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Impact of vacuum frying on quality of potato crisps and frying oil

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A B S T R A C T

This research was focused on a critical assessment of vacuum frying as a technology enabling minimization of acrylamide formation in potato crisps and reducing undesirable chemical changes that occur in frying oil at high temperatures. The potato slices were fried in rapeseed oil under vacuum at 125 °C and atmospheric pressure at 165 °C. The experiments were performed on two potato varieties, Saturna and Impala. Vacuum frying reduced the formation of acrylamide by 98% and also other Maillard reaction products, specifically alkylpyrazines. Concurrently a lower extent of oxidative changes was observed in the frying oil, while 3-MCPD esters decreased fairly quickly during conventional frying. Sensory characteristics of the vacuum and conventionally fried potato crisps were evaluated by a 23-member panel. The majority of panellists preferred the flavour of 'conventional crisps', while only a few of them appreciated potato-like fresh flavour of 'vacuum crisps' and classified this product as 'tasty'.

1. Introduction

Deep-fat frying, similar to other heat processing practices, may change sensorial properties and nutritional value of the respective product. Moreover, food safety concerns may arise due to formation of toxic 'processing contaminants' (Stadler, 2012, chap. 9). A lot of attention has been paid to acrylamide, classified by the International Agency for Research on Cancer (IARC) as a 'probable human carcinogen' (Group 2A) (IARC, 1994), since it was found in heat processed starch-rich foods in 2002. The potentially increased risk of developing cancer for consumers in all age groups due to dietary exposure has been confirmed in the recent EFSA 'Scientific Opinion on Acrylamide in Food' (EFSA, 2015).

Acrylamide and its formation pathways in various foodstuffs have been investigated in many studies (EFSA, 2015; Keramat, LeBail, Prost, & Soltanizadeh, 2011; Nguyen, Van der Fels-Klerx, Peters, & Van Boekel, 2016; Nguyen, Van der Fels-Klerx, & Van Boekel, 2017). In general terms, acrylamide naturally originates *via* Maillard reaction in starchy rich foods with low moisture content when heated above 120 °C, especially in foods containing asparagine and reducing sugars (Biedermann, Biedermann-Brem, Noti, & Grob, 2002; Mottram, Wedzicha, & Dodson, 2002). According to EFSA Scientific Panel (EFSA, 2015), potato fried products, such as potato crisps, may significantly contribute to the total dietary exposure in some population groups.

Much effort has been spent on optimisation of processing conditions, enabling the mitigation of this processing contaminant in potato crisps and similar potato-based products fried at high temperatures. The FoodDrinkEurope acrylamide "Toolbox" (Acrylamide Toolbox, 2013) summarises methods to manage levels of acrylamide as a process contaminant. Firstly, agronomic factors are put in place to reduce the sugar content in potato tubers. Secondly several effective intervention steps, which may prevent and/or reduce acrylamide formation in potato crisps ('French fries and other cut deep-fried potato products' category), have been found, including: (i) pre-treatment such as blanching and washing (reduction of acrylamide precursors); (ii) use of asparaginase (asparagine deamination); and (iii) regulation of thermal input and moisture.

In the last case, vacuum frying is mentioned as an alternate thermal input control system that, due to lower temperatures, reduces the extent of Millard reactions, including acrylamide formation. The application of these preventive/mitigation measures resulted in a significant downward trend for mean levels of acrylamide in potato crisps, from 763 ± 91.1 $\mu g\,kg^{-1}$ in 2002 to 358 ± 2.5 $\mu g\,kg^{-1}$ in 2011 (EFSA, 2015). However, a small proportion of potato crisps with concentrations exceeding the 'indicative' level set to 1000 $\mu g\,kg^{-1}$ by the EU Commission 2013/647/EU (Commission Recommendation, 2013) can still be found on the market. In this context, it is evident that strategies and measures allowing minimization of acrylamide content in this 'risky' commodity are needed. So far, the only currently known published study (Granda, Moreira, & Tichy, 2004) focused on acrylamide

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formation in vacuum fried potato crisps (prepared from varieties grown in the USA) without evaluating the quality of oil absorbed into crisps fried under low pressure.

Potato crisps absorb relatively high amounts of frying oil, typically around 30% (*w/w*) and some products even more (Moreira, Castell-Perez, & Barrufet, 1999). Both nutritional and sensorial quality of the oil is closely associated with changes that occur throughout the frying process. During conventional frying, where temperatures reach 170 °C, many chemical reactions, amongst the most significant being oxidation and polymerisation, take place. In addition to hydroperoxy, epoxy, hydroxy, and carbonyl groups, these large molecules contain -C-O-C- and -C-O-O-C- linkages (Choe & Min, 2007). The extent of linkaging depends on the composition of the frying oil, specifically on the degree of unsaturation in fatty acids. Key factors playing an important role in these chemical reactions are oxygen and moisture content. The indicators of oil bath quality are not only free fatty acids (released by triacylglycerol hydrolysis), but also various, both low and high molecular weight, oxidation products forming through auto-oxidation reactions. In addition to the deterioration of sensory properties, some of these products are anti-nutritional or even toxic (Zhang, Saleh, Chen, & Shen, 2012). In this context, at the 3rd International Symposium on Deep-Fat Frying in 2000, delegates from the German Society for Fat Science published recommendations for the classification of frying oil quality with limits for total polar compounds in oil (< 24%) and for polymerised triacyglycerols (< 12%) (Stier, 2013). Limited information regarding the quality of different frying oils during vacuum frying of potato crisps is presented (Basuny, Arafat, & Ahmed, 2012; Crosa et al., 2014).

In the past decade, a concern has emerged regarding the content of 3-monochloropropane-1,2-diol (3-MCPD) esters that occur especially in refined edible fats and oils. Since there is a suspicion, that free 3-MCPD (classified as possible human carcinogen) may be released from its bound form by action of gastrointestinal lipases (IARC, 2012), the changes of 3-MCPD esters during frying should be investigated in more detail as they are transferred into potato crisps together with the frying oil.

In the frame of this study, we have tested vacuum frying as a process that is carried out under pressures well below atmospheric levels. Due to lower frying temperatures, vacuum frying reduces undesirable reactions that may occur both in the respective matrix and oil bath. Most of the relevant studies were aimed at its potential to preserve 'freshness/nutritional value' of respective product through preventing degradation of natural components, e.g., vitamins, pigments, etc., but also preventing toxic compounds formation (Dueik & Bouchon, 2011; Moreira, 2014). The purpose of our study was not only to minimise acrylamide formation under optimised vacuum frying conditions and to assess the palatability of the final product, but also to evaluate adverse chemical changes in the frying oil, both in terms of the formation of breakdown products and the occurrence of 3-MCPD esters.

2. Materials and methods

2.1. Chemicals

Acrylamide (purity 99.5%) was from Sigma-Aldrich (Buchs, Switzerland). $^{13}C_3$-Acrylamide (isotopic purity ≥99%) was from Cambridge Isotope Laboratories (Tewksbury, MA). Magnesium sulfate (p.a. purity ≥98%) was from Fluka (Tokyo, Japan). Sodium chloride (purity ≥99%), sodium phosphate dibasic dodecahydrate, ethylenediaminetetraacetic acid disodium salt dehydrate (Na_2EDTA), aqueous ammonia solution (25%, *v/v*) (all of purity ≥99%) and anhydrous sodium sulfate were from Penta (Chrudim, Czech Republic). Methanol, *n*-hexane, toluene, tetrahydrofuran (HPLC grade) and aluminium oxide, and silica gel sorbent (technical grade, pore size 60 Å, 70–230 mesh, and 63–200 μm) were from Merck (Darmstadt, Germany) Acetonitrile, amino acid asparagine, homoserine; sugars (glucose, fructose, sucrose; all of purity ≥99.5%) and ammonium formate (purity, ≥95%) were supplied by Sigma-Aldrich (Steinheim, Germany). De-ionised water was obtained from a Millipore apparatus (Billerica, MA). Alkylpyrazines (a mixture of 2-ethyl-5-methylpyrazine and 2-ethyl-6-methylpyrazine, a mixture of 2-ethyl-3,5-dimethylpyrazine and 2-ethyl-3,6-dimethylpyrazine, 2,3-diethyl-5-methylpyrazine, 2,3-diethylpyrazine, 2,3-dimethylpyrazine, 2,5-dimethylpyrazine, 2,6-dimethylpyrazine, 2-ethyl-3-methylpyrazine, ethylpyrazine, methylpyrazine, tetramethylpyrazine, trimethylpyrazine) were purchased from Pyrazine Specialties, Inc. (Atlanta, GA). Standards of nine 3-MCPD diesters: 1,2-dipalmitoyl-3-chloropropanediol (1,2-diP-3-MCPD), 1-palmitoyl-2-linoleoyl-3-chloropropanediol (1-P-2-L-3-MCPD), 1-palmitoyl-2-oleoyl-3-chloropropanediol (1-P-2-O-3-MCPD), 1-palmitoyl-2-stearoyl-3-chloropropanediol (1-P-2-St-3-MCPD), 1,2-dilinoleoyl-3-chloropropanediol (1,2-diL-3-MCPD), 1-oleoyl-2-linoleoyl-3-chloropropanediol (1-O-2-L-3-MCPD), 1-oleoyl-2-stearoyl-3-chloropropanediol (1-O-2-St-3-MCPD), 1,2-dioleoyl-3-chloropropanediol (1,2-diO-3-MCPD), and 1,2-distearoyl-3-chloropropanediol (1,2-St-3-MCPD); 1,2-dipalmitoyl-3-chloropropanediol-d5 (1,2-diP-3-MCPD-d5) (all of purity, ≥97%) were purchased from Toronto Research Chemicals (Ontario, Canada).

2.2. Samples

Potato sample varieties Saturna A and B were kindly supplied by the Potato Research Institute (Czech Republic) and variety Impala was purchased from the retail market. Prior to frying experiments, potatoes were washed, peeled and sliced on a WS slicer (A. Börner GmbH, Germany) to get uniform thickness of slices (1.5–2 mm). Potato slices were rinsed with water for 15 s and blotted with paper towels to remove surface water.

2.3. Vacuum frying experiments

Vacuum frying was conducted in a 4-L capacity frying vessel, specially manufactured by ProjectSoft, Hradec Kralove, Czech Republic, for our experimental purposes. The inner diameter of the vessel was 20 cm and the wall thickness was 5 cm. A vacuum pump was used to generate vacuum (10 kPa) to the vessel. The frying basket was fixed to a rod mounted to the lid ensuring closing of the vessel. The vacuum vessel was set to the target temperature (125 °C) and heated until equilibration was reached.

Potato slices (100 g) were fried at 125 °C for 180, 240, 300 and 360 s in rapeseed oil. Frying was done in six replicates. Fried potato crisps were gently blotted with paper towels to remove oil droplets, cooled at room temperature and stored in PE bags for further analysis.

2.4. Conventional frying experiments

Atmospheric frying was conducted in a 3.5-L home fryer (DeLonghi Premium Fry, Italy). The conventional fryer was set to the required temperature (165 °C) and heated till equilibration was reached. Potato slices (100 g) prepared from variety Saturna B and Impala were fried at 165 °C for 105, 120, 135 s in rapeseed oil. Frying was done in six replicates. Fried potato crisps were quickly and gently blotted with paper towels to remove oil droplets, cooled at room temperature and stored in PE bags for analysis.

2.5. Experimental determinations

2.5.1. Reducing sugars

The sugar content in potato tubers was determined applying high-performance liquid chromatography (HPLC) coupled to refractometric detector. Raw potatoes (30.0 g) were mixed with 70 mL of 50% methanol and homogenised by Ultra-Turrax® T50 for 1 min. The homogenised sample was then filtered under vacuum, washed with methanol (50%, *v/v*) and subsequently analysed. The HPLC system consisted of