PAPER

EFFECTIVENESS OF A TEMPERATURE CONTROL SYSTEM IN HOME INDUCTION HOBS TO REDUCE ACRYLAMIDE FORMATION DURING PAN FRYING

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ABSTRACT

Three trials were conducted to determine the influence of the use of temperature control systems on physico-chemical characteristics and acrylamide formation in the domestic preparation of potatoes. French fries were pre-treated by soaking in water or acidified water, and then they were cooked using a range of home-cooking procedures. Soaking raw potatoes in acidified water (pH=3.17) before frying at a controlled temperature (180 °C) was the most efficient pretreatment for reducing acrylamide formation (76%). For the same temperature, roasted frozen par-fried potatoes contained less fat and acrylamide than similar pan-fried potatoes. Potatoes butter fried at 140 °C had an acrylamide concentration similar to that of potatoes fried in oil at 180 °C, but this value was reduced by 71% when the frying was carried out using a temperature control system. Controlling the frying temperature reduced acrylamide formation at all the temperatures studied.

Keywords: acrylamide, frying, induction hob, temperature control, potatoes, home-cooking, pretreatments, roasting

1. INTRODUCTION

In 2002, TAREKE *et al.* detected high concentrations of acrylamide in heat-processed foodstuffs. This compound is classified as being likely carcinogenic to humans (ROSÉN and HELLENÄS, 2002). Since then, scientists have identified different factors affecting the formation of acrylamide in food. STADLER *et al*. (2002) have shown that acrylamide can be released by the thermal treatment of certain amino acids such as asparagine, particularly in combination with reducing sugars, and by the thermal treatment of early Maillard reaction products. Because potato products are especially high in asparagine, it is currently thought that this amino acid is responsible for the majority of the acrylamide formation in potato crisps and French fries. Considerable research has been carried out to develop strategies to reduce acrylamide formation (GÖKMEN, 2006; FRIEDMAN and LEVIN, 2008; KUMAR *et al*., 2014; URBANCIC *et al*., 2014; KAHKESHANI *et al*., 2015; ZUO *et al*., 2015). The main problem in developing such strategies is that the main pathway is the same as that for the formation of compounds with desirable aromas during frying (MATTHÄUS, 2009). Therefore, the use of reliable temperature control systems during frying to avoid overheating is necessary to prevent further acrylamide formation (GERTZ and KLOSTERMANN, 2002; MAJCHER and JELEN, 2007; ARIAS-MENDEZ, 2013). Some authors have studied the effect of different pretreatments on acrylamide formation during frying. For example, lowering the pH by adding acids before frying has been found to be an efficient way of considerably diminishing acrylamide formation for French fries (JUNG *et al*., 2003; PEDRESCHI *et al*., 2007). Roasting produces lower acrylamide contents than microwaving. Hence, the important factors influencing acrylamide formation are not only the heating temperature and time but also the modality of the heat transfer process (CLAEYS *et al*., 2005; YUAN *et al*., 2007).

The heating source is one of the most sensitive parts of the equipment for the formation of acrylamide in the product. It is important to ensure a consistent transfer of heat from the heating source to the product (MATTHÄUS, 2009). With most household appliances, the temperature settings are uncertain. Recently, induction hobs have been introduced on the market. The hob is equipped with infrared sensors that measure the heat emitted by the pan and accordingly adjust the temperature of the food being fried so that the desired temperatures are maintained within ± 2 °C.

The main objective of the present study is to evaluate the possible effect of the use of temperature control systems on the formation of acrylamide, taking into account the organoleptic characteristics of the fried product together with color, water loss and oil uptake. Three trials were conducted for this purpose. The aim of the first test was to determine the effect of using induction hobs with temperature control systems on the abovementioned factors. In addition, the effect of preparation by par-frying and freezing of fresh potatoes was studied. In the second trial, the possible additional effects of two pretreatments (water immersion or immersion in water acidified with vinegar) on the temperature-controlled frying were studied. Finally, in the third trial the aim was to establish a comparison between pan-frying and other cooking methods for potatoes (oven roasting and pan frying in butter at medium temperature), given the lack of data in the literature on the presence of acrylamide in home-cooked potato dishes.

2. MATERIALS AND METHODS

2.1. Materials

Fresh Potatoes (variety Bintje) and frozen par-fried potatoes (variety Fontana) were provided by Flensted A/S (Ansager, Denmark). High oleic sunflower oil (Riquísimo Koipesol, Deoleo, Madrid, Spain), vinegar (X-tra vinegar, FDB, Copenhagen, Denmark) and butter (X-tra butter, FDB, Copenhagen, Denmark) were obtained from local supermarkets.

2.2. Cooking procedures

Fresh potatoes were stored at 4 °C and subsequently washed, peeled and cut into strips (5 cm x 1 cm x 1 cm) or slices of 3 mm thickness before frying. The samples were fried on an induction hob provided with an automatic control system to maintain a specific temperature once it was reached (Power induction, BOSCH PIB675L34E, BSH, Munich, Germany). Pan frying was done in a saucepan (18 cm diameter) using a ratio of 100 g of potatoes per 100 mL of oil. To evaluate the effect of the temperature control (trial 1), fresh and frozen par-fried potato strips were fried for 10 min at initial oil temperatures of 160 °C, 180 °C and 200 °C with and without temperature control. The aim of trial 2 was to test if soaking pretreatment of the potato strips could mitigate the amount of acrylamide even in the potatoes fried using the temperature control. Fresh potato strips (100 g) were soaked for 20 min in a tap water bath (1 L) at room temperature or in an acidified water bath with vinegar (pH= 3.17). Once the superficial water retained in the samples was eliminated with paper towels, the potatoes were then fried following the same frying conditions as used in trial 1. In trial 3 alternative domestic preparations to frying were carried out: a) fresh potato slices (100 g) were fried for 7 min on each side in butter (5 g) at lower than usual initial frying temperatures (140 °C), with and without temperature control, and b) frozen par-fried potatoes (100 g) were placed in a universal pan and roasted for 25 min at 170, 175 and 180 °C in a pre-heated electric oven with forced-air circulation (iQ500 Siemens, BSH, Munich, Germany). During frying the temperature profiles of the oil were monitored by a type K thermocouple probe and recorded by a Data-logger (Testo Loger 177.T4). Three batches were made for each of the experimental conditions. Superficial oil retained in the potatoes was eliminated with paper towels and the samples were analyzed.

2.3. Acrylamide determination

The liquid chromatography-tandem mass spectrometry method described by NIELSEN *et al.* (2006) was used for the determinations, with slight modifications. Thirty mL of MilliQ water was added to a 0.3 g aliquot homogenate. Acrylamide (2-propene amide) [CAS No. 79-06-1] (>99.5%) was obtained from Sigma-Aldrich (St. Louis, MO, USA). Labelled d_3-acrylamide (> 98%) was supplied by Polymer Source Inc. (Dorval, Quebec, Canada). The potato strips were homogenized using a mixer (model 4169/4297, Braun AG, Kronberg, Germany). The acrylamide analysis was performed on 3 g aliquots of homogenized fried potato samples with an added internal standard comprised of 150 µL of 10 µg mL^{-1} d_3-acrylamide and 30 mL of deionized water. The sample was extracted by a homogenizer (model Ultra Turrax T25, Janke and Kunkel, Staufen, Germany) at 1,000-1,200 rpm for 2 min. The sample was then centrifuged at 500 *g* for 20 min (Heraeus Multifuge, Osterode, Germany) and an aliquot of 2 mL was transferred to an Eppendorf vial, frozen to -18 °C for at least 30 min and subsequently centrifuged in an Eppendorf centrifuge at 12,100 *g* for 10 min (Minispin Centrifuge, Eppendorf Ag, Hamburg, Germany). The sample was thawed during centrifuging, and starch precipitated from the supernatant at this low temperature. The SPE (Solid Phase Extraction) cleanup was performed by an automated sampler (Gilson Aspec Xl, Gilson Company Inc., Lewis Center, OH, USA) using LiCrhoLut Rp-C18 SPE-cartridges (500 mg) from Merck (Darmstadt, Germany). The SPE columns were conditioned with 2 mL of methanol, 2×2 mL of water, and 0.5 mL of sample lead to waste. Subsequently, 1.75 mL of sample was loaded onto the cartridge and the eluate transferred to Miniprep PTFE filter HPLC vials with a pore diameter of 0.45 μm (Whatman Inc., Little Chalfont, UK). The LC system consisted of a liquid chromatograph (model HP1100, Agilent Technologies, Santa Clara, CA, USA). Separation was performed with 0.1% formic acid in water, with a flow of 0.2 mL min^{-1} on a Hypercarb column (dimensions 2.1 mm x 100 mm, particle size 5 μm). The MS-MS detection was performed using a Micromass Quattro Ultima triple quadrupole instrument (Waters Corporation, Milford, MA, USA). The source was maintained at 120 °C and the desolvation gas at 400 °C. Nitrogen was used as the cone and desolvation gas with flow rates of 150 and 500 L h^{-1}, respectively. Argon was used as the collision gas and maintained at a pressure of 0.24 Pa. The detection was performed by multiple reactions monitoring (MRM). Acrylamide was detected in positive ion mode. Quantification of the fragmentations was done using the MassLynx software version 4.1 including QuanLynx. Each determination was performed in triplicate.

2.4. Color determination

The potato strip color was measured using digital image analysis. For image acquisition an HP Scanjet G4010 scanner (Hewlett-Packard, Palo Alto, CA, USA) delivering 4800 x 9600 dpi hardware resolution was used. The image resolution was set at 200 ppp. Digital image processing was performed using the Matrox Inspector 8.0 software (Matrox Electronic Systems Ltd., Quebec, Canada). Calibration of the digital system was done using the UNE 48-103-94 Spanish color norm (AENOR). The correlation with CIELab values was calculated using a quadratic model (LEÓN *et al.*, 2006). Once tempered, the surfaces of 5 potatoes for each batch (15 potatoes for each condition) were scanned. The corresponding RGB (Red, Green and Blue) coordinates were obtained and, applying the transformation model, the corresponding CIELab coordinates were calculated.

2.5. Fat content

Samples previously finely ground in a cooled mill homogenizer IKA A10 (Janke and Kunkel, Staufen, Germany) were extracted with 80 mL of petroleum ether to a 2055 Soxtec (Foss, Hillerød, Denmark). The extraction program was operated at 115 °C and included 30 min of immersion and 1 h 20 min of extraction and draining. The fat content was determined by weight difference, Method 30-25(AACC, 2000). Each determination was performed in triplicate.

2.6. Statistical analysis

Statistical analysis was performed using XLSTAT 2014 software (Addinsoft, New York, USA). One-way analysis of variance (ANOVA) followed by Tukey's multiple range test for comparisons of means and least significant differences ($p<0.05$) were performed with the data. All the data were expressed as the mean±standard deviation. The standard deviation was calculated from 3 (for acrylamide and fat content) or 5 (for color) determinations for each of the three independent experiments.

3. RESULTS AND DISCUSSION

3.1. Temperature monitoring

The oil temperature evolution recorded at different initial temperatures with and without activating the temperature control system is shown in Fig. 1 for fresh potatoes. During the frying, the oil temperature undergoes sharp changes, even in the case of frying with temperature control, due to the abrupt temperature decrease caused by the addition of the potatoes (up to 45 °C). The oil temperature evolution in the frying of frozen par-fried potatoes follows a similar trend, but the initial temperature drop is more marked (up to 49 °C). For the same initial temperature, the oil is hotter if frying is carried out without control. After a decreasing stage, when the control of temperature is switched off, the temperature begins to increase in an almost linear fashion overshooting the initial value by 36.8 °C when the initial temperature of the oil is 200 °C, by 23.5 °C when the oil is at 180 °C, by 17.2 °C when the oil is at 160 °C and by 11.8 °C when the oil temperature is at 140 °C. However, in the event that temperature control is switched on, the temperature trends asymptotically to its initial value ±2 °C. The temperature differences between frying with or without temperature control decrease as the initial oil temperature decreases.

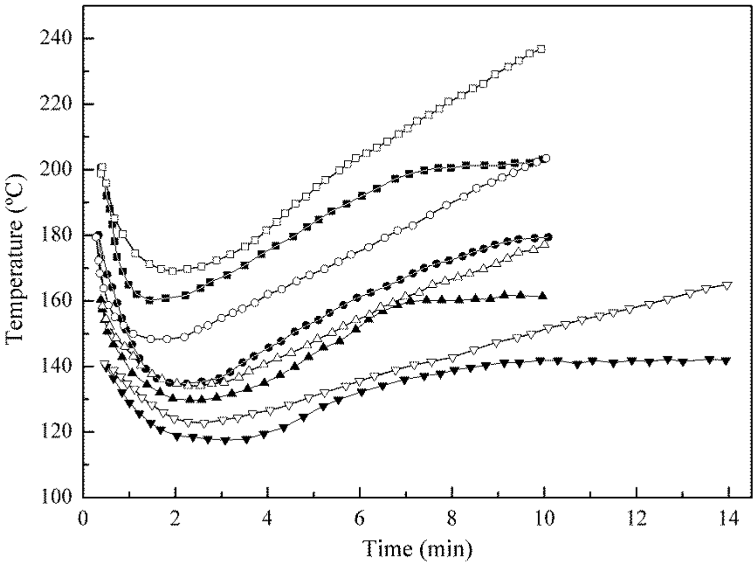

Figure 1. Oil temperature during the frying of raw potatoes. Filled symbols correspond to frying with temperature control and hollow symbols to frying without temperature control. Initial temperature: squares, 200 °C; circles, 180 °C; triangles, 160 °C and inverted triangles, 140 °C.

3.2. Effect of par-frying-freezing and temperature controlled frying

Table 1 shows the weight loss, color, fat and acrylamide concentration of fresh and frozen par-fried potatoes of trial 1. The weight loss increased with the temperature, and there were no differences in this respect between samples that were fried at the same initial temperature. The oil uptake in fresh potatoes during temperature-controlled frying was unchanged with increasing temperature. However, it increased in the absence of temperature control. Furthermore, these samples had a higher oil content than the corresponding samples that were fried with temperature control. In the case of frozen par-fried potatoes, the oil concentration increased as the temperature increased, and again the use of the temperature control had a positive effect by reducing the uptake of oil at a higher frying temperature (200 °C). Temperature is a factor that directly affects the three main mechanisms of absorption (DANA and SAGUY, 2006; HUANG and FU, 2014).

Table 1. Effect of par-frying-freezing and temperature controlled frying on the physico-chemical data, fat and acrylamide contents of potatoes.

Potatoes	T_i (°C)	Temperature control	Weight loss (%)	Color		Fat content (g/100 g)	Acrylamide content (mg/kg)
				*L**	*a**		
Fresh	160	with	32.6±2.9 ^{b}	69.3±1.3 ^{f}	-1.7±0.8 ^{a}	6.4±1.7 ^{a}	403±40 ^{a}
	180	without	45.3±2.2 ^{cde}	60.8±2.5 ^{c}	5.3±0.7 ^{d}	9.4±0.4 ^{b}	1547±120 ^{d}
		with	44.0±1.6 ^{cde}	68.7±0.3 ^{ef}	2.6±0.7 ^{c}	6.5±1.3 ^{a}	1154±150 ^{c}
	200	without	52.1±0.7 ^{e}	59.5±0.8 ^{c}	6.6±0.1 ^{e}	12.3±0.6 ^{c}	5600±560 ^{h}
		with	50.8±0.6 ^{e}	64.1±0.6 ^{cde}	4.9±0.9 ^{d}	6.9±0.8 ^{a}	3030±180 ^{f}
Par-fried-frozen	160	with	28.7±1.1 ^{a}	65.7±2.8 ^{def}	0.9±0.2 ^{b}	16.4±1.1 ^{cd}	450±30 ^{a}
	180	without	38.2±3.9 ^{bc}	61.7±2.5 ^{cd}	5.5±0.2 ^{d}	18.9±1.3 ^{d}	1905±97 ^{e}
		with	41.2±1.5 ^{cd}	64.3±0.6 ^{cde}	3.2±0.6 ^{c}	18.0±1.3 ^{d}	1632±121 ^{d}
	200	without	47.6±0.2 ^{de}	47.0±1.7 ^{a}	10.7±0.3 ^{f}	36.6±1.9 ^{f}	5247±260 ^{h}
		with	46.7±3.3 ^{de}	53.1±1.2 ^{b}	10.0±1.0 ^{f}	24.9±1.3 ^{e}	4267±304 ^{g}

Significant differences ($p<0.05$) between potato types and temperatures are indicated by different letters.

A higher frying temperature causes further degradation of the surface of the potato structure, favoring oil absorption. It also favors a more rapid removal of water, enhances the absorption of oil during cooling, and leads to a faster degradation of the frying medium producing the formation of surface-active substances promoting an increase in the oil uptake. The frozen par-fried potatoes had an initial fat content of 6.0 g/100 g, and showed a markedly higher final fat content than fresh potatoes under the same frying conditions. Color changes in French fries during frying caused by the Maillard reaction depend on factors such as the content of reducing sugars, the temperature and the frying time (MÁRQUEZ and AÑÓN, 1986). The *L** and *a** coordinates are color parameters that best reflect this darkening (PEDRESCHI *et al.*, 2006) and therefore show greater differences between samples. The *L** decreases when increasing the frying temperature of fresh and frozen par-fried potatoes. For the same initial temperature, fresh potatoes are lighter than frozen par-fried potatoes. As a result of frying, the *a** coordinate value increases from negative values in fresh potatoes at the lowest initial temperature, 160 °C, (-1.7±0.8), to values which become greater when increasing the frying temperature. These changes in the *L** and *a** coordinates occur as a result of the Maillard reaction, generating compounds that give brownish tones. The rate at which the Maillard reaction occurs is strongly dependent on temperature and the concentration of the compounds involved (PEDRESCHI *et al.*, 2006). The frozen par-fried potatoes previously acquire some color in the industrial pre-frying process which could explain the lower value of *L** and higher *a** for the same frying conditions. French fries fried with the temperature control activated had a lower *a** and a higher *L** than those fried without controlled temperature. Numerous studies suggest a link between acrylamide formation and the development of non-enzymatic browning during frying (PEDRESCHI and MOYANO, 2005; PEDRESCHI *et al.*, 2006; ROMANI *et al.*, 2009). This is a result of the good correlations between changes in the color parameters *L** and *a** and the concentration of acrylamide. The concentrations of acrylamide in French fries under different conditions are shown in Table 1. The color changes show that the acrylamide content increases with temperature. This is consistent with data found in the literature (GERTZ and KLOSTERMANN, 2002; RYDBERG *et al.*, 2003; PEDRESCHI *et al.*, 2006; MIAO *et al.*, 2014). Furthermore, it can be observed that the temperature control reduces the formation of acrylamide. GERTZ and KLOSTERMANN (2002), FISELIER *et al.* (2006), and MATTHÄUS (2009) noted the importance of using efficient temperature control fryers to ensure the recovery of the initial oil temperature after adding the food to achieve the formation of a crispy crust on the fried product and to avoid overheating during frying that could produce an increase in the formation of acrylamide. In all cases, frozen par-fried potatoes had higher acrylamide contents than the corresponding fresh potatoes.

3.3. Pre-treatments

Pre-treatment by soaking 20 min in tap water or in acidified water (vinegar pH= 3.17) had no impact on the weight loss or oil uptake, but it had an effect on the color of the potatoes; they were paler and less brown (higher L^* and lower a^*), especially when the initial frying temperature was 200 °C, as shown in Table 2. Acidification of the soaking water exerted a positive effect with respect to the coordinate L^*; therefore, the French fries were slightly brighter. In the control and the pre-treated samples, the a^* increased with the temperature. However, soaking in acidified water reduced the development of brownish tones as the a^* color coordinate was lower than in the control sample. Other authors have found the same trend after soaking in an aqueous NaCl solution (PEDRESCHI *et al.*, 2007; SANTIS *et al.*, 2007). This reduction of the coordinate a^* could be due to a more limited development of brownish compounds caused by the lixiviation of the precursors of the Maillard reaction, reducing sugars and asparagine in the soaking water (MÁRQUEZ and AÑÓN, 1986). The pretreatments influenced the concentration of acrylamide in the French fries (Table 2). The pre-soaked samples had a lower concentration of acrylamide at all frying temperatures. The results also indicate that the addition of vinegar to the soaking water makes this pretreatment more effective when potatoes are fried at the initial temperatures of 160 and 180 °C. At 200 °C, acidification of the soaking water did not reduce the concentration of acrylamide compared to the sample soaked in water at a higher pH. Soaking produced a reduction in the acrylamide content of between 23% and 50%. The lower the temperature, the greater the relative reduction. With the pretreatment with acidified water, the acrylamide content was reduced up to 76%.

Table 2. Influence of soaking on the physico-chemical data, fat and acrylamide contents ($\mu g\ kg^{-1}$) of potatoes fried with temperature control.

T_i (°C)	Pre-treatment	Weight loss (%)	Color		Fat content (g/100 g)	Acrylamide content (mg/kg)
			L^*	a^*		
160	Without soaking	32.6 ± 2.9^{a}	68.8 ± 0.5^{d}	-2.1 ± 0.5^{a}	6.3 ± 1.5^{ab}	412 ± 34^{c}
	Water bath	33.6 ± 2.3^{a}	72.2 ± 3.7^{d}	-2.2 ± 0.3^{a}	5.1 ± 0.6^{a}	206 ± 23^{b}
	Acidified water bath	33.1 ± 3.4^{a}	73.1 ± 0.7^{d}	-2.2 ± 1.0^{a}	5.2 ± 1.2^{a}	160 ± 12^{a}
180	Without soaking	42.0 ± 0.3^{b}	60.0 ± 3.1^{b}	2.3 ± 0.3^{b}	6.4 ± 1.4^{ab}	1109 ± 134^{e}
	Water bath	42.6 ± 3.0^{b}	64.0 ± 3.0^{bc}	1.9 ± 0.4^{b}	7.1 ± 0.1^{bc}	734 ± 58^{d}
	Acidified water bath	45.2 ± 2.7^{bcd}	66.0 ± 2.0^{c}	1.8 ± 0.5^{b}	7.2 ± 0.9^{bc}	267 ± 43^{b}
200	Without soaking	52.4 ± 4.1^{de}	54.6 ± 0.9^{a}	5.5 ± 0.4^{d}	6.9 ± 0.7 b^{c}	3056 ± 155^{h}
	Water bath	50.0 ± 2.3^{cd}	58.9 ± 1.7^{b}	5.6 ± 0.9^{d}	7.1 ± 0.5^{bc}	2348 ± 134^{f}
	Acidified water bath	$50.\pm2.0^{cd}$	61.3 ± 3.0^{bc}	4.0 ± 0.7^{c}	6.9 ± 0.2^{bc}	2457 ± 113^{fg}

There are significant differences ($P < 0.05$) between values with different letters within the same column.

Some authors, such as PEDRESCHI *et al.* (2004) and MESTDAGH *et al.* (2008), have noted that reducing sugars by blanching or soaking prior to frying reduces acrylamide levels up to 60% in potatoes. Furthermore, PEDRESCHI *et al.* (2007) found that the reduction in the acrylamide concentration was related to the soaking time. Compared to the control, they found a reduction of 15% after 60 min and 30% after 120 min of soaking. Acidifying the soaking water with citric acid further reduced the acrylamide in the potato slices, especially at lower temperature frying (PEDRESCHI *et al.*, 2004). This is consistent with the results of the vinegar addition in the present study. JUNG *et al.* (2003) found the same trend in potatoes pretreated in a solution of citric acid, achieving a 25% reduction in the acrylamide concentration in French fries. They attributed this decline to the decrease in the pH as well as the leaching of free asparagine and reducing sugars from the surface of the potatoes into the solution. The formation of acrylamide is strongly dependent on the pH (RYDBERG *et al.*, 2003).

3.4. Alternative cooking methods

Table 3 shows the physico-chemical parameters such as weight loss and color as well as the fat and acrylamide contents of roasted or butter fried potatoes. No significant differences between oven temperatures were obtained (P>0.05) for the studied parameters except the acrylamide content. Comparing roasted potatoes with those fried in oil (trial 1), it can be concluded that the roasted potatoes had lower levels of fat than the fried ones and they were less brown. The roasted potatoes had acrylamide values between 213 and 742 mg/kg. The temperature strongly influences the acrylamide concentration, as the concentration increased with the oven temperature. However, in this case there was no correlation with the color development, as there was no significant difference in the *L** or *a** coordinates with the temperature. Even at the highest roasting temperature (180 °C), the acrylamide formation was lower than that generated when frying with oil temperature control at the same initial temperature (1632 mg/kg). Butter fried potatoes showed significant differences in the color coordinate *a** and in the acrylamide content depending on whether or not the temperature control was used. Thus, good temperature control markedly diminished the acrylamide content (71% reduction) and reduced the appearance of the brown tones while maintaining the other parameters such as weight loss and fat content. The high concentration of acrylamide in butter fried potatoes, even at a lower temperature than usual for frying (140 °C), could be explained by the reaction between butter, sugars and amino acids such as lysine (URIBARRI *et al.*, 2010; NIQUET-LERIDON *et al.*, 2015).

Table 3. Physico-chemical data, fat and acrylamide contents of roasted and butter fried potatoes.

Cooking condition	Weight loss (%)	Color		Fat content (g/100 g)	Acrylamide content (mg/kg)
		*L**	*a**		
Roasted					
170 °C	47.0±2.4 ^{b}	63.0±1.3 ^{a}	2.1±0.6 ^{ab}	11.2±0.5 ^{c}	213±60 ^{a}
175 °C	47.6±1.4 ^{b}	63.1±4.4 ^{a}	2.6±1.4 ^{bc}	10.2±1.4 ^{bc}	625±45 ^{c}
180 °C	48.4±1.4 ^{b}	64.9±2.0 ^{a}	1.9±0.7 ^{ab}	11.4±1.1 ^{abc}	742±47 ^{d}
Butter fried at T_i=140 °C					
Without control	44.9±1.1 ^{a}	63.3±4.0 ^{a}	3.3±1.2 ^{c}	10.4±1.3 ^{bc}	1123±80 ^{e}
With control	45.3±2.0 ^{ab}	64.7±6.1^{a}	2.3±0.6 ^{ab}	9.4±1.1 ^{ab}	323±43 ^{b}

Significant differences (p<0.05) between cooking conditions and temperatures are indicated by different letters.

4. CONCLUSIONS

The results of this study indicate that it is important to include a system of temperature control in domestic cooking equipment to optimize culinary quality while at the same time mitigating the acrylamide content. Such control prevents overheating during frying and enables the formation of acrylamide to be limited in domestic preparations. During frying, potatoes lose more water and capture more oil under higher temperature conditions. Potatoes prepared at higher temperatures become darker as they develop more brown colors. Frying at controlled and moderate temperatures (180 °C or less) reduces the acrylamide concentration of potatoes up to 46% with respect to potatoes fried without temperature control. The reduction improves to 76% if the potatoes are previously soaked in acidified water (pH = 3.17 for 20 min). The formation of acrylamide varies greatly depending on the method of cooking the potatoes. For the same temperature, roasted potatoes contained less acrylamide than fried potatoes. Not only is the temperature control an important factor in acrylamide formation during frying, but the type of frying fat is also critical. The dissociation of the lactose present in butter into reduced sugars is suggested as an explanation for this high concentration in butter fried potatoes. In addition, frying with butter must be performed at moderate temperatures because of its lower smoke point. The substitution of butter with a mixture of sunflower oil and butter could be a solution to obtain a higher smoke point. Frozen par-fried potatoes gained more fat, developed a darker color and contained more acrylamide than fresh potatoes when prepared under the same conditions; therefore, frozen par-fried potatoes should be prepared at lower heating conditions than those selected for fresh potatoes.

ACKNOWLEDGEMENTS

The project: Application of culinary technology for the improvement and development of automatic systems for controlling temperature (2012/0138) was financially supported by BSH Electrodomésticos España, S.A.

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Paper Received December 12, 2016 Accepted February 22, 2017