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Multiple optimization of chemical and textural properties of roasted expanded purple maize using response surface methodology

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ABSTRACT

Intensification of Vaporization by Decompression to the Vacuum is a new texturizing process proposed as a pre-treatment for roasting purple maize. It consists in exposing humid kernels to a high steam pressure followed by a decompression to the vacuum. Three variables were considered: initial water content (W), steam pressure (P) and processing time (T). Using response surface methodology, the effects of these variables were studied on the response parameters: Total Anthocyanins Content, Total Polyphenols Content, Free Radical Scavenging Activity, Expansion Ratio, Hardness and Work Done. *P* and *T* had the highest effects. They decreased anthocyanins and polyphenols content but increased Expansion Ratio, Hardness and Work Done. Interactions between the variables had interesting effects on texturization as crunchiness, popping or shrinkage. Multiple optimization was conducted in order to find a compromise between chemical and textural parameters. The optimum ($W = 30\%$, $P = 7$ bar, $T = 10$ s) conserved the phenolic compounds while conferring expansion and crunchiness.

1. Introduction

Maize (*Zea mays* L.), or corn is a worldwide consumed cereal. It is the major source of energy for certain human populations. There are many varieties of corn having various colors such as white, yellow, red, purple, brown, green and blue. Purple corn is a pigmented variety originally cultivated in Latin America (Yang and Zhai, 2010). Among other varieties it is found to have the highest phenolic content, anthocyanin content and radical scavenging activity (Lopez-Martinez et al., 2009). The nutritional value of purple maize lies in the fact that it is rich in phenolic substances. Its excellent antioxidant activity is mainly due to the anthocyanins (Lopez-Martinez et al., 2009; Yang and Zhai, 2010) which are natural pigments widely distributed in the plant kingdom. Their spectrum ranges from orange to blue and they are considered to be food colorants (Yang and Zhai, 2010).

Worldwide, maize is processed in many different ways. In the Mediterranean region, it is consumed raw or grilled directly on the cob, boiled, processed as maize grits, maize flour, corn bread or transformed into crunchy products such as corn flakes, popcorn and snacks. Recently, demand on crunchy snack products is increasing and competition for better products is growing in the industrial sector. Roasting is a technique known to produce healthy crunchy maize. However, studies reported that roasting may have a negative impact on phenolic compounds and their radical scavenging activity due to the prolonged use of high temperatures. For instance, roasting was found to reduce total polyphenols by 26% and antioxidant activity by 34% in almonds (Bolling et al., 2010) as well as total phenolic substances of mangrove legume (Seena et al., 2006) and chickpea seeds (315.9–281.3 mg/100 g) (Daur et al., 2008). Anthocyanins were also found to be subjected to thermal degradation (Gregorio et al., 2009; Wu et al., 2013). In order to alleviate these drawbacks, a treatment such as expansion, can be applied prior to roasting. Consequently, the production of crunchy roasted maize snacks with high nutritional values requires a well-controlled texturizing pre-treatment to be used.

Abbreviations: DIC, Détente Instantanée Contrôlée; ER, expansion ratio; HARD, hardness; IVDV, Intensification of Vaporization by Decompression to the Vacuum; *P*, saturated steam pressure; RSA, Free Radical Scavenging Activity; *T*, processing time; TAC, Total Anthocyanins Content; TPC, Total Polyphenols Content; W, initial water content; WD, work done; ΔP, difference in pressure; $\Delta \Theta$, difference in temperature; Θ, temperature.

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Expansion has played a fundamental role in improving the texture of dried foodstuffs. It consisted in texturizing by self-vaporization of the moisture present in a partially dried product. The product is subjected to steam pressure for a defined extent of time, then a sudden decompression to the atmospheric pressure takes place, inducing a partial evaporation of the water within the product (Clark, 1986). The steam thus formed is at the origin of mechanical constraints within the viscoelastic product, conferring thereby a porous structure. During this phenomenon, the product undergoes an irreversible adiabatic transformation. It must be suitably prepared for the expansion in regard to its rheological properties, mainly determined by temperature and water content (Louka et al., 2002).

The expansion-puffing underwent several modifications over the years, until a new expansion process with a sudden decompression towards the vacuum "Détente Instantanée Contrôlée" (DIC) has been developed in the nineties (Allaf et al., 1992). DIC consists in carrying out a decompression towards a vacuum of 0.1 bar instead of the atmospheric pressure. The amount of steam generated by self-vaporization is therefore greatly sufficient with a lower treatment temperature (e.g. from 150 °C to 30 °C instead of 220 °C–100 °C where the decompression is towards the atmospheric pressure) (Louka and Allaf, 2002). These milder conditions, followed by a rapid and intensive cooling, are suitable for expanding heat sensitive products while preserving very satisfactory final organoleptic qualities (shape, texture, color and flavor) (Louka, 1996). Recently, an even better improvement has been added to the DIC, resulting in a new process called « Intensification of Vaporization by Decompression to the Vacuum » (IVDV) (Mrad et al., 2014). IVDV consists in a very rapid compression to high pressures (up to 15 bars) in less than 1 s while compression required about 10 s in the DIC technology to reach the same pressure level. The great advantage of this rapid compression is the possibility to treat heat-sensitive products that cannot withstand more than few seconds under high pressure. IVDV process seems to be a good pre-treatment to modify the structure of raw maize kernels in order to obtain a better quality of roasted maize (Mrad et al., 2014). The expansion is supposed to preserve, as much as possible, the original shape of the kernels without an excessive deformation that can reach popping or disintegration.

In the present work, maize kernels differently expanded by IVDV were roasted following the same conditions. The aim is to study the effect of operating parameters (initial water content (W), steam pressure (P) and processing time (T)) on the final products. This investigation was realized by measuring the antioxidant components (anthocyanins, polyphenols and radical scavenging activity) and the physical properties (expansion ratio and texture analysis) of the roasted kernels. Response surface methodology was used to optimize the different response parameters and to find a compromise between them. The ultimate goal is the optimization of chemical and textural properties by IVDV in order to be used as a pre-treatment for maize roasting.

2. Materials and methods

2.1. Chemicals and reagents

All chemicals and reagents used in the experiments were of analytical grade. Folin-Ciocalteau reagent, gallic acid (GA), Tris–HCl buffer, 2,6-di-tert-butyl-4-methylphenol (BHT), resveratrol, acetone, ethanol and methanol were purchased from Sigma–Aldrich Chemical Co. (St. Louis, MO, USA). Sodium carbonate and potassium chloride were obtained from Fluka (Buchs, Switzerland), sodium acetate from Scharlau (Barcelona, Spain) and 2,2-diphenyl-picrylhydrazyl (DPPH) radical from Merck (Darmstadt, Germany).

2.2. Characteristics of raw sample

Purple maize (*Zea mays indurata* L.) was studied in this work. Samples of Peruvian origin, naturally dried to a moisture content of 14.11 ± 0.67 g/100 g DM, were supplied from a local market (Al Kazzi). They were all purchased from the same source. Only whole healthy kernels with approximate dimensions 13 × 4.5 × 11.5 (l × h × w) mm were selected. Kernels were of flint type, characterized by a hard pericarp and a hard outer endosperm layer enclosing soft endosperm. Tapped density ρ was equal to 950 ± 29.4 kg/m^3 while test weight was 349.83 ± 19.7 g/0.5 L. One thousand kernel weight was equivalent to 476.7 ± 13.2 g.

2.3. Rehydration and homogenization

Maize kernels were rehydrated prior to the expansion process. This operation was done by soaking the kernels in distilled water at 25 °C with a ratio of 1/5 g of kernels/ml water. Preliminary testings were done in order to determine the time of soaking necessary to obtain the following water contents: 16.6, 20, 25, 30 and 33.4%. The hydrated samples were then kept for three to four days at 4 °C, a step allowing a better homogenous redistribution of water. These conditions were set by our laboratory after a series of trials.

2.4. IVDV reactor

Experiments were carried out in a processing reactor consisting of the following three main components:

I. A treatment chamber having an internal volume of 100 L where the samples are treated with high steam pressure. Pressure is reached within 1 s using a steam generation system. II. A vacuum system consisting of a vacuum tank with a volume 100 times greater than the treatment chamber. The vacuum in the tank is ensured by a combination of mechanical (vacuum pump) and cooling effect (cooling water that circulates in the double jacket of the tank). III. A decompression system where a pneumatic valve (200 mm diameter) operating in less than 0.5 s separates the treatment chamber from the vacuum tank.

2.5. Expansion procedure by IVDV

Having carried out the rehydration and homogenization, the maize kernels were placed in the treatment chamber in which an initial vacuum was established. This primary vacuum will improve the heat transfer and make the material more accessible for steam. After that, saturated steam at a pressure "*P*" (up to 15 bars) and a temperature "Θ" was generated quickly into the treatment chamber for a defined processing time "T" (from 1 to 200 s). This high-temperature/short time stage was followed by an instant pressure release towards a vacuum that could reach 1 mbar. The abrupt pressure release, at a rate $\Delta P/\Delta t$ higher than 12 bar/sec, simultaneously produces a self-vaporization of a part of the water in the product, and an instantaneous cooling of the product, which stops thermal degradation (Louka, 1996). A porous structure is then observed. Afterwards, the treated product is subjected to an atmospheric air injection under vacuum to ensure its rapid cooling before returning back to atmospheric pressure.

2.6. Dehydration

Finally, expanded maize kernels underwent a further dehydration in a forced-convection oven at 50 °C for 24 h.