Understanding the impact of sodium on the structural properties of sweet biscuits

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Abstract

The impact of sodium inclusion on the structural properties of sweet biscuits was investigated. Mass loss behaviour of four biscuit doughs (four levels of added salt) during baking (rate of loss, mass loss) was monitored using TGA, and texture properties of the baked biscuits were established with a texture analyser. Reducing the amount of added salt significantly increased the rate of mass loss at the baking phase, and hence, impacted biscuit hardness. Furthermore, less sodium chloride in the dough decreased the intrinsic break strength of the biscuits. This could be explained at a molecular level by changes in the glutenin gliadin cross-linking leading to changes in the gluten network. In contrast, when high levels of sodium chloride were added to the dough, an increased intrinsic biscuit break strength was observed. The present study demonstrates the significant impact of sodium on gluten polymerization during biscuit baking and confirms that sodium inclusion led to a retention of free water necessary for the gluten formation.

Introduction

Although sodium is required for normal body functions, it is often consumed in excess, this has led to a major global health problem for both adults and children. A high consumption of salt causes an increase in blood pressure and therefore increased risks of cardiovascular disease, stroke and coronary heart disease. The World Health Organization (WHO) recommends that adults consume less than 5g of salt daily. However, the average global intake significantly exceeds this level (e.g. 10g/day in the UK) [1]. Salt is used for 3 principal applications: processing, sensory (enhancement properties of others ingredients) and preservation [2]. More precisely, sweet biscuits have been highlighted because they often contain significant amounts of hidden salt. In 2013, a survey found that biscuits are in the top ten contributors of salt intake in the UK diet [3]. To ensure that biscuits with a lower sodium content remain appealing to consumers, sodium reduction in food products must not modify quality such as texture, or preservation and taste properties. Several studies have investigated the impact of sugar and fat in sweet biscuits, but to the best of the authors' knowledge, the impact of sodium reduction was exclusively performed on bread and salty snacks [4]. Sweet biscuits are a complex food matrix composed of various ingredients such as wheat flour (containing gluten and starch), fat (butter), sugar (sucrose), salt, and a low amount of water (< 5 %). During dough making, high sugar and fat levels and low water levels result in poor gluten hydration [5], leading to a non-elastic dough with a low gluten development [6]. During dough heating, fat, sugar, and gluten react. Starch granules could potentially swell but in short dough, this phenomenon might be very limited. A degradation of starch particles could also be observed but the high sucrose and low water levels prevent complete gelatinization [7]. Gaines (1990) stated that gluten proteins remain functional during the baking phase in this kind of matrix. Chevallier *et al.* (2000) and Pareyt *et al.* (2009) observed that the level of extractable proteins after baking decreased significantly, suggesting the formation of a gluten network in the dough during baking [8]. Moreover, Chevallier *et al.* suggest that

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the structure of the matrix after baking could be attributed to the sucrose [8a]. As the biscuit could be defined as a complex matrix made of sugars, lipids, starch granules and protein aggregates, they suggested that the structure cohesiveness might be mainly achieved by sugars that become glassy after the baking phase during the cooling step. It still appears that the quality of the gluten network is the most important factor that affects the structural properties of the biscuits [9]. The aim of this study was to observe and understand the impact of sodium on gluten polymerization in sweet biscuits and the impact on the structure after baking.

Experimental

Materials

Reference dough (L3) was prepared from the ingredients listed below: (1) Unsalted Butter 23.2 g/100 g; (2) Caster sugar 18.6 g/ 100 g; (3) Semi-skimmed long life milk 11.1g/100 g; (4) Salt, 0.6 g/100 g; (5) Flour containing self-raising agent 46.5 g/100 g. Unsalted butter, caster sugar, semi-skimmed long life milk and sodium chloride were sourced from Sainsburys (Supermarket company, UK), and flour was sourced from Morrisons (Supermarket company, UK).

Biscuit dough making and baking

The ingredients from (1) to (4) were weighed and blended manually then (5) was added and the dough mixed by a Food processor blender (Multipro Home, Kenwood, UK). A homogeneous dough was then formed, rolled to 40 mm thickness using an industrial laminator (Fritsch, Rollfix, Germany), and shaped by a model cutter (24 mm diameter, round with a smooth edge). The biscuits were placed on the same tray, placed in a Deck oven (Tom Chandley Compacta, UK) and baked at 180°C for 12 min. Subsequently, the biscuits were cooled to room temperature (20°C). The biscuit dimensions and weight were (average): height: 0.6mm; diameter: 32mm, and weight 3g. The biscuits were carefully packed and stored in sealed aluminium bags with a minimum headspace within the bag to reduce the effect on moisture content. Four doughs, from L0 to L3, were formulated and each contained different quantities of sodium chloride (respectively: 0.53; 0.75; 0.96; 1.20g of salt/100g of dough). L3 was the reference, comparable to the higher quantity of salt in commercial biscuits available in supermarkets (i.e. 1.3g per 100g of biscuit).

Thermogravimetry (TGA)

The weight loss of samples was measured with a Mettler-Toledo TGA/SDTA 851 thermal gravimetric analyser, using a nitrogen atmosphere (3 replicates). TGA is an analytical technique used to determine a material's thermal stability by monitoring the weight change that occurs as a specimen is heated; the weight is recorded as a function of the increasing temperature. In dynamic measurements, 10.0 ± 0.2mg of sample were placed in the aluminium pans and heated from 30 to 200°C at a heating rate of 10°C/min.

Moisture content

Moisture content of all biscuits was assessed by drying the biscuit using an OHAUS MB25 moisture balance. 2 g of sample were ground using a pestle and mortar and then placed on the moisture balance pan. The balance was programmed to run at 120°C for 12 min. 12 replicates of each type of biscuit were run.

Three-point bend

A Texture Analyser (TAXT Texture Analyser, Stable Micro Systems) was used to measure fracture force (Newton, N) of biscuits in compression mode, in a 3-point bending test using a 3-point bending rig (HDP/3PB), a heavy-duty platform (HDP/90) and a load cell of 5 kg. The inner gap distance between 2 plates was 18 mm and the upper blade linked to the probe moved vertically with 5.5 mm either side of the plate.

Statistical analysis

The data obtained from colour, moisture content, water activity, texture analyser and aroma release experiments were statistically evaluated using the software Microsoft® Excel 2010/XLSTAT©-Pro (2013.4.03, Addinsoft, Inc., Brooklyn, NY, USA). Data were subjected to univariate analysis of variance (ANOVA). The significance level was set at p-value<0.05. Significant differences among means of treatments were evaluated by the post-hoc multiple comparisons Fisher test.

Results and discussion

Reducing the salt content resulted in more rapid weight loss probably due to a lower water retention during baking. Rates for L0 and L3 were -4.12 and -3.28 µg/s respectively. Fessas & Schiraldi (2001) suggested that water in the dough would mainly be in two states, namely, i) free to diffuse through a medium, whose viscosity increases with increasing temperature because of the drying and transformations affecting starch and gluten, and ii) tightly bound to the gluten network and thus able to flash off only at higher temperatures [10]. The observed phenomena here could be due to release of "free water" in L0 (high rate of release; low temperature) and the added sodium in L3 might lead to an increase of the amount of "bound water". This could also explain why we need a higher temperature to release water in L3 (maximum rate of loss for L3=106°C while for L0=104°C). Moisture content analysis of biscuits showed a significant difference between the samples L0 to L3 with respectively 3.13 and 3.60 %.

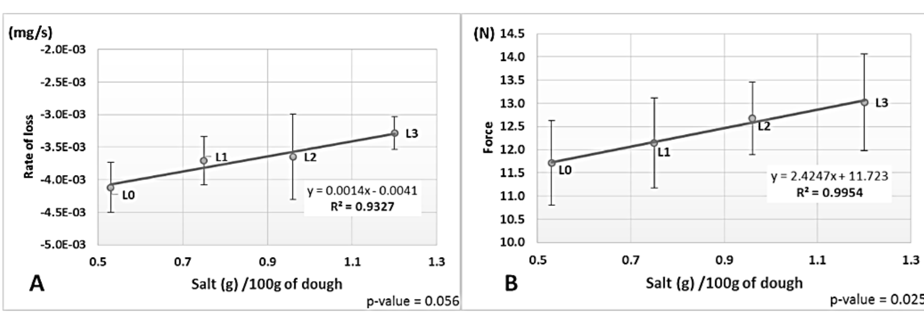

Figure 1: Maximum rate of mass loss (mg/s) between 104 and 106°C (**A**) and force (Newton) required to fracture (**B**) biscuits L0 to L3

However, there is no difference between L1 and L2 but the global trend shows a decrease of the moisture content when the quantity of added sodium chloride decreases. This observation tends to confirm our hypothesis that reducing the amount of added salt led to a matrix which retains less water leading to a smaller moisture content of L0 than L3. The force required to bend and fracture the samples was measured and a significant decrease in the force needed to reach the point of break was observed (p-value < 0.05) in biscuits without added salt, meaning less resistance to fracture and lower elastic response in L0 (11.70 N) than L3 (12.75 N). Decreasing values from L3 to L0 could be here related to the development of a less elastic structure in biscuits during baking. However, it must be stressed that due to the low moisture content in these doughs before baking (≈17%), and a high fat level (23.4%) and sugar level (18.6%), gluten proteins may not be properly hydrated and may form a non-continuous network [11]. Lynch *et al.* showed that sodium chloride increased the strength of the gluten network in bread doughs by enhancing the orientation uniformity [12]. The impact of the sodium on the gluten network strength was established by McCann & Day as added sodium chloride reduced the proteins charge leading to less repulsive forces (enhanced non-covalent hydrophobic interactions), and they observed higher interactions between them, leading to an increase in the gluten network strength [13]. Therefore, the added sodium chloride increased the force required to break the biscuits due to the formation of the gluten network being more resistant after baking. This is hypothesised to be due to the sodium chloride retaining more water in the matrix and decreasing the quantity of free water. So, the increase of the force required to break the salted biscuits could be due to the strengthening of the gluten network mixed with sugar in a glassy state (forming a more elastic matrix – lowering Young modulus).

Conclusion

The objective of this study was to understand the impact of sodium on the physico-chemical characteristics (colour, aroma release, texture) and sensory properties of sweet biscuit by baking biscuits with less added salt. When sodium chloride was added up to 1.20% (L3 as reference), the biscuit required more force to be broken, and had a higher moisture content than the biscuits with no added sodium chloride. Salt reduction may reduce the formation/strength of the gluten network [13]. It was suggested that there is an increase of "free water" in L0 (high rate of release at a lower temperature) and that the added sodium chloride in L3 might lead to an increased amount of "bound water" due to a more developed/strengthened gluten network (lower rate of release; higher temperature). A good gluten network might retain more water in the matrix (L3) and that more "bound water" will lead to a more resistant and elastic matrix which could potentially retain more aroma compounds in the matrix during the baking step.

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