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Effect of boiling, roasting and frying on disintegration of peanuts in simulated gastric environment

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ABSTRACT

The objective of this study was to investigate the influence of boiling, roasting and frying on the digestion of peanuts in simulated gastric environment. Raw and processed peanuts were tested for disintegration in a model stomach system. The differences in disintegration rate were explained with respect to the changes in moisture absorption and texture. The absorption of moisture and the swelling of peanuts during gastric digestion were studied using Magnetic Resonance Imaging (MRI). The results show that processing improved the gastric disintegration of peanuts, and the disintegration rate was in an order of fried > roasted > boiled > raw peanuts. The changes in total weight, moisture and the dry solid loss in the samples were described by Linear–exponential equation, Peleg's equation and the Weibull equation, respectively. Absorption of gastric juice played a critical role in softening the texture contributing to the breakdown of peanuts. Static soaking test indicated that the disintegration rate, as indicated by half time, has a good exponential relationship with the textural parameters of soaked samples. MRI shows potential as being used to analyze the mass transfer phenomenon in solid foods under digestion.

1. Introduction

Peanut is a common food material in the world. Annual consumption of peanut products in the United States has reached 1.1 billion kg, approximately 3.6 kg for each American (The Peanut Institute, www.peanut-institute.org). Peanut production in the world is 34.4 billion kg/year (http://www.wikipedia.com). The published evidence indicates that nut consumption may have various health benefits. Peanuts are rich in mono-unsaturated fatty acids like oleic acids that prevent coronary artery disease and strokes by favoring healthy blood lipid profile; they also contain high concentrations of polyphenolic antioxidants, primarily p-coumaric acid and resveratrol, which have protective function against cancers, heart disease, and reduce stroke risk (Kris-Etherton, Hu, Ros, & Sabate, 2008). Peanuts are also an excellent source of vitamin E (a-tocopherol), a powerful lipid soluble antioxidant (Shin, Huang, Pegg, Phillips, & Eitenmiller, 2009). Moreover, recent studies have indicated that consumption of peanuts could contribute to weight control, presenting a potential solution to obesity, a critical health problem facing the US and world. A number of studies have indicated an inverse association between the frequency of nut consumption and body mass index. This has been partly attributed to the satiety properties they give, and the limited release of oils contained in peanuts during digestion (King, Blumberg, Ingwersen, Jenab, & Tucker, 2008; Traoret et al., 2008). Cassady, Hollis, Fulford, Considine, and Mattes (2009) reported a significant increase in fecal fat and energy loss in participants fed a non-vegetarian diet supplemented with whole peanuts. The limited bioaccessbility of lipids was due to the resistance of nut parenchyma cell walls restricting microbial and enzyme degradation in the gastrointestinal (GI) tract (Cassady et al., 2009).

Processing of foods may significantly affect their digestion properties. Peanuts in the United States are mostly roasted. Boiled peanuts are popular in southern United States. Although not very common in the US, fried peanuts are very popular in Asian countries such as China and India. The knowledge of how processing conditions modify digestion and the underlying mechanisms is critical to assess bioaccessbility and bioavailability of nutrients trapped in food matrix and to develop structured foods targeted for health purposes. Our previous study indicated that roasting improved disintegration of almonds (Kong & Singh, 2009b). No

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study has been done on peanut disintegration in stomach as related to different processing approaches. Magnetic Resonance Imaging (MRI) is becoming increasingly important in revealing the interaction of food and ambient environment such as the diffusion of moisture (Duynhoven et al., 2009). To our knowledge, no study has been reported in using MRI to evaluate the moisture absorption of peanuts during gastric digestion. This information could be useful in developing MRI as a research tool to study food digestion *in vivo*.

The objectives of this study are: 1) investigate the influence of boiling, roasting and frying on disintegration of peanuts in simulated gastric environment, with a custom-designed model stomach system; 2) determine the correlation between disintegration rates of peanuts and their textural changes during digestion; and 3) using MRI to study the absorption of gastric juice and swelling of peanuts during gastric digestion. This study could provide valuable information of peanut digestion properties as affected by processing and contribute to understanding of the various health effects as related to consumption of different form of peanut products.

2. Materials & methods

2.1. Preparation of samples

California grown Spanish peanuts (Diamond, CA) were purchased from local grocery store. Boiled peanuts were prepared by cooking 65 g peanut in 150 mL boiling water for 15 min. Roasted peanuts were prepared at 170 °C for 8 min using a household toaster oven (Hamilton Beach Brands, Inc., 234 Springs Road, Washington, NC, USA). The temperature of the oven was calibrated using a thermocouple to detect actual temperature at the sample location. Fried peanuts were prepared in peanut oil at 170 ± 5 °C for 5 min using an electric deep fryer (National Presto Industries, Inc., 3925 N. Hastings Way Eau Claire, WI, USA). A thermocouple was used to monitor the oil temperature, and the fryer was manually powered on/off to maintain the temperature fluctuation <10 °C. The moisture content (g/100 g) in the raw and processed samples was 5.29 ± 0.09; 25.76 ± 0.17; 1.46 ± 0.03; and 0.26 ± 0.01, respectively, for raw, boiled, roasted and fried peanuts. Cube samples were cut using a kitchen knife from raw and processed peanuts with a size approximately 5 × 5 × 3.5 mm (length × width × height) measured by using a caliper.

Simulated gastric juice was prepared by dissolving pepsin (1 g/L), gastric mucin (1.5 g/L), and NaCl (8.775 g/L) in deionized water (pH = 1.8, adjusted by using 1 mol equi/L HCl). Simulated saliva is comprised of gastric mucin (1 g/L), α-amylase (2 g/L), NaCl (0.117 g/L), KCl (0.149 g/L), and $NaHCO_3$ (2.1 g/L), dissolved in distilled water (Kong & Singh, 2008). All chemicals were purchased from Sigma–Aldrich, Inc. (USA).

2.2. In vitro digestion of raw and processed peanuts in the model stomach system

Raw and roasted peanut samples were first soaked in the simulated saliva for 15 s (37 °C) to incorporate effect of oral processing. The sample surfaces were blotted using a filter paper, and the weight was determined as the initial weight W_0 (g). The samples were then tested in a model stomach system as described in our previous paper (Kong & Singh, 2008). The system was composed of a turn table, a glass chamber to hold water whose temperature was controlled by a water bath, and an annular container to hold simulated gastric juice. Plastic beads were added into the simulated gastric juice to mimic food particulates present in human stomach, having a size of 3 mm diameter and specific gravity of 1.03. In this study, 330 g plastic beads were combined with 170 mL simulated gastric juice to make 500 mL simulated gastric content. Samples were attached to a sample holder and were immersed into the simulated gastric contents. The turn table was operated at 30 rpm. When the turn table was running, a mechanical force was created resulting from the beads impacting and grinding the samples simulating the contraction forces present in human stomach due to peristaltic movement. A torque cell (Omega Engineering, TQ201-25Z) was installed on the top of the sample holder to measure the impacting force on food samples. For each trial, 4 samples were tested. The mechanical force generated by beads impacting on a sample was approximately 0.1 N, which is comparable to the maximum force present in the human stomach (Kong & Singh, 2009a).

The simulated digestion trials were continued for 1, 2, 3, 4, 5 h, respectively. Then the system was stopped and samples were taken out, blotted with a filter paper to remove surface moisture, and measured for weight W_t(g). The moisture of samples was determined by using a hot air oven at 105 °C to reach a constant weight. M_0 (g/100 g) and M_t (g/100 g) were denoted as initial moisture and the moisture after trial time t (wet basis), respectively. Dry solid mass of samples (S) was calculated based on the sample weight and moisture. Weight retention ratio was calculated as $(\mathrm{WR} = W_t/W_0)$, and dry solids loss ratio was defined as $(\mathrm{SL} = (S_0 - S_t)/S_0)$, where S_0 is initial dry solids (g) and S_t (g) is the dry solids after trial time t (min). The S_0 and S_t were calculated by subtracting moisture from the total weight. Water uptake ratio was calculated as $(\mathrm{MR} = (M_t - M_0)/M_0)$.

2.3. Static soaking test

To study the absorption of gastric juice in the peanuts and the changes of peanut texture, raw and processed peanut sample halves were soaked in the simulated gastric juice at 37 °C for 16 h. Moisture and dry solids content were determined as described above.

The texture of raw and soaked samples was determined using a TA.XT2 texture analyzer (Texture Technologies Corp., Scarsdale, NY/Stable Micro Systems, Godalming, Surrey, UK) with a 2 mm flat-ended needle probe. The probe traveled to 3 mm depth transversal to the sample height at a speed of 1 mm/s. From the force–distance curves, two parameters were defined: a) Stiffness (N mm^{-1}), which is the slope of the line joining the origin and the peak force, and b) Penetration work (N mm), which is the area under the force–distance curve.

2.4. Magnetic Resonance Imaging (MRI) & relaxation time measurements

MRI imaging and relaxation experiments were carried out using a 1.03T (43.8 MHz) NMR spectrometer (Aspect AI, Industrial Area Hevel Modi'in, Shoham Israel) with a circular RF coil (60 mm ID). Peanut halves were used for the trials. Spin–lattice relaxation (T_1) measurements using saturation recovery pulse sequence with a delay time changing in the range of 1 ms–3000 ms with 1024 acquisition points and 4 scans were performed before digestion. The spin–spin relaxation (T_2) measurements were also measured for the samples with/without digestion, in which a Carr–Purcell–Meiboom–Gill (CPMG) pulse sequence was used with an echo time (TE) of 1 ms, 16 acquisition points, 1024 echoes, and 128 scans. T_1 and T_2 measurements were replicated three times.

For the samples under digestion, two types of imaging sequences were used to study the diffusion of gastric juice into the peanuts. The first one was a multi slice gradient recalled echo (GRE) sequence with an echo time of 1.8 ms and repetition time of 4.7 ms. The number of slices was 32 with a slice thickness of 3 mm. The number of phase encoding steps was 128, the number of acquisition points 128, with a field of view (FOV) of 45 mm. The second