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Effect of different processing conditions on release of ingredients in solutions simulating gastric fluid and saliva

Vasiliki Oikonomopoulou [a,*], Antonis Karantonis [a], Vaios T. Karathanos [b], Magdalini K. Krokida [a]

[a] School of Chemical Engineering, National Technical University of Athens, Zografou Campus, 9 Iroon Polytechneiou, Athens 15780, Greece
[b] Department of Nutrition, Harokopio University of Athens, Kallithea, 70 El. Venizelou, Athens 17671, Greece

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ABSTRACT

The fundamental understanding of the behavior of various foods in environments that simulate the human organism is of crucial importance. The study of the release of various components in solutions simulating the human gastric fluid and saliva helps in understanding their availability in the human body. In the present study, disintegration of salt and sugar particulates contained in processed agricultural products was examined. Potatoes and bananas were osmotically dehydrated in salt and sucrose solutions, respectively, and then dried using two drying methods, air drying and freeze drying. The dried products were soaked in simulated saliva and gastric fluid at 37 °C. During immersion, salt release in saliva and gastric fluid was determined using three methods; electrochemical impedance spectroscopy, for measuring the resistance of the solution, titration with silver nitrate, for measuring the amount of salt in the solution and conductivity measurements, for measuring the conductivity of the solutions. Sugar release was determined by measuring degrees brix of the solutions at regular intervals. One Brix corresponds to 1 g of sugars/100 g of solution. The results indicated that different process conditions caused different impact on release kinetics of salt and sugar particulates in saliva and gastric fluid, influencing their taste perception and the bioavailability in the human body.

1. Introduction

The decomposition of foods in the human body depends on various factors, such as the structure and the physicochemical properties, as well as the physical forces and the chemical reagents that are present in the stomach. The knowledge of disintegration of food particulates in the human stomach is necessary for the evaluation of their bioavailability and allows the improvement of processing methods for nutrient supply. This can particularly contribute to the development of functional foods and supplements that ensure the controlled release of nutrients in the human body (Kong & Singh, 2008b).

The consumption of foods includes the mastication in the mouth and the digestion of food in the stomach and the small intestine. The procedure that takes place in the mouth includes, firstly, the stimulation of salivary glands and the production of saliva. The foods are mixed with saliva and, depending on their initial structure, are broken into small pieces during chewing (Ertekin & Aydogdu, 2003). The second step is the oral propulsion that involves the movement of the tongue to the palate compressing and inducing food to the back of the mouth, and the final step is the ingestion (Drago et al., 2011; Mills, Spyropoulos, Norton, & Bakalis, 2011). In recent years, studies on saliva have increased due to the development of new techniques describing its biochemical and physicochemical properties (Schipper, Silletti, & Vingerhoeds, 2007). Many studies report and compare the properties of synthetic saliva solutions (Preetha & Banerjee, 2005; Rabe, Krings, & Berger, 2004; Takahashi et al., 2009). Various factors, such as the collapse of structure and the mixing with saliva can influence the taste perception during chewing (Koliandris, Lee, Ferry, Hill, & Mitchell, 2008). Liquids with high viscosity that contain the same salt content as low viscosity liquids are perceived as less salty, due to differences in mixing (Ferry et al., 2006). Boland, Buhr, Giannouli, and van Ruth (2004) studied gelatin starch and pectin gels, and they observed that the flavor release was significantly affected by products' texture. Gelatin gel with higher modulus showed the lowest release of flavor. Similar results were reported by Guinard and Marty (1995). Morris (1994) correlated the sweetness of gels with rheology and observed a strong negative correlation between the force required during chewing and the perception. For the better understanding of the phenomena that take place during chewing *in vitro* models describing the oral system are being developed (Mills et al., 2011).

Digestion is the chemical breakdown of food into smaller molecules. During digestion, complex phenomena are performed simultaneously. Gastric fluid is mixed with food and causes enzymatic degradation

* Corresponding author at: Laboratory of Process Analysis and Design, National Technical University of Athens, Zografou Campus, 9 Iroon Polytechneiou, Athens 15780, Greece.
E-mail addresses: vasiaoik@central.ntua.gr (V. Oikonomopoulou), antkar@central.ntua.gr (A. Karantonis), vkarath@hua.gr (V.T. Karathanos), mkrok@central.ntua.gr (M.K. Krokida).

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and acid hydrolysis. Food is also degraded due to mechanical motion of the stomach walls (Chen, 2009; Kong & Singh, 2008a; Kong & Singh, 2010; Tharakan, Norton, Fryer, & Bakalis, 2010). Following, in the duodenum the chyme is mixed with bile and pancreatic secretion and flows to the small intestine, where digestive reactions, absorption of water and nutrients take place (Tharakan et al., 2010). The digestion process is being studied using both *in vivo* and *in vitro* models. The *in vitro* models are widely used in order to study the structural changes, the digestibility and the release of food ingredients under simulated conditions of the digestion process. *In vitro* digestion models have been studied in various products, such as starch, tea, rice, meat, etc. (Hur, Lim, Decker, & McClements, 2011). Many *in vitro* models mimic gastric digestion by mixing the food with the gastric fluid using a shaking bath (Muir & O'Dea, 1992) or a magnetic stirrer (De Boever, Wouters, Vermeirssen, Boon, & Verstraete, 2001). The decomposition of various foods in the stomach has been studied by some researchers (Tharakan et al., 2010). Bordoloi, Singh, and Kaur (2012) studied the *in vitro* digestibility of starch of different potato varieties. Paramera, Konteles, and Karathanos (2011) studied the *in vitro* removal of curcumin in solutions simulating gastric and pancreatic fluid. Mennah-Govela and Bornhorst (in press) studied the influence of cooking on structural changes during *in vitro* gastric digestion. During digestion, both the biochemical environment and the food properties affect food degradation (Bornhorst & Singh, 2013). Singh, Dartois, and Kaur (2010) and Dartois, Singh, Kaur, and Singh (2010) reported that one of the major factors affecting the enzymatic starch digestibility is the viscosity of the food matrix.

Salt and sugar particulates are major ingredients of human diet, however, they are correlated with severe health problems. As a result, their consumption and availability in the human body should be controlled. The objective of this paper was the examination of the release of sugar and salt particles from dried agricultural products, during food consumption, from mixing with saliva to digestion in the stomach.

2. Materials and methods

2.1. Materials preparation

Potatoes were washed, peeled and blanched in hot water for 3 min (Krokida, Kiranoudis, Maroulis, & Marinos-Kouris, 2000), while bananas were cleaned and their epidermis was removed manually. All samples were then dipped into 2% (w/w) sodium bisulfite solution for 5 min in order to prevent browning (Van Arsdel & Copley, 1964), and gently dried with blotting tissue. Potatoes and bananas were cut into circular disks of 15 mm diameter and a thickness of 5 and 8 mm, respectively, using a cork borer and a knife.

2.2. Osmotic treatment

NaCl and sucrose were used as osmotic agents. Potatoes were immersed into 10% (w/w) salt solution contained in jars, and bananas into 40% (w/w) sucrose solution, for 2 h. The osmotic solutions were prepared by blending sodium chloride and sucrose with deionized water. The jars were placed into a temperature-controlled water bath at 40 °C. The ratio of material to solution was 1:5 w/w, to avoid dilution of the osmotic solution during processing. After the osmotic treatment, samples were blotted with tissue paper in order to remove adhering solution.

2.3. Drying

The osmotically pre-treated samples were dried using two different methods; freeze drying and air drying. *Freeze-drying*: Samples were frozen at −30 °C for 72 h, in a biomedical freezer (SANYO, MDF-236, Osaka, Japan). The materials were then dried for 24 h using a laboratory freeze-dryer (Leybold-Heraeus GT 2A, Koln, Germany) operating at 6 Pa absolute pressure. *Air drying*: The samples were placed in an experimental air dryer, consisting of an air flow rate control, a heating control, a humidity control and drying test compartments. The air temperature was 70 ± 2 °C, the air velocity was 2 m/s and the dehydration was performed at atmospheric pressure. The samples were placed on shelves, perpendicular to the air flow. Two replicates for each drying condition were performed.

2.4. Immersion into solutions simulating saliva and gastric fluid

Dried potatoes and bananas (1.2 to 1.5 g) were immersed into 100 ml of synthetic saliva and gastric fluid solutions. The synthetic saliva was prepared according to the method described by Takahashi et al. (2009) and Blackburn et al. (1984) and consisted of the following components: mucin (2.8 g/L), lysozyme (0.11 g/L), α-amylase (0.5 g/L), glucose (0.01 g/L), urea (0.13 g/L), uric acid (0.03 g/L), K_2HPO_4 (0.68 g/L), KCl (0.94 g/L), $CaCl_2$ (0.16 g/L), NaCl (0.75 g/L) and $NaHCO_3$ (1.09 g/L). The pH of the solution was adjusted between the values 6.8 and 7.0 using NaOH (10 M) or concentrated HCl (12 M). The synthetic gastric fluid was prepared according to the method described by Paramera et al. (2011) and contained the following components: glucose (0.4 g/L), yeast extract (3.0 g/L), bacto-peptone (1.0 g/L), porcine mucin (4.0 g/L), cysteine (0.5 g/L), NaCl (0.08 g/L), $NaHCO_3$ (0.4 g/L), K_2HPO_4 (0.04 g/L), KH_2PO_4 (0.04 g/L), $CaCl_2 \cdot 2H_2O$ (0.008 g/L), $MgSO_4 \cdot 7H_2O$ (0.008 g/L), xylan (1.0 g/L), soluble starch (3.0 g/L), pancreatin (0.05 g/L). Also 2.0 g/L pectin και 1 mL/L Tween 80 were added. The pH of the solution was adjusted to the value 2.0 by adding concentrated HCl (12 M) and the solution was sterilized. The pH was then corrected with the addition of concentrated HCl (12 M) or NaOH (10 M) and 3.0 g/L pepsin were added.

2.5. Weight gain of the samples

The dried samples were immersed into gastric fluid solution at 37 °C. The samples were weighed at regular intervals (0, 10, 20, 40, 60, 90, 120, 150, 180, 210, 300 min). The weight gain of the samples was calculated from the equation:

$$WG = \frac{M - M_o}{M_o} \quad (1)$$

where WG is the weight gain, μ (g) is the mass of the samples at time t and μ_o (g) is the initial mass of the samples. Three replicates were performed for each condition.

2.6. Concentration of sugars

Banana samples were immersed into synthetic saliva and gastric fluid solutions at 37 °C and were stirred periodically. At predetermined intervals (0, 0.25, 0.5, 1, 2, 3, 5, 10 min for saliva and 0, 20, 40, 60, 90, 120, 180, 240 min for gastric fluid) 1 mL of the solution was taken from each sample. The concentration of sugars was measured using a refractometer, determining the degrees Brix (Kambiranda, Vasanthaiah, & Basha, 2011). A degree Brix corresponds to 1 g of sugar per 100 g of solution. Three replicates were performed for each condition.

2.7. Concentration of salts

The determination of the salt release in saliva and gastric fluid solutions was performed using three methods: (a) titration with silver nitrate, (b) measurement of the solution conductivity and (c) application of electrochemical impedance spectroscopy. Three replicates were performed for each condition.