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Internal scattering as an optical screening method to identify peeled potatoes giving rise to an excess of acrylamide

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ABSTRACT

The formation of acrylamide during the frying of potatoes is nowadays one of the major concerns of the potato-processing agriculture industry. Much research has been carried out to identify the acrylamide precursors in raw potatoes in order to minimize its formation during frying. Raw potatoes that give rise to an excess of acrylamide can currently not be detected in a fast, sensitive and non-destructive way. Therefore, we investigate the use of spatially-resolved spectroscopy to optically identify raw potatoes with high acrylamide precursors concentrations, on basis of their internal scattering properties. To obtain potatoes that induce high acrylamide concentrations, we stored the potatoes in a fridge at 4 °C. Measurements of the potatoes after different storage times (11, 15, 21 and 28 weeks), corresponding with different acrylamide concentrations in the French fries, show an evolution of the scatter pattern. Furthermore, when comparing the scatter properties at different wavelengths for potatoes giving rise to low (<600 ppb) and high (>600 ppb) acrylamide concentrations during frying, an optimized classification of the potato batches was obtained at 1444 nm. We can conclude that the internal scatter properties of peeled, raw potatoes can be used to monitor the acrylamide precursors, enabling a non-destructive exclusion of the potatoes that are not suited for French fries production.

1. Introduction

Acrylamide, a 2A-classified carcinogen chemical, has come into global awareness since its discovery in heated starch-rich food products in 2002 (National Food Agency Sweden, 2015; World Health Organization, 2015). Generally, it is a side product of the Maillard reaction, which occurs during the high-temperature processing of potatoes, cereals and coffee (EFSA, 2015). Although there are no official governmental regulations yet, the European Commission recommends maximum acrylamide concentrations. To compare the contamination level of the French fries with these recommendations, the acrylamide concentrations are nowadays determined by the use of chemical analyses, like liquid chromatography – tandem mass spectrometry (LC-MS/MS).

Current research mainly focussed on the minimization of the acrylamide formation during high-temperature processing, by studying the Maillard reaction and the acrylamide precursors (reducing sugars, asparagine, starch and dry matter) and by investigating the influence of the food-processing conditions (Becalski et al., 2004; Douny et al., 2012; Mestdagh et al., 2008; Parker et al., 2012; Romani et al., 2008). Decreasing acrylamide concentrations were obtained by modifying the frying process (Gökmen et al., 2006), improving the storage conditions (De Wilde et al., 2005), optimizing the selection of raw materials (De Wilde et al., 2006) and using pre-treatment techniques with chemical or natural additives (Jung et al., 2003; Medeiros Vinci et al., 2012; Morales et al., 2014; Pedreschi et al., 2007). However, all these methods are difficult to be implemented at an industrial level and influence the colour, taste and texture of the resulting French fries.

We pursue a non-destructive optical detection of raw potatoes giving rise to an excessive acrylamide formation during frying. We focus on potatoes, because they are one of the worlds' major staple food crops. Potatoes are grown in approximately 80% of all countries and its worldwide production is higher than 300 million tons/year (The Food and Agriculture Organization of the United Nations, 2008). Furthermore, we specifically focus on the formation of acrylamide in French fries, since they belong to the products with the highest detected acrylamide levels. Acrylamide concentrations

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up to 12000 ppm have been quantified in fried potatoes, while the European Commission stated an indicative value for ready-to-eat French fries to 600 ppb (European Commission, 2013; Friedman, 2003). The composition of potatoes is already widely investigated by the use of visible and near-infrared spectroscopy (Haase, 2006; Helgerud et al., 2015; Rady et al., 2014; Subedi and Walsh, 2009). Rady et al. used the 446 nm–1125 nm spectral range to predict glucose and sucrose in potato tubers. Helgerud et al. and Subedi et al. illustrated the monitoring of the dry matter content, using the 449 nm–1040 nm and the 750 nm–950 nm spectral range respectively. However, spectroscopic data was never used to directly monitor nor predict the acrylamide formation.

We investigate the use of spatially-resolved spectroscopy for the non-destructive identification of raw potatoes with high acrylamide precursors concentrations. Spatially-resolved spectroscopy enables the simultaneous monitoring of the reflectance and internal scattering properties of the products. This method has already been employed to assess the quality of air-dried apple slices and for the identification and characterization of plant leaves (Nguyen Do Trong et al., 2014; Vrindts, 2000). Since water and starch concentrations are related to the acrylamide formation, while largely determining the firmness of the potato tissue and thus influencing the internal scattering properties, we expect spatially-resolved spectroscopy to be a promising technique to predict the acrylamide formation. Furthermore, the use of this non-destructive screening method on peeled raw potatoes has the double advantage of increasing food safety and decreasing waste, since the potatoes unsuited for frying can still be used for other products that require low-temperature processing, such as mashed potatoes and potato soup. In addition, since it enables a screening of individual potatoes, it is suited for implementation in industrial in-line scanning configurations.

This paper demonstrates the use of spatially-resolved spectroscopy to monitor the scatter properties of peeled, raw potatoes, enabling the identification of potatoes giving rise to excessive acrylamide formation during frying. We first discuss the storage and preparation of the investigated potato batches. Subsequently, we explain the broadband optical scanning configuration and measurement methodology. Following, the chemical and optical results are discussed. Based on the scatter characteristics, we examine the relationship between the internal structure of the potato tubers and the acrylamide formation during frying. Finally, a detection criterion enabling the identification of the unsuited potatoes for frying is discussed.

2. Materials and methods

To accurately study the optical differences between raw potatoes giving rise to low (<600 ppb) and high (>600 ppb) acrylamide concentrations during frying, the availability of reliable samples and the development of a sensitive measurement setup are of major importance. In this section, we first give an overview of the investigated potato batches, after which we explain the operation of our developed spatially-resolved spectroscopic measurement configuration.

2.1. Sample preparation

We investigate potatoes of the subtype Bintje (Solanum tuberosum), that are typically used for French fries production. The potatoes are harvested in Belgium in October 2013. In order to obtain potatoes with low and high acrylamide formation during frying, we used two different storage procedures. Low acrylamide formation is assured by the storage in the farmer's root cellar, taking into account the best known practices for long-term potato storage, guaranteeing a good quality preservation of the fresh potatoes (Linsinska and Leszczynski, 1989; Voss et al., 2015). High acrylamide formation is obtained by storing potatoes at 4 °C. According to previous research, the latter storage procedure influences the acrylamide precursors, inducing a boost in the acrylamide formation (Ciesarová et al., 2006; De Wilde et al., 2005; Hebeisen et al., 2007; Matsuura-Endo et al., 2006). From here onwards, the potatoes stored in the root cellar and fridge, inducing low and high acrylamide contents, will be referred to as 'fresh potatoes' and 'fridge-stored potatoes' respectively.

We performed spectroscopic measurements after different times of storage, enabling the study of the evolution of the raw potato tissue with increasing acrylamide formation during frying. Our spectroscopic measurements are performed after 11, 15, 21 and 28 weeks of storage. Previous research showed no significant difference in acrylamide concentration between fresh and fridge-stored potatoes before 11 weeks of storage (De Wilde et al., 2005). Between 11 and 21 weeks of storage, we presume a steep increase of the acrylamide formation, while above 21 weeks of storage the acrylamide content should have reached saturation.

To monitor the acrylamide precursors in raw potatoes and the acrylamide concentrations after frying, we outsourced the chemical analyses to SGS. In both potatoes and French fries, the fructose, glucose and asparagine concentration was measured by the use of high-performance liquid chromatography (HPLC), the starch concentration was determined by the use of Ewers method and the moisture concentration was measured with a dehydrator. In addition, for the French fries, the acrylamide concentrations are determined by the use of the LC-MS/MS method. A first chemical analysis of the fresh and fridge-stored potatoes was performed after 18 weeks of storage. These analyses enabled to determine the detection limit, since after 15 weeks of storage the first optical contrast between the fresh and fridge-stored potatoes was observed. Because we outsourced the chemical analyses, a delay of 3 weeks occurred between the optical and chemical measurements. A second chemical analysis on the fridge-stored potatoes was performed after 28 weeks of storage. For each analysis a subsample of 500 g of the fresh and fridge-stored potatoes, and their corresponding French fries, was used. To obtain French fries of the fresh and fridge-stored potatoes, we fried the potatoes using a 2000 W fryer with 3.5 l natural frying oil, while following the procedure explained by De Wilde et al. First, the potatoes were cut with a fry cutter, in a cuboid shape with a height and thickness of 9 mm and a length between 20 mm and 90 mm, depending on the size of the potato tuber. Subsequently, the cut potatoes were fried in a 2-stage frying process: during the first stage, the potatoes were fried for 3 min at 180 °C, while during the second stage, they were fried for 2 min at 180 °C. In-between both frying stages, the fries cooled down for 10 min (De Wilde et al., 2005).

2.2. Scatter measurement setup

To investigate the internal scatter properties of the fresh and fridge-stored potatoes, we use a measurement configuration based on spatially-resolved reflectance spectroscopy. Specifically, we separately monitor the specular reflection and internal scattering by examining the optical spectrum at different positions along the potatoes' surface, over a distance of 10 mm starting from the point of illumination. At the position of the incident laser beam, the specular reflected light is captured, while at larger distances from the illumination position, the internally scattered light can be measured (Fig. 1a). The specular reflected light comprises incident light rays that have reflected on the surface of the potato tuber, with an angle of reflection equal to the angle of incidence. The internal scattered light is emitted around the illumination position, after