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The Properties of Potato Snacks Influenced by the Frying Medium

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ABSTRACT

Potato products, such as French fries and chips are very popular due to their flavour, aroma and other sensory properties, which to a large extent depend on the frying process affecting the colour, taste and texture of the product. The oil used for frying is absorbed by the product and thus becomes its ingredient, which plays a significant qualitative role. The quantity of the absorbed fat is found within the range of 20-45% and its impact on the properties of the product is enormous. The type and quality of the frying medium influence the fat content and texture of the finished product. Besides, the parameters of the frying process and the type of oil influence the formation of acrylamide in subsequent products, which has an adverse effect on their quality. The type and the quality of the frying medium also affect the shelf-life of potato products. The changes due to storage are primarily connected with fat degradation, reducing flavour and odor of potato products (French fries and chips) as well as their moisture content, affecting the texture.

Keywords: acrylamide content, fat uptake, frying, potato chips, snacks, texture

CONTENTS

CHARACTERISTIC OF FRIED POTATO SNACK PRODUCTS

Fried potato products include French fries, chips and snacks. Although the production technologies used for their manufacturing vary, all of them exhibit similar sensory properties, typical of these products, such as crispy and delicate texture and oily-potato flavour and aroma.

The term 'French fries' is used for potato strips, over 6 cm long, the cross-section of which is usually 1 × 1 cm or 0.7 × 0.7 cm. In the UK, the same product is referred to as 'chips'. The French fries manufactured on an industrial scale and available on the market, can be divided into three types:

- fried and frozen, ready for consumption after heating in an oven or a microwave;
- pre-fried (after one stage of frying) and frozen, which need further frying (second stage of frying) in hot oil;
- pre-fried (after one stage of frying) and refrigerated, of short shelf-life, which need further frying in hot oil before eating (Lisińska and Leszczyński 1989).

The process of French fries manufacturing is divided into the following stages: potato washing, cutting, blanching, pre-drying, frying stage I, cooling, freezing or refrigeration, frying stage II (**Fig. 1**). Irrespective of the technology used for French fries production, the finished product should be light golden in colour, with no discoloration and regular in shape. The external surface must be crispy and delicate, while the internal portion should be mealy, firmly sticking to the skin (Lisińska and Leszczyński 1989).

The term 'chips' is used for thin potato slices (1.0-1.7 mm thick) fried in oil to the moisture content below 2%. The production technology for chips is relatively simple and comprises the following stages: potato washing, peeling, slicing, frying, spicing and packaging (**Fig. 2**). The length of time from potato peeling to packaging of chips is barely half an hour (Lisińska and Leszczyński 1989; Yee *et al.* 2007).

Snacks are potato products obtained from ready-made semi-products, which need further frying. These semi-products, referred to as 'pellets', are obtained by blending a variety of ingredients (dehydrated potato, potato starch and wheat flour) in a process of extrusion performed at 60-80°C. Throughout frying, the pellets are expanding (expansion is from 3- to 5-fold), so that a crispy texture is developed. The moisture content of snacks is below 4.5%. Their flavour and aroma depend on the ingredients and spices (Banks and Lusas 2002).

Table 1 Temperature and frying time of potato products (Lisińska and Leszczyński 1989; Gupta *et al.* 2004).

	Temperature (°C)	Frying time
French fries (fried)	175-180	3-5 minutes
French fries (pre-fried)	175-180	1 minut
Potato chips	175-185	3-5 minutes
Potato snacks	185	6-10 seconds

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Invited Mini-Review

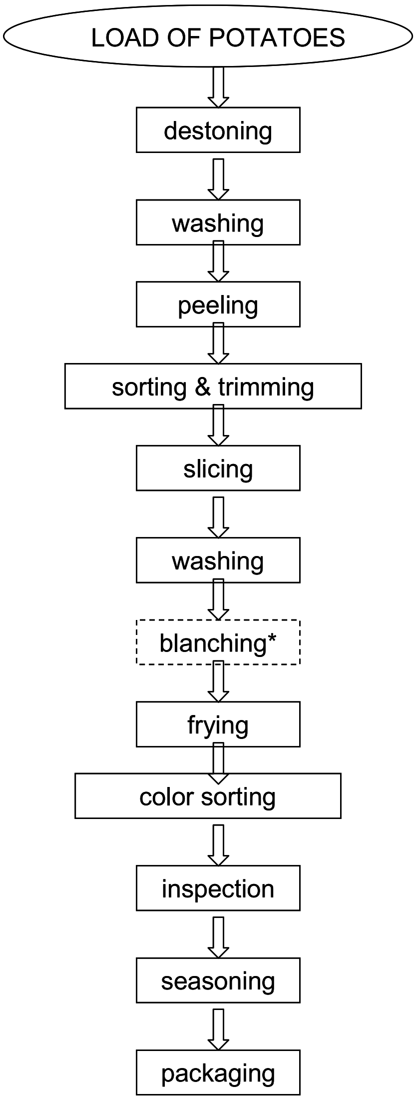

Fig. 1 Flow sheet of potato chips processing (*optional). Based on Gould (2002) and Lisińska and Leszczyński (1989).

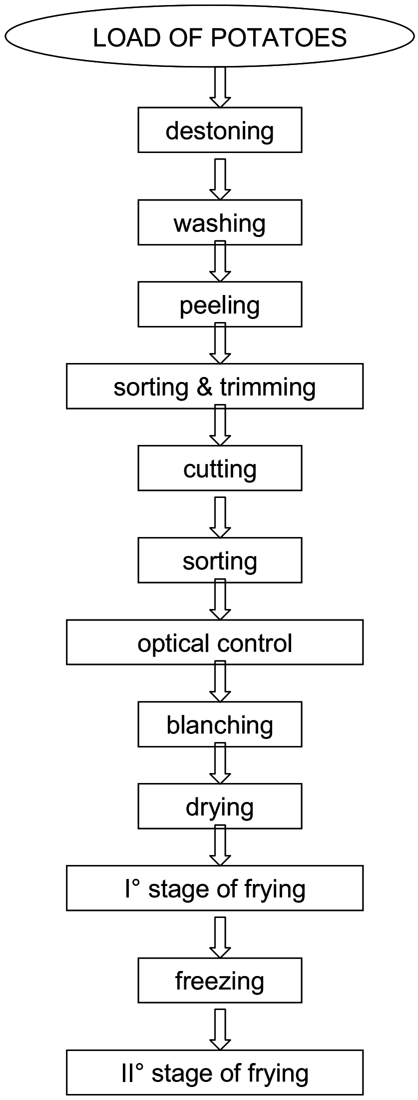

Fig. 2 Flow sheet of French fries processing. Based on Lisińska and Leszczyński (1989).

The properties, characteristic of all these products, are enhanced, primarily during frying, although the length of time and parameters of the process vary (**Table 1**).

FRYING OF POTATO SNACKS

Frying of potato products is one of the most common methods used in food processing, either at home or in restaurants and food industry. It has become so popular because it is not as time consuming as cooking or baking, let alone, palatability of fried potato products. Frying changes the colour of potatoes into golden-yellow and develops characteristic flavour and aroma as well as crispy texture resulting from the loss of moisture of the outer surface of the product.

Frying is the immersing and cooking of foods in hot oil. The process is complex and involves many factors, some of which are dependent on the process itself, and the others on the food and the type of fat used. Basically, frying is a dehydration process with three distinctive characteristics as: high oil temperature (usually 160-180°C) which enables rapid heat transfer and a short cooking time; law product temperature (except for the crust region) which does not exceed 100°C; minimal leaching of water-soluble compounds (Saguy *et al*. 2003; Kochhar and Gertz 2004).

Both vegetable and animal fat and oils can be used as frying media. Vegetable, liquid oils are most frequently used for deep frying. The type of oil/fat depends to a large extent, on local habits and availability of the product. The majority of refined oils have no flavour and aroma, but cotton and arachide oils are exceptions, which give a specific nut aroma to the frying product (Banks and Lusas 2002). The latter two are very popular in the US, while sunflower and rapeseed oils are commonly used in Europe. Since most vegetable oils are high in unsaturated fatty acids, they are prone to thermooxidative changes, which occur mainly and much faster in oils high in polyunsaturated fatty acids (PUFAs) than in oils containing high amounts of monounsaturated fatty acids (MUFAs). Linoleic acid is oxidized 40-times faster than oleinic acid and for this reason, many countries have introduced limitations in its content of oils to < 2%) (Brinkmann 2000). The presence of PUFAs in oils can be reduced and even eliminated by hydrogenation of frying processes, whereby, apart from the desired saturation of some double bonds, also the occurrence of *trans* isomers is observed, which is undesired in food products. For this reason, for several years, a tendency to reduce the use of hydrogenated oils has been observed. As a consequence, the permissive level of *trans* isomers in edible oils has been limited to 2% (Timms 2004). However, no hydrogenation in the production of frying oils requires substitution for the oils used so far. One of the solutions to this problem can be seen in the studies of genetically modified crops containing oil with a programmed content of fatty acids, high in oleinic acid, but low in PUFAs, especially linoleic acid. The results of these studies have already been used by oil industries, and as a consequence, new soya, sunflower and rapeseed oils have been produced (Rossel 2003). Modified fatty acids exhibit thermooxidative stability and frying tests with the

Table 2 Fat uptake and quality of fat in fried potato products (Lisińska and Leszczyński 1989; PN-A-74780).

	Fat uptake (%)	Water loss (%)	Quality of extracted oil	
			Peroxide value (mmol O_2/kg)	Free fatty acids (%)
French fries (fried)	7	35	4	1.5
French fries (pre-fried)	about 4	37	4	1.5
Potato chips	33-39	74	6	0.5
Potato snacks	< 45	9	6	1

use of these acids have been successful. Besides, their stability can be improved by antioxidants (Abdalla 1999; Che Man and Tan 1999; Jaswir *et al.* 2000; Satyanarayana *et al.* 2000; Barrena-Arellano *et al.* 2002; Houhoula *et al.* 2003). One of the examples is "Good Fry Oil" obtained with the use of sunflower oil, high in oleinic acid supplemented with rice and oat oils. Antioxidants present in rice and oat oils are effective stabilizers in this new type of oil, but the procedure has also affected the price of the oil and consequently its applications for frying on a wide industrial scale (Kochhar 2000a; Kristott 2003). Recently, palm oil and its fractions, especially palm oleine have become an alternative for dehydrogenated, expensive oils, high in oleinic acid (du Plessis and Meredith 1999). Non-hydrogenated palm oil with its high content of saturated fatty acids (about 50%) also has a high oxidative stability, which makes it ideal for industrial frying, as it fulfills the requirements of food processing industry – especially for fried snacks (Banks and Lusas 2002).

Since frying is performed at high temperatures, oil is exposed to atmospheric oxygen and various ingredients of the fried product for a long time. Under such conditions, oil is subject to several changes, and for some time, subsequent products of these changes favourably affect the quality of the frying product ensuring adequate contact and heat exchange between the frying medium and the product being fried (Blumental 1991). However, continuous synthesis of these products and subsequent conversions adversely affect the quality of the oil, causing its degradation. The most important reactions undergoing in oil during frying are: hydrolysis, oxidation and polymerization.

All products absorb certain amounts of oil upon frying (**Table 2**) and it becomes an integral component of the subsequent product, also affecting its properties. Chips and snacks, which are almost completely dehydrated, absorb large quantities of oil. In contrast, fat content of French fries is much lower. In addition to fat content, also its quality is significant, and for this reason, limitations have been determined for the content of peroxides and free fatty acids present in fat extracted from the finished products (PN-A-74780). The content of free fatty acids is also described by Gould (1999) in quality levels for potato chips. In an excellent product the free fatty acid content is below 0.3% while in off > 0.9%. Other parameters determining fat quality, e.g. the content of polar fraction, are also monitored (Erickson 2007).

THE EFFECT OF FRYING ON QUALITY OF POTATO SNACKS

The amount of fat adsorbed during frying of potato snacks is a major factor affecting their quality. High fat content of chips and snacks deteriorates their sensory properties and has a major impact on them during storage.

Fat absorption is described with regard to two mechanisms: 1) continuous fat absorption as a consequence of partial exchange of mass between the frying medium and evaporated water, and 2) the process of absorption, which occurs when the process of frying has been finished (Saguy and Dana 2003). The loss of moisture in the first mechanism results in some changes in the cell structure of the product being fried, forming a matrix of small canals, which are penetrated by the frying fat immediately after water evaporation. A major proportion of fat is adsorbed for the first 20 s of frying (McDonough *et al.* 1993; Moreira *et al.* 1997). The other mechanism describes fat adsorption as a phenomenon that occurs when the product is cooled after frying. A portion of water present in the product is converted to vapour upon frying, at the same time inducing some pressure. Next, the water is removed outside through the capillars and canals present in the cell structure. The oil present on the surface of the product being fried or partially penetrating free spaces, is continuously expelled by the vapour formed during frying. This process lasts as long as water vapour is formed and removed from the product fried. When the product is cooled, the inner sub-pressure decreases due to water condensation, resulting in the so-called "vacuum effect". This enables fat penetration into the product, but it is limited to the depth of 1 mm (Lamberg *et al.* 1990; Ufheil and Escher 1996; Saguy *et al.* 1997).

The quantity of adsorbed fat due to frying depends on a number of factors, which are connected both with the raw material and technological processes (Lisińska and Leszczyński 1989; Garayo and Moreira 2002; Mellema 2003). It is well known that the higher the dry matter content of potato tubers, the lower the fat content of chips. In turn, the adsorption of fat during frying by such products as snacks, is markedly affected by the ingredients of the pellets. As has been reported, even a small percentage of fiber added to the product, markedly reduces the fat content of subsequent snacks (Pęksa *et al.* 2004). The quantity of adsorbed fat is also, to a large extent, dependent on the shape and size of fried portions. The results of the studies on the effects of the thickness of potato slices on the amount of fat adsorbed by potato chips show that the fat content decreased with the increasing thickness of potato slices (Kita *et al.* 1998).

The quantity of adsorbed fat is also dependent on the type of oil used for frying. Rani *et al.* (1995) fried potato chips in refined soy and peanut oils and in hydrogenated oil and found that the greatest quantities of fat were adsorbed by the chips fried in the hydrogenated oil. Kita *et al.* (2007) compared fat content of chips fried in various types of vegetable oils and found the lowest adsorption of fat with the use of rapeseed oil, while the highest fat content was found when hydrogenated oil was used for frying. In turn, French fries containing 7-10% of fat adsorbed the lowest amounts of fat from rapeseed and olive oils (Kita and Lisińska 2005).

The quantity of adsorbed fat depends on the properties of the frying medium. As has been reported, the lower the quality of oil (containing large quantities of the products of degradation) used for frying, the higher the fat content of fried (Dobarganes *et al.* 2000). In our studies with the use of refined rapeseed and hydrogenated oils, this relationship was found only with French fries fried in the modified oils. On the other hand, French fries fried in rapeseed oil adsorbed the same quantities of fat, irrespective of the degradation degree of the frying medium (Kita *et al.* 2005). A similar relationship was reported by Moreira *et al.* (1997) who compared fat content of tortillas fried in fresh and degraded soy oils. Although the tortillas fried in fresh oil adsorbed higher amounts of frying oil throughout the cooling time, the fat content of these products remained at the same levels.

The fat content of potato products is to large extent dependent on technological parameters, especially those connected with frying. Such treatments as blanching, predrying or using edible coatings prevent the product from fat absorption during frying (Gamble *at al.* 1987; Garcia *et al.* 2002; Bunger *at al.* 2003; Debnath *et al.* 2003; Mellema 2003). The greater the surface or the ratio of the oil volume to the amount of the product in the frying medium, the higher the fat content of the finished product (Lusas and Rooney 2002). The data on the effects of frying temperatures on fat adsorption by the product upon frying are not unanimous. Some researchers report that the higher the temperature the higher the fat adsorption by the fried product (Krokida *at al.* 2000). Other authors found opposite relationships – products fried at high temperatures contained less fat (Pinthus *at al.* 1995). Gamble *et al.* (1987) and Guillaumin (1988) did not find any relationship between frying temperatures (ranging from 150 to 180°C) and fat content of the finished product. Garayo and Moreira (2002) compared fat content of chips fried under the conditions of atmospheric pressure and that of chips fried at lower pressure and found that the chips fried at lower pressure contained less fat, irrespective of the frying temperatures.

Crispy texture is considered the most important of all sensory properties of snacks. According to International Organization for Standardization texture is described as all the mechanical (geometrical and surface) attributes of a food product perceptible by means of mechanical, tactile and, appropriate, visual and auditory receptors (Standard 5942, 1992). Texture could be measured using objectives tests that are performed by instruments and sensory tests that are performed by people. Objectives tests can be divided into direct tests that measure real textural properties of materials, and indirect tests that measure physical properties that correlate well with one or more textural properties. Sensory tests can be classified into oral (those tests that are performed by mouth) and nonoral (in which some part of the body other than the mouth is used to measure the textural properties) (Bourne 2002; Miranda and Aquilera 2006). Although a snack's texture is developed during frying, it is affected by a number of different factors. So far, much attention has been directed to study the relationships between chemical composition of the raw material and the texture of the finished product (Segnini *at al.* 1999; Kita *et al.* 2000; Kita 2002a). It was found that the texture of potato chips and French fries depended not only on the content level of starch and protein substances present in potato tubers, but to a large extent, also on the content of non-starch polysaccharides and lignin. These substances contribute to building up the cell walls, thus affecting not only the texture of the raw material, but also the texture of the finished product (Kita 2002b; Lisińska and Gołubowska 2005). Chemical composition of the blend used for the production of pellets for snacks manufacturing also contributes markedly to the texture of the finished product (Pęksa 2006). As has been found, even a small percentage of fiber added to the blend increased the hardness of snacks (Kita *et al.* 2002; Pęksa *et al.* 2004). Another important factor is the moisture content of semi-products, which should be within a range from 10 to 12%. Snacks from pellets that have been over-dried are harsh, while those obtained from pellets that have not been dried to adequate moisture content are not crispy. The texture is also dependent on the quantity and quality of fat adsorbed during the frying process. The products containing too much fat are greasy and oily. On the other hand, the texture of chips too low in fat is harsh and unpleasant. Fat content is by no means the only factor determining the quality of fried potato products. Another important factor is the type of oil used for frying. The products fried in palm or hydrogenated oils are usually harder as compared to those fried in refined vegetable oils. Within this group of oils, the best for texture proved to be rapeseed oil. A relationship between the composition of fatty acids in the frying medium and hardness (expressed as maximum shear force (Fg_{max}) necessary to cut the sample) of potato products (chips containing oleic acid and French fries containing PUFAs) was also determined (Kita and Lisińska 2005; Kita *et al.* 2007).

Apart from the effects of the raw material, the texture of the finished product is also affected by the parameters of technological processes. Chips made from thin potato slices are more delicate and less hard than those made from thicker slices. Besides, it is also important to perform the frying process until the product reaches adequate moisture content. When the moisture content is too high, the finished product is neither crispy nor delicate. Low moisture content plays a key role in storage of potato products (Lisińska and Leszczyński 1989; Kita 2002a).

Frying, baking and roasting of carbohydrate-containing products lead to the formation of acrylamides, cancerogenic compounds, very dangerous to human health. Particularly high acrylamide (group 2A) content was found in potato chips (100-6500 μg/kg) and French fries (50-1900 μg/kg) (Becalski *et al.* 2003). Acrylamide is one of the compounds that emerges as a result of browning discoloration (Maillard's reaction) in potato products. It is a reaction between amino acids (asparagine) and reactive carbonyl (e.g. glucose and fructose). Some researchers also mention acroleine, which is formed, among others, as a result of fat conversion (Gertz and Klostermman 2002; Becalski *et al.* 2003; Friedman 2003). Acrylamide is developed during processes performed at temperatures >120°C and the higher the temperature the faster the rate of its formation. Optimal temperatures at which acrylamide formation is most rapid have been determined as well as those above which the processes of its degradation predominate (Friedman 2003). In potato products processing, the rate of acrylamide formation significantly increases at >175°C and for this reason, lower temperatures became the first modifications of the technological processes. Acrylamide is formed at the final stage of frying when the moisture content of the raw material is below 20%. Prolonged frying, therefore, increases acrylamide content of the finished product. It is also important to load a fryer with an appropriate amount of the raw material. The most effective in preventing acrylamide formation proved to be a 10% ratio of the frying oil to the volume of one load input (10:1) (Grob *et al.* 2003; Gökmen and Palazoğlu 2008).

Another factor is the type of oil use for frying. Gerzt and Klostermman (2002) compared acrylamide content of French Fries fried in various types of oil and found that the French Fries fried in palm oil were higher in acrylamide than the others. Besides, it was found that anti-foaming substances (as silicone) added to the oil used for frying also increased acrylamide content. The rate of acrylamide formation is also affected by some antioxidants. Vattem *et al.* (2003) stated that the acrylamide content increased with the increase in phenolic content and antioxidant capacity during frying. On the other hand Becalski *et al.* (2003) observed a decrease in acrylamide content when rosemary was added to frying oil.

STORAGE STABILITY OF FRIED POTATO SNACKS

Potato snacks are deteriorated during storage by physical and chemical reactions such as lipid oxidation. Because of that the composition and quality of frying oil are very important in determining the quality of fried foods. Thermal and oxidative reactions occur in the frying oil during frying and produce oxidized compounds and breakdown products in the oil, which are mostly prooxidants (Chung *et al.* 2006). Potato products fried in oils containing low quantities of PUFAs (palm and hydrogenated oils) exhibit good oxidative stability when kept stored for several months. The use of refined oils, such as rapeseed, soybean or sunflower oil, markedly reduce suitability of the products for storage (Petukhov *et al.* 1999). The stability of frying oils and obtained products is sometimes increased by careful blending of polyunsaturated oils with more saturated oils (Kochhar 2000; Pangloli *et al.* 2002). It was also stated that the addition of antioxidants to the oil during frying decreased the lipid oxidation of fried products during storage (Che Man and Tan 1999; Marquez-Ruiz *et al.* 1999; Houhoula *et al.* 2003; Lalas and Dourtoglu 2003; Chung *et al.* 2006). The stabilization of frying oils with Good-Fry Constituents (blend of specially refined sesame oil and rice brain oil) results in improvement not only in shelf life of the fried products but also in their flavour quality (Kochhar 2000b). Another factor influencing shelf life of fried snack is degree of degradation of frying oil used for snack preparation. Degraded oils, irrespectively of the type of the frying medium, accelerate the occurrence of adverse effects in the products stored (Kita 2006). The pace of oil deterioration in stored products depends also on different packaging materials and storage conditions (temperature, light, relative humidity (Jonnalagadda *et al.* 2001; Gupta *et al.* 2004).

Changes in the texture of snacks due to storage result mainly from increasing moisture content (chips and snacks absorb water, lose crispiness and become harsh). The rate of these unfavourable changes is primarily dependent on the initial moisture content of the product, the type of ingredients (e.g. spices) and packages and also storage conditions and length of time (Kita *et al.* 2000; Kita 2002a; Kita *et al.* 2003). The higher the initial moisture content of the finished product (snacks), the more rapid are the changes in the texture. Some ingredients (spices) also affect water absorption by the product throughout storage. The data in literature show that cheese and onion ingredients absorbed much less water than paprika chips, which also had an impact on the texture (Kita 2002a). Packaging, especially those types of packages that prevent the product from exposure to water vapour, are also good protection against adverse effects. Storage conditions also play an important role. Short storage tests showed that chips kept under critical conditions (40°C, 80% humidity) absorbed greater amounts of water than those kept under standard conditions (20°C, 40-50% humidity) (Kita *et al.* 2003).

CONCLUSIONS

Oil used for frying as well as the entire technological process are major factors affecting the quality of fried potato products. The type and the quality of the oil used for frying have an impact on the quantity of fat adsorbed by the finished product as well as on the texture. Frying parameters, especially temperature, affect acrylamide formation. The properties of the fat present in potato products (chips, snacks) affect the changes due to storage (shelf-life of the product is determined by these changes).

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