Food Chemistry 182 (2015) 1–8

Contents lists available at ScienceDirect

Food Chemistry

journal homepage: www.elsevier.com/locate/foodchem

Acrylamide in potato crisps prepared from 20 UK-grown varieties: Effects of variety and tuber storage time

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ARTICLE INFO

Article history:
Received 24 October 2014
Received in revised form 19 February 2015
Accepted 20 February 2015
Available online 26 February 2015

Keywords:
Acrylamide
Reducing sugars
Free amino acids
Potato
Solanum tuberosum
Crisps
Colour
Maillard reaction
Storage
Cultivar

ABSTRACT

Twenty varieties of field-grown potato were stored for 2 months and 6 months at 8 °C. Mean acrylamide contents in crisps prepared from all varieties at both storage times ranged from 131 μg/kg in Verdi to 5360 μg/kg in Pentland Dell. In contrast to previous studies, the longer storage period did not affect acrylamide formation significantly for most varieties, the exceptions being Innovator, where acrylamide formation increased, and Saturna, where it decreased. Four of the five varieties designated as suitable for crisping produced crisps with acrylamide levels below the European Commission indicative value of 1000 μg/kg (Saturna, Lady Rosetta, Lady Claire, and Verdi); the exception was Hermes. Two varieties more often used for French fries, Markies and Fontane, also produced crisps with less than 1000 μg/kg acrylamide. Correlations between acrylamide, its precursors and crisp colour are described, and the implications of the results for production of potato crisps are discussed.

1. Introduction

Cooked potato products, such as crisps, chips (French fries) and oven-cooked potatoes, contribute a substantial proportion of the estimated intake of acrylamide in the adult population of Europe, the other major contributors being coffee and cereal products, in particular bread but also biscuits, crispbreads and breakfast cereals (European Food Safety Authority, 2014). There are considerable differences in dietary preferences across Europe, but crisps account for between 0.6% and 6.6% of adult dietary acrylamide intake and other fried potato products account for between 9.6% and 49%. The percentage contribution of potato products may be even higher for children and adolescents (Dybing et al., 2005), partly because this group drinks less or no coffee. A similar picture has emerged in other parts of the world; Katz, Winter, Buttrey, and Fadel (2012), for example, suggested that 55% of the acrylamide consumed in a typical US diet could be derived from cooked potato products.

Although it has not been established that acrylamide at the levels found in food is harmful to humans, there is a broad consensus based on animal studies that it potentially increases the risk of developing cancer, and in 2011 the Joint FAO/WHO Expert Committee on Food Additives recommended that food manufacturers should make "further efforts on developing and implementing mitigation methods for acrylamide in foods of major importance for dietary exposure" (WHO Technical Report Series No. 959, 2011). A concerted effort by the European snack foods industry in response to this and previous recommendations has led to a significant reduction in acrylamide levels in crisps over the past 10 years (Powers, Mottram, Curtis, & Halford, 2013). Nevertheless, crisp and French fry manufacturers still have to contend with a highly variable raw material and the identification of potato varieties with consistently low concentrations of acrylamide precursors (free asparagine and reducing sugars) in the tubers would make it easier for manufacturers to ensure that acrylamide levels in their products were always low.

Many strategies have been suggested for acrylamide reduction in cooked foods (Taeymans et al., 2004; Vinci, Mestdagh, & De Meulenaer, 2012) and these have been compiled in a 'Toolbox' for acrylamide reduction by Food Drink Europe (2014). However, most of these strategies are not applicable to potato crisps and fries, or have an adverse effect on product quality because they

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http://dx.doi.org/10.1016/j.foodchem.2015.02.103
0308-8146/

affect the Maillard reaction (the heat-induced reaction between free amino acids and reducing sugars), which is the primary mechanism for acrylamide formation but is also crucial for the development of flavour and colour in cooked foods (Mottram, Low, & Elmore, 2006).

A complementary approach is to reduce the concentrations of the precursors for acrylamide formation in the raw material, for example by variety selection (Halford et al., 2012b; Muttucumaru, Powers, Elmore, Mottram, & Halford, 2013; Muttucumaru et al., 2014; Olsson, Svensson, & Roslund, 2004). Raw materials with low precursor concentration would generate less acrylamide in any form of cooking, industrial or domestic, and would reduce the need to adapt processes (Halford et al., 2012a). Hence, potato varieties that are low in acrylamide precursors but give desirable sensory attributes when fried or oven baked are keenly sought.

The aim of this work was: (1) to show that varieties being grown and used for crisp manufacture in the UK are appropriate with regard to their acrylamide-forming potential; (2) to examine the potential of other varieties for crisp manufacture; (3) to provide more data on the effect of tuber storage on acrylamide formation and quality in crisps.

2. Materials and methods

2.1. Potato samples

Twenty different potato (*Solanum tuberosum*) cultivars grown at the Woburn farm site of Rothamsted Research in Bedfordshire, United Kingdom (Grid reference SP968364; 52°01′06″N, 0°35′30′W; sandy clay loam), in 2011 were analysed in this study. The varieties analysed were Lady Claire, Lady Blanca, Lady Olympia, Lady Rosetta, Daisy, King Edward, Maris Piper, Fontane, Hermes, Markies, Harmony, Pentland Dell, Desiree, Challenger, Ramos, Innovator, Umatilla Russet, Russet Burbank, Saturna and Verdi. Three plots of each variety were grown using a randomised block design; each plot served as a replicate for all subsequent analyses. Uniform application of fertiliser (Nitram (ammonium nitrate; 34.5% N) at 290 kg/ha; triple superphosphate (46% phosphate) at 111 kg/ha; muriate of potash (potassium chloride) at 500 kg/ha) took place immediately prior to planting, in mid-April 2011. Tubers were harvested in September and October 2011, according to whether they were early-, mid- or late-maturing varieties and to when canopy senescence was complete. Plots were irrigated and sprayed as and when deemed necessary by the farm manager. The varieties chosen covered a range of possible food uses, in particular crisps, French fries, and fresh ware (i.e., domestic use, such as mashed, jacket and roast potatoes). Potatoes were all grown at the same site, so that the effect of location on tuber composition was minimised.

Tubers were stored at 8 °C for either 2 or 6 months at the Potato Council Sutton Bridge Crop Storage Research (SBCSR) facility. These conditions were chosen as a suitable compromise for all of the varieties; some varieties used for crisping are stored at higher temperatures while others are not stored for as long as 6 months. Tubers were treated with the anti-sprout agent chlorpropham (CIPC), with applications just after storage commenced and two further applications for the 6-month samples (all applications at 28 mL/tonne of ProLong (50% w/v CIPC in methanol)). Solids contents of tubers were measured when the tubers came out of storage (Tai, Misener, Allaby, & McMillan, 1985).

2.2. Crisps

Potatoes from each variety at each storage point (40 treatments) were made into crisps at SBCSR. Three batches of crisps were prepared and analysed for each treatment; each batch corresponded to the contents of a field plot. The procedure used for cooking was typical of that used in the preparation of commercial crisps and gives crisps with an average moisture content of 1.5%.

Tubers were peeled then sliced longitudinally to give slices 0.12–0.15 cm thick. Slices (300 g fresh weight) were washed in cold water for 45 s, stirring continuously and then cooked in 15 L of high oleic sunflower oil for 3 min at a starting temperature of 177 °C, using a Bartlett Yeoman D-11E30 single tank 9 kW electric fryer (Bartlett, Exeter, UK). Crisp samples were allowed to cool, and then heat-sealed in laminated foil. Crisps were stored at −18 °C until analysis. These conditions were chosen as being suitable for all of the varieties but may differ slightly from commercial practice.

2.3. Free amino acids and sugars in freeze-dried tubers

Free amino acids and sugars were measured in flour samples prepared from individual freeze-dried tubers (Halford et al., 2012b). Free amino acids (sample size 0.100 ± 0.005 g) were extracted in 10 mL of 0.01 M HCl, derivatised using EZ-Faast (Phenomenex, Torrance, CA) and then analysed by GC–MS. Amino acid concentrations were expressed as mmol/kg dry weight. This method is not suitable for the measurement of arginine. Sugars (sample size 0.100 ± 0.005 g) were extracted in 10 mL of 50% aqueous methanol containing 100 mg/L trehalose and quantified by ion chromatography with pulsed amperometric detection. Sugar concentrations were expressed as mmol/kg dry weight.

2.4. Acrylamide analysis

The method of Halford et al. (2012b) was adapted. Potato crisps were ground in a food processor and ground samples (0.500 ± 0.005 g) were weighed into 50-mL Falcon tubes. Samples were extracted with water (40 mL, containing 50 μg/L $^{13}C_3$-acrylamide internal standard) at room temperature. After shaking for 20 min, tube and contents were centrifuged at 9000 rpm for 15 min at 15 °C. A discrete fat layer formed on the surface of the sample. Two millilitres were removed from the aqueous layer and passed through a 0.2-μm syringe filter into a 2-mL vial.

Samples were analysed by liquid chromatography-mass spectrometry/mass spectrometry (LC–MS/MS) using an Agilent 1200 high-performance liquid chromatography (HPLC) system connected to a 6410 triple quadrupole mass spectrometer with electrospray ion source in positive ion mode. An isocratic separation was carried out at room temperature using a 100 × 3.0 mm Hypercarb column with a 10 × 3.0 mm Hypercarb pre-column (both 5 μm particle size; Thermo Fisher, Waltham, MA). The mobile phase was 0.1% aqueous formic acid at a flow rate of 0.3 mL/min. Injection volume was 25 μL. The transitions m/z 72 → 55 and m/z 72 → 27 were measured for acrylamide and the transition m/z 75 → 58 was measured for $^{13}C_3$-acrylamide. Concentrations of acrylamide in crisps were expressed as μg/kg fresh weight.

2.5. Crisp colour measurement

Fried crisp samples were first graded in a light cabinet to remove any surface defects, such as greening, bruising and excessively dark fry colour. Removal of defects often resulted in insufficient sample to present to the Hunter Lab, so *Lab* values could not be obtained for some samples. The sample remaining was placed in a shallow dish, and the surface was crushed flat before presenting to the viewing port of a Hunter DP-9000 colorimeter (Hunter Associates Laboratory Inc., Reston, VA). The sample dish was turned through approximately 120° before taking a second reading, and again for a third reading. Samples did not leave the dish between