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Resistant starch in potatoes deep-fried in olive oil

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Resistant starch (RS) and oil uptake were determined in potatoes (french fries and crisps) fried in olive oil. The RS content of crisps was very low (1% dry matter, DM), while an appreciable amount of RS was found in french fries (5% DM). A high correlation between RS content and cross-section (CS) of french fries was found: $RS = 2{\cdot}64 + 0{\cdot}54CS$, $r = 0{\cdot}999$.

When samples (potato starch standards and freeze-dried crisps) were dehydrated before frying, the thermal process caused a high increase of RS (18–32% DM). Moisture and thickness seem to be important factors affecting oil uptake and RS values in fried potatoes.

INTRODUCTION

Deep-oil frying is a procedure widely used by both the food industry and consumers. Fried potatoes constitute a major food item in Western diets.

Potatoes are fried following two main models: (1) french fry model, where samples have a significant internal volume, external surface and good crust differentiation; (2) crisp (or chip) model, without a significant internal volume and with a very high external surface area, similar to an all-crust, no-centre product (Blumenthal, 1991).

Crust formation is one of the most palatable characteristics of fried foods and it is closely linked to fat penetration. It is a complex process in which many factors are involved, such as temperature of the heated fat, length of frying time, the method used (i.e. household or industrial deep-fryers), food-weight/frying-fat volume and surface-area/volume ratios, some food characteristics and the fat source (Guillaumin, 1988). When the frying fat is olive oil, foods have good acceptance because the fat remains on the surface of the food (Varela, 1988).

Frying in hot oil involves both mass and heat transfer (Du Pont *et al.*, 1992). The frying procedure reduces the food moisture while the oil content increases as oil is taken up from the frying medium (Gamble & Rice, 1988*b*). The colour and flavour of fried potatoes are the result of Maillard reactions between constituents sugars and amino acids (Roe *et al.*, 1990; Roe & Faulks, 1991).

Oxidation, molecular breakdown and leaching of food materials during frying change the pure oil into a mixture of hundreds of compounds (Przybylski & Hougen, 1989; Sebedio *et al.*, 1991; Mazza & Qi, 1992).

On the other hand, the long-held assumption that starch is completely hydrolysed and absorbed within the small intestine has changed over the last decade. It is now known that a substantial amount of starch enters the colon after escaping digestion in the small intestine. This fraction is defined as resistant starch (RS), which is the sum of starch and products of starch degradation not absorbed in the small intestine of healthy individuals (EURESTA, 1992).

Nutritional studies on fried potatoes are mainly related to oil uptake. Nevertheless, although starch is the major constituent of potatoes (80% of the dry matter), no information about the digestibility of starch and formation of RS in fried potatoes has been found in the literature.

The objective of this work was to determine the effect of deep-frying with olive oil on the resistant starch content of potatoes.

MATERIALS AND METHODS

Samples

Fresh potatoes

Samples were peeled and chopped following two shape models:

French model Potatoes were mechanically cut with different square cross-sections (2·2 mm×2·2 mm,

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4·5 mm×4·5 mm, 8 mm×8 mm and 16 ×16 mm) and a constant length of 5 cm. Half of the fresh potatoes with a 2·2 mm×2·2 mm section were freeze-dried before frying.

Crisp model Potatoes were cut into 1·2 mm slices and thickness was checked for evenness using a calliper.

Commercial standards

Potato starch (S-4251), amlylose type III (A-0512) and amylopectin (A-8518) (Sigma, St Louis, MO, USA) were used.

Frying procedure

Samples were completely immersed in hot commercial olive oil. Crisp potatoes were fried at different temperatures (130°C, 150°C and 180°C) and for different times (1, 3, 8, 15 and 30 min). The 15 and 30 min frying times were tested to assay the effect of long frying times on RS values, although these times are not suitable to obtain an edible, good-quality product. French potatoes and standards were fried at 180°C for 8 min. After frying, potatoes were removed from the oil, allowed to drain, milled and defatted by Soxhlet extraction with petroleum ether (Soxtec System HT Tecator, Högannas, Sweden). Fried standards were centrifuged (15 min at 3000*g*) to remove oil excess before defatting. Moisture was determined by drying to constant weight in a forced convection oven at 105°C. Oil uptake was expressed as a percentage of total weight of the fried samples. Triplicate determinations of moisture and oil uptake were carried out.

Resistant starch analysis

RS content was determined by the method of Goñi *et al.* (1996). This procedure was used in the EURESTA ring test and it was recommended for the quantification of RS in starchy foods (Dysseler & Hoffem, 1994). The main features of the procedure are the following: protein removal from defatted samples with pepsin (EC 3.4.23.1); incubation with α-amylase (EC 3.2.1.1) for 16 h to hydrolyse digestible starch; treatment of the residue with 2 M KOH to solubilize resistant starch; incubation with amyloglucosidase (EC 3.2.1.3) and determination of glucose using a glucose oxidase–peroxidase anti peroxidase (GOD-PAP reagent) (Boehringen, Mannheim, W, Germany). Resistant starch was calculated as glucose (mg)×0·9.

RS was determined by sextuplicate in each sample. Results were expressed as percentage of defatted and dried sample.

RESULTS AND DISCUSSION

Raw potato starch is indigestible because it is encapsulated within granules, which hinders the accessibility of digestive enzymes (Gallant *et al.*, 1992). When potatoes are cooked the starch granules are gelatinized and the starch becomes readily digestible. The amount of RS basically depends on the degree of gelatinization and amylose retrogradation during cooling of the cooked food (Englyst & Cummings, 1987).

RS may be made up of retrograded starch, physically inaccessible starch, starch–nutrient complexes and thermally or chemically modified starch (Englyst *et al.*, 1992; Englyst & Macfarlane, 1986; Saura-Calixto & Abia, 1991). The high RS content reported in raw potato (70–75%) corresponds to the physically inaccessible type (Faisant *et al.*, 1994).

The results of RS determination in fried standards and potatoes (crisps and french fries) are shown in Table 1. The frying procedure used (180°C, 8 min, olive oil) is a common one in Mediterranean cooking (Varela, 1988).

Potato starch is made up of a mixture of amylose and amylopectin (21:79) with an average degree of polymerization of 3000 and 2 000 000, respectively (Swinkels, 1985). The high RS content found in fried amylose (22·12%) indicates that this is the starch constituent mainly responsible for the formation of RS, while amylopectin was practically not affected by the frying process (0·68% RS). Potato starch showed intermediate values of RS (18·18%). Taking into account that the standards are dry powders, RS formation must be due to structural modifications of amylose by thermal treatment in the absence of water. It is well known that amylose content is the main factor determining the formation of RS in the presence of water—retrograded starch—and the influence of amylopectin seems to be negligible (Swinkels, 1985). Our data suggest that amylose is also the starch constituent affecting RS formation in fried samples heated in the absence of water.

The amount of RS in crisps was very low (Table 1). Water dissipates thermal energy from the hot frying oil surrounding the frying food and prevents burning caused by excessive dehydration. Therefore, the actual temperature of the potato (100–103°C) is much lower than the oil temperature (180–190°C) (Blumenthal, 1991; Kozempel *et al.*, 1991). Our results suggest that indigestible raw starch granules are broken during

Table 1. Resistant starch content of fried standards and potatoes (% dry defatted sample)

	Resistant starch[a]	Moisture (%)
Standards		
Potato amylose	22·12 ± 1·45	2·6
Potato amylopectin	0·68 ± 0·17	2·8
Potato starch	18·18 ± 4·64	3·1
Potatoes		
Crisps	1·0 ± 0·06	2·4
Freeze-dried crisps	31·91 ± 0·91	2·6
French fries (whole sample)	5·16 ± 0·23	10·0
French fries (internal part)[b]	1·17 ± 0·06	—

Frying conditions: olive oil, 180°C, 8 min.
[a]Mean value ± standard deviation ($n = 6$ determinations).
[b]Analysed just after frying.

frying, becoming accessible to digestive enzymes, and a high moisture level in the samples (80% in fresh samples) prevents thermal degradation of potato starch during frying. The absence of water in fried samples (2·4%) also avoids further crystallization of the amylose chains; therefore, the RS content is very low in fresh fried crisps.

However, when crisps were freeze-dried before frying, the RS content increased up to 32%. This suggests that RS is produced by thermal degradation of starch in the absence of water, similarly to the standards.

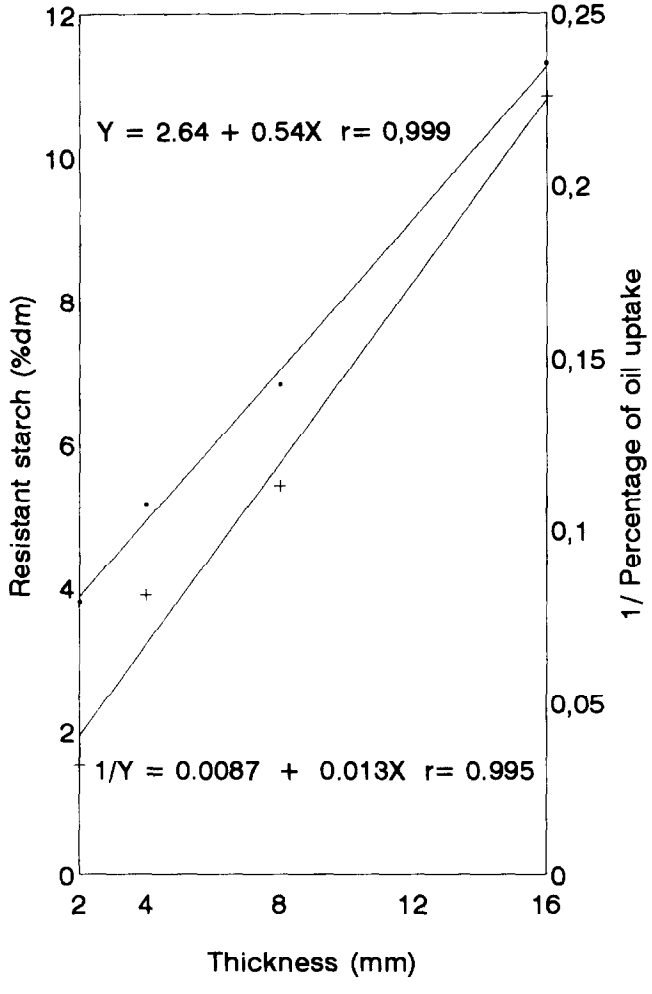

Fig. 1. Resistant starch, oil uptake and thickness relationship of french fried potatoes.

In french fries (cross-section 4·5 mm), the dehydration process is incomplete because oil penetrates 1 mm or less (Lamberg *et al.*, 1990) and the remaining water in fried samples (10%) may allow partial amylose retrogradation during cooling; 5·16% of RS was found in the whole french fries. When a portion was taken from the internal part of the sample without oil, just after frying, a very low amount of RS was found (1·17%), suggesting complete gelatinization of starch. These results indicate that starch in french fries is readily digestible when potatoes are eaten hot, just after frying,

Many factors have been reported to affect oil uptake, such as potato moisture, temperature and time of frying, product shape, porosity, prefrying treatments and others (Pinthus *et al.*, 1992, 1995). In our samples, thickness was correlated with RS content and oil uptake in french fries (Fig. 1). The higher the thickness, the higher the RS content of the fried potatoes and the lower the oil uptake.

There was also a relationship between the thickness and the moisture content of the fried samples (2·2, 4·5, 8·0 and 16·0 mm versus 6·1%, 10·0%, 19·8% and 35·5%, respectively). A linear relationship between oil uptake and water removal in french fries was also reported by Gamble *et al.* (1987). The high moisture content in thick potatoes may enhance the retrogradation of starch, increasing the RS values. Incomplete disruption of starch granules may be another factor affecting RS values.

Resistant starch and oil uptake were also determined in crisp potatoes fried at different temperatures and times (Table 2). Small differences were found in RS values. The frying procedure increases the oil content from less than 0·1% to 40% as oil is taken up from the frying medium. Longer times than 3 min did not increase the oil uptake. Similar results were found when frying for 8 min at lower temperatures (150–130°C). The lowest moisture content was observed in samples fried for 8 min at 180°C; longer times did not reduce the water content.

Leaching of starch breakdown fragments and other potato constituents into the frying oil can occur. Gamble and Rice (1988*a*) reported solid losses (determined by hygrometry) ranging from 0·6% to 8·6% in potato chips. Solid losses from 6% to 10% were observed in our samples.

Table 2. Oil uptake, moisture and resistant starch of crisp potatoes[a] fried at different temperatures and times

Temperature (°C)	Time (min)	Oil uptake (% DM)	Moisture (%)	RS (% defatted DM)
180	30	35·90 ± 4·21	2·5	1·00 ± 0·01
180	15	40·71 ± 3·92	2·3	0·9 ± 10·01
180	8	40·81 ± 2·98	2·4	1·0 ± 0·02
180	3	40·52 ± 3·01	3·3	1·4 ± 0·01
180	1	31·40 ± 2·79	5·4	1·0 ± 0·02
150	8	39·84 ± 3·06	4·9	1·3 ± 0·02
130	8	42·81 ± 2·95	5·6	1·7 ± 0·02

[a]Thickness: 1·2 mm.
DM, dry matter' RS, resistant starch.

In summary, a significant amount of RS was found in french fries, while the RS content in crisp potatoes was very low. Water content and thickness of the samples seem to be the main factors affecting RS values of fried potatoes. Further research to establish the chemical and structural changes in this process is needed.

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