Fat Uptake in French Fries as Affected by Different Potato Varieties and Processing

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ABSTRACT: The uptake of lipid into French fries was investigated using two varieties of potato ('Russet Burbank' and 'Agria') and the New Zealand sweet potato, *Ipomoea batatas*, (kumara). The variety of potato used had a significant effect on lipid uptake, with 'Agria' having the lowest lipid content. The different cellular structures may have affected the fat uptake in the French fries by influencing either the loss of moisture during finish-frying or the damage done to the original anatomy during processing before pre-frying. The French fries that had undergone frozen storage had a higher amount of lipid contained in their inner core than did those that had been either chilled or prepared freshly for frying.

Keywords: potatoes, kumara, French fries, fat uptake, frying

Introduction

Potatoes

Solanum tuberosum are native to the Andean regions of South America. They belong to the family Solanaceae along with other well known cultivated plants, including eggplant, chillies, and tomatoes. Potatoes were introduced into Europe in the last quarter of the 16th century. Once introduced into a country, new varieties were developed to suit the local conditions and consumer preference (Hawkes 1978). Today, hundreds of varieties of this popular vegetable are grown around the world. These varieties differ in texture, flavor, shape, and color and hence suitability for end use. Potatoes are the number one vegetable eaten in New Zealand with 87% of the population eating them at least 3 times per wk, and 35% of New Zealanders eating them every day (Vegfed 1999).

New Zealand kumara, *Ipomoea batatas*, was a staple food of the indigenous population, the Maori, and is becoming increasingly popular as an alternative for "take-out" French fries.

Many factors have been reported to affect fat uptake into French fries, including oil quality, frying temperature, and duration, product shape and content (such as moisture, solids, fat, gel-strength, and proteins), pre-frying techniques (that is, drying, blanching, frying) and coating (Pinthus and others 1995). Potatoes are high in moisture (78%) and pretreatment can greatly affect fat uptake. Gamble and others (1987a) found that the loss of moisture during frying exhibited a classic drying profile. At higher temperatures, there was an initial rapid fall followed by a continuous drying period. The moisture content decreased sharply by as much as 20% over a 3 min frying time and then more slowly to the final moisture content. The authors found that the loss of moisture and the uptake of oil were interrelated and recommended reducing the initial moisture content by drying to decrease the fat uptake into the potatoes.

Blanching is a common practice undertaken in French fries production. It is done to leach out soluble solids (including reducing sugars that can lead to nonenzymatic browning during frying) and reduce enzymic activity that may otherwise cause undesirable odor, flavor, color, or texture. In a study of the effect of the sequence of blanching, drying, and frying steps undertaken during French fries production, Lamberg and others (1990) found that the highest fat content was observed for blanched, undried potato strips. French fries that had been blanched, then dried with air at 2% relative humidity (RH), showed a lower fat uptake than the undried fries. They concluded that when drying with air, at 2% RH, a skin was formed that reduced the ability of fat to penetrate into the product.

Toma and others (1986) found that partial surface freezing (-20 °C for 25 min) of 'Russet Burbank' chips resulted in more oil absorbed during pre-frying but less oil during finish-frying, compared with untreated samples. The overall oil content was lower in the partially frozen French fries and they contained less reducing sugar and ascorbic acid and were lighter in color than the untreated samples.

The present study investigated the fat uptake of French fries from 2 potato cultivars, 'Russet Burbank' and 'Agria'. It also looked at the effects of different French frying production processes on fat uptake. The investigation differentiated between fat uptake of whole French fries and also between their outer layer and inner core. For comparison, the fat uptake by kumara French fries was determined.

Materials & Methods

Materials

Commercially refined, bleached, and deodorized beef tallow, Chefade™ (Goodman Fielder, 70% beef tallow, 30% oleo oil), was donated by a local supplier. Commercially pre-fried, frozen, crinkle-cut French fries (A) and commercially pre-fried, frozen, straight-cut French fries (B) were donated by a supplier of a major, international, take-out chain and were produced from locally grown 'Russet Burbank' potatoes. French fries C, D, and F were produced from the potato variety, 'Agria'. Commercially pre-fried, frozen, straight cut French fries (C), commercially pre-fried, chilled, straight-cut French fries (D), commercially pre-fried, chilled, straight-cut kumara (*Ipomoea batatas*), 'Owairaka Red' fries (E), and peeled 'Agria' potatoes (containing preservative metabisulfite) were all obtained from this same supplier. The peeled 'Agria' potatoes were sliced into French fries (F) using the Potato Chipper (Redco Model 185. Lincoln F.S.P. Ft. Wayne, Ind., U.S.A.). The freshly cut potatoes had excess moisture removed by blotting with paper towels and were then pre-fried at 180 °C for 1 min. A comparison of the processing undergone by all the French fries before finish frying is given in Table 1. All French fries, straight-cut and crinkle-cut, were 13 × 13 mm and had a range of lengths from 5 to 8 cm. The French fries were weighed into 1-kg batches for each frying procedure.

Frying parameters

Ten batches of each type of French fries (A-F) were deep-fried in sequence (that is, all of A, followed by all of B, and so on). All batches were completed over a 3-d period. The French fries were fried for 3.5 min at the initial temperature of 180 °C and then the basket was banged vigorously on the side of the fryer twice and allowed to hang for 20 s. The fryer used was the Pitco Frialator Tube Fired Gas Fryer Model 18 (Pitco, Concord, N.H., U.S.A.), with an oil capacity of 29.4 to 36.3 kg. The fat was topped up by addition of 3-kg Chefade™ at the end of each 10 batches (that is, 15 kg of Chefade™ were added in total).

Determination of triglyceride and free fatty acids in used tallow

In order to determine if there were any changes in the tallow composition, samples were taken directly from the fryer after every 10th frying procedure and analyzed for triglyceride fatty acids and free fatty acids by gas chromatography of their fatty acid methyl esters, using previously published procedures (Lai and others 1997).

Statistical Analysis

Analysis of variance and least significant difference test for the variables was conducted using the Statistical Analysis System (SAS) program.

Analysis of fat uptake into French fries

Samples (approximately 100 g) of French fries from each batch were homogenized to a 0.2 to 0.5 mm size using a Waring blender on high speed for 20 s. Samples (5 ± 0.8 g) were then accurately weighed into sample holders. All samples were analyzed in duplicate. Fat was extracted using a Büchi B-811 Universal Extraction System (Büchi Labortechnic AG, Flawil, Switzerland). The Soxhlet was programmed to run as a hot extraction, wherein the heated sample is first treated with hot cycled solvent (hexane) for 60 min and then rinsed with solvent for 5 min. The solvent was then vaporized for 10 min. The fat content present (3.5 ± 0.4%) in the commercial French fries was determined before they were finish-fried.

The outer layer (approximately 1 mm thick) was also removed by hand from the finish-fried French fries using a sharp razor to expose the inner core (remainder). Fat was then extracted from the outer layer and inner core of the dissected French fries.

Microscopy of French fries from different varieties of potatoes

Brightfield microscopy was carried out using a Leica DM LS microscope (Leica Microscopy and Scientific Instruments Group, Heerbrugg, Switzerland) fitted with a Ricoh 35 mm SLR camera (Ricoh Co. Ltd., Tokyo, Japan). Kodak Gold 35 mm color print film was used at a film speed of ASA 100. Thin slices of French fries were taken and stained with iodine (0.2%) in potassium iodide (2%) solution (Jensen 1962). The slice was immersed in the staining solution for 1 min and then rinsed with water to remove excess stain. This procedure was repeated 3 times for each type of French fry. The samples were examined under the microscope and representative samples were photographed.

Table 1—Processing undergone before finish-frying potato French fries

French fries[a]	Processing				
	Blanching	Drying	Pre-frying	Freezing	Chilling
A	×	×	×	×	
B	×	×	×	×	
C	×	×	×	×	
D	×	×	×		×
E	×	×	×	×	
F			×		

A = crinkle cut; [a]B, C, D, E, F = straight cut; A, B = 'Russet Burbank'; C, D, F = 'Agria', E = Kumara

Results

Fat uptake into different types of French fries

Figure 1 shows the mean fat uptake of 5 different types of potato French fries. The fat uptake in the 'Russet Burbank' variety was significantly different from that in the 'Agria' variety. The homemade 'Agria' French fries (F) (5.8%) had almost half the fat of the crinkle cut, 'Russet Burbank' (A) (10.9%). The 2 frozen, straight-cut varieties ('Russet Burbank' (B) and 'Agria' (C)) had undergone similar processing, as shown in Table 1, but the fat uptakes were 10.2% and 7.1%, respectively. The variety of potato seemed to have at least as much effect on fat uptake than the processing it had undergone to produce French fries. Notably, the homemade French fries (F) had the lowest fat uptake. The difference between these French fries and the other 'Agria' types (C and D) was that the homemade type had not undergone blanching or drying (Table 1).

Effect of solids and moisture content on fat uptake

The 'Agria' variety of French fries had a significantly higher moisture content than the 'Russet Burbank' variety after finish-frying. The loss of moisture from different types of French fries during frying is detailed in Table 2. The pre-fried French fries all had similar moisture contents. The two 'Russet Burbank' French fries (A and B) lost the greatest amount of moisture during frying, 21% and 23% respectively.

The French fries made from 'Agria' potatoes (C, D and F) all had similar finish-fried moisture contents. These values were higher ($p < 0.01$) than in the 'Russet Burbank' French fries, thereby reducing the total moisture loss in 'Agria' French fries. The pre-fried French fries that had undergone a drying process during production (A, B and C) did not have a different moisture content ($p < 0.01$) from the other two types that had not (D and F). However, both 'Russet Burbank' types of French fries (A and B) had a higher fat uptake than the 'Agria' French fries (C, D and F).

Comparison of fat uptake in different types of French fries at a constant moisture content

As moisture is lost from French fries, the data presented show it is related to an increase in fat uptake and in nonfat solids (Figure. 1). The fats extracted as a percentage of dry weights were : A (26.3 ± 1.4%), B (26.3 ± 1.3%), C (21.7 ±

0.9%), D (22.7 ± 1.0%) and F (16.6 ± 0.8%).

These data confirmed the difference between the two varieties, with the 'Russet Burbank' French fries (A and B) having a higher fat content than the 'Agria' French fries (C, D and F). The least processed French fries (F) had a lower fat content ($p < 0.01$) than the other 'Agria' types (C and D). The French fries A and B had undergone similar processing and had similar fat contents as a percentage of dry weight, as did the frozen (C) and chilled (D) 'Agria' French fries.

Fat uptake into different areas of the French fries

Figure 2 shows the fat uptake (after finish-frying) into the outer 1 mm layer and the inner core of the French fries. The weight ratio (of water, lipid and nonfat solids) of outer 1 mm to inner core was approximately 1:1. In all the types of French fries fat uptake into the outer 1 mm was significantly higher than in the inner core. There was a difference in the ratio of fat uptake between the outer and inner areas in the different types of French fries. The chilled (D) and homemade (F) French fries had a ratio of lipid in outer layer to inner core of 16:1, indicating little penetration of fat into the core of the fries. However, in the 3 frozen types, straight-cut (B and C) and crinkle cut (A) French fries, this ratio was about 4:1; indicating significantly more penetration.

The moisture and solids-content ratios were very similar in all groups of French fries. The moisture-content was 1.2 times higher in the inner core showing less water loss from this area during the frying procedure. The reverse was true for the solids-content, the solids being 1.3 times higher in the outer surface due to the loss of moisture in this area.

Microscopy of the different types of French fries

Sections of the different French fries were magnified under the microscope to observe the anatomical composition of the potatoes. Figures 3 and 4 show the differing anatomy of the 2 types of potato, 'Russet Burbank' and 'Agria', respectively; both samples were from frozen pre-fried French fries (B and C, respectively). The slides were unstained and the color difference was obvious between the 2 varieties of potatoes. The 'Agria' potato was yellow and had a definite lattice-type anatomy. It had many large spaces (approximately 0.8 mm × 0.2 mm), between the groups of cells, that were not present in the 'Russet Burbank' variety. The 'Russet Burbank' section was white and all the cells were tightly adhered to each other. These photo micrographs also show the fat absorption into the pre-fried French fries. The fat was most obvious on the outer surface of the French fries, penetrating into the fries about 0.3 to 0.4 mm. Staining of the different types of French fries with iodine in KI to observe starch did not show any large variations between them.

Fat uptake in kumara French fries

The average fat uptake of kumara French fries (E) after finish-frying was 8.3 ± 1.1%. The fat extracted as a percentage of dry weight was 18.8 ± 0.6 %. These values fell between those for the 2 potato varieties. The average moisture content was 48 ± 1.1% and the solids-content was 44 ± 2.0%. The moisture and solids-content were very similar, as also seen in the 'Russet Burbank' French fries. The variety, 'Owairaka Red', had undergone the same processing as the French fries A, B and C. The kumara fries had lower moisture content (63%) before finish-frying than the 'Russet Burbank' or 'Agria' varieties and the moisture lost during finish frying (15%) was between that for the 2 potato varieties. The kumara fries had been frozen before finish-frying and had a ratio of lipid in outer layer (1-mm thick) to inner core of 4:1, the same as the other frozen French fries (A, B, and C). Under brightfield microscopy, the cellular arrangement was more similar to the 'Russet Burbank' variety, with the cells adhering to each other and no large spaces between them.

Monitoring fatty acid composition and free fatty acids

The fatty acid composition did not change significantly throughout the frying procedures of the different types of French fries. The free fatty acids were less than 1% at every sampling, indicating there was no fat deterioration throughout the frying procedures.

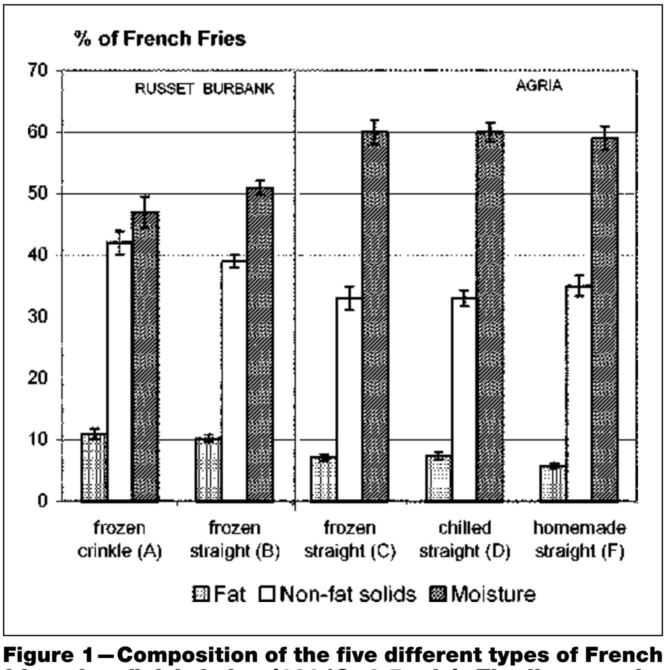

Figure 1—Composition of the five different types of French fries after finish-frying (180 °C, 3.5 min). The lines on the bars are standard deviation.

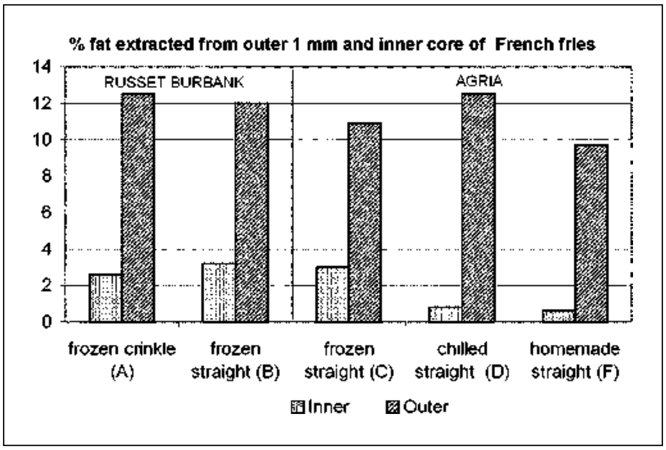

Figure 2—Fat uptake after finish-frying (180 °C, 3.5 min) into outer 1 mm layer and inner core of five different types of French fries. The standard deviation on all values was < 10%.

Discussion

POTATOES ARE GROUPED INTO 2 TEXTURAL TYPES WHEN DEscribed for cooking: floury and waxy. A floury potato is low in moisture and sugar and high in starch. Floury potatoes are generally used for frying, mashing, baking, and roasting. Waxy potatoes are higher in sugar and are, therefore, not used for French fries, since the sugar undergoes nonenzymatic browning. Waxy potatoes tend to hold their shape after cooking. Some potato varieties fall between these 2 extremes and can be used for multiple purposes (Vegfed 1999).

The 2 varieties used most commonly in New Zealand for French fries' production are 'Russet Burbank', and 'Agria'. Both are full flavored, floury potatoes, with a low moisture and high starch content, but whereas 'Russet Burbank' has white flesh, that for 'Agria' is yellow, as is that of kumara. The cultivar, 'Owairaka Red', is the most common variety of kumara grown in New Zealand, comprising 80 – 90% of the total crop. Recently, there has been an increase in research for processed kumara products, including French fries (Lewthwaite 1993).

The 'Agria' variety of finish-fried French fries had a lower fat content than the 'Russet Burbank' variety, as shown in Figure 1 The two 'Russet Burbank' French fries had a final fat content of 10.9% (crinkle cut, A) and 10.2% (straight cut, B). This difference was expected since the crinkle cut had a greater surface area in which the fat could be absorbed. The 'Agria' French fries had a range of final fat contents from 5.8% in the homemade type to 7.4% in the chilled type. This difference between the 2 cultivars is striking if one considers that a consumer who eats a scoop of French fries of about 200 g produced from the 'Agria' potato variety would be consuming approximately 14 g of fat, whereas consumption from the 'Russet Burbank' potato variety would be 20 g of fat. For 200 g of kumara French fries consumption would be 16 g of fat.

Table 2—Moisture content in different types of French fries during various stages of processing

Type of French fries[a]		Storage	Moisture content (%) Pre-fried	Finish-fried	Moisture loss %
Russet Burbank	A	frozen	70	47	23
Russet Burbank	B	frozen	70	49	21
Agria	C	frozen	70	60	10
Agria	D	chilled	72	60	12
Agria	F	fresh	71	59	12
Kumara	E	frozen	63	48	15

[a]A = crinkle cut; B, C, D, E, F = straight cut.

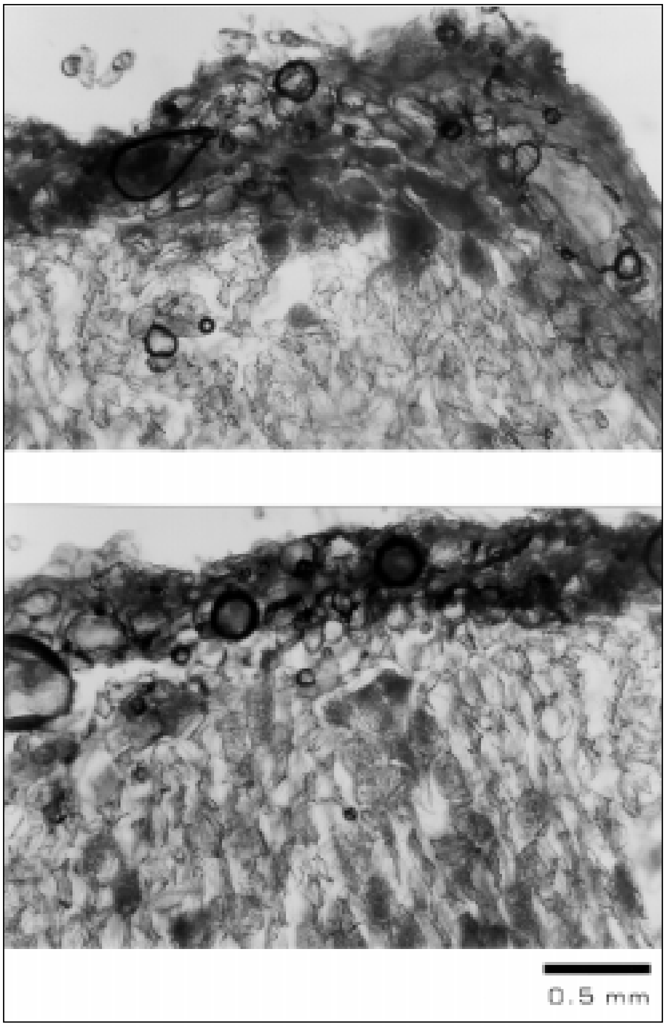

Figure 3—Brightfield microscopy of outer (above) and inner (below) sections of potato variety 'Russet Burbank' after finish-frying (180 °C, 3.5 min).

The higher fat content in the 'Russet Burbank' French fries may have been due to the greater decrease in moisture content during finish frying (Figure 1 and Table 2). The loss of moisture from the finish-fried French fries was directly related to the final fat uptake (Figure 1, Table 2); that is, the less moisture lost, the lower is the fat uptake. This result is in agreement with the work of Gamble and others (1987a). Although the commercial protocol for the fries used in this study included a drying step before prefrying, this step apparently removed only surface water and did not greatly decrease the total moisture content of the flesh of the potato fries. The correlation between moisture loss and fat uptake was not seen when comparing the 3 different types of French fries in the 'Agria' variety, since the chilled and homemade French fries lost the same amount of water but had significantly different fat contents. There must, therefore, be another reason for this difference in fat uptake between the 5 types of French fries.

Specific gravity and solids-content have also been shown to have an effect on fat uptake into French fries. The specific gravity of potatoes is determined by weighing the sample in air and then in water. Potatoes with a high specific gravity (> 1.090) have been shown to produce a high yield of French fries with a lower fat content than lower specific gravity potatoes (Lulai and Orr 1979). In sweet potatoes, a linear relationship between dry matter content and fat uptake in thin-sliced crisps was shown, with fat uptake decreasing as dry matter increased (Hagenimana and others 1998).

Within 1 variety of potato, the specific gravity may vary over a wide range. For 'Russet Burbank' the range is 1.070 to 1.095. However, in New Zealand, the quality of potatoes chosen for processing as French fries is generally strictly controlled by limits on their specific gravity (solids-content). For 'Russet Burbank' and 'Agria' these limits are 1.090 to 1.095 (22 to 23%) and 1.080 to 1.090 (20 to 22%), respectively (Davison 2000). The results of this investigation, therefore, do not lead to the conclusion that the specific gravity alone controls the amount of lipid uptake.

The 2 varieties of potatoes used in the production of these French fries showed differences in their anatomy after cooking. It is these differences which seem to have had the most influence on fat uptake in the French fries. The distinctive lattice-like anatomy observed in tissues of 'Agria' was revealed when examined using brightfield microscopy (Figure 4). The cells were not stained in these slides. In contrast to the 'Agria' variety, the cells of 'Russet Burbank' potato (and kumara) adhered to each other with no obvious interstitial spaces (Figure 3). These different anatomical arrangements found in the two varieties may have affected fat uptake, either by affecting the loss of moisture during finish-frying, or by influencing the amount of damage done to the original anatomy during processing before pre-frying. Certainly, the greater loss of water by the 'Russet Burbank' variety correlated with the greater fat uptake.

The major physical processes the potato undergoes during production of commercial fries are blanching, drying, and frying. These may affect the anatomy of the potato, especially the surface. Blanching temperatures range from 70 °C to 80 °C, for times between 14 to 25 min, depending on the sugar content of the potatoes. Low sugar varieties require shorter amounts of time (14 min) to remove soluble solids and the thicker cut of potatoes (13 mm) requires a greater time (25 min) to ensure the entire chip is blanched. The dryer is a thermal fluid-heat exchanger with sequential trays in which the temperature varies, depending on the solids and moisture content of potatoes being used, between 30 and 80 °C. The pre-frying of the French fries is typically 45 s at 175 to 185 °C, depending on the sugar content of the potato (the higher sugar varieties require a lower temperature).

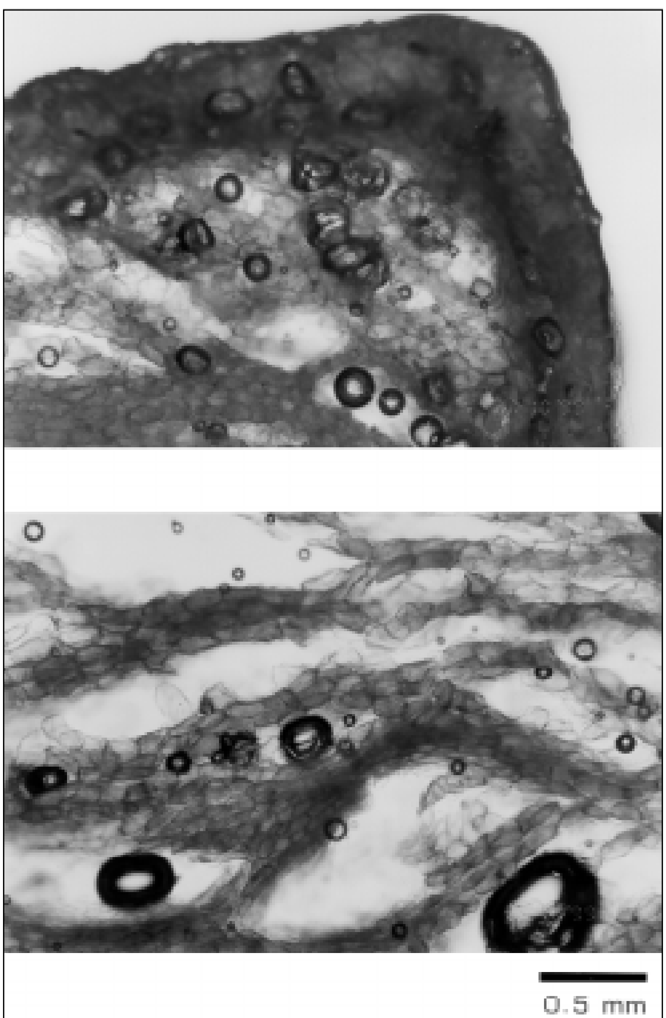

Figure 4—Brightfield microscopy of outer (above) and inner (below) sections of potato variety 'Agria' after finish-frying (180 °C, 3.5 min).

In order to ensure that the loss in moisture in the finish-fried French fries was not the only cause of increasing fat, the fat content was calculated as a percentage of dry weight. The effect of processing was seen to be significant on fat uptake in the 'Agria' variety —(frozen (C) 21.7%, chilled (D) 22.2%, fresh (F) 16.6%. Unfortunately, seasonal variations in availability meant that these measurements could not be made for 'Russet Burbank' homemade or chilled French fries. The value for frozen 'Russet Burbank' was 26.3% and that for frozen kumara 18.8%. Since the values for frozen (C) and chilled (D) 'Agria' French fries were similar, the freezing process itself did not have a major influence on the total fat uptake into French fries during finish-frying. The other processes undergone in French fries C and D but not in French fries F were blanching and drying. These processes may affect the potato tissue leading to internal damage, including tissue breakdown. This damage may aid the frying fat flow into the French fries, leading to a higher final fat content than in the homemade type. We found no evidence that blanching, followed by drying, resulted in a reduced fat uptake. The difference between the fat content of the five comparable blanched and dried French fries (A, B, C, D and E) showed that the 'Russet Burbank' French fries had a higher fat content than the 'Agria' French fries, with that for kumara being intermediate. In essence, it is the effect of the cultivar that dominates fat uptake, with freezing prior to finish frying also playing a smaller role.

In absolute terms, the fat content in the 1 mm surface layer, or crust, was higher than in the inner core for all 6 types of French fries. This difference has been shown in previous studies, with most of the fat absorbing to the surface due to the formation of an outer crust that protects the inner layers (Gamble and others 1987b; Keller and others 1986; Ufheil and Escher 1996). The frozen storage did, however, affect the depth of fat penetration into the French fries. The French fries that had been stored frozen (A, B, C and E) had a higher inner core fat percentage than the French fries that had not (D and F) (Figure 2). The higher percentage may have been due to the formation of ice crystals that can damage the original anatomy of the food (Pilar Cano 1996) and particularly the surface, leading to more fat penetrating into the center of the French fries. Such would not be true for the chilled and homemade 'Agria' French fries (D and F). Nevertheless, the chilled 'Agria' French fries (D) had the same overall fat content as frozen 'Agria' French fries (C).

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