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Analytical Methods

On-line monitoring of fat, dry matter and acrylamide contents in potato chips using near infrared interactance and visual reflectance imaging

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ABSTRACT

The contents of dry matter, oil and acrylamide are some of the most relevant parameters in the quality control of potato chips. Near infrared spectroscopy (NIR) is a common technique for routine analysis of bulk chemistry in different raw materials and products because it allows a fast and non-destructive analysis of samples. The objective of this research was to investigate the possibilities of using on-line NIR monitoring of acrylamide, moisture and oil content in potato chips. Sixty samples of potato chips from individual frying runs were measured on-line using a VIS/NIR interactance line scanner. The same samples were analysed in the laboratory to determine their corresponding moisture, acrylamide and oil contents. The mean VIS and NIR spectra for the 60 samples were modelled against the reference values for acrylamide, fat and dry matter using partial least squares regression (PLSR), and the regression models were validated using full cross-validation. On-line NIR interactance was found to predict fat and dry matter of potato chips with high accuracy, i.e. prediction errors of 0.99 and 0.86% (w/w), respectively. The corresponding correlations between predicted values and reference values were 0.99 and 0.97 for fat and dry matter. For acrylamide an average prediction error of 266 μg/kg was achieved using NIR and VIS signals in combination. The correlation between predicted values and reference values was 0.83 for this model. The system may be used to separate samples with very high acrylamide contents from samples with average to low contents.

1. Introduction

In the potato chip industry, the quality of each batch of potato tubers must be tested before processing. The colour of potato chips is the first quality parameter evaluated by consumers and is critical for the acceptance of the product (Pedreschi, León, Mery, & Moyano, 2006). Surface colour reflects not only the heterogeneous surface formed as a result of frying but also the non-homogeneous oil distribution. In addition, it is strongly related to the level of acrylamide in products such as potato chips. This induced process contaminant that is formed in potatoes during frying has been recently found to be a critical compound for human health due to its carcinogenic activity in rats (Mottram & Wedzicha, 2002; Pedreschi, Moyano, Kaack, & Granby, 2005; Rosen & Hellenäs, 2002; Stadler et al., 2002). Potato chip colour is affected by the Maillard reaction that mainly depends on the content of reducing sugars and amino acids at the surface as well as the frying temperature and time (Márquez & Añón, 1986).

In European factories, computer vision systems are used for on-line evaluation of potato chips, allowing chips to be sorted according to defects such as black spots or blisters (Marique, Pennincx, & Kharoubi, 2005). Some researchers have also been working on a promising device that is able both to classify chips according to colour and to predict acrylamide levels using neural networks (Marique et al., 2005; Marique, Kharoubi, Bauffe, & Ducatillon, 2003). Statistical pattern recognition for colour classification of potato chips, a non-neural network approach, has been employed in the past (Gokmen, Senyuva, Dulek, & Cetin, 2007; Marique et al., 2003; Pedreschi, Mery, Mendoza, & Aguilera, 2004).

Determination of acrylamide contents in potato chips is currently necessary due to its potentially toxic attributes, and the fact that very high concentrations can be produced in amylaceous fried foodstuffs (Rosen & Hellenäs, 2002). However, standard procedures for acrylamide determination are based on time consuming and expensive methods of chromatography and mass spectroscopy, which can hardly be implemented as routine analysis at industrial sites. CARAH (Centre por l'Agronomie et l'Agro-industrie de la Province de Hainaut, Belgium) and a Belgian industrial partner Rovi-Tech s.a. (Presles, Belgium) developed a high speed imaging system incorporated with an artificial neural network (ANN). For

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every chip snapshots are taken and then the colour and acrylamide concentration are obtained. The system is intended to analyse incoming potato batches of pre-fried chips for quality control in food distribution. The heart of the system is Rovi-Tech's ILB-25 (An Image Learning Box), a very efficient ANN that allows easy and powerful correlations of complex visual data analysis. Segtnan, Kita, Mielnik, Jorgensen, and Knutsen (2006) studied the acrylamide content in potato chips using near infrared (NIR) and visual (VIS) spectroscopy and proposed this technique as a possible tool for screening and identification of potato chips with high acrylamide content.

NIR spectroscopy is a common technique for routine analysis because it allows a fast and non-destructive analysis of samples. Different compounds present in food samples can be detected and quantified due to differences in the vibrational and rotational energies of specific bonds involving hydrogen that are found in this spectral region, typically C–H, O–H and N–H (Osborne & Fearn, 1986).

PLSR (partial least squares regression) is a multivariate regression technique that is commonly used for calibration of NIR systems. It is used to model the relationship between a set of predictor variables (*X*; spectral variables) and a set of response variables (*Y*; chemical variables). The purpose of this technique is to reduce the complexity of the data with the minimal loss of information (Geladi & Dabakk, 1995).

The objective of this research was to predict the acrylamide, moisture and oil content in potato chips using on-line near infrared interactance imaging.

2. Materials and methods

2.1. Materials

Potatoes (variety Saturna, approx. 20% of dry solids) stored at 6 °C and partially hydrogenated palm oil were the raw materials. Slices (thickness of 2.2 mm) were cut from the pith of the parenchymatous region of potato tubers using an electric slicing machine. A circular cutting mould was used to provide chips with an exact diameter of 30 mm.

2.2. Frying experiments

Slices were rinsed immediately after cutting for 1 min in distilled water to eliminate some starch material adhering to the surface prior to frying. Then, ~100 g of potato slices were placed in a fryer containing 10 l of oil at the initial temperature of 175 °C. The oil temperature reached 165 °C after 1 min and 160 °C after 4 min of frying and finally about 158 °C when fried at maximum time (290 s). The profile was reproducible as concluded from previous experiments (results not shown). Potato slices were fried at different durations. Potato slices fried for the longest time reached an approximately final moisture content of ~2.0 g water/100 g (wet basis). Sampling times ranged from 100 to 310 s at intervals of 15 s. Experiments were run in duplicate. Collected samples coming from each batch of fried potato slices were used for subsequent NIR spectroscopy experiments.

2.3. Analysis

For moisture content determination, samples were dried overnight at 105 °C in a convective oven (WTB Binder) until constant weight. Oil content was determined by low-field ^{1}H NMR spectroscopy (MARAN Ultra, 23 MHz, Oxford Instruments Molecular Biotools Limited, UK). Samples were homogenised in a blender, and approximately 1.3 g was transferred to the NMR tube with an 18 mm probe. The instrument was calibrated with palm oil prior to analysis Sorland, Larsen, Lundby, Rudi, & Guiheneuf, 2004). Results were in agreement with standard commercial analysis performed at Norwegian Institute for Food and Environmental analysis in accordance with AOAC 922.06.

For acrylamide analysis, potato chip samples were analysed at EELA, Finland using liquid chromatography–tandem mass spectrometry (LC–MS/MS) with detection and determination limits of 20 μg/kg and 40 μg/kg, respectively (Eerola, Hollebekkers, Hallikainen, & Peltonen, 2007), The total uncertainty of the method is ±20 μg/kg.

2.3.1. NIR spectroscopy and data analysis

For each of the 60 samples, a black plastic box (13 × 22 cm) was filled with potato chips, put on a conveyor belt and measured with the VIS/NIR scanner (QVision AS, Oslo, Norway). The instrument has two individual spectrometers: A visual part that measures in pure reflectance and a near infrared part that measure in interactance mode. Light from 12 halogen lamps is focused onto a line on the conveyor belt. Between the light sources and the NIR imaging detector is a blackened plate that prevents detection of pure surface reflection from the sample. The detected light is collected from a line approximately 2 cm away from the illuminated line. Thus, only photons that have travelled this distance horizontally are detected. Both spectrometers measure at 60 equally spaced points along the breadth of the conveyor belt. The spectrometers both have 15 wavelength channels, covering the spectral regions 460–740 nm and 760–1040 nm, respectively. Both spectrometers are able to collect approximately 10,000 spectra per second.

Each sample provided approximately 15 × 100 NIR and VIS spectra. Spectra from the potato chips were separated from those from the conveyor band and the blastic box using a simple segmenting routine. Each individual spectrum was SNV-transformed (Standard Normal Variate), in order to correct for physical differences within the sample (Barnes, Dhanoa, & Lister, 1989). The transformed NIR and VIS spectra were averaged, providing one NIR spectrum and one VIS spectrum per sample.

The mean VIS and NIR spectra for the 60 samples were modelled against reference values for acrylamide, fat and dry matter using partial least squares regression (Martens & Næs, 1989). The regression models were evaluated using full cross-validation (Stone, 1974).

3. Results and discussion

3.1. Relationship between chemical responses and frying time at 175 °C

The results from the reference analysis for fat, dry matter and acrylamide contents are summarised in Table 1. The table shows that the values for fat, dry matter and acrylamide are centered around 40%, 95% and 804 μg/kg, respectively. The acrylamide variation is very large compared to the variation in fat and dry matter contents.

It can be seen that just after 30 s of frying at 175 °C, the average fat content is around 30% (dry basis) in potato chips (Fig. 1). This value could increase up to approximately 50% (dry basis) in potato

Table 1
Fat, dry matter and acrylamide of analysed potato chips.

	Minimum	Maximum	Mean	Median	Standard deviation
Fat (%)	26.7	49.3	40.0	40.1	5.9
Dry matter (%)	82.9	98.6	94.7	96.4	4.0
Acrylamide (mg/kg)	40	1770	803.7	903.0	493.4