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# Effect of Pre-Treatments, Frying Temperature and Oven Re-Heating on the Acrylamide Content and Quality Characteristics of French Fries from 'Rooster' Potato Tubers

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## ABSTRACT

Acrylamide levels in food, and especially in potato products, are perceived world wide as a potential public health problem. The current trials on 'Rooster' potato tubers purchased (as ware samples) in a supermarket and fried under domestic conditions showed that soaking (citric acid vs. water) and pre-treatments such as blanching in water and pre-frying in oil were useful for lowering the content of acrylamide precursors (reducing sugars and asparagine) in potato tuber strips and also the acrylamide content in the corresponding French fried samples. However, this effect was small relative to that of frying temperature where an increase in acrylamide content from 243 (150°C/6 min) to 761 µg/g (190°C/6 min) was demonstrated in French fries. Oven-reheating (convection vs. microwave) of fully fried samples had no effect on acrylamide content. Soaking, blanching, frying and re-heating treatments had an effect on fry colour and on textural properties. However, the extent of the effects was generally small for the latter. A sensory panel indicated that Hunter values in the ranges 68-70 L or 2.8-3.0 L/b represented ideal French fry colour.

**Keywords:** acrylamide, asparagine, French fry colour, pre-treatment, reducing sugars
**Abbreviations: ANOVA**, Analysis of variance; **FSA**, Food Standards Agency; **HPLC**, high performance liquid chromatograph; **OPA**, *O*-phthalaldehyde; **TPA**, texture profile analysis

## INTRODUCTION

The finding in 2000 by a group of Swedish researchers (Tareke *et al.* 2000, 2002) that acrylamide, a substance classified as a potential carcinogen, occurred in heated starchy foods at concentrations many times in excess of levels permitted in drinking water has prompted widespread research into the critical factors affecting acrylamide formation. Early surveys indicated that levels of acrylamide in potato products such as French fries and potato crisps were the highest of the foodstuffs investigated (Tareke *et al.* 2002). A structured debate with dieticians in 2002 concluded that acrylamide in food was an emerging public health concern (Gormley *et al.* 2003), and levels of acrylamide in certain foods were still unacceptably high in 2006 as indicated by a feature article 'Acrylamide-the food scare the world forgot' in *New Scientist* (Coghlan 2006). A recent review (Zhang *et al.* 2007) on acrylamide in food concludes that there is no single method for eradicating acrylamide in foods, and suitable methods for reducing acrylamide levels must be assessed on a case-by-case basis. Many papers have been published since 2003 on acrylamide in French fried potatoes and have dealt with its formation (Granda *et al.* 2004; Matthaeus *et al.* 2004; Fiselier *et al.* 2005; Gökmen *et al.* 2005; Gökmen and Senyuva 2006b), its reduction/minimisation (Haase 2005; Baardseth *et al.* 2006; Gökmen and Senyuva 2006b), and the relationship between acrylamide content and colour development (Hebeisen *et al.* 2004; Olsson *et al.* 2004; Gökmen *et al.* 2006c; Pedreschi *et al.* 2006). The effects of cultivar (Amrein *et al.* 2003), acrylamide precursors (asparagine and reducing sugars) (Mottram *et al.* 2002; Stadler *et al.* 2002), and in-store bulk-conditioning of the potato tubers (Noti *et al.* 2003) on the acrylamide content of French fries have also been evaluated.

Many of the studies conducted above deal mainly with the industrial preparation of potato products. However, in recent times some work has been carried out on factors affecting levels of acrylamide formation in domestically prepared foods such as French fries. In 2007 the Food Standards Agency (FSA) in the U.K. published a report on the effect of domestic preparation practices on acrylamide levels in a number of foods including potato chips (FSA 2007). They provided a number of recommendations for practices to reduce acrylamide formation in potato chips including pre-soaking the chipped potatoes in water for 2 hours prior to frying. In addition, Romani *et al.* (2008) examined the effect of frying time on the quality and acrylamide contents of French fried potatoes, under conditions simulating home cooking. They concluded that after 4 minutes of cooking acrylamide contents increased exponentially with increases in frying time. Pedreschi *et al.* (2007) used a range of pre-treatments including immersion in water, citric acid and sodium pyrophosphate and blanching in water to examine acrylamide formation in chipped potato tubers at temperatures from 150-190°C. They also concluded that temperature was the most important factor influencing acrylamide formation with levels decreasing when frying temperatures were reduced from 190 to 150°C. While some work has been done the effect of pre-treatments such as soaking and blanching on acrylamide levels in chipped potatoes under domestic conditions, the present study is the first to our knowledge to consider the effect of these practices in sequence rather than as single unit operations. In addition, the present work is the first to our knowledge to consider the effect of reheating in convection or microwave ovens on acrylamide levels in French fries.

The current project was conducted in late 2005/early 2006 and was a component of a much larger study on acryl-

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amide in cooked potato products (Brunton *et al.* 2007a) which also assessed dietary exposure in an Irish context (Cummins *et al.* 2008). It embraced three trials with Rooster potato tubers purchased as ware samples in a supermarket: As this variety is popular with Irish consumers and is sometimes used for chipping in the home. The objective of the study was to examine the effect of a number of factors including frying time, pre-treatments and oven reheating on acrylamide in a domestic context. The trials conducted were:

- Trial 1 dealt with the effects of water vs. citric acid soaks, and of pre-frying in oil vs. water blanching on the reducing sugar and amino acid content of potato tuber strips, i.e. acrylamide precursors.
- Trial 2 addressed the effects of water vs. acid soaks, and of pre-frying in oil vs. water blanching coupled with three frying temperatures on the acrylamide content and selected quality parameters of French fries.
- Trial 3 investigated the effects of two oven-finishing methods on the acrylamide content and selected quality parameters of French fries.

## MATERIALS AND METHODS

### Effect of pre-treatments on the content of acrylamide precursors (Trial 1)

Potatoes (*Solanum tuberosum* L.), cv. 'Rooster', were purchased from a local supermarket in January of 2006 and were peeled mechanically (IMC VC 7T). Remaining eyes were removed by a hand peeler. The samples were dipped in a 0.25% (w/w) sodium metabisulphite solution for 5 min to prevent browning. The potato tubers were cut into typical commercial-size French fry shapes (12 × 12 × 50 mm) using a domestic French fry press and were held in a sodium metabisulphite solution (1.5% w/w) for 1 min. Batches (500 g) of tuber slices received a soaking treatment at 3°C [3L of aqueous citric acid solution (2% w/w) vs. water for 60 sec] followed by pre-frying in sunflower oil (150°C/45 sec) or blanching in water (85°C/3.5 min). The samples were cooled (5 min) to 4°C in a blast freezer and were extracted and tested for amino acid (aspartic acid, glutamic acid, asparagine, glutamine, threonine, valine, lysine) and reducing sugar (glucose, fructose) contents as outlined in the section on test procedures below. The experimental design was 2 soak treatments (citric acid vs. water) × 3 pre-frying operation (Blanching in water vs. pre-frying in sunflower oil vs. none) × 3 replicates [analysis of variance (ANOVA)].

### Effect of pre-treatments and frying temperature on the acrylamide content and quality parameters of French fries (Trial 2)

'Rooster' potato tubers were sourced in a supermarket in January of 2006 and were peeled and pre-treated (soaking and blanching treatments) as described for Trial 1. Batches of samples were then fried using a domestic deep fat fryer (Tefal Smart Clean 1250 g) in Trial 1. sunflower oil at 150, 170, and 190°C for 6 min and were packed in polythene bags and blast frozen (-35°C for 2 h). Samples were tested (over a 2-week period) following thawing in a chill room at 4°C overnight. Tests were conducted for acrylamide content, fry colour and for texture [TPA (texture profile analysis)] as outlined in the section on test procedures below. The experimental design was 2 soak treatments (citric acid vs. water) × 2 pre-frying operation (Blanching in water vs. pre-frying in oil) × 3 frying temperatures (150, 170, 190°C) × 3 replicates (ANOVA).

### Effect of oven-reheating on the acrylamide content and quality parameters of French fries (Trial 3)

Trial 3 focussed on the affects of microwave and oven reheating on potato tubers that had not been pre-treated by soaking, blanching or pre-frying therefore for this trial 'Rooster' potato tubers were sourced from a supermarket and were peeled and sulphited as in Trial 1 but not pre-treated. Samples (500 g/5 L oil) were fried (170°C/6 min), cooled, packed in polythene bags, blast frozen (-35°C/6 min) and stored (-20°C). Batches of the frozen fries were reheated in microwave (1000 W/6 min) or convection (Bacbar Turbofan; Monofood Equipment Ltd., Ireland) (175°C/7 min) ovens while a third batch was left unheated (control). Tests were conducted for acrylamide content, fry colour and for texture profile analysis (TPA) as outlined in the section on test procedures below. It is important to conduct the TPA post freezing-thawing to assess the effect of the freezing step on fry texture; this is in line with commercial practice where a large proportion of French fries are sold as frozen product to the consumer. The experimental design was 3 finishing treatments on French fries that had not been pre-treated [microwave oven, convection oven, none (control)] × 3 replicates (ANOVA).

### Chemical and physical test procedures

#### *Reducing sugars and amino acids*

Ethanolic extracts of homogenised samples were prepared to extract reducing sugars and amino acids. This involved adding 70% aqueous ethanol (25 ml) to finely grated potato tubers (3 g) and homogenising at 24,000 RPM for 70 sec (Brunton *et al.* 2007b). Reducing sugar content was determined using a Varian GC 3400 CX gas chromatograph (Varian Ltd., Oxford, U.K.) and a modified version of the alditol acetate assay (Brunton *et al.* 2007b). Analysis of amino acids was carried out using a modified version of the method of Bartok *et al.* (1994) as described by Brunton *et al.* (2007a) using *O*-phthalaldehyde (OPA) derivatisation and an Agilent 1100 high performance liquid chromatograph (HPLC). Amino acid levels were calculated in µg/100 g fresh weight (FW) of sample by external calibration using authentic aqueous standards.

#### *Acrylamide content*

French fry samples were prepared for acrylamide analysis using the procedure of Rosēn and Hellenäs (Rosēn *et al.* 2002). Matrix matched standards were prepared by fortifying mashed boiled potato samples (4 g) with acrylamide stock solutions. Recovery standards were prepared with each batch of samples by spiking empty tubes with acrylamide and acrylamide-d3 (same volumes and concentrations as for the matrix matched standards), and diluting with water (40 ml). Recovery standards were stored in the dark until the start of the analyses. Calibration curves, for the matrix matched standards were prepared by plotting response as a function of concentration (0-5000 µg/kg). Recovery was measured by expressing the slope of the calibration line for matrix matched standards as a percentage of the slope of the calibration line for recovery samples.

#### *French fry colour*

French fry colour was measured using a HunterLab colour meter (Model No. DP-900, Hunter Associates, Reston, Virginia, USA) with a 2.5 cm specimen port. The instrument was calibrated using the black and white tiles provided. Three individual fries were pressed together for each measurement and were placed under the aperture of the colour meter; 15 replicates were recorded and the mean figure calculated.

#### *Texture profile analysis (TPA)*

The different elements of TPA were defined in 1978 (Bourne 1978) and the terms have been used extensively since. The TPA tests were conducted using a Texture Analyser (TA-XT2i; Stable Microsystems$^{TM}$, UK) equipped with expert software for Windows. The analyzer was fitted with a 5 mm diameter probe needle for the puncture tests (probe speed 8 mm/sec) and it penetrated to the centre of each fry. A 35 cm cylindrical probe with a flat base was used for the compression of fries along their 9 mm edge-length. Pre-test speed was 5 mm/sec and test speed was 1.6 mm/sec. The fry cubes were compressed by 40% as compressions in excess of this resulted in complete loss of fry structure. Each cube was compressed twice to determine recovery.

## Statistical analysis

Data were analysed by one-way analysis of variance using Gen-Stat (Version 3.2, VSN International Ltd., Hemel Hempstead, U.K.).

## RESULTS AND DISCUSSION

### Effect of pre-treatments on the content of acrylamide precursors (Trial 1)

A number of studies have indicated that levels of acrylamide precursors have a direct influence on the quantity of acrylamide formed in the cooked product. In potato products, levels of reducing sugars have a critical influence on acrylamide formation (Oku *et al.* 2005; Olsson *et al.* 2005; Reust *et al.* 2005; Williams 2005; Brunton *et al.* 2007a; Cummins *et al.* 2008) since they are usually more variable than asparagine levels, i.e. both reaction partners enter the kinetic equation, but one (asparagine) varies little. In addition, asparagine levels are usually in excess making reducing sugar levels the limiting factor. Therefore a priciole objective of the present study was to assess the effect of pre-treatments on these acrylamide precursors.

Levels of reducing sugars and amino acids reported here are within the range of values reported elsewhere by other authors (Brierley *et al.* 1997; Amrein *et al.* 2003; Becalski *et al.* 2004). There were no statistically significant interactions in Trial 1 between the soak and blanch treatments for any of the variables indicating that the effects of soak and blanch treatments can be considered individually ($P_{interaction} \geq 0.05$). A citric acid soak was more effective than a water soak for lowering reducing sugar levels in the uncooked chips. However, the effect was not statistically significant in the case of glucose (**Table 1**). There was no difference between the soaking treatments in terms of asparagine (**Table 1**), aspartic acid (mean 210), glycine (530), threonine (558), valine (204), lysine (158 µg/g) or total amino acid contents (**Table 1**). However, glutamic acid levels were lower (P<0.05) for the water-soaked samples (i.e. 157 vs. 207 µg/g). Both soak treatments were effective in lowering the acrylamide precursors as the untreated samples had reducing sugar and asparagine levels of 3476 µg/g and 1686 µg/g respectively. The effects of water and pre-frying in oil on levels of the acrylamide precursors were minimal except for total reducing sugars where pre-frying in oil gave a lower level (2674) than the water soak (3109) or no-blanch (3574 µg/g) treatment (P<0.05). This lack of effect may be due to the lowering of precursor levels by the preceding soak treatments, or because blanch times were short. Blanching temperature/times from 50°C-90/3-80 min (Pedreschi *et al.* 2006) to 90°C/9 min (Pedreschi *et al.* 2004) have been reported with long times being most effective in lowering the acrylamide precursors. In contrast in a more recent study Pedreschi *et al*. (2007) reported that neither the glucose nor the asparagine content of the potato strips immersed in water or a citric acid solution (10 g/L) diminished significantly after being immersed up to 120 min. This approach may be suitable for domestic preparation however long blanching times are more difficult to implement in-factory on a potato processing line. Mestdagh *et al*. (2008) concluded that blanching at high temperatures (70°C) for a short period of time (about 10 min) was more efficient in reducing acrylamide levels in potato crisps and French fries than blanching at lower temperatures. Water blanching times in the present study were also comparatively short and at a high temperature (85°C/3.5 min), however, little affect on acrylamide precursors was observed. As stated previously this may be due to the fact that precursor levels were lowered by the preceding soak treatments. Jung *et al*. (2003) attributed the reduction of acrylamide formation in French fries pre-dipped in citric acid solutions to both pH lowering and leaching of free asparagine and reducing sugars from the cut surface of the potatoes into the solutions. This is partially supported by the results of the present study were fructose (P<0.001) and total reducing sugar content (P<0.05) of the soaked tubers were significantly reduced. However, free asparagine levels were unaffected.

### Effect of pre-treatments and frying temperature on the acrylamide content and quality parameters of French fries (Trial 2)

For all the variables tested except acrylamide there were no statistically significant interactions between the three factors (soaks, pre-frying operation type, frying temperatures) in this trial ($P_{interaction} \geq 0.05$) so the effects of soak, pre-frying operation type and frying temperature treatments can be presented individually. For acrylamide levels a significant interaction occurred between pre-frying operation type and fry temperature ($P_{interaction} \leq 0.05$). Levels of acrylamide reported here are within the wide range of values reported elsewhere for fried chipped potatoes (Becalski *et al.* 2004; Fiselier *et al.* 2005; Brunton *et al.* 2007a).

The citric acid soak pre-treatment gave a lower level of acrylamide in the fries than the water soak (**Table 2**). This agrees with the findings in Trial 1 where this treatment gave a lower reducing sugar level in the chipped tubers than the water soak. There was a significant (P<0.05) interaction between soak treatment and frying temperature, i.e. acrylamide contents for acid vs. water soaked samples were 263 vs. 222 (150°C), 338 vs. 463 (170°C) and 620 vs. 902 µg/kg (190°C). A study carried out by the FSA concluded that potato tuber chips washed or soaked in water for 30 minutes or 2 hours had lower acrylamide levels than untreated samples, with samples pre-soaked in water for 2 hours having the lowest levels of acrylamide (FSA 2007). Pedreschi *et al.* (2007) also showed that immersion of potato strips in water or citric for up to 120 minutes reduced acrylamide formation in the cooked product. In addition Jung *et al.* (2003) found that dipping potato cuts in 1 and 2% citric acid solu-

**Table 1** Effect of water vs. citric acid [a] soaking pre-treatments on the reducing sugar and amino acid contents (µg/g fresh weight) of potato tuber strips (cv. 'Rooster').

| Parameter | Water soak | Citric acid soak [a] | F-test | LSD [b] |
|---|---|---|---|---|
| Fructose | 1840 | 1467 | P< 0.01 | 245 |
| Glucose | 1552 | 1351 | NS [c] | 431 |
| Total reducing sugars | 3391 | 2819 | P< 0.05 | 396 |
| Asparagine | 803 | 754 | NS | 256 |
| Glutamic acid | 157 | 207 | P< 0.05 | 39 |
| Glycine | 546 | 513 | NS | 172 |
| Aspartic acid | 226 | 193 | NS | 88 |
| Threonine | 581 | 534 | NS | 184 |
| Valine | 219 | 190 | NS | 77 |
| Lysine | 157 | 159 | NS | 46 |
| Total amino acids | 2690 | 2550 | NS | 502 |

[a] 2% (w/w) aqueous solution
[b] Least significant difference
[c] Not significant

**Table 2** Effect of water vs. citric acid [a] soaking pre-treatments on French fry [b] acrylamide content (µg/kg fried weight) and quality parameters (cv. 'Rooster').

| Parameter | Water soak | Citric acid soak [a] | F-test | LSD [c] |
|---|---|---|---|---|
| Acrylamide content | 529 | 407 | P< 0.05 | 88 |
| Hunter L [d] | 51.9 | 55.3 | P< 0.05 | 3.2 |
| Hunter L/b [e] | 2.27 | 2.24 | NS [f] | 0.12 |
| Texture profile analysis | | | | |
| -puncture force (N) [g] | 6.36 | 3.11 | P< 0.001 | 0.66 |
| -hardness (N) [g] | 3.22 | 4.80 | P< 0.001 | 0.67 |
| -springiness | 0.60 | 0.70 | P< 0.001 | 0.03 |
| -gumminess | 1.12 | 1.93 | P< 0.001 | 0.30 |

[a] 2% (w/w) aqueous solution
[b] Data averaged over three frying temperatures (150, 170, 190°C)
[c] Least significant difference
[d] Whiteness (lightness)
[e] White/yellow ratio
[f] Not significant
[g] Newtons force

**Table 3** Effect of frying temperature on French fry [a] acrylamide content (µg/kg fried weight) and quality parameters (cv. 'Rooster').

| Parameter [b] | 150°C | 170°C | 190°C | F-test | LSD [c] |
|---|---|---|---|---|---|
| Acrylamide content | 243 | 401 | 761 | P <0.001 | 124 |
| Hunter L | 62.1 | 54.7 | 44.0 | P> 0.001 | 4.54 |
| Hunter L/b | 2.50 | 2.23 | 2.03 | P< 0.001 | 0.17 |
| Texture profile analysis | | | | | |
| -puncture force (N) | 4.98 | 4.91 | 4.31 | NS [d] | 0.93 |
| -hardness (N) | 3.79 | 4.00 | 4.25 | NS | 0.95 |
| -springiness | 0.60 | 0.65 | 0.70 | P< 0.001 | 0.04 |
| -gumminess | 1.41 | 1.46 | 1.71 | NS | 0.42 |

[a] Data averaged over pre-treatments (see Tables 3 and 4)
[b] See footnotes, Table 3
[c] Least significant difference
[d] Not significant

**Table 4** Effect of water blanching vs. pre-frying in oil on French fry [a] acrylamide content (µg/kg fried weight) and quality parameters (cv. 'Rooster').

| Parameter [b] | Water blanch [c] | Pre-frying in oil [d] | F-test | LSD [e] |
|---|---|---|---|---|
| Acrylamide content | 537 | 399 | P< 0.01 | 108 |
| Hunter L | 53.6 | 53.6 | NS [f] | 3.94 |
| Hunter L/b | 2.29 | 2.22 | NS | 0.15 |
| Texture profile analysis | | | | |
| -puncture force (N) [b] | 4.09 | 5.38 | P< 0.001 | 0.81 |
| -hardness (N) [b] | 4.80 | 3.22 | P <0.001 | 0.82 |
| -springiness | 0.68 | 0.64 | P< 0.001 | 0.04 |
| -gumminess | 1.92 | 1.13 | P< 0.001 | 0.37 |

[a] Data averaged over three frying temperatures (150, 170, 190°C)
[b] See footnotes, Table 3
[c] 3 min/85°C
[d] 45 s/150°C
[e] Least significant difference
[f] Not significant

tions for 1 hour before frying showed 73.1 and 79.7% inhibition of acrylamide formation in French fries. The pre-fried in oil fries had a lower acrylamide content than the water-blanched samples which is in line with the lower level of reducing sugar in the former (as shown in Trial 1). This was probably caused by flash exudation of contents (water and soluble solids, including reducing sugars) from the outermost cells due to the high oil temperature. Frying temperature had a strong influence on the acrylamide content of the French fries (**Table 3**) as shown recently by other authors (Granda *et al.* 2004; Matthaeus *et al.* 2004; Gökmen *et al.* 2006a; Pedreschi *et al.* 2006; Pedreschi *et al.* 2007; Romani *et al.* 2008). There was little (circa 5°C) fall-off in oil temperature during frying due to the 1:10 chip to oil ratio.

As expected, the citric acid pre-treatment gave a lighter fry colour than the water soak due to a reduction in the level of enzymatic browning. This has been reported by a number of authors for fruit and vegetable products including potato tuber strips (O'Beirne 1990). Increasing the frying temperature had a darkening effect on fry colour which agrees with the findings of other authors (Olsson *et al.* 2004; Pedreschi *et al.* 2005; Pedreschi *et al.* 2006). The Hunter L and L/b data indicated more extensive Maillard browning with increasing frying temperature (**Table 3**). The correlation coefficient between Hunter L values and acrylamide content was -0.85 ($R^2$ = 72%, $P \leq 0.05$). The citric acid soak gave a much lower puncture force value than the water soak indicating a softer surface. However, the fry hardness value (defined as the peak force during the first compression cycle (Bourne 1978) was highest for the citric acid treatment as were the springiness [(defined as the height the food recovers during the time that elapses between the end of the first bite and the start of the second (Bourne 1978)] and gumminess values [defined as the product of hardness × cohesiveness (Bourne 1978) (**Table 2**)]. Pre-fried in oil fries had a higher puncture force but lower values for hardness, springiness and gumminess than water-blanched fries (**Table 4**). Texture profile parameters were unaffected by frying temperature with the exception of springiness values which increased with frying temperature.

## Effect of oven and microwave reheating on the acrylamide content and quality parameters of French fries (Trial 3)

Oven-reheating or microwaving reheating of fully fried frozen French fries has become a common practice in catering and domestically, and some commercial fry brands are marketed as oven-ready and/or suitable for microwaving.

**Table 5** Effect of reheating [a,b] method on French fry acrylamide content (µg/kg reheated weight) and quality parameters (cv. 'Rooster').

| **Parameter** [c] | **Convec.** [a] | **Microw.** [b] | **None** | **F-test** | **LSD** [d] |
|---|---|---|---|---|---|
| Acrylamide content | 220 | 193 | 252 | NS [e] | 81 |
| Hunter L | 57.7 | 61.2 | 69.4 | P< 0.05 | 5.94 |
| Hunter L/b | 2.40 | 2.43 | 2.67 | P< 0.05 | 2.23 |
| Texture profile analysis | | | | | |
| -puncture force (N) [b] | 5.27 | 2.57 | 5.10 | P< 0.001 | 0.39 |
| -hardness (N) [b] | 2.63 | 2.73 | 3.23 | NS | 0.95 |
| -springiness | 0.63 | 0.57 | 0.53 | P< 0.05 | 0.06 |
| -gumminess | 1.47 | 1.10 | 0.93 | NS | 0.77 |

[a] Convection oven (175°C/7 min)
[b] Microwave oven (1000 W/3 min)
[c] See footnotes, Table 3
[d] Least significant difference
[e] Not significant

These procedures could, potentially, further increase the acrylamide content in the product, the former more so than the latter. This trial was conducted to quantify the effects of these procedures on acrylamide content of fried 'Rooster' potato tuber strips and also on fry colour and textural properties. Reheating had no effect on acrylamide content in the convection or microwave ovens used. This outcome, at first sight, was unexpected but may be due to the fact that air is a good insulator, even at high temperature, and is much less severe in a contact and heat transfer sense than immersion in hot oil. Evaporation of surface moisture from the fries in the oven may also have reduced surface temperature and hence the formation of acrylamide. A study by the Food Standards Agency in the U.K. found that cooking oven chips in both microwave or convection oven resulted in an increase in acrylamide levels as compared to the uncooked product (FSA 2007). However little effect for method of heating was noted which agrees with the results in the present study. In contrast, Erdogdu *et al.* (2007) did conclude that microwave application *prior* to frying resulted in a marked reduction of acrylamide level in the surface region. Yuan *et al.* (2007) observed that microwave heating facilitated more acrylamide to be formed as compared to the boiling method at identical pH and treatment time.

With respect to quality parameters oven reheating resulted in a darker fry colour (**Table 5**). Outcomes from a small sensory trial (6 judges) indicated that fry lightness values corresponding to a Hunter L range of 68-70 or to an L/b ratio range of 2.8-3.0 were ideal. Microwaving gave a much softer fry surface (lower puncture force) than the convection oven or no-oven, while oven-finishing resulted in fries with a higher level of springiness (**Table 5**).

## CONCLUSIONS

These trials used 'Rooster' potato tubers purchased as ware samples in supermarkets. Chipped potato tubers were soaked blanched, pre-fried and batch fried using a domestic deep fat fryer to simulate home preparation of French fries. The trials showed that (given similar precursor levels) frying temperature/time is by far the most important factor for the development of acrylamide in French fried Rooster potato tubers. Pre-treatments involving soaking, water blanching and pre-frying in oil contribute to acrylamide reduction but may be difficult to apply in practice. Reheating of the cooked French fries in either a convection or microwave oven had no effect on acrylamide levels. While some studies have examined the effect of pre-treatments such as soaking and blanching on acrylamide levels in chipped potatoes under domestic conditions (Pedreschi *et al.* 2004; Fiselier *et al.* 2005; FSA 2007; Pedreschi *et al.* 2007), the present study is the first to our knowledge to consider the effect of these practices in sequence rather than as single unit operations. It is interesting to note that while soaking in water or citric acid was effective in reducing acrylamide precursors, a similar effect was not observed for a pre-frying in oil or blanching in water. This lack of effect may be due to the lowering of precursor levels by the preceding soak treatments, or because blanch times were short. An assessment of the effect of pre-treatments on quality parameters such as texture and colour is also included in the present study since effective practices for acrylamide reduction must also be capable of producing a product of comparable quality to that currently available. In addition the present work is the first to our knowledge to consider the effect of reheating in convection or microwave ovens on acrylamide levels in French fries.

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