Food Control 62 (2016) 216–223

Contents lists available at ScienceDirect

Food Control

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

Influence of the frying process and potato cultivar on acrylamide formation in French fries

Yali Yang, Isabel Achaerandio, Montserrat Pujolà*

Department d'Enginyeria Agroalimentària i Biotecnologia, Escola Superior d'Agricultura de Barcelona, Universitat Politècnica de Catalunya BarcelonaTech, Barcelona, Spain

ARTICLE INFO

Article history:
Received 22 June 2015
Received in revised form
7 October 2015
Accepted 22 October 2015
Available online 24 October 2015

Keywords:
Asparagine
Colour
Oil uptake
Reducing sugars
Sucrose
Texture

ABSTRACT

Acrylamide formation during the production of French fries is attributed to Maillard reactions from reducing sugars and asparagine and is dependent on the frying temperature. Low reducing sugars content in potatoes has been recommended to produce fried potato products. However, the influence of the complexity of the potato medium in the chemical reactions that promote the acrylamide formation during deep frying are not well understood. In this study, three potato cultivars (Kennebec, Red Pontiac and Agria) commonly used for fried potato products were evaluated to determine the relationships between the precursors of acrylamide in the fresh potato tubers and the properties of the fried potato strips with the acrylamide content after frying. Frying experiments were conducted at three conditions (time-temperature) to obtain French fries of similar visual colour. Acrylamide formation increased with frying temperature but different behaviour was observed between cultivars. For Red Pontiac, a remarkably increase in acrylamide content was found at 170 °C (~40%) together with the increase in colour. However, lower oil uptake and higher moisture content was obtained as temperature increase. Significant positive correlations were observed between the acrylamide level and the reducing sugars and sucrose content on fresh potatoes (0.652, 0.699, $p \le 0.01$, respectively). The acrylamide content obtained in Agria cultivar may be obtained from the hydrolysis of sucrose during the frying process. In fried potato strips, positive significant correlation was found between the shear force and acrylamide (0.749, $p \le 0.01$). The significant correlations obtained between colour, and texture, colour and oil uptake and texture and acrylamide content indicate the intrinsic relationship between the properties of the fried potato strips and the acrylamide content.

1. Introduction

The potato (*Solanum tuberosum*) is one of the world's major agricultural crops and is consumed daily by millions of people from diverse cultural backgrounds (Pedreschi & Moyano, 2005). French fries have been a popular salty snack for 150 years, and their retail sales in the US are almost one-third of the total sales in this market (Garayo & Moreira, 2002).

Frying has been defined as the immersion of a food product in edible oil above the boiling point of water (Hubbard & Farkas, 1999), with colour, texture and flavour development. It is a complex process because of the two mass transfers in opposite directions within the material being fried; for starchy products, water and some soluble material escapes from the products and oil enters the food (Blumenthal & Stier, 1991). The reports of acrylamide intake indicate that fried potato products, bread and bakery products, coffee and breakfast cereals are the food commodities that contribute the greatest dietary acrylamide exposure (Vinci, Mestdagh, & Meulenaer, 2012). EFSA (2011) reported that the 95th percentiles of the acrylamide intake for adults and for children are estimated to range between 0.6 and 2.3 μg kg^{-1} bw/day and 1.5–4.2 μg kg^{-1} bw/day, respectively. Acrylamide is a neurotoxin in humans, and it has been considered to be a probable human carcinogen (Hogervorst, Schouten, Konings, Goldbohm, & Van den Brandt, 2007; Pedreschi, Kaack, & Granby, 2004; Hu, Xu, Fu, & Li, 2015). Researchers and industry need to find solutions to reduce or prevent acrylamide formation, despite the lack of legal limits for this contaminant, in foods, especially fried potato products.

* Corresponding author. Universitat Politecnica de Catalunya BarcelonaTech (UPC), Departament d'Enginyeria Agroalimentaria i Biotecnologia, Campus Baix Llobregat, Edifici D4, C/Esteve Terradas, 8, 08860 Castelldefels, Barcelona, Spain.
E-mail address: montserrat.pujola@upc.edu (M. Pujolà).

http://dx.doi.org/10.1016/j.foodcont.2015.10.028
0956-7135/

The content of acrylamide (by-product of the Maillard reaction in food processed at a temperature > 120 °C) is dependent on factors such as the cultivar, fertilization, storage, blanching, cooking temperature and time, and the amount of reducing sugars and free amino acids, such as asparagine, present in the potatoes (Cheong, Hwang, & Hyong, 2005; Daniali, Jinap, Hanifah, & Hajeb, 2013; Halford et al., 2012; Marquez & Anon, 1986;). There have been several reports on reducing acrylamide formation, and these strategies were compiled in a "Toolbox" by Food Drink Europe (http://www.fooddrinkeurope.eu/uploads/publications_documents/Toolboxfinal260911.pdf).

The reducing sugars and asparagine, as acrylamide precursors, are very important for reducing the acrylamide content in fried potato products (Palazoğlu, Savran, & Gökmen, 2010). However, the relationship between the asparagine and reducing sugars concentrations in the fresh potatoes and the acrylamide formation during processing are surprisingly complicated. According to the report of Vinci et al. (2012), asparagine concentrations are relatively high compared to the reducing sugars content, which represents the limiting factor in acrylamide formation in fried potato products. In contrast, Shepherd et al. (2010) found that the asparagine and sugar concentrations contributed approximately equally to the acrylamide formation. In addition, Halford et al. (2012) suggested that when the sugar concentration was relatively high, acrylamide formation during processing was proportional to the sugar content, whereas when the sugar level was low, acrylamide formation was proportional to the asparagine content.

The selection of the potato cultivar is very important to reduce acrylamide formation. Some cultivars are more suitable than others for frying in strips, due to their large, long tubers and low reducing sugar content. The frying conditions produce dramatically affect the levels of acrylamide, as well as the browning, texture, and flavour development caused by the Maillard reaction (Mottram, Wedzicha, & Dodson, 2002; Stadler et al., 2002). The frying time and oil temperature should be controlled to reduce the acrylamide content, and the temperature should not exceed 170–175 °C, as lower temperatures towards the end of the Maillard reaction may reduce acrylamide formation (Vinci et al., 2012). Longer frying periods may result in higher acrylamide contents.

During the frying process, oil is used as the heating medium and as an ingredient producing calorific products. Oil uptake is considered the major nutritional critical point of fried products because of the epidemic obesity prevalent in developed and even in developing countries caused by meals rich in fat (FAO, 2002). In addition, Zamora and Hidalgo (2008) and Capuano, Oliviero, Acar, Gökmen, and Fogliano (2010) indicated that lipid oxidation positively influences the formation of acrylamide. However, other studies have not discovered any significant negative effect of the oil uptake on acrylamide formation. To date, there is still some confusion and misunderstanding regarding the influence of oil uptake on acrylamide formation. Due to health concerns, consumer preference for low-fat and fat-free products has been the driving force of studies to understand the oil uptake to control and reduce the oil uptake and acrylamide content while still retaining the desirable texture and flavour of fried potato products.

This study aimed to evaluate the influence of frying conditions on acrylamide formation and to investigate the existence of a relationship between acrylamide levels and the factors potentially involved in the formation of acrylamide, such as the frying temperature, reducing sugars, asparagine, moisture, oil uptake and instrumental sensory parameters (colour and texture) in three potato cultivars commonly used for fried products in Europe.

2. Materials and methods

2.1. Sample preparation

In accordance with the report by Yang, Achaerandio, and Pujola (2015), potato tubers (*Solanum tuberosum*) of three cultivars (Red Pontiac, Kennebec and Agria) were selected. Tubers were commercialized in Spain and obtained from Mercabarna (Mercados de Abastecimientos de Barcelona SA, Barcelona, Spain). All potato cultivars were grown in Europe and had the same postharvest storage conditions prior to use. The dry matter content of all potato cultivars was greater than 200 g kg^{-1}. The flesh colour of the Red Pontiac and Agria cultivars was yellow, and the colour of the cv. Kennebec was white. The potatoes were stored at 8 °C and 95% relative humidity. In our experiment, 8 kg of potatoes from the same industrial lot were classified by size. The mean weights of all the potato cultivars were similar, higher than 200 g. Potatoes were hand peeled and then cut into strips (1 × 1 × 6 cm) with a stainless steel slicer. A fraction of 200 g of potato strips were randomly selected for the frying process. Sunflower oil containing 65% oleic acid was used in the frying. The potato strips of each sample were fried in an electrical fryer (Taurus, Spain) at the following temperature-time conditions: (i) 190 °C for 160 s, (ii) 170 °C for 240 s, (iii) 150 °C for 330 s. The frying period was previously determined by the final colour of the frying strips. The final colour of the fried strips was fixed to standard 3 on the colour scale of the USDA standard for frozen French fries (USDA, 1988). The potato strips' mass to oil mass ratio (g/g) was 1:5. Each cultivar was fried in triplicate under the same frying conditions. After frying, portions of the samples were lyophilized using a Cryodos-45 freeze-drying instrument (Terrasa, Spain), packed in plastic bags and maintained at −20 °C until further use. Another fraction of 200 g of fresh potato strips was homogenized and then the required weight was taken to undergo with the sugar and asparagine analysis.

2.2. Instrumental analysis of colour and texture

2.2.1. Colour

The colour of the potato strips was measured using a Minolta CR-400 colorimeter (Osaka, Japan) in the CIE lab space. The L* (lightness), a* (greenness [−] to redness [+]), and b* (blueness [−] to yellowness [+]) were recorded and evaluated. The parameters of hue angle (H°) and chroma (C) were calculated as $H^\circ = \tan^{-1}(b^*/a^*)$ and $C = (a^{*2} + b^{*2})^{1/2}$. Six measurements were taken for each experiment, and the results were expressed as the mean value ± standard deviation.

2.2.2. Texture analysis: shear force and texture profile analysis

2.2.2.1. Shear force.

The shear force of the samples was measured using a texture analyser (TAXT plus, Stable Microsystems, Surrey, UK), as described by Singh, Kaur, McCarthy, Moughan, and Singh (2008). The test conditions used for the measurement were pre-test speed 1 mm/s; test speed 1 mm/s; post-test speed 1 mm/s; target distance of 30 mm into the samples and trigger force of 2 g. Six potato strips were taken for each experiment, and the shear force (N) was expressed as the mean value ± standard deviation.

2.2.2.2. Texture profile analysis.

Each potato strip was cut to a length of 10.0 mm using a knife. The texture profile analysis (TPA) was performed with the parameters set to pre-test speed 0.83 mm/s, test speed 0.83 mm/s and post-test speed 0.83 mm/s; a rest period of 5 s between the two cycles; and a trigger force of 5 g. The maximum extent of the deformation was 10% of the original length. According to the