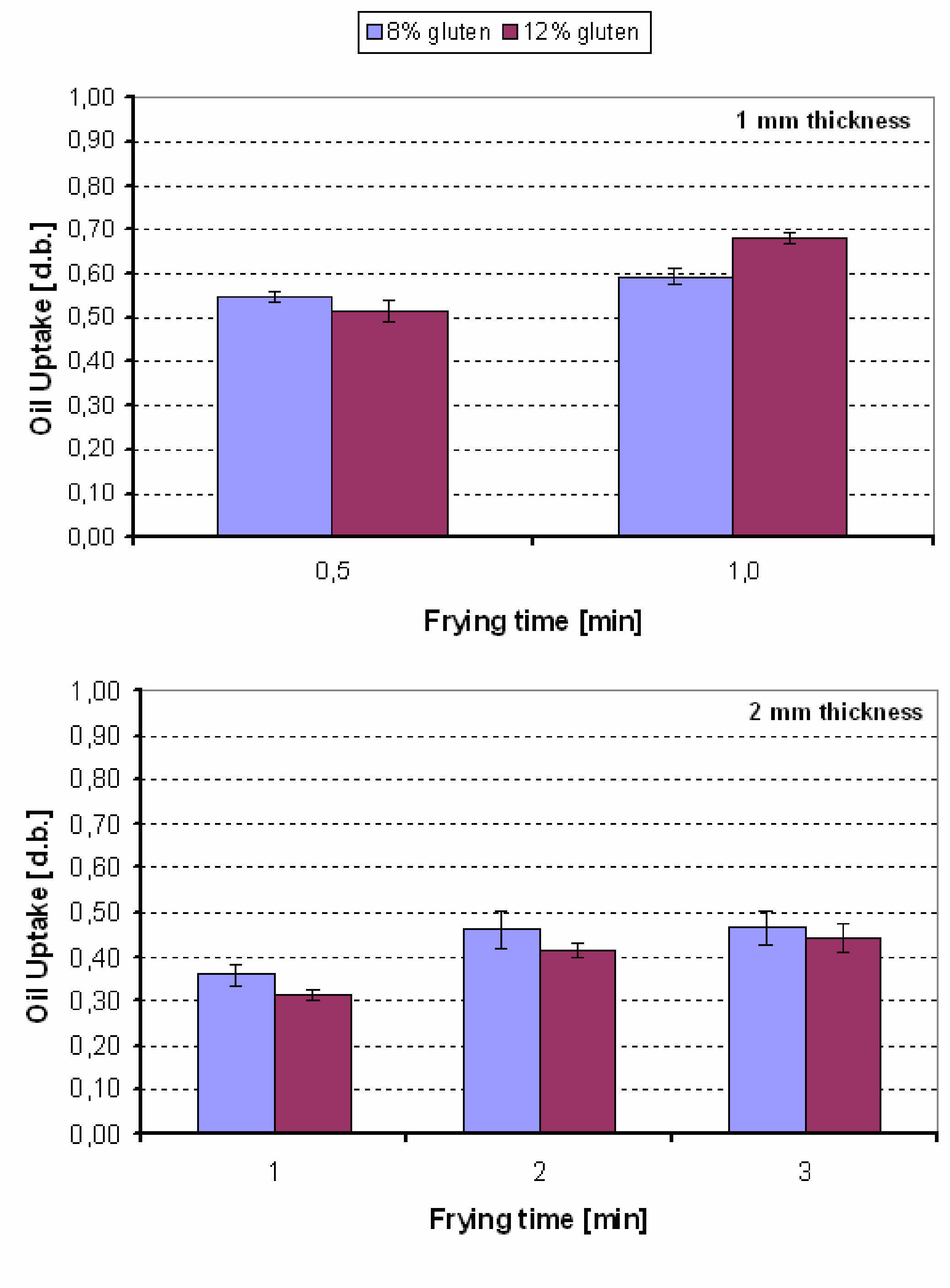


Figure 5.5: Oil uptake for increasing frying times when frying 44% water content discs, with two different gluten contents and thicknesses. (Points are means ± standard error, n=3).

Figures 5.6 and 5.7 show the effect of gluten content in oil uptake of the predried products. Gluten has a significant effect in all products both with 38% and 44% initial water content whether they are sheeted into thin or thick discs (ANOVA, p<0,01) Interestingly, even though the samples with higher gluten content had a higher initial moisture level after drying (Table 5.1), they absorbed a significantly lower amount of oil. As previously explained, the amount of oil uptake has been shown to be related to the amount of moisture lost. In fact, several studies claim that higher initial moisture content results in an increased oil uptake, since water evaporation defines the volume of the oil reservoir, through the empty spaces, as it leaves the structure (Gamble et al., 1987). However, in these results moisture content is not the most relevant parameter determining the oil absorbed, but the gluten content. In fact, products with a higher gluten content had a higher initial moisture level, so the amount of water loss during frying until reaching bubble-end point, was also higher, however oil absorption was significantly lower. Therefore gluten's film forming capability and its ability to decrease surface permeability seems to be the most relevant attributes influencing oil uptake.

Comparing the oil uptake at bubble-end point, the thin products with 8% gluten content absorbed 25% more oil than those with 12% gluten content, the difference being similar for both levels of initial water content. On the other hand, in thick products, the effect is more pronounced in products with 38% water content compared to those with 44% water content. Interestingly, in predried products with 44% water content, the increase in gluten content has a significant effect in oil uptake reduction, in contrast to what happens with the undried discs. This result reinforces the hypothesis that an increase in gluten content would reduce oil absorption when frying dough with lower moisture content.

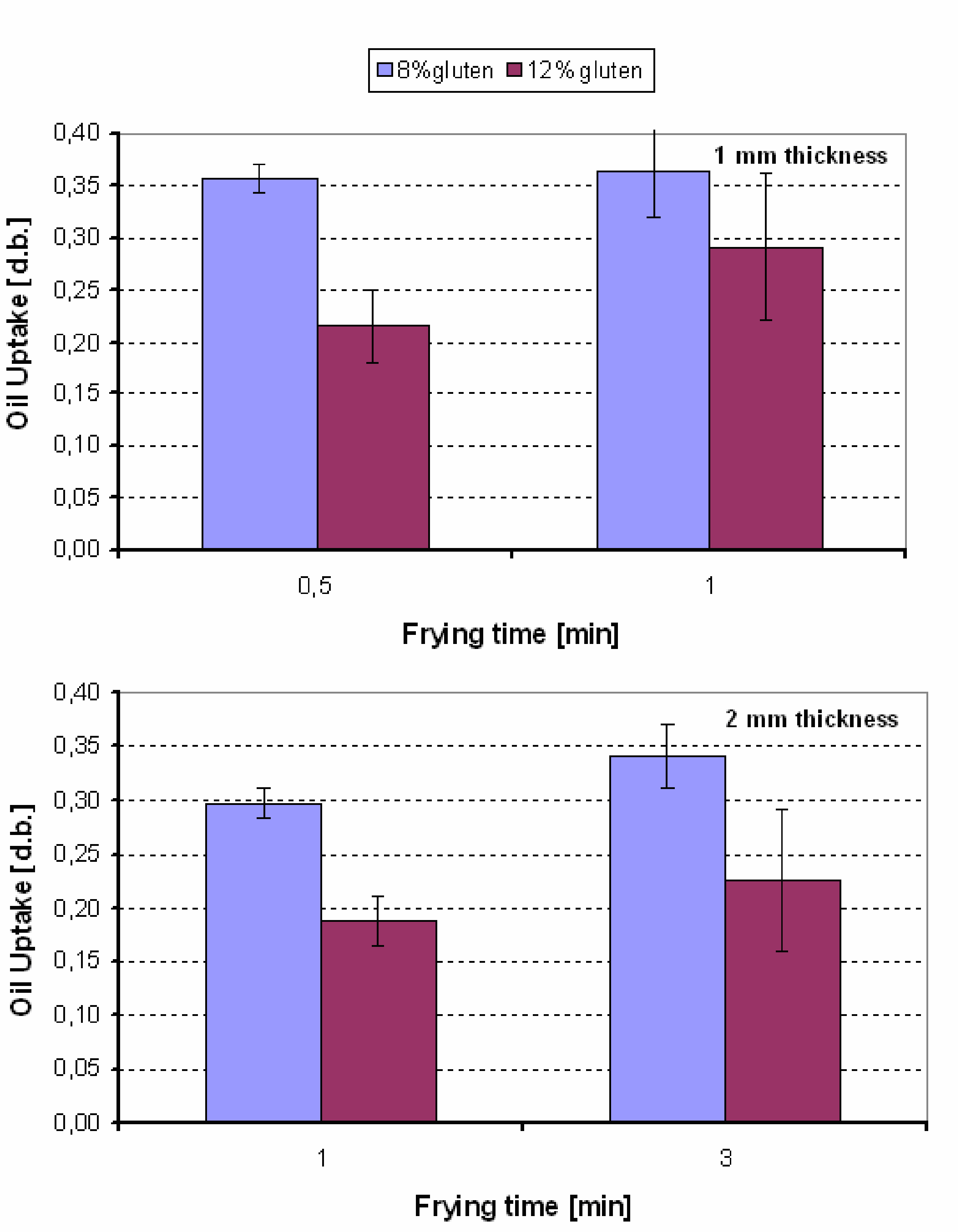


Figure 5.6: Oil uptake for increasing frying times when frying 38% water content predried discs, with two different gluten contents and thicknesses. (Points are means ± standard error,n=3).

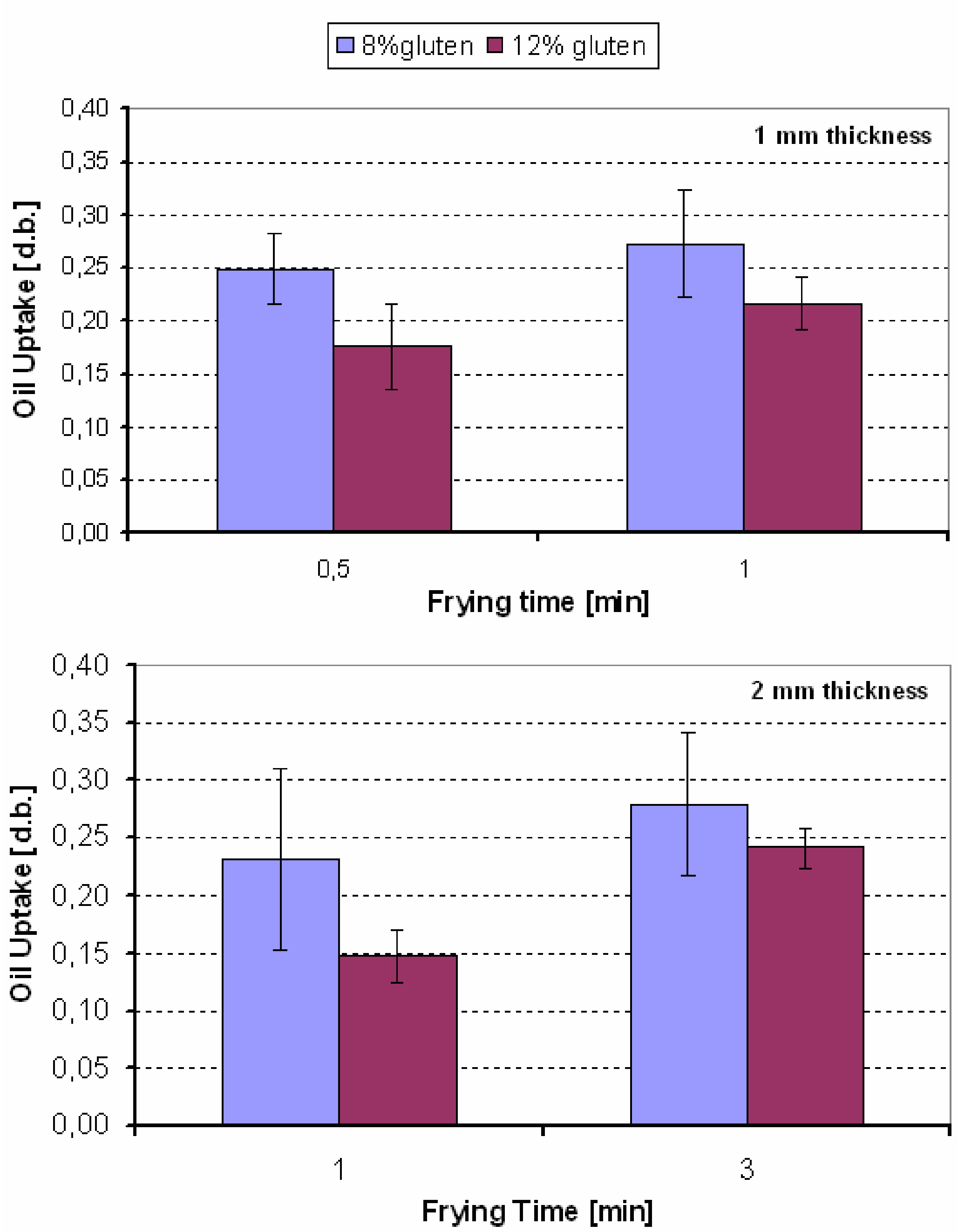


Figure 5.7: Oil uptake for increasing frying times when frying 44% water content predried discs, with two different gluten contents and thicknesses. (Points are means ± standard error, n=3).

A general overview that helps to observe the effect of the predrying step in oil uptake is presented in figure 5.8. There is a significant reduction in oil uptake for the predried samples in every individual case. Predied products absorbed on average half the amount of oil when comparing to the undried samples. The effect of the drying treatment is mainly due to crust development and surface changes occurring during the drying step that causes shrinkage and case hardening decreasing surface permeability (Moreno and Bouchon, 2008). In the thick products, trends in oil uptake are similar when comparing different formulations whereas they are previously dried or not. That is, formulations that showed the highest oil absorption when directly fried, also present the highest oil pick-up when they were predried and the same for the ones with the lowest oil absorption. The same does not occur when examining oil absorption in thin products. Particularly, the product with 12% gluten and 44% water-content absorbed the lowest amount of oil when compared to other predried products, but it absorbed the second highest amount of oil when no pretreatment was applied. Interestingly, this product is the one with the highest moisture content after drying. So, maybe the higher amount of water increases gluten network strength and consequently decreases surface permeability.

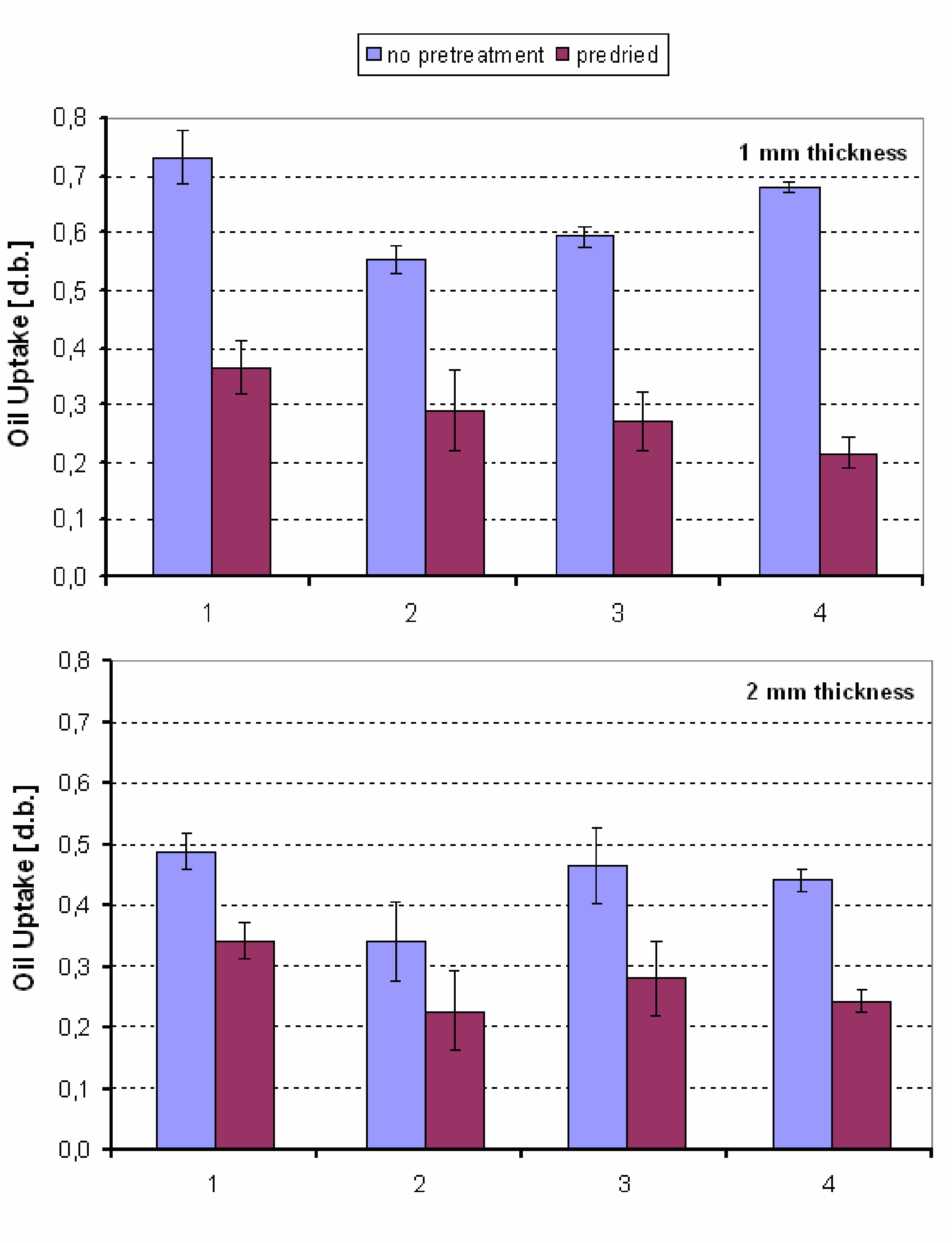


Figure 5.8: Oil uptake when frying to bubble-end point, 1 and 2 mm thicknesses discs, with and without pretreatment, for different product formulations. (1): 8%gluten, 38%water, (2): 12%gluten, 38%water; (3): 8%gluten, 44%water; (4): 12%gluten, 44%water. (Points are means ± standard error, n=3).

5.3 Color development analysis

The color of fried food is one of the most significant quality factors for its acceptance. Non-enzymatic browning during frying is a result of reaction between reducing sugar and aminoacids at high temperatures. The concentration of proteins, aminoacids and reducing sugars, the process temperature and the frying time affect color and flavor development in the fried product (Sahin, 2000; Maroulis et al., 2001).

Figure 5.9 and 5.10, show images of the 1 mm and 2 mm thickness products for increasing frying times. It may be observed that in the thin products, there is almost non noticeable change in colour for increasing times. On the other hand, thick products show a clear change in color as the frying time increases. Usually a decrease in moisture content associated with crust formation and increasing temperature in the crust layer may accelerate non-enzymatic browning and normally higher protein content is associated with darker products (Sahin, 2000). Although thin and thick products at bubble-end point have the same moisture content (less than 5%), the color change is greater in the thick product, since the outer surface is exposed to high temperatures for a much longer time.

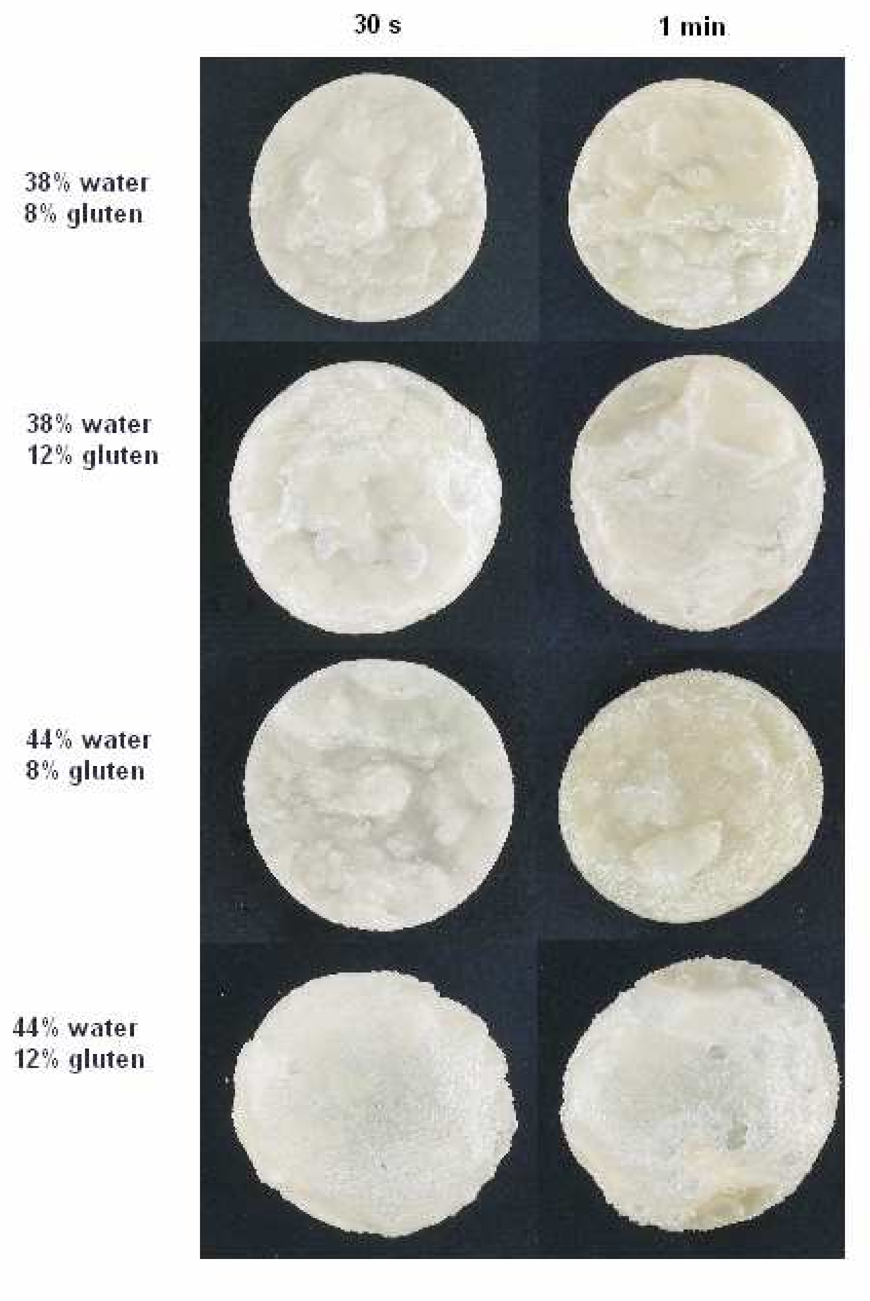


Figure 5.9: Images of thin fried discs for 30 s and 1 min.

Figure 5.10: Images of thick fried discs for 1, 2 and 3 min.

Overall impact of the frying procedure on the color of the product is determined according to equation 4.4. ΔE* shows the color difference between raw (L_o^*, a_o^*, b_o^*) and fried products (L^*, a^*, b^*). Figure 5.11 shows the change in ΔE* for all samples for increasing frying times. ΔE* increased progressively as the frying time increased, enhancing the difference with the raw counterpart, resulting in darker products. The values of ΔE* are between 2 and 4 times higher for the 2 mm thickness products when comparing to the thin samples at bubble-end point. If same frying times are compared, conclusions change. For instance, ΔE* for a thin product is approximately twice the value obtained for a thick one, after frying for 1 min. This may be explained by the higher temperature of the thin product surface compared to the thick one that is achieved after frying for 1 min.

ΔE* was significantly different when increasing gluten or water content (Kruskal-Wallis contrast, p=0,0357 with gluten content and p=0,0044 with water content). Both higher gluten content and higher water content resulted in lighter products. Probably both effects are related, given the previous discussion about gluten's role in retaining water in the structure. If a higher water content implies a lower ΔE* value, then it is expected that a higher gluten content will have the same effect. Normally, a higher protein content is associated with darker products (Fiszman et al., 2005). In this case, products with higher gluten content do not present a higher ΔE* value, probably because protein content is not the limitant reactant in the non-enzimatic browning reactions, since it is high for all formulations, being maybe limited by reducing sugar content. Overall significant differences were observed in thicker products at longer frying times (2 min and 3 min). The results for the individual color coordinates (L*, a* and b*) are shown in appendix B.

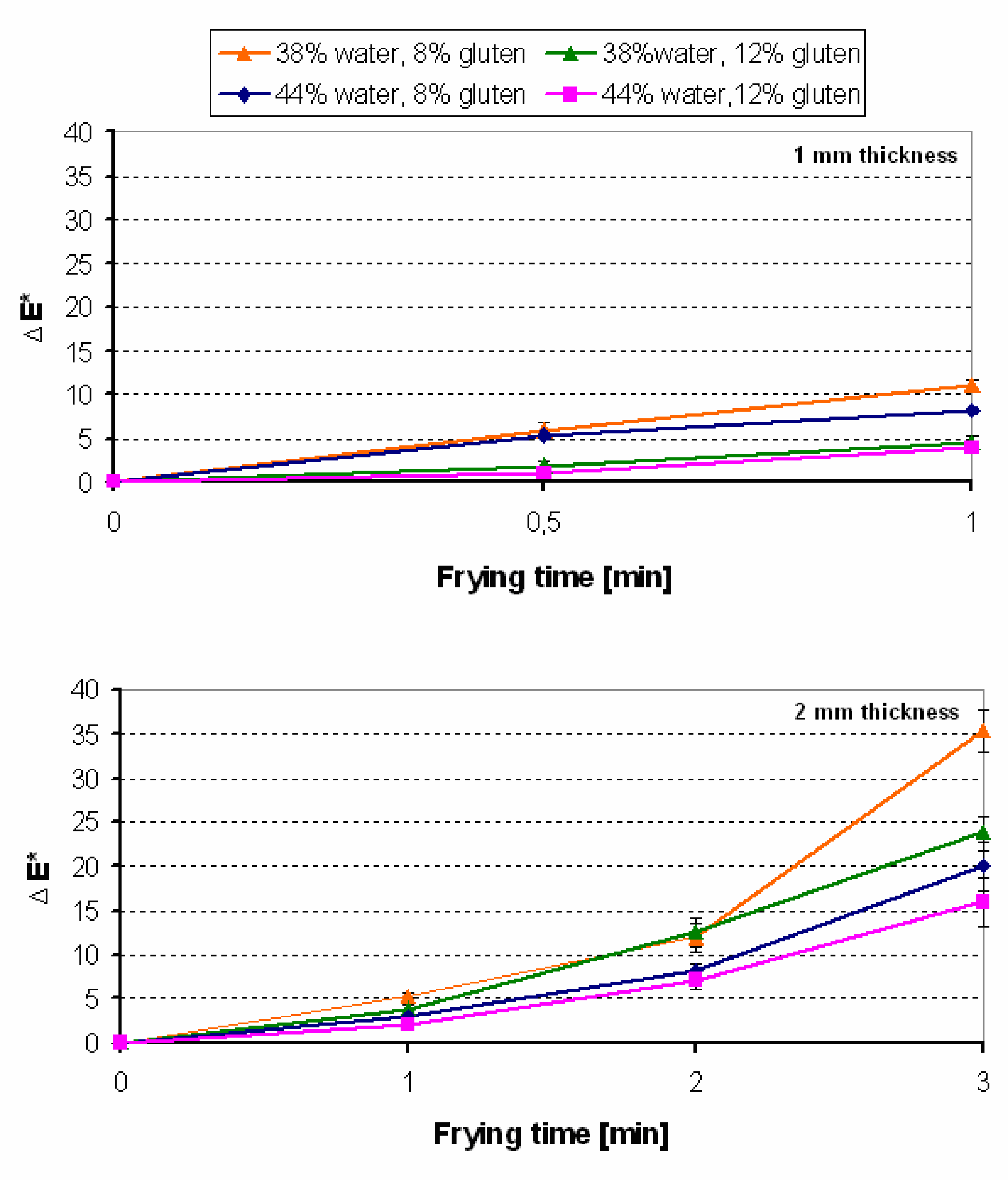


Figure 5.11: ΔE* when frying 1mm and 2mm thickness discs for increasing frying times. (Points are means ± standard error, n=10).

Figures 5.12 and 5.13 show fried samples that have been previously dried. For short frying times there are no noticeable differences between dried and undried samples. But at bubble-end point, for both thin and thick products, the drying pretreatment has a significant effect in the final color developed, resulting in darker products compared to undried ones (Kruskal-Wallis contrast, $p<0.01$).

Figure 5.14 shows the change in ΔE* of predried samples for increasing frying times when sheeted into thin and thick products. In predried samples ΔE* was also determined as the difference between tha raw (L_0*,a_0*,b_0*) and the processed product (L*,a*,b*). Consequently, it is possible to determine the effect of the predrying step on color, before frying begins (frying time = 0, in figure 5.14). The products that experimented the greatest change in ΔE* during drying were the ones with the highest moisture content, but overall change was minimum.

Analysis of the whole set of data showed that in predried samples gluten and water content do not have a statistically significant effect. During frying, the highest ΔE* was found in the 44%water-8%gluten product. From Figure 5.3, it may be observed that this product has a high moisture loss rate at the beginning of frying, which means that the crust is rapidly formed during the first minute and therefore exposed to a higher temperature for a longer time resulting in a darker product.

Figure 5.12: Fried thin predried discs for increasing frying times.

Figure 5.13: Fried thick predried discs for increasing frying times.

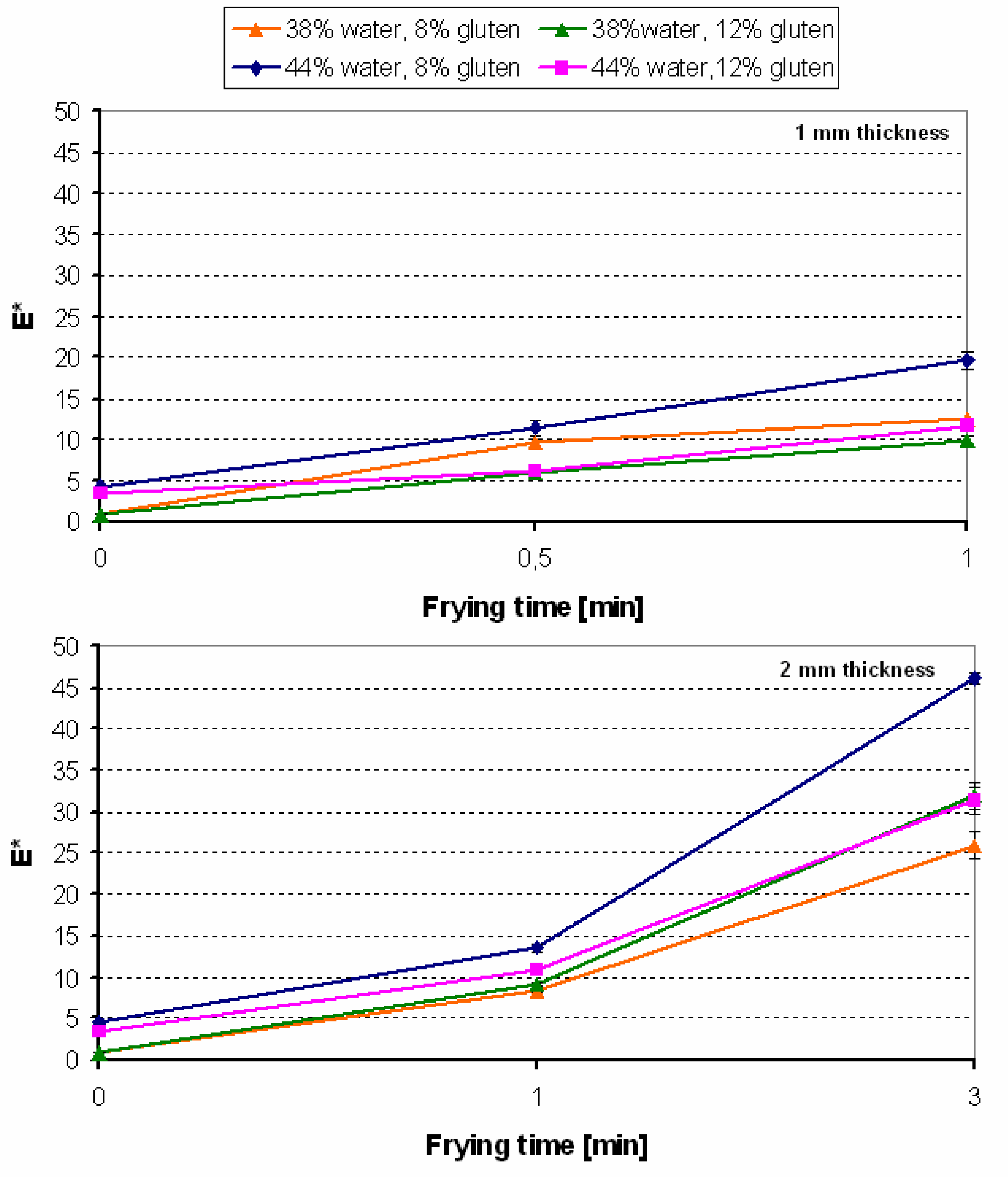


Figure 5.14: ΔE* when frying 1mm and 2mm thickness predried discs for increasing frying times. (Points are means ± standard error, n=7).

5.4 Expansion Analysis

Figure 5.15 shows the expansion experimented by the thin and thick products, for different compositions and increasing frying times. The products with higher gluten content and higher water content are the ones that expand more. The maximum height developed (H) was experimented by the 12%gluten-44%water in all cases. High gluten content helps to develop an elastic structure that traps the vapor that escapes during frying, producing an expanded product.

In thin products, gluten has a more significant effect than water content. Probably, the structure is weak, so even when there is a high amount of vapor, it can not be retained within it, since the dough is not elastic enough in the low gluten products. So, the 12% gluten products are much more expanded than the low gluten ones.

On the other hand, in the thick products, expansion is similar for the 38%water-12% gluten and the 44%water-8%gluten products. This may be a combined effect of a stronger structure compared with the thin products, which can retain the vapor even with low gluten content. But also a low water content will not be able to expand the strong structure formed by the thick 12% gluten product. High water content in one product is compensated by high gluten content in the other one, resulting in similarly expanded products. This does not occur in a thin product, where a high gluten content is necessary to get an expanded product. So comparing the thick and thin products, the 38% water-12%gluten thick product is less expanded than the thin one and the 44%water-8%gluten more. In all cases, the 8%gluten-38%water product is the less expanded one and the 12%gluten-44%water is the most expanded one.

There was not a significant difference in the product diameter (D) between the different compositions (ANOVA, p=0.13). The average diameter was in all cases near 3.7 cm, similar to the 3.8 cm diameter of the original product.

Contrasting figure 5.15 with the oil uptake results (figures 5.4 and 5.5), it may be observed that product expansion does not seem to be related to oil absorption, showing that oil absorption is a superficial phenomenon.

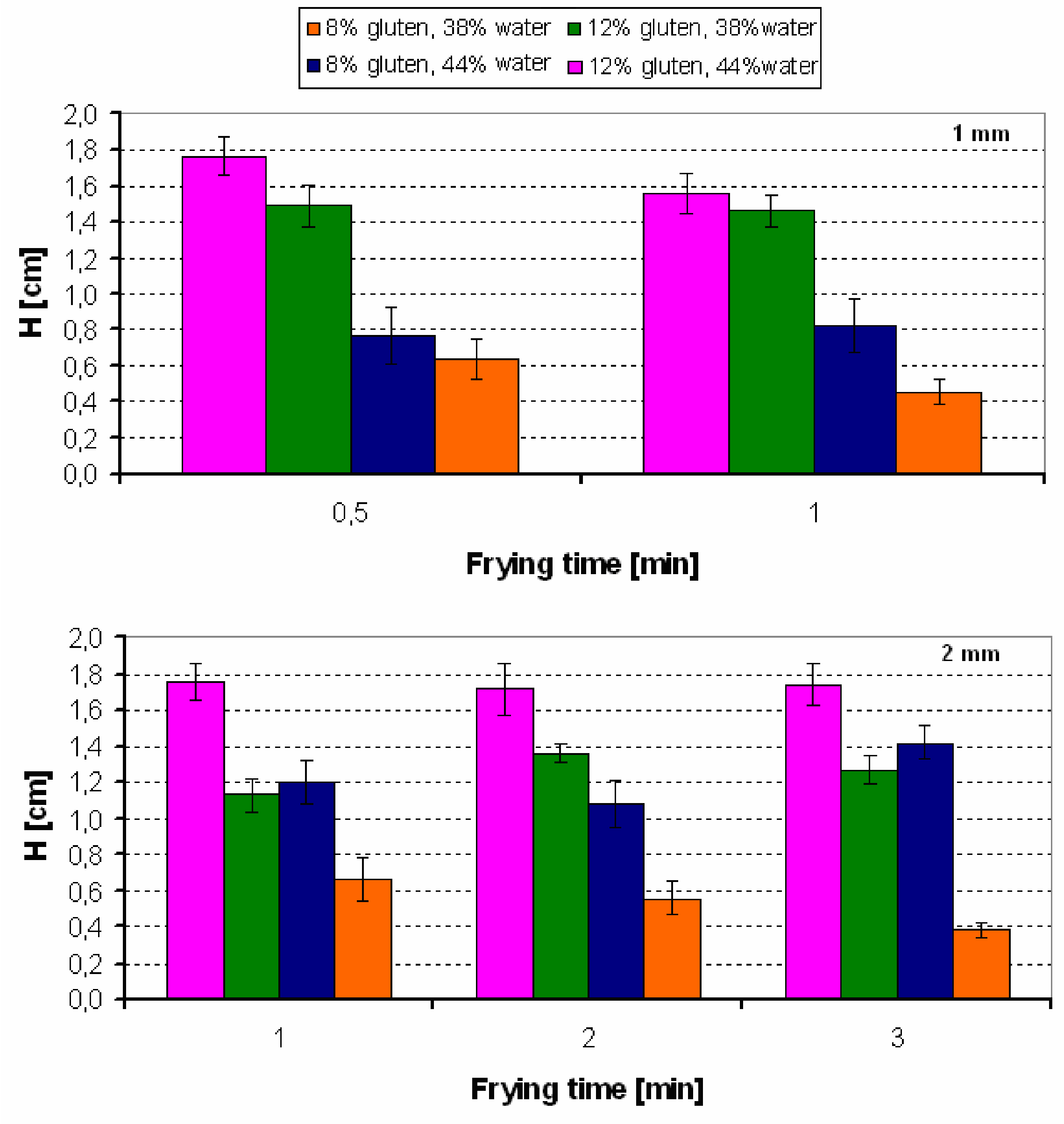


Figure 5.15: Maximum height developed when frying 1mm and 2mm thickness discs for increasing frying times and different product formulations. (Points are means ± standard error, n=9).

Figure 5.16 shows the results for the expansion experimented by the predried products. The H value is significantly lower than the one obtained in undried samples. On average, dried samples are 40% less expanded than the undried ones. The drying treatment decreases the water content in the products that are being fried, so there is fewer vapor generated in the structure that can expand the product. Besides the effect that the drying treatment has on the water content, case hardening that occurs during drying might have an effect making the structure less elastic and consequently less expanded.

The most important difference is experimented by the 8%gluten-44%water products, where dried samples where more than 60% less expanded than undried ones. As previously explained, high water content in this product compensates the effect of gluten content in the thick samples. In predried products this effect is less significant since there is less water available and the structure is less elastic after drying.

Comparing the expansion between the different formulations, in dried products gluten content has the most important role determining product expansion. Products with 12% gluten content show a significant higher H value compared to the 8% ones and, although 12%gluten-38%water products have 30% less water than 12%gluten-44%water products when sheeted into thick products (Table 5.1), the expansion developed by both of them is nearly the same.

In fried products, surface roughness is associated to oil uptake because it difficults oil drainage. Dried products with 12% gluten content are the most expanded ones and this expansion resulted in a visually smoother outer surface. So, maybe gluten is contributing to develop an expanded product with an even surface that eases oil drainage, resulting in a decrease in oil uptake, as was found in 44%water-12%gluten product compared to 44%water-8%gluten ones (figure 5.7). The effect of surface smoothness consequence of product's expansion has also been noted by Bouchon and Pyle (2004) when frying formulated products based on potato flakes.

Figure 5.17 shows the mean diameter ($D = (D_1 + D_2)/2$) of dried products after frying. Mean diameter was 3.45 cm, significantly lower than the original 3.8 cm. Product shrinkage is probably a result of the water loss that occurs during drying. A significantly lower value was found for the 12%gluten-44%water product, which also corresponds to the sample with the lowest oil uptake (figure 5.7), showing that case hardening and shrinkage occurring during drying should be intimately related to oil uptake, through surface permeability reduction.

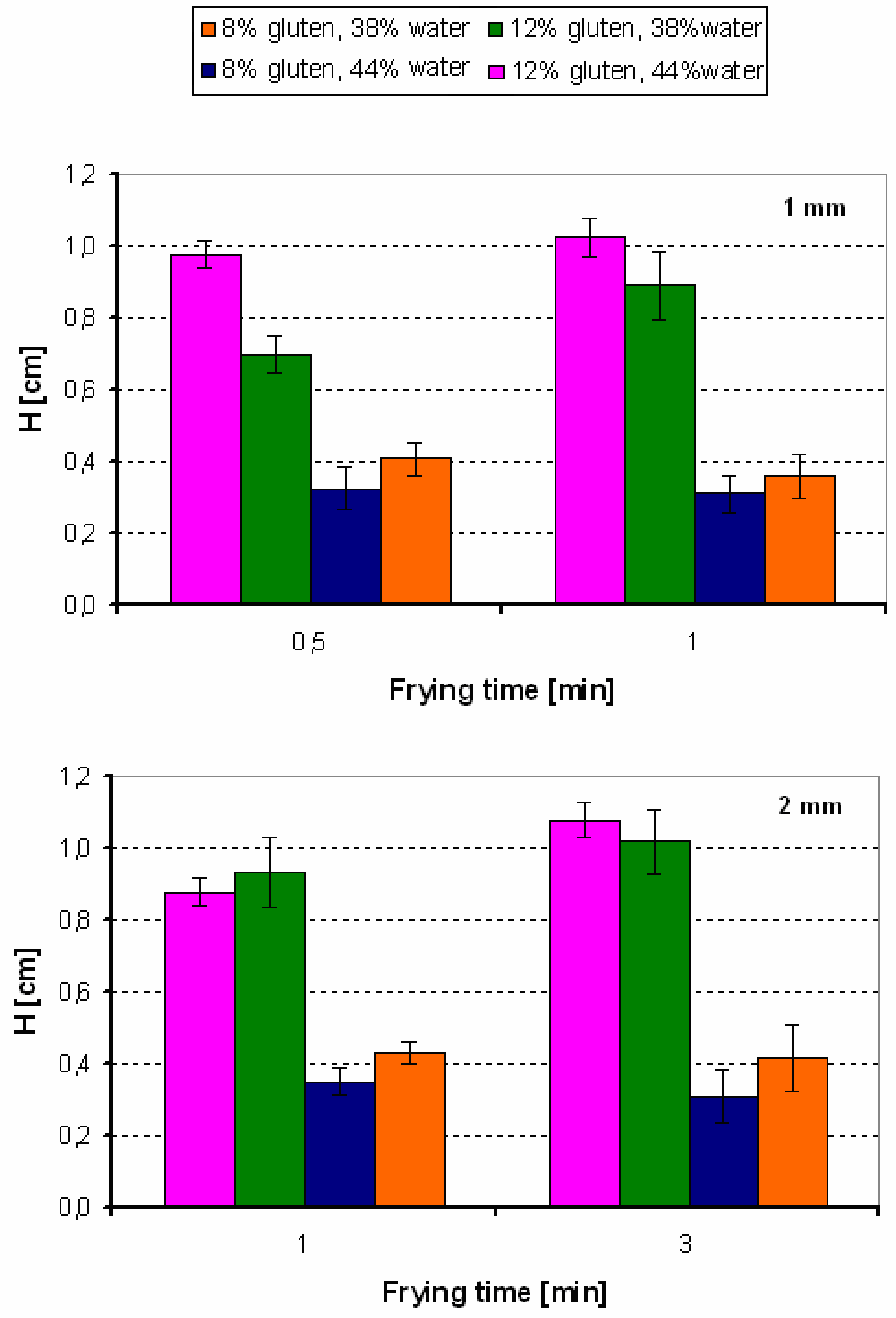


Figure 5.16: Maximum height developed when frying predried 1mm and 2mm thickness discs for increasing frying times and different product formulations. (Points are means ± standard error, n=5).

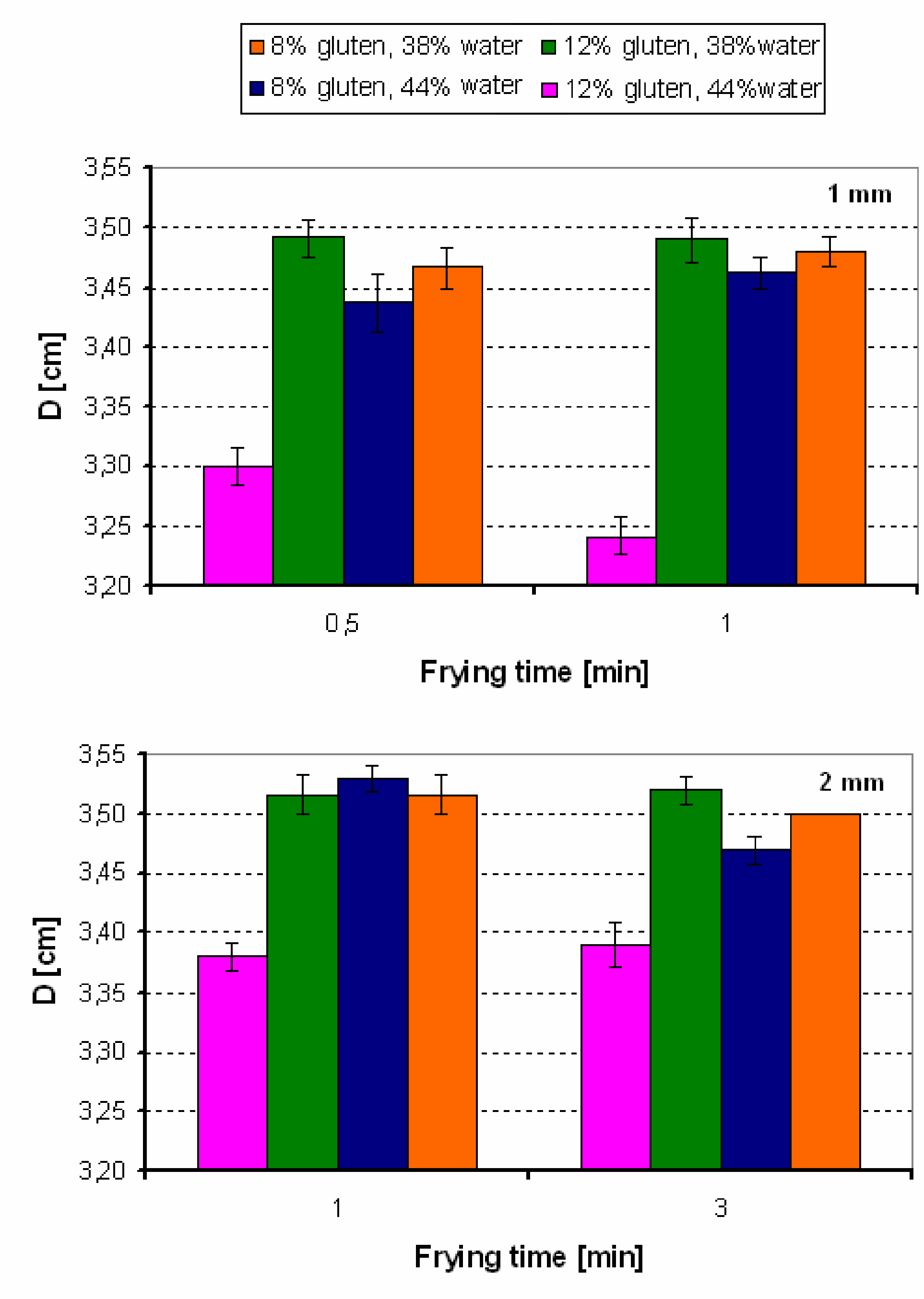


Figure 5.17: Average product diameter when frying predried 1mm and 2mm thickness discs for increasing frying times and different product formulations. (Points are means ± standard error, n=5).

6. CONCLUSIONS

Formulated products based on wheat flour are an alternative for the design of fried products with a reduction in the amount of oil absorbed. The use of a blend of gluten and starch made possible to study the effects of different formulations, and to test maximum and minimum quantities of gluten and water that allow the production of a sheeted product.

Gluten had a significant effect in reducing oil uptake in almost every case with the exception of the products with high moisture content. In undried products, gluten did not show an effect in products with 44% water content, probably because high water content led to explosive vaporization, creating tissue disruption and therefore increasing surface permeability and the volume available for oil absorption. In addition, bubbles escape may increase surface roughness, difficulting oil drainage. Consequently, the combined effect is believed to annulle the role of gluten in the structure.

In predried products, gluten had a significant effect in oil uptake in all products for both initial water content levels. Moisture content results after drying showed that gluten had an important role retaining water in the structure. Products with 8% gluten (d.b.) lost more water during the drying step compared to the products with 12% gluten (d.b.), but yet, they absorbed a significantly higher amount of oil, showing that oil uptake is not so clearly related to the amount of moisture lost but to product microstructure and external layers permeability. Gluten’s film forming capability and its ability to decrease surface permeability seems to be the most relevant attributes influencing the oil uptake in this case.

As well as gluten content, drying pretreatment also resulted in a significant reduction in oil uptake in every case under study. Predried products absorbed on average half the oil when compared to undried samples. The effect of the drying treatment is mainly associated to crust development and surface changes occurring during the drying step like shrinkage and case hardening, decreasing surface permeability.

When comparing thin and thick products, significant differences between them were found in oil uptake for undried products. For all product formulations, thicker samples absorbed a significantly lower amount of oil, explained by a greater surface area per volume and the weaker structure formed in the thinner product that provides little resistance and therefore more permeability to the oil. The difference was more important for the 12% gluten (d.b.) products than for the 8% (d.b.) ones, probably because the effect of a stronger structure is increased by higher gluten content in the thick products.

With respect to color, ΔE* showed a significant difference between different levels of gluten and water. Both higher gluten content and higher water content resulted in lighter products. Both effects may be related, given gluten’s role retaining water in the structure. The most significant differences were found for the thick products for frying times longer than 2 min, and few differences were found in thin products.

In terms of expansion, gluten content and water content contributed to develop expanded products. The elastic structure formed by gluten traps the vapor that is escaping during frying, producing an expanded product. Results did not show a relationship between product expansion and oil absorption, showing that oil uptake is a surface phenomenon.

This study shows the importance of controlling microstructure development when designing food products as a way to control quality parameters. The structure developed during frying, mainly determined by gluten and water content, was the most important factor in order to explain the differences in the oil absorbed by each product. Gluten had a significant role making the structure less permeable to oil absorption, and developing lighter colored and more expanded products.

It would be desirable to extend the study on the drying pretreatment using different drying temperatures in order to clarify the mechanisms involved in the structure alteration that occurs during the predrying step and the possible effects that the drying temperature has on the food structure.

Also, microscopy observations are recommended to visualize the microstructure formation and the structural changes. In this way it would be possible to approximate to definitive conclusions about gluten’s role in microstructure development.

Finally, it would be interesting to analyze the effect of adding other ingredients to the formulations that may contribute to improve products quality attributes. Some hydrocolloids like methylcellulose or hydroxipropil methyl cellulose have shown to decrease oil uptake during frying.

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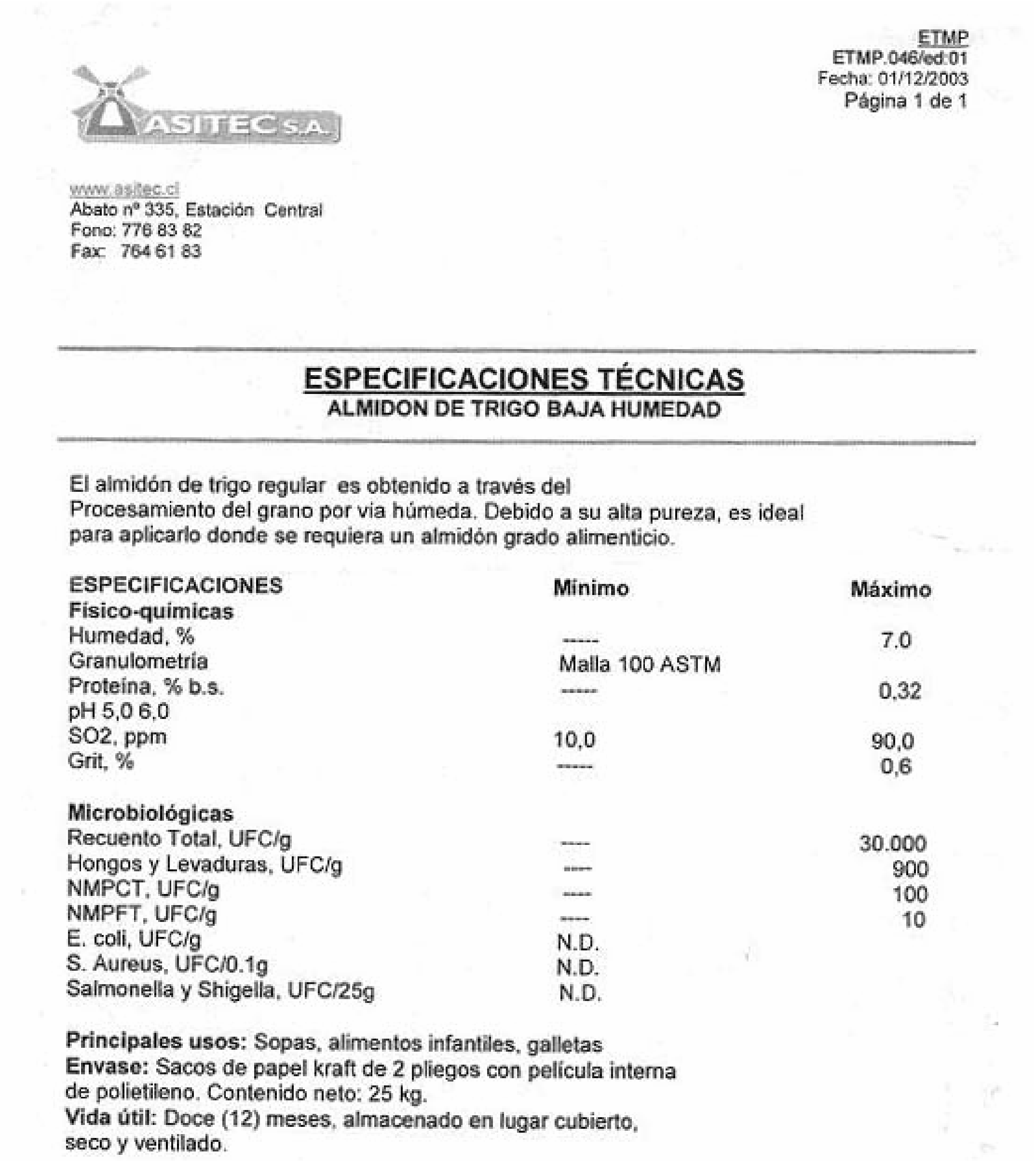
APPENDIXES

APPENDIX A: TECHNICAL FILES



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ESPECIFICACIONES TÉCNICAS

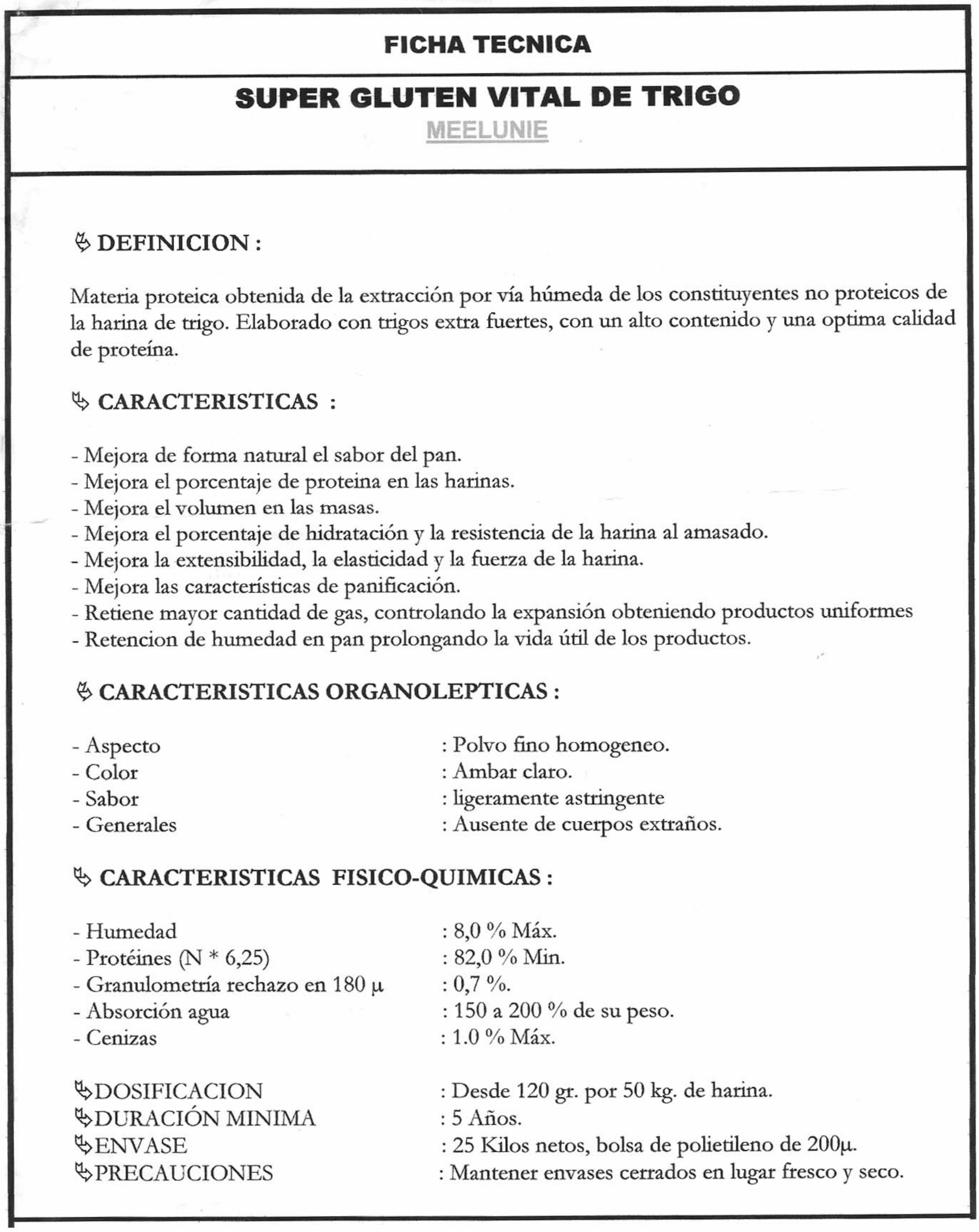
ALMIDON DE TRIGO BAJA HUMEDAD

El almidón de trigo regular es obtenido a través del Procesamiento del grano por via húmeda. Debido a su alta pureza, es ideal para aplicarlo donde se requiera un almidón grado alimenticio.

ESPECIFICACIONES	**Mínimo**	**Máximo**
Físico-químicas		
Humedad, %	-----	7.0
Granulometría	Malla 100 ASTM	
Proteína, % b.s.	-----	0,32
pH 5,0 6,0		
SO2, ppm	10,0	90,0
Grit, %	-----	0,6
Microbiológicas		
Recuento Total, UFC/g	----	30.000
Hongos y Levaduras, UFC/g	----	900
NMPCT, UFC/g	----	100
NMPFT, UFC/g	----	10
E. coli, UFC/g	N.D.	
S. Aureus, UFC/0.1g	N.D.	
Salmonella y Shigella, UFC/25g	N.D.	

Principales usos: Sopas, alimentos infantiles, galletas
Envase: Sacos de papel kraft de 2 pliegos con película interna de polietileno. Contenido neto: 25 kg.
Vida útil: Doce (12) meses, almacenado en lugar cubierto, seco y ventilado.

Figure A.1: Starch technical file.



FICHA TECNICA

SUPER GLUTEN VITAL DE TRIGO

MEELUNIE

➪ DEFINICION :

Materia proteica obtenida de la extracción por vía húmeda de los constituyentes no proteicos de la harina de trigo. Elaborado con trigos extra fuertes, con un alto contenido y una optima calidad de proteína.

➪ CARACTERISTICAS :

- Mejora de forma natural el sabor del pan.
- Mejora el porcentaje de proteina en las harinas.
- Mejora el volumen en las masas.
- Mejora el porcentaje de hidratación y la resistencia de la harina al amasado.
- Mejora la extensibilidad, la elasticidad y la fuerza de la harina.
- Mejora las características de panificación.
- Retiene mayor cantidad de gas, controlando la expansión obteniendo productos uniformes
- Retencion de humedad en pan prolongando la vida útil de los productos.

➪ CARACTERISTICAS ORGANOLEPTICAS :

- Aspecto	: Polvo fino homogeneo.
- Color	: Ambar claro.
- Sabor	: ligeramente astringente
- Generales	: Ausente de cuerpos extraños.

➪ CARACTERISTICAS FISICO-QUIMICAS :

- Humedad	: 8,0 % Máx.
- Protéines (N * 6,25)	: 82,0 % Min.
- Granulometría rechazo en 180 µ	: 0,7 %.
- Absorción agua	: 150 a 200 % de su peso.
- Cenizas	: 1.0 % Máx.

➪DOSIFICACION	: Desde 120 gr. por 50 kg. de harina.
➪DURACIÓN MINIMA	: 5 Años.
➪ENVASE	: 25 Kilos netos, bolsa de polietileno de 200µ.
➪PRECAUCIONES	: Mantener envases cerrados en lugar fresco y seco.

Figure A.2: Gluten technical file.

APPENDIX B: STATISTICAL ANALYSIS

B.1 Moisture Loss with Gluten content

Undried simples

```
Variable dependiente: Moisture Loss
Factor: Gluten
Resumen Estadístico para Moisture Loss

Gluten             Frecuencia      Media           Varianza        Desviación típica
Mínimo
-------------------------------------------------------------------------------------------
8                  30              0,517067        0,00538772      0,0734011
0,338
12                 30              0,4612          0,0120061       0,109572
0,228
-------------------------------------------------------------------------------------------
Total              60                  0,489133            0,009343            0,0966592
0,228

Gluten             Máximo          Rango           Asimetría        Asimetría tipi.
Curtosis
-------------------------------------------------------------------------------------------
8                  0,62            0,282           -0,171439       -0,38335      -0,589403
12                 0,634           0,406           -0,178875       -0,399976      -0,78431
-------------------------------------------------------------------------------------------
Total              0,634               0,406               -0,471562           -1,49121
-0,265371

Gluten             Curtosis típificada
-------------------------------------------------------------------------------------------
8                  -0,658972
12                 -0,876886
-------------------------------------------------------------------------------------------
Total              -0,419588

Tabla ANOVA para Moisture Loss según Gluten

                            Análisis de la Varianza
-----------------------------------------------------------------------------
Fuente            Sumas de cuad.     Gl  Cuadrado Medio  Cociente-F   P-Valor
-----------------------------------------------------------------------------
Entre grupos           0,0468163      1    0,0468163       5,38       0,0239
Intra grupos            0,504421     58   0,00869691
-----------------------------------------------------------------------------
Total (Corr.)           0,551237     59


Contraste Múltiple de Rango para Moisture Loss según Gluten

--------------------------------------------------------------------------------
Método: 95,0 porcentaje Duncan
Gluten         Frec.     Media            Grupos homogéneos
--------------------------------------------------------------------------------
12             30        0,4612           X
8              30        0,517067          X
--------------------------------------------------------------------------------
Contraste                                 Diferencias
--------------------------------------------------------------------------------
8 - 12                                   *0,0558667
--------------------------------------------------------------------------------
```

```
* indica una diferencia significativa.
```

- 38% Water Content

```
Variable dependiente: Moisture Loss
Factor: Gluten

Resumen Estadístico para Moisture Loss

Gluten              Frecuencia      Media         Varianza      Desviación típica   Mínimo
--------------------------------------------------------------------------------------------
8                   15              0,457467      0,00157984    0,0397472           0,338
12                  15              0,371933      0,00416492    0,0645362           0,228
--------------------------------------------------------------------------------------------
Total               30              0,4147        0,00466539    0,0683037           0,228

Gluten              Máximo          Rango        Asimetría     Asimetría tipi.     Curtosis
--------------------------------------------------------------------------------------------
8                   0,495           0,157        -2,13397      -3,37411            5,4874
12                  0,462           0,234        -0,875415     -1,38415            0,448285
--------------------------------------------------------------------------------------------
Total               0,495           0,267        -1,05786      -2,36545
0,695352

Gluten              Curtosis típificada
--------------------------------------------------------------------------------------------
8                   4,33817
12                  0,3544
--------------------------------------------------------------------------------------------
Total               0,777427

El StatAdvisor
--------------
   Esta tabla muestra varios estadísticos de Moisture Loss para cada
uno de los 2 niveles de Gluten.  El análisis de la varianza simple
está pensado principalmente para comparar las medias de los diferentes
niveles, listados aquí bajo la columna Media.  Seleccione Gráfico de
Medias de la lista de Opciones Gráficas para mostrar gráficamente las
medias.

ADVERTENCIA: La asimetría y/o curtosis estandarizadas esta fuera del
rango de -2 a +2 para los 1 niveles de Gluten.  Esto indica algo de no
normalidad significante en los datos, lo cual viola la asunción de que
los datos proceden de distribuciones normales.  Podría pensar en la
transformación de los datos o utilizar el tests de Kruskal-Wallis para
comparar las medianas en lugar de las medias.


Contraste de Kruskal-Wallis para Moisture Loss según Gluten

Gluten              Tamaño muestral     Rango Promedio
------------------------------------------------------------
8                   15                  21,8667
12                  15                  9,13333
------------------------------------------------------------
Estadístico = 15,6977   P-valor = 0,0000743142
```

- **44% Water Content**

```
Variable dependiente: Moisture Loss
Factor: Gluten

Resumen Estadístico para Moisture Loss

Gluten              Frecuencia      Media           Varianza        Desviación típica
Mínimo
-------------------------------------------------------------------------------------------
8                   15              0,576667        0,00196867      0,0443697         0,492
12                  15              0,550467        0,00362941      0,0602446         0,426
-------------------------------------------------------------------------------------------
Total               30              0,563567        0,00288005      0,0536661         0,426

Gluten              Máximo          Rango           Asimetría tipi.     Curtosis típificada
-------------------------------------------------------------------------------------------
8                   0,62            0,128           -1,76415            -0,130726
12                  0,634           0,208           -0,897841           -0,30202
-------------------------------------------------------------------------------------------
Total               0,634           0,208           -1,92567            -0,11944


Tabla ANOVA para Moisture Loss según Gluten

                            Análisis de la Varianza
-----------------------------------------------------------------------------
Fuente            Sumas de cuad.     Gl  Cuadrado Medio  Cociente-F   P-Valor
-----------------------------------------------------------------------------
Entre grupos           0,0051483      1    0,0051483       1,84       0,1859
Intra grupos           0,0783731     28   0,00279904
-----------------------------------------------------------------------------
Total (Corr.)          0,0835214     29

Contraste Múltiple de Rango para Moisture Loss según Gluten

-------------------------------------------------------------------------------
Método: 95,0 porcentaje Duncan
Gluten         Frec.     Media            Grupos homogéneos
-------------------------------------------------------------------------------
12             15        0,550467         X
8              15        0,576667         X
-------------------------------------------------------------------------------
Contraste                                 Diferencias          +/-  Límites
-------------------------------------------------------------------------------
8 - 12                                    0,0262               0,0395723
-------------------------------------------------------------------------------
* indica una diferencia significativa.
```

Dried simples

```
Resumen del Procedimiento

Variable dependiente: Moisture Loss
Factor: Gluten

Resumen Estadístico para Moisture Loss

Gluten           Frecuencia       Media          Varianza        Desviación típica   Mínimo
-------------------------------------------------------------------------------------------
8                24               0,311917        0,0115216       0,107339           0,186
12               24               0,312833        0,00853936      0,0924087          0,187
-------------------------------------------------------------------------------------------
Total            48               0,312375        0,0098173       0,0990823          0,186

Gluten           Máximo           Rango           Asimetría       Asimetría tipi.  Curtosis
-------------------------------------------------------------------------------------------
8                0,507            0,321           0,742969        1,48594         -0,670644
12               0,533            0,346           0,674246        1,34849          0,451612
-------------------------------------------------------------------------------------------
Total            0,533            0,347           0,696038        1,96869         -0,315851

Gluten              Curtosis típificada
-------------------------------------------------------------------------------------------
8                   -0,670644
12                  0,451612
-------------------------------------------------------------------------------------------
Total               -0,44668

Tabla ANOVA para Moisture Loss según Gluten

                            Análisis de la Varianza
------------------------------------------------------------------------------
Fuente             Sumas de cuad.     Gl  Cuadrado Medio  Cociente-F   P-Valor
------------------------------------------------------------------------------
Entre grupos         0,0000100833      1 0,0000100833       0,00       0,9748
Intra grupos             0,461403     46    0,0100305
------------------------------------------------------------------------------
Total (Corr.)            0,461413     47


Contraste Múltiple de Rango para Moisture Loss según Gluten

--------------------------------------------------------------------------------
Método: 95,0 porcentaje Duncan
Gluten         Frec.     Media             Grupos homogéneos
--------------------------------------------------------------------------------
8              24        0,311917          X
12             24        0,312833          X
--------------------------------------------------------------------------------
Contraste                                  Diferencias
--------------------------------------------------------------------------------
8 - 12                                     -0,000916667
--------------------------------------------------------------------------------
* indica una diferencia significativa.
```

- 38 % Water Content

```
Variable dependiente: Moisture Loss
Factor: Gluten

Resumen Estadístico para Moisture Loss

Gluten           Frecuencia      Media          Varianza        Desviación típica    Mínimo
-------------------------------------------------------------------------------------------
8                12              0,244667       0,00336715      0,0580272           0,186
12               12              0,255667       0,00434624      0,065926            0,187
-------------------------------------------------------------------------------------------
Total            24              0,250167       0,00372058      0,0609966           0,186

Gluten            Máximo          Rango          Asimetría      Asimetría tipi.    Curtosis
-------------------------------------------------------------------------------------------
-----------------------------
8                 0,332           0,146          0,652597       0,922911           -1,37918
12                0,362           0,175          0,632953       0,895131           -1,12005
-------------------------------------------------------------------------------------------
Total             0,362           0,176          0,62888        1,25776            -1,12433

Gluten              Curtosis típificada
-------------------------------------------------------------------------------------------
8                   -0,975229
12                  -0,791997
-------------------------------------------------------------------------------------------
Total               -1,12433


Tabla ANOVA para Moisture Loss según Gluten

                            Análisis de la Varianza
------------------------------------------------------------------------------
Fuente             Sumas de cuad.     Gl  Cuadrado Medio  Cociente-F   P-Valor
------------------------------------------------------------------------------
Entre grupos             0,000726      1     0,000726       0,19       0,6686
Intra grupos            0,0848473     22    0,0038567
------------------------------------------------------------------------------
Total (Corr.)           0,0855733     23

Contraste Múltiple de Rango para Moisture Loss según Gluten

--------------------------------------------------------------------------------
Método: 95,0 porcentaje Duncan
Gluten         Frec.     Media            Grupos homogéneos
--------------------------------------------------------------------------------
8              12        0,244667         X
12             12        0,255667         X
--------------------------------------------------------------------------------
Contraste                                 Diferencias
--------------------------------------------------------------------------------
8 - 12                                    -0,011
--------------------------------------------------------------------------------
* indica una diferencia significativa.
```

- 44 % Water Content

```
Variable dependiente: Moisture Loss
Factor: Gluten

Resumen Estadístico para Moisture Loss

Gluten              Frecuencia      Media           Varianza        Desviación típica
Mínimo
-------------------------------------------------------------------------------------------
8                   3               0,446667        0,00128233          0,0358097
0,425
12                  3               0,324667        0,000702333         0,0265016
0,295
-------------------------------------------------------------------------------------------
Total               6               0,385667        0,00525907          0,0725194
0,295

Gluten              Máximo         Rango         Asimetría     Asimetría tipi.     Curtosis
-------------------------------------------------------------------------------------------
8                   0,488          0,063         1,72597       1,22045
12                  0,346          0,051        -1,2751       -0,901631
-------------------------------------------------------------------------------------------
Total               0,488          0,193         0,196098      0,196098            -1,37232

Gluten              Curtosis típificada
-------------------------------------------------------------------------------------------
8
12
-------------------------------------------------------------------------------------------
Total               -0,686158

Tabla ANOVA para Moisture Loss según Gluten

                            Análisis de la Varianza
------------------------------------------------------------------------------
Fuente             Sumas de cuad.     Gl  Cuadrado Medio  Cociente-F   P-Valor
------------------------------------------------------------------------------
Entre grupos             0,022326      1     0,022326      22,50       0,0090
Intra grupos           0,00396933      4  0,000992333
------------------------------------------------------------------------------
Total (Corr.)           0,0262953      5


Contraste Múltiple de Rango para Moisture Loss según Gluten

--------------------------------------------------------------------------------
Método: 95,0 porcentaje Duncan
Gluten         Frec.     Media             Grupos homogéneos
--------------------------------------------------------------------------------
12             3         0,324667          X
8              3         0,446667           X
--------------------------------------------------------------------------------
Contraste                                  Diferencias
--------------------------------------------------------------------------------
8 - 12                                    *0,122
--------------------------------------------------------------------------------
* indica una diferencia significativa.
```

B.2 Oil Uptake with Gluten content

Undried simples

```
Variable dependiente: Oil Uptake
Factor: Gluten

Resumen Estadístico para Oil Uptake

Gluten          Frecuencia       Media           Varianza        Desviación típica   Mínimo
-------------------------------------------------------------------------------------------
-
8               30               0,502467        0,0162145       0,127336            0,32
12              30               0,430233        0,017803        0,133428            0,26
-------------------------------------------------------------------------------------------
-
Total           60               0,46635         0,018047        0,134339            0,26

Gluten          Máximo          Rango           Asimetría        Asimetría tipi.
Curtosis
-------------------------------------------------------------------------------------------
-
8               0,799           0,479          0,534052         1,19418            -
0,105745
12              0,697           0,437          0,462551         1,03429            -0,77716
-------------------------------------------------------------------------------------------
-
Total           0,799           0,539          0,394823         1,24854            -
0,451256

Gluten              Curtosis típificada
-------------------------------------------------------------------------------------------
-
8                   -0,118227
12                  -0,868892
-------------------------------------------------------------------------------------------
-
Total               -0,713498

Tabla ANOVA para Oil Uptake según Gluten

                            Análisis de la Varianza
------------------------------------------------------------------------------
Fuente             Sumas de cuad.     Gl  Cuadrado Medio  Cociente-F   P-Valor
------------------------------------------------------------------------------
Entre grupos            0,0782648      1    0,0782648       4,60       0,0361
Intra grupos             0,986507     58    0,0170087
------------------------------------------------------------------------------
Total (Corr.)             1,06477     59


Contraste Múltiple de Rango para Oil Uptake según Gluten

--------------------------------------------------------------------------------
Método: 95,0 porcentaje Duncan
Gluten         Frec.     Media             Grupos homogéneos
--------------------------------------------------------------------------------
12             30        0,430233          X
8              30        0,502467           X
--------------------------------------------------------------------------------
Contraste                                  Diferencias
--------------------------------------------------------------------------------
8 - 12                                    *0,0722333
--------------------------------------------------------------------------------
* indica una diferencia significativa.
```

- 38% Water Content

```
Variable dependiente: Oil Uptake
Factor: Gluten

Número de observaciones: 30
Número de niveles: 2

Resumen Estadístico para Oil Uptake

Gluten          Frecuencia      Media           Varianza        Desviación típica   Mínimo
-------------------------------------------------------------------------------------------
-
8               15              0,519           0,0230799       0,151921            0,336
12              15              0,387133        0,0154648       0,124358            0,26
-------------------------------------------------------------------------------------------
-
Total           30              0,453067        0,0231049       0,152003            0,26

Gluten          Máximo          Rango           Asimetría       Asimetría tipi.
Curtosis
-------------------------------------------------------------------------------------------
-
8               0,799           0,463           0,559511        0,884665            -
0,57195
12              0,628           0,368           0,543055        0,858646            -
1,10069
-------------------------------------------------------------------------------------------
-
Total               0,799               0,539               0,605552            1,35405
-0,247529

Gluten              Curtosis típificada
-------------------------------------------------------------------------------------------
-
8                   -0,452166
12                  -0,870176
-------------------------------------------------------------------------------------------
-
Total               -0,276746

Tabla ANOVA para Oil Uptake según Gluten

                            Análisis de la Varianza
------------------------------------------------------------------------------
Fuente             Sumas de cuad.     Gl  Cuadrado Medio  Cociente-F   P-Valor
------------------------------------------------------------------------------
Entre grupos             0,130416      1     0,130416       6,77       0,0147
Intra grupos             0,539626     28    0,0192723
------------------------------------------------------------------------------
Total (Corr.)            0,670042     29

Contraste Múltiple de Rango para Oil Uptake según Gluten

--------------------------------------------------------------------------------
Método: 95,0 porcentaje Duncan
Gluten         Frec.     Media             Grupos homogéneos
--------------------------------------------------------------------------------
12             15        0,387133          X
8              15        0,519              X
--------------------------------------------------------------------------------
Contraste                                  Diferencias
--------------------------------------------------------------------------------
8 - 12                                    *0,131867
--------------------------------------------------------------------------------
* indica una diferencia significativa.
```

-44% Water Content

```
Variable dependiente: Oil Uptake
Factor: Gluten

Número de observaciones: 30
Número de niveles: 2


Resumen Estadístico para Oil Uptake

Gluten          Frecuencia      Media           Varianza         Desviación típica   Mínimo
-------------------------------------------------------------------------------------------
-
8               15              0,485933        0,0099215       0,0996067           0,32
12              15              0,473333        0,0174322       0,132031            0,29
-------------------------------------------------------------------------------------------
-
Total           30              0,479633        0,0132463       0,115093            0,29

Gluten          Máximo         Rango           Asimetría        Asimetría tipi.
Curtosis
-------------------------------------------------------------------------------------------
-
8               0,623           0,303           -0,258159       -0,408185           -
1,54614
12              0,697           0,407            0,483643        0,764706           -
0,89779
-------------------------------------------------------------------------------------------
-
Total               0,697               0,407               0,204131            0,456451
-1,01532

Gluten              Curtosis típificada
-------------------------------------------------------------------------------------------
-
8                   -1,22233
12                  -0,709765
-------------------------------------------------------------------------------------------
-
Total               -1,13516


Tabla ANOVA para Oil Uptake según Gluten

                            Análisis de la Varianza
------------------------------------------------------------------------------
Fuente             Sumas de cuad.     Gl  Cuadrado Medio  Cociente-F   P-Valor
------------------------------------------------------------------------------
Entre grupos            0,0011907      1    0,0011907       0,09       0,7701
Intra grupos             0,382952     28    0,0136769
------------------------------------------------------------------------------
Total (Corr.)            0,384143     29


Contraste Múltiple de Rango para Oil Uptake según Gluten

--------------------------------------------------------------------------------
Método: 95,0 porcentaje Duncan
Gluten         Frec.     Media             Grupos homogéneos
--------------------------------------------------------------------------------
12             15        0,473333          X
8              15        0,485933          X
--------------------------------------------------------------------------------
Contraste                                  Diferencias
--------------------------------------------------------------------------------
8 - 12                                     0,0126
--------------------------------------------------------------------------------
* indica una diferencia significativa.
```

Predried samples

```
Resumen del Procedimiento

Variable dependiente: Oil Uptake
Factor: Gluten

Resumen Estadístico para Oil Uptake

Gluten          Frecuencia      Media           Varianza        Desviación típica   Mínimo
-------------------------------------------------------------------------------------------
-
8               24             0,298875        0,00378559      0,0615272           0,151
12              24             0,212417        0,00303547      0,0550951           0,125
-------------------------------------------------------------------------------------------
-
Total           48             0,255646        0,00524649          0,0724327
0,125

Gluten          Máximo          Rango           Asimetría tipi.   Curtosis típificada
-------------------------------------------------------------------------------------------
-
8               0,404          0,253            -0,947339           -0,104022
12              0,367          0,242            1,72675              1,28293
-------------------------------------------------------------------------------------------
-
Total           0,404          0,279            0,488411            -1,28151


Tabla ANOVA para Oil Uptake según Gluten

                            Análisis de la Varianza
------------------------------------------------------------------------------
Fuente             Sumas de cuad.     Gl  Cuadrado Medio  Cociente-F   P-Valor
------------------------------------------------------------------------------
Entre grupos            0,0897005      1    0,0897005      26,30       0,0000
Intra grupos             0,156884     46   0,00341053
------------------------------------------------------------------------------
Total (Corr.)            0,246585     47

Contraste Múltiple de Rango para Oil Uptake según Gluten

--------------------------------------------------------------------------------
Método: 95,0 porcentaje LSD
Gluten         Frec.     Media             Grupos homogéneos
--------------------------------------------------------------------------------
12             24        0,212417          X
8              24        0,298875           X
--------------------------------------------------------------------------------
Contraste                                  Diferencias         +/-  Límites
--------------------------------------------------------------------------------
8 - 12                                    *0,0864583           0,0339346
--------------------------------------------------------------------------------
* indica una diferencia significativa.
```

- 38% Water Content

```
Variable dependiente: Oil Uptake
Factor: Gluten

Número de observaciones: 24
Número de niveles: 2


Resumen Estadístico para Oil Uptake

Gluten          Frecuencia      Media           Varianza        Desviación típica   Mínimo
-------------------------------------------------------------------------------------------
-
8               12             0,339917        0,00135627       0,0368275           0,281
12              12             0,229583        0,00357481       0,0597897           0,163
-------------------------------------------------------------------------------------------
-
Total           24             0,28475         0,00553402       0,074391            0,163

Gluten          Máximo         Rango           Asimetría       Asimetría tipi.     Curtosis
-------------------------------------------------------------------------------------------
-
8               0,404          0,123           0,0170812       0,0241565           -
0,928334
12              0,367          0,204           1,09211         1,54447             1,2466
-------------------------------------------------------------------------------------------
-
Total           0,404          0,241          -0,217904       -0,435808           -1,21011

Gluten              Curtosis típificada
-------------------------------------------------------------------------------------------
8                   -0,656431
12                  0,881477
-------------------------------------------------------------------------------------------
-
Total               -1,21011


Tabla ANOVA para Oil Uptake según Gluten

                            Análisis de la Varianza
------------------------------------------------------------------------------
Fuente             Sumas de cuad.     Gl  Cuadrado Medio  Cociente-F   P-Valor
------------------------------------------------------------------------------
Entre grupos            0,0730407      1    0,0730407      29,62       0,0000
Intra grupos            0,0542418     22   0,00246554
------------------------------------------------------------------------------
Total (Corr.)            0,127282     23


Contraste Múltiple de Rango para Oil Uptake según Gluten

--------------------------------------------------------------------------------
Método: 95,0 porcentaje Duncan
Gluten         Frec.     Media             Grupos homogéneos
--------------------------------------------------------------------------------
12             12        0,229583          X
8              12        0,339917           X
--------------------------------------------------------------------------------
Contraste                                  Diferencias
--------------------------------------------------------------------------------
8 - 12                                    *0,110333
--------------------------------------------------------------------------------
* indica una diferencia significativa.
```

- **44% Water Content**

```
Variable dependiente: Oil Uptake
Factor: Gluten

Número de observaciones: 24
Número de niveles: 2


Resumen Estadístico para Oil Uptake

Gluten          Frecuencia      Media           Varianza        Desviación típica   Mínimo
-------------------------------------------------------------------------------------------
-
8               12              0,257833        0,00288397      0,0537026           0,151
12              12              0,19525         0,00212911      0,0461423           0,125
-------------------------------------------------------------------------------------------
-
Total           24              0,226542        0,0034193       0,0584748           0,125

Gluten          Máximo          Rango           Asimetría       Asimetría tipi.
Curtosis
-------------------------------------------------------------------------------------------
-
8               0,345           0,194          -0,186494       -0,263742           0,227991
12              0,276           0,151           0,0949811       0,134324          -0,987821
-------------------------------------------------------------------------------------------
-
Total           0,345           0,22            0,142393        0,284786         -0,461644

Gluten              Curtosis típificada
-------------------------------------------------------------------------------------------
-
8                   0,161214
12                  -0,698495
-------------------------------------------------------------------------------------------
-
Total               -0,461644


Tabla ANOVA para Oil Uptake según Gluten

                            Análisis de la Varianza
------------------------------------------------------------------------------
Fuente             Sumas de cuad.     Gl  Cuadrado Medio  Cociente-F   P-Valor
------------------------------------------------------------------------------
Entre grupos               0,0235      1       0,0235       9,38       0,0057
Intra grupos            0,0551439     22   0,00250654
------------------------------------------------------------------------------
Total (Corr.)            0,078644     23

Contraste Múltiple de Rango para Oil Uptake según Gluten

--------------------------------------------------------------------------------
Método: 95,0 porcentaje Duncan
Gluten         Frec.     Media             Grupos homogéneos
--------------------------------------------------------------------------------
12             12        0,19525           X
8              12        0,257833           X
--------------------------------------------------------------------------------
Contraste                                  Diferencias
--------------------------------------------------------------------------------
8 - 12                                    *0,0625833
--------------------------------------------------------------------------------
* indica una diferencia significativa.
```

B.3 Oil Uptake with Product Thickness

Undried Samples

```
Resumen del Procedimiento

Variable dependiente: Oil Uptake
Factor: Grosor

Resumen Estadístico para Oil Uptake

Grosor            Frecuencia    Media        Varianza           Desviación típica   Mínimo
-------------------------------------------------------------------------------------------
1                 24            0,586875     0,00845881          0,0919718          0,469
2                 36            0,386        0,00826194          0,0908952          0,26
-----------------------------------------------------------------------------------------
Total               60            0,46635      0,018047            0,134339           0,26

Grosor              Máximo      Rango       Asimetría     Asimetría tipi.     Curtosis
-------------------------------------------------------------------------------------------
1                   0,799       0,33        0,837639      1,67528             0,388153
2                   0,58        0,32        0,679542      1,66453             -0,181612
-------------------------------------------------------------------------------------------
Total               0,799               0,539               0,394823            1,24854
-0,451256

Grosor              Curtosis típificada
-------------------------------------------------------------------------------------------
1                   0,388153
2                   -0,222428
-------------------------------------------------------------------------------------------
Total               -0,713498

Tabla ANOVA para Oil Uptake según Grosor

                            Análisis de la Varianza
-----------------------------------------------------------------------------
Fuente             Sumas de cuad.     Gl  Cuadrado Medio  Cociente-F   P-Valor
-----------------------------------------------------------------------------
Entre grupos             0,581051      1     0,581051      69,67       0,0000
Intra grupos             0,483721     58   0,00834001
-----------------------------------------------------------------------------
Total (Corr.)             1,06477     59


Contraste Múltiple de Rango para Oil Uptake según Grosor

--------------------------------------------------------------------------------
Método: 95,0 porcentaje Duncan
Grosor         Frec.     Media             Grupos homogéneos
--------------------------------------------------------------------------------
2              36        0,386             X
1              24        0,586875           X
--------------------------------------------------------------------------------
Contraste                                  Diferencias
--------------------------------------------------------------------------------
1 - 2                                     *0,200875
--------------------------------------------------------------------------------
* indica una diferencia significativa.
```

Predried Samples

```
Variable dependiente: Oil Uptake
Factor: Grosor

Resumen Estadístico para Oil Uptake

Grosor          Frecuencia      Media           Varianza         Desviación típica   Mínimo
-------------------------------------------------------------------------------------------
1               24             0,267625         0,0054419        0,0737692           0,149
2               24             0,243667         0,00497971       0,0705671           0,125
-------------------------------------------------------------------------------------------
Total           48             0,255646         0,00524649       0,0724327           0,125

Grosor          Máximo          Rango           Asimetría        Asimetría tipi.   Curtosis
------------------------------------------------------------------------------------------
1               0,404          0,255            0,284613         0,569226         -0,976428
2               0,365          0,24             0,0222375        0,044475         -1,13748
-------------------------------------------------------------------------------------------
Total           0,404          0,279            0,172679         0,488411         -0,906164

Grosor              Curtosis típificada
-------------------------------------------------------------------------------------------
1                   -0,976428
2                   -1,13748
------------------------------------------------------------------------------------------
Total               -1,28151


Tabla ANOVA para Oil Uptake según Grosor

                            Análisis de la Varianza
------------------------------------------------------------------------------
Fuente             Sumas de cuad.     Gl  Cuadrado Medio  Cociente-F   P-Valor
------------------------------------------------------------------------------
Entre grupos           0,00688802      1   0,00688802       1,32       0,2562
Intra grupos             0,239697     46    0,0052108
------------------------------------------------------------------------------
Total (Corr.)            0,246585     47

Contraste Múltiple de Rango para Oil Uptake según Grosor

--------------------------------------------------------------------------------
Método: 95,0 porcentaje Duncan
Grosor         Frec.     Media             Grupos homogéneos
--------------------------------------------------------------------------------
2              24        0,243667          X
1              24        0,267625          X
--------------------------------------------------------------------------------
Contraste                                  Diferencias
--------------------------------------------------------------------------------
1 - 2                                      0,0239583
--------------------------------------------------------------------------------
* indica una diferencia significativa.
```

B.4 Oil Uptake with Pretreatment

```
Variable dependiente: Oil Uptake
Factor: Con Secado

Número de observaciones: 108
Número de niveles: 2


Resumen Estadístico para Oil Uptake

Con Secado      Frecuencia      Media          Varianza         Desviación típica   Mínimo
-------------------------------------------------------------------------------------------
-
0               60              0,46635        0,018047          0,134339            0,26
1               48              0,255646       0,00524649        0,0724327           0,125
-------------------------------------------------------------------------------------------
-
Total           108             0,372704       0,0233202         0,152709            0,125

Con Secado      Máximo          Rango          Asimetría        Asimetría tipi.
Curtosis
-------------------------------------------------------------------------------------------
-
0               0,799          0,539          0,394823         1,24854             -
0,451256
1               0,404          0,279          0,172679         0,488411            -
0,906164
-------------------------------------------------------------------------------------------
-
Total           0,799          0,674          0,64807          2,74953             -
0,203188

Con Secado          Curtosis típificada
-------------------------------------------------------------------------------------------
-
0                   -0,713498
1                   -1,28151
-------------------------------------------------------------------------------------------
Total               -0,431028


Contraste de Varianza

Contraste C de Cochran: 0,774766   P-valor = 0,0000139152

El StatAdvisor
--------------
   Dado que el p-valor es inferior a 0,05, hay diferencia
estadísticamente significativa entre las desviaciones
típicas para un nivel de confianza del 95,0%. Esto infringe
una de las asunciones importantes que subyacen en el
análisis de la varianza e invalidará la mayoría de los tests
estadísticos estándar.


Contraste de Kruskal-Wallis para Oil Uptake según Con Secado

Con Secado          Tamaño muestral     Rango Promedio
------------------------------------------------------------
0                   60                  74,8083
1                   48                  29,1146
------------------------------------------------------------
Estadístico = 56,7592   P-valor = 0,0
```

B5. ΔE with water content, gluten content and pretreatment

With Water Content

```
Variable dependiente: dE
Factor: Agua

Número de observaciones: 202
Número de niveles: 2

Resumen Estadístico para dE

Agua            Frecuencia     Media          Varianz        Desviación típica   Mínimo
-------------------------------------------------------------------------------------------
38              92            10,9519         96,2409         9,81024             0,735923
44              110            7,74644        59,0787         7,68627             0,516412
-------------------------------------------------------------------------------------------
-
Total           202            9,20634        78,1704         8,8414              0,516412

Agua            Máximo         Rango          Asimetría       Asimetría tipi.     Curtosis
-------------------------------------------------------------------------------------------
-
38             40,8993        40,1633         1,47929         5,79258             1,53466
44             39,1194        38,603          1,95977         8,39125             3,80639
-------------------------------------------------------------------------------------------
-
Total          40,8993        40,3828         1,72584        10,0138              2,57095

Agua                Curtosis típificada
-------------------------------------------------------------------------------------------
-
38                  3,00469
44                  8,149
-------------------------------------------------------------------------------------------
Total               7,45872


Contraste de Varianza

Contraste C de Cochran: 0,619631   P-valor = 0,0154377

Contraste de Kruskal-Wallis para dE según Agua

Agua                Tamaño muestral     Rango Promedio
------------------------------------------------------------
38                  92                  114,293
44                  110                 90,8
------------------------------------------------------------
Estadístico = 8,09203   P-valor = 0,00444473
```

With Gluten Content

```
Variable dependiente: dE
Factor: Gluten


Resumen Estadístico para dE

Gluten          Frecuencia       Media          Varianza         Desviación típica   Mínimo
-------------------------------------------------------------------------------------------
-
8               92              10,6329         80,8997          8,99443
1,90342
12              110             8,01325         73,4549          8,57058
0,516412
-------------------------------------------------------------------------------------------
-
Total          202              9,20634         78,1704          8,8414
0,516412

Gluten          Máximo           Rango          Asimetría       Asimetría tipi.
Curtosis
-------------------------------------------------------------------------------------------
-
8              40,8993          38,9958         2,06676          8,09298
3,89965
12            35,7088           35,1924         1,49275          6,39157
1,13532
-------------------------------------------------------------------------------------------
Total         40,8993          40,3828         1,72584          10,0138             2,57095

Gluten              Curtosis típificada
-------------------------------------------------------------------------------------------
8                   7,63508
12                  2,43056
-------------------------------------------------------------------------------------------
-
Total               7,45872


Contraste de Varianza

Contraste C de Cochran: 0,524116   P-valor = 0,630234

Contraste de Kruskal-Wallis para dE según Gluten

Gluten              Tamaño muestral     Rango Promedio
------------------------------------------------------------
8                   92                  120,783
12                  110                 85,3727
------------------------------------------------------------
Estadístico = 18,3828   P-valor = 0,0000180683
```

With Pretreatment

```
Variable dependiente: dE
Factor: Con Secado

Resumen Estadístico para dE

Con Secado      Frecuencia      Media          Varianza        Desviación típica   Mínimo
-------------------------------------------------------------------------------------------
0               202             9,20634        78,1704         8,8414              0,516412
1               145            15,0188         134,653         11,604              2,18857
-------------------------------------------------------------------------------------------
Total          347            11,6352         109,694         10,4735             0,516412

Con Secado      Máximo          Rango         Asimetría        Asimetría tipi.     Curtosis
-------------------------------------------------------------------------------------------
0              40,8993         40,3828        1,72584          10,0138             2,57095
1              45,1888         43,0002        1,33393          6,55756             0,522613
-------------------------------------------------------------------------------------------
Total          45,1888         44,6724        1,56479         11,9                1,68826

Con Secado          Curtosis típificada
-------------------------------------------------------------------------------------------
0                   7,45872
1                   1,28457
------------------------------------------------------------------------------------------
Total               6,41947

Contraste de Varianza

Contraste C de Cochran: 0,632698   P-valor = 0,000393497

Contraste de Kruskal-Wallis para dE según Con Secado

Con Secado          Tamaño muestral     Rango Promedio
------------------------------------------------------------
0                   202                 144,064
1                   145                 215,703
------------------------------------------------------------
Estadístico = 43,049   P-valor = 5,33873E-11
```

B. 6 Expansion development with water content, gluten content

With Water Content

```
Resumen del Procedimiento

Variable dependiente: H
Factor: Agua

Número de observaciones: 182
Número de niveles: 2


Resumen Estadístico para H

Agua           Frecuencia     Media       Varianza            Desviación típica   Mínimo
----------------------------------------------------------------------------------------
38             83              1,02349       0,232277            0,481951            0,3
44             99              1,38737       0,272773            0,522276            0,2
-------------------------------------------------------------------------------------------
-
Total         182             1,22143        0,285947            0,53474             0,2

Agua           Máximo         Rango         Asimetría           Asimetría tipi.
Curtosis
-------------------------------------------------------------------------------------------
-
38            1,9              1,6        -0,00836073         -0,0310962          -1,20345
44            2,4              2,2        -0,400394           -1,62641            -
0,684229
-------------------------------------------------------------------------------------------
-
Total         2,4              2,2       -0,136827           -0,753584           -0,961942

Agua                Curtosis típificada
-------------------------------------------------------------------------------------------
38                  -2,238
44                  -1,38968
-----------------------------------------------------------------------------------------
Total               -2,64898


Contraste de Varianza

Contraste C de Cochran: 0,540091   P-valor = 0,44738


Contraste de Kruskal-Wallis para H según Agua

Agua                Tamaño muestral     Rango Promedio
------------------------------------------------------------
38                  83                  71,8434
44                  99                  107,98
------------------------------------------------------------
Estadístico = 21,3128   P-valor = 0,00000390124
```

With Gluten Content

```
Variable dependiente: H
Factor: Gluten

Número de observaciones: 182
Número de niveles: 2


Resumen Estadístico para H

Gluten         Frecuencia      Media          Varianza       Desviación típica   Mínimo
-------------------------------------------------------------------------------------------
-
8              82              0,851829       0,21725         0,466101            0,2
12             100             1,5245         0,139116        0,372982            0,6
-------------------------------------------------------------------------------------------
-
Total          182            1,22143         0,285947        0,53474             0,2

Gluten         Máximo          Rango          Asimetría      Asimetría tipi.     Curtosis
-------------------------------------------------------------------------------------------
-
8              1,9            1,7             0,572831        2,11767             -0,966681
12             2,4            1,8             0,00335259      0,0136869           -0,517338
-------------------------------------------------------------------------------------------
-
Total         2,4             2,2            -0,136827       -0,753584           -0,961942

Gluten              Curtosis típificada
-------------------------------------------------------------------------------------------
-
8                   -1,78684
12                  -1,05601
-------------------------------------------------------------------------------------------
-
Total               -2,64898


Contraste de Varianza

Contraste C de Cochran: 0,609626   P-valor = 0,0357413


Contraste de Kruskal-Wallis para H según Gluten

Gluten              Tamaño muestral     Rango Promedio
------------------------------------------------------------
8                   82                  56,3415
12                  100                 120,33
------------------------------------------------------------
Estadístico = 66,6891   P-valor = 0,0
```

APPENDIX C: COLOR COORDINATES DEVELOPMENT

C.1 Lightness (L*)

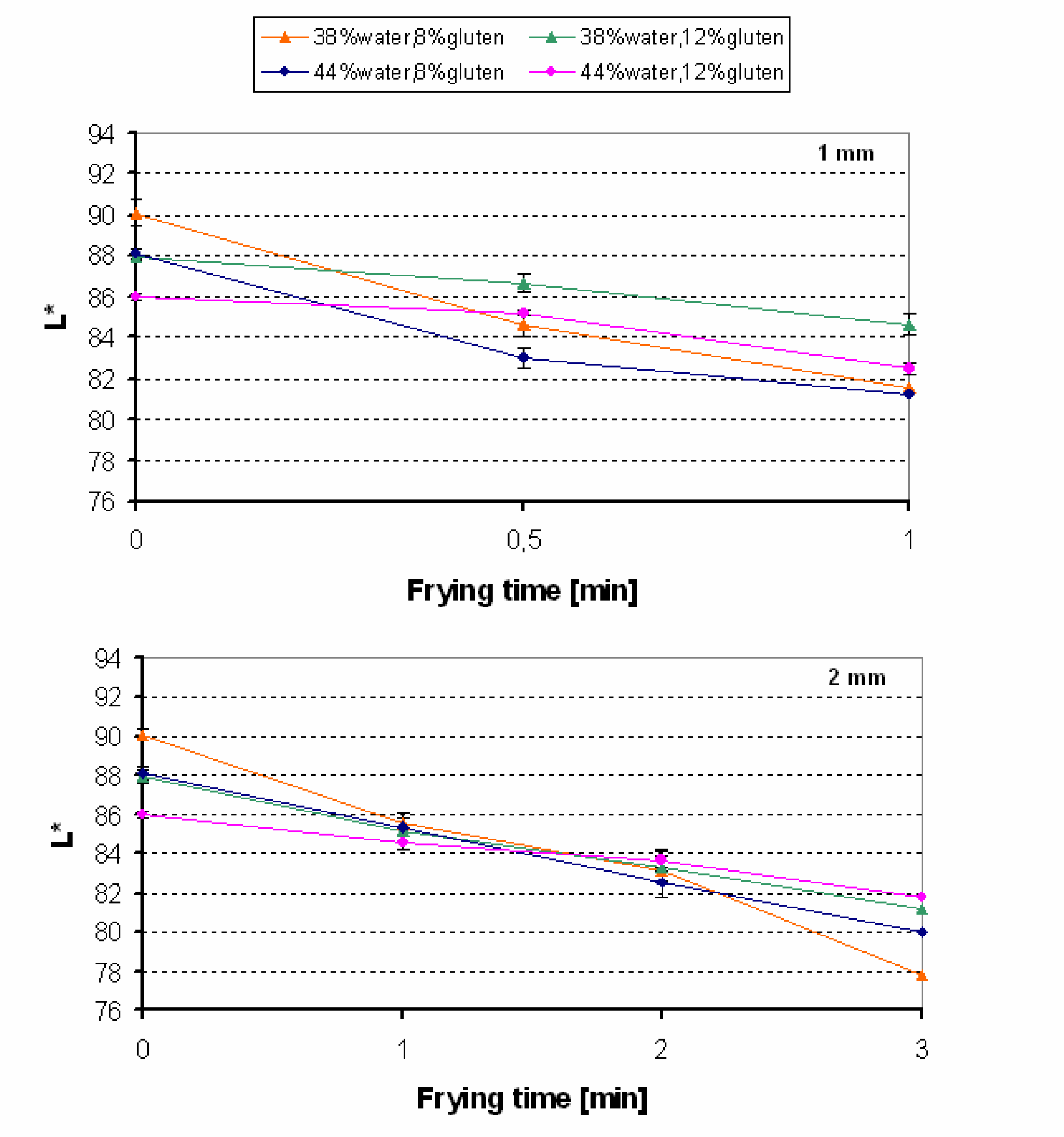


Figure C.1: L* when frying 1mm and 2mm thickness discs for increasing frying times. Points are means ± standard error.

C.2 Red-Green chromaticity (a*)

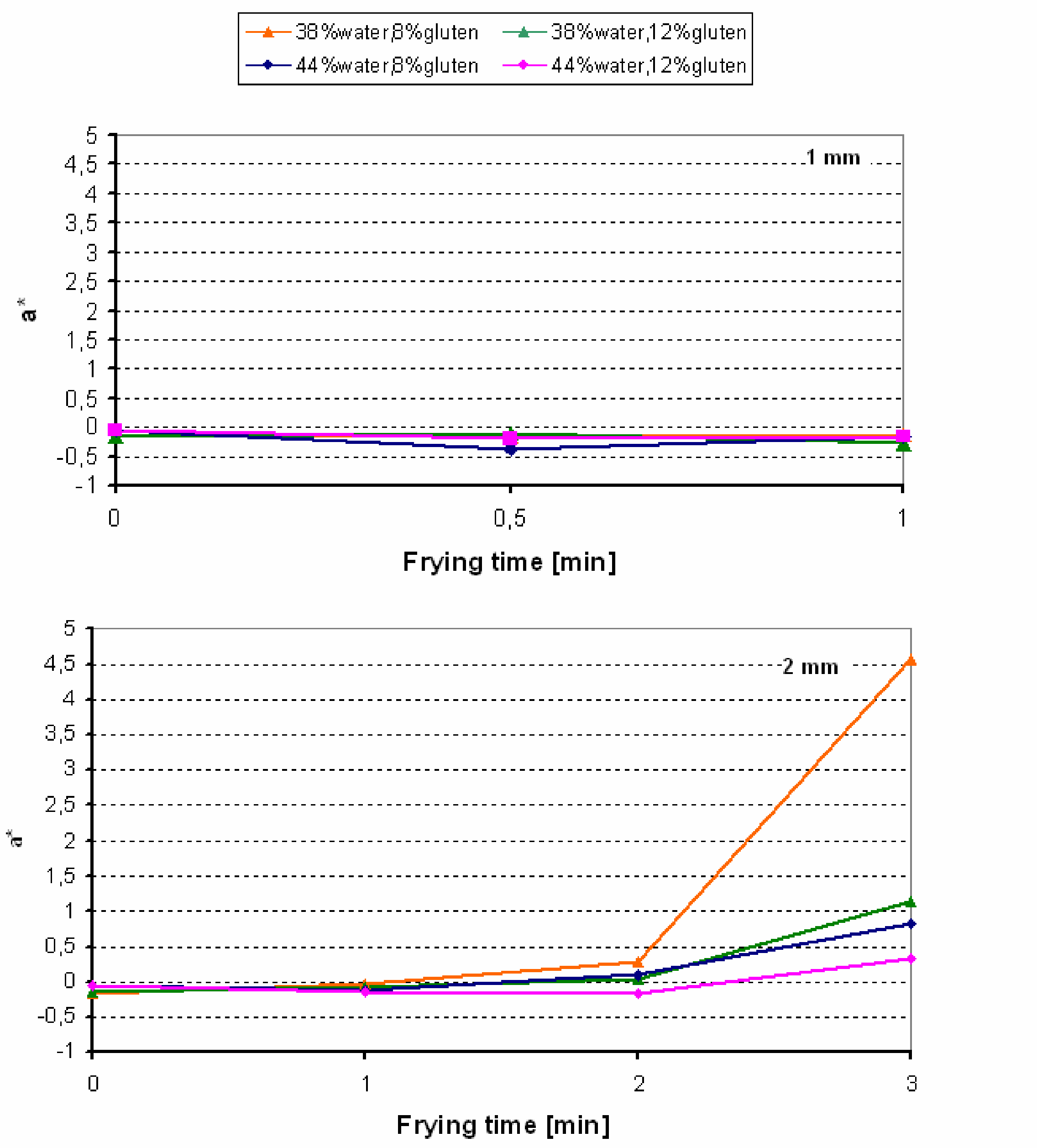


Figure C.2: a* when frying 1mm and 2mm thickness discs for increasing frying times. Points are means ± standard error.

C.3 Yellow-blue chromaticity (b*)

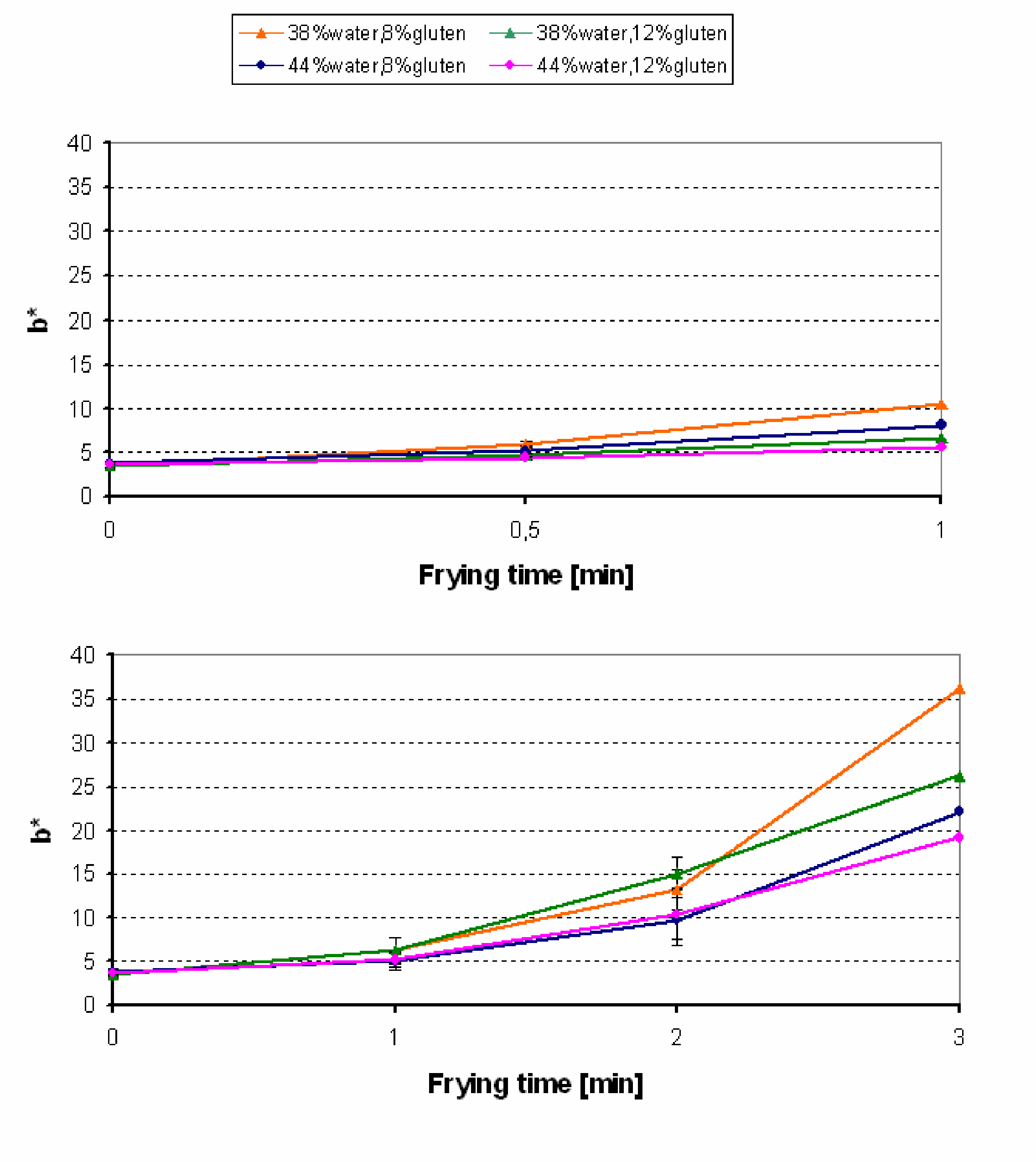


Figure C.3: b* when frying 1mm and 2mm thickness discs for increasing frying times. Points are means ± standard error.

APPENDIX D: DETAIL OF OIL UPTAKE AND MOISTURE LOSS RESULTS

D.1 Moisture loss results for undried and predried samples

MOISTURE LOSS

UNDRIED

grosor: 1 mm | **grosor: 2 mm**

gluten:8%; water:38%

Frying Time	1°	2°	3°	Mean	Frying Time	1°	2°	3°	Mean
0,5	0,433	0,471	0,474	**0,459**	1,0	0,447	0,429	0,338	**0,405**
1,0	0,476	0,466	0,472	**0,471**	2,0	0,480	0,491	0,426	**0,466**
					3,0	0,480	0,484	0,495	**0,487**

gluten:8%; water:44%

Frying Time	1°	2°	3°	Mean	Frying Time	1°	2°	3°	Mean
0,5	0,612	0,589	0,508	**0,569**	1,0	0,492	0,496	0,551	**0,513**
1,0	0,611	0,593	0,591	**0,598**	2,0	0,618	0,567	0,602	**0,596**
					3,0	0,620	0,595	0,605	**0,606**

gluten:12%; water:38%

Frying Time	1°	2°	3°	Mean	Frying Time	1°	2°	3°	Mean
0,5	0,363	0,394	0,419	**0,392**	1,0	0,228	0,267	0,329	**0,275**
1,0	0,412	0,443	0,462	**0,439**	2,0	0,333	0,337	0,394	**0,354**
					3,0	0,367	0,407	0,424	**0,399**

gluten:12%; water:44%

Frying Time	1°	2°	3°	Mean	Frying Time	1°	2°	3°	Mean
0,5	0,512	0,560	0,542	**0,538**	1,0	0,471	0,480	0,426	**0,459**
1,0	0,614	0,616	0,608	**0,613**	2,0	0,512	0,571	0,553	**0,545**
					3,0	0,590	0,634	0,568	**0,597**

PREDRIED

grosor: 1 mm | **grosor: 2 mm**

gluten:8%; water:38%

Frying Time	1°	2°	3°	Mean	Frying Time	1°	2°	3°	Mean
0,5	0,205	0,192	0,186	**0,194**	1,0	0,190	0,272	0,269	**0,244**
1,0	0,205	0,213	0,216	**0,211**	3,0	0,330	0,332	0,326	**0,330**

gluten:8%; water:44%

Frying Time	1°	2°	3°	Mean	Frying Time	1°	2°	3°	Mean
0,5	0,261	0,281	0,267	**0,270**	1,0	0,427	0,425	0,488	**0,447**
1,0	0,303	0,292	0,295	**0,297**	3,0	0,501	0,507	0,503	**0,504**

gluten:12%; water:38%

Frying Time	1°	2°	3°	Mean	Frying Time	1°	2°	3°	Mean
0,5	0,264	0,247	0,192	**0,234**	1,0	0,266	0,263	0,187	**0,239**
1,0	0,277	0,292	0,235	**0,268**	3,0	0,362	0,360	0,362	**0,362**

gluten:12%; water:44%

Frying Time	1°	2°	3°	Mean	Frying Time	1°	2°	3°	Mean
0,5	0,282	0,320	0,322	**0,308**	1,0	0,295	0,333	0,346	**0,325**
1,0	0,358	0,354	0,355	**0,356**	3,0	0,506	0,436	0,533	**0,492**

D.2 Oil uptake results for undried and predried samples

OIL UPTAKE

UNDRIED

gluten:8%; water:38%

grosor: 1 mm					grosor: 2 mm				
Frying Time	**1°**	**2°**	**3°**	**Mean**	**Frying Time**	**1°**	**2°**	**3°**	**Mean**
0,5	0,641	0,593	0,535	**0,590**	1,0	0,395	0,372	0,336	**0,368**
1,0	0,799	0,792	0,602	**0,731**	2,0	0,555	0,340	0,365	**0,420**
					3,0	0,576	0,447	0,437	**0,487**

gluten:8%; water:44%

Frying Time	**1°**	**2°**	**3°**	**Mean**	**Frying Time**	**1°**	**2°**	**3°**	**Mean**
0,5	0,521	0,566	0,557	**0,548**	1,0	0,401	0,320	0,359	**0,360**
1,0	0,597	0,560	0,623	**0,593**	2,0	0,580	0,413	0,397	**0,463**
					3,0	0,555	0,380	0,460	**0,465**

gluten:12%; water:38%

Frying Time	**1°**	**2°**	**3°**	**Mean**	**Frying Time**	**1°**	**2°**	**3°**	**Mean**
0,5	0,481	0,494	0,475	**0,483**	1,0	0,261	0,260	0,265	**0,262**
1,0	0,628	0,470	0,563	**0,554**	2,0	0,302	0,299	0,292	**0,297**
					3,0	0,316	0,434	0,267	**0,339**

gluten:12%; water:44%

Frying Time	**1°**	**2°**	**3°**	**Mean**	**Frying Time**	**1°**	**2°**	**3°**	**Mean**
0,5	0,536	0,541	0,469	**0,515**	1,0	0,290	0,329	0,327	**0,315**
1,0	0,697	0,681	0,664	**0,681**	2,0	0,444	0,413	0,385	**0,414**
					3,0	0,408	0,539	0,377	**0,441**

PREDRIED

gluten:8%; water:38%

grosor: 1 mm					grosor: 2 mm				
Frying Time	**1°**	**2°**	**3°**	**Mean**	**Frying Time**	**1°**	**2°**	**3°**	**Mean**
0,5	0,367	0,343	0,363	**0,358**	1,0	0,281	0,308	0,301	**0,297**
1,0	0,315	0,404	0,374	**0,364**	3,0	0,365	0,350	0,308	**0,341**

gluten:8%; water:44%

Frying Time	**1°**	**2°**	**3°**	**Mean**	**Frying Time**	**1°**	**2°**	**3°**	**Mean**
0,5	0,276	0,259	0,212	**0,249**	1,0	0,233	0,309	0,151	**0,231**
1,0	0,261	0,327	0,228	**0,272**	3,0	0,345	0,270	0,223	**0,279**

gluten:12%; water:38%

Frying Time	**1°**	**2°**	**3°**	**Mean**	**Frying Time**	**1°**	**2°**	**3°**	**Mean**
0,5	0,174	0,232	0,237	**0,215**	1,0	0,166	0,213	0,184	**0,188**
1,0	0,228	0,278	0,367	**0,291**	3,0	0,220	0,163	0,293	**0,225**

gluten:12%; water:44%

Frying Time	**1°**	**2°**	**3°**	**Mean**	**Frying Time**	**1°**	**2°**	**3°**	**Mean**
0,5	0,149	0,157	0,222	**0,176**	1,0	0,170	0,125	0,146	**0,147**
1,0	0,190	0,220	0,240	**0,217**	3,0	0,212	0,236	0,276	**0,242**