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Effect of sodium replacement in cookies on the formation of process contaminants and lipid oxidation

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ABSTRACT

Replacing sodium chloride by salt substitutes in the recipe is one of the main strategies applied in the food industries to prevent unwanted health effects into population. However the reduction in NaCl may affect to the oxidative balance and the formation of process contaminants in the food, besides of sensorial and technological aspects already known. The effect of replacing NaCl by different salts and two commercial salt-replacers on the formation of acrylamide and furfurals, as well as the influence on the lipid oxidation after storage was evaluated in a cookie model. Acrylamide content was reduced by up to 58% in the cookie containing $CaCl_2$ and 35–40% when NaCl was partly substituted by commercial salt-replacers. Hydroxymethylfurfural and furfural content did not greatly varied by the recipe, except by $CaCl_2$, which significantly increased the furfurals formation. Although no significant relationship was found between mineral composition and lipid oxidation after storage, products of lipids oxidation were detected. In conclusion, the type of salts used in the cookie recipe affects the extent of lipid oxidation and the formation of process contaminants and, therefore, these potential side effects should be carefully considered by the food industries when implementing sodium reduction strategies in their products.

1. Introduction

There is a strong link between dietary sodium intake and increase in blood pressure, which is a major cause of cardiovascular diseases and a leading risk factor for global mortality (Strazzullo, D'Elia, Kandala, & Cappuccio, 2009). In addition, high sodium consumption is related to other negative health effects such as gastric cancer, decreased bone mineral density and obesity (He & MacGregor, 2008; Matkovic et al., 1995; Tsugane, Sasazuki, Kobayashi, & Sasaki, 2004). Changes in the dietary habits of the population have led to an increase of sodium intake and a decrease of potassium intake, mainly due to the extended consumption of processed foods and the declined intake of fresh foods such as fruits and vegetables. These changes, therefore, elevate the sodium:potassium ratio, which is directly associated with the blood pressure. Elevated amounts of sodium in food are consumed far in excess of public health recommendations. In this regard, the adequate intake for sodium is set at 1.5, 1.3 and 1.2 g for young adults, older adults and the elderly, respectively (Institute of Medicine, 2010), whereas epidemiological studies have described sodium intakes of about 3.8 g/day at ages 19–30 years for American population or even 4.8 g/day for European adolescents (Institute of Medicine, 2010; Lambert et al., 2004). In the past few years, several population-based interventions to reduce sodium intake have been successfully implemented in various countries worldwide (WHO, 2011). The major source of sodium in foods is common salt or sodium chloride. Therefore, the main strategy to decrease the sodium intake levels is to lower the salt content in food products. In this sense, one of the strategies applied by food industries to decrease sodium consumption is to replace NaCl by different salt substitutes (Dötsch et al., 2009).

Sodium chloride has been traditionally used during the manufacture of baked products as it causes several important changes in rheological, technological and sensory parameters. Rheological properties are influenced by NaCl content since it is involved in the structure and formation of the gluten matrix, increasing stability, flexibility and resistance of the dough and decreasing stickiness and water absorption (Beck, Jekle, & Becker, 2012). Therefore, decreasing sodium chloride concentration may induce less desirable properties such as more liquid and stickier dough, lack of stability and less resistance and extensibility. Regarding sensorial characteristics, NaCl is related to the perception of the salty taste but also increases sweetness and masks metallic or bitter taste (Miller & Hoseney, 2008).

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On the other hand, sodium chloride is involved in the inhibition and enhancement of the formation of certain processing contaminants, such as acrylamide, 5-hydroxymethylfurfural (HMF) and furfural. Acrylamide in foods is generated during the thermal process, as a consequence of the Maillard reaction between asparagine and reducing sugars as main precursors (Stadler & Scholz, 2004). Due to its neurotoxic and genotoxic potential, acrylamide has been classified as "probably carcinogenic to humans" (Group 2A) by the International Agency for Research on Cancer (IARC, 1994). In a similar way, HMF and furfural are formed as intermediate products of the Maillard reaction and, moreover, HMF is generated by the caramelization of sugars at high temperature (Hodge, 1953; Kroh, 1994). HMF is suspected to have genotoxic and mutagenic effects whereas furfural may lead to hepatotoxicity (EFSA, 2005). It has been reported that NaCl has a considerable inhibitory effect on acrylamide formation and, on the contrary, promotes the formation of HMF and furfural, which has been demonstrated both in model systems and in food models like cookies or baked products (Gökmen & Senyuva, 2007a; Kolek, Simko, & Simon, 2006; Levine & Smith, 2005; Marcotullio & De Jong, 2010).

Another aspect to take into account is the possible though practically unknown relationship between NaCl content and lipid oxidation. There is general agreement that potentially harmful compounds can result from lipid oxidation in foods (Dobarganes & Márquez-Ruiz, 2003). In a food product, lipid oxidation can be promoted by copper and iron, which are well known catalysts (Schaich, 1992) that can interact with NaCl (Kanner, Harel, & Jaffe, 1991). On the other hand, as NaCl can condition the water activity of the food product, it can affect oxidative rancidity (Kaya, Kaya, & Oner, 1999).

In spite of the reduction of total sodium intake, the side effects related with the use of salt replacers or modifications in the NaCl content in the food product, such as oxidative aspects and formation of contaminants, should be carefully controlled by the food industries. The aim of the present study was to investigate the effect of different salt replacers on the formation of acrylamide, HMF and furfural in cookie models; as well as the possible influence on the development of lipid oxidation in cookie models after storage.

2. Material and methods

2.1. Reagents and chemicals

Flour and shortening were supplied by local producers, and other ingredients were purchased from local supermarkets. Commercially available food-grade salt-replacer I (SR-I) and salt-replacer II (SR-II) were acquired from national suppliers of food additives. The composition of both commercial salts is the following: (SR-I) Na: 13.8 g/100 g, K: 20.0 g/100 g; (SR-II) Na: 14.3 g/100 g, K: 17.1 g/100 g. Acrylamide, HMF and furfural standards were purchased from Sigma (St. Louis, MO, USA). Hydrogen peroxide, nitric acid, and ethylendiaminetetraacetic acid was obtained from Panreac (Madrid, Spain). Acetonitrile, formic acid, glacial acetic acid, potassium hexacyanoferrate and zinc acetate were purchased from Merck (Darmstadt, Germany). [$^{13}C_3$]-acrylamide (isotopic purity 99%) was from Cambridge Isotope Labs (Andover, MA, USA). Milli-Q water used was produced using an Elix3 Millipore water purification system coupled to a Milli-Q module (model Advantage10) (Millipore, Molsheim, France). All other chemicals, solvents and reagents were of analytical grade.

2.2. Preparation of cookies

Model cookies were prepared according to a recipe described in AACC (American Association of Cereal Chemists) method 10–54 (AACC, 2000) following the procedure described by Gökmen, Açar, Arribas-Lorenzo, and Morales (2008) with some modifications. Recipes were formulated with 130 g of wheat flour, 35 g of sucrose, 30 g of deionized water, 26 g of sunflower oil, 0.8 g of sodium bicarbonate, 0.4 g of ammonium bicarbonate and 1 g of different salts as follows: (i) NaCl, (ii) $CaCl_2$, (iii) KCl, (iv) commercial SR-I, (v) commercial SR-II, (vi) 0.5 g NaCl + 0.5 g commercial SR-I, (vii) 0.5 g of NaCl + 0.5 g of commercial SR-II. The ingredients were thoroughly mixed and the dough was rolled out to disks with the diameter of 5–6 cm and the thickness of 2 mm, and baked at 190 °C for 20 min in a natural convection oven (Simsek Laborteknik, Turkey). Six different cookies for each formulation were prepared by duplicate.

2.3. Determination of moisture

Moisture was determined gravimetrically. Sample (1 g) was accurately weighed (0.1 mg) and dried to constant weight in an oven at 110 °C for 4 h. Percentage of moisture was calculated with the following formula: [(weight of capsule with fresh samples − weight of capsule with dry samples)/(weight of fresh samples)] × 100. Analysis was done in duplicate.

2.4. Determination of water activity (A_w)

The water activity values of cookies were measured by an AquaLAB CX-2 (Decagon Devices Inc., Pullman, WA). The ground cookie sample was placed into the specimen holder of the device to record its water activity. The mean of two measurements was reported.

2.5. Measurement of pH

Ground cookies (1 g) were mixed with 100 mL of water and vortexed for 3 min. The mixture was held at room temperature for 1 h to separate solid and liquid phases. After carefully removing the supernatant layer, the pH was measured using a CG-837 pH meter (Schott, Mainz, Germany). Analysis was performed in duplicate.

2.6. Determination of total protein content

Total protein content was determined in the samples using an automated nitrogen analyzer (FP-2000; Dumas Leco Corp., St. Joseph, MI), after calibration of the instrument with ethylendiaminetetraacetic acid. The nitrogen-to-protein conversion factor was $N \times 6.25$. The results were expressed as g of protein/100 g of product (dry matter). Analysis was done in duplicate.

2.7. Determination of total lipid content

Six g of grounded cookie samples were weighed and total fat content was determined by Söxhlet extraction (Soxtec System HT6, Tecator AB, Höganäs, Sweden) using petroleum ether. Analysis was performed in duplicate. The results were expressed as g of lipid/100 g of product (dry matter).

2.8. Determination of minerals

Samples were digested with HNO_3 and H_2O_2 in a Microwave Digestion Lab station (Milestone, mod. Ethos 1: Milestone, Shelton, CT 148 , USA) and the digested samples were then diluted with ultrapure deionized water. The mineral content was evaluated using an Optima 4300 DV ICP-149 OES (inductively coupled plasma optical emission spectroscope: Perkin–Elmer, Norwalk, CT, USA).

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