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Effects of moisture and salt migration on cheese firmness in cheese-in-sausage products

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ABSTRACT

Moisture and salt migration are responsible for the softening of cheese, called cold melt, found in cheese-in-sausage products. By characterizing the rate of moisture and salt migration in model cheese-in-sausage systems, diffusion coefficients for water and salt in cheese were obtained. As expected, the rate of moisture migration was greater when the initial driving force (difference in water activities of cheese and sausage) were greatest. These conditions also led to most rapid softening of the cheese. An edible barrier was found to reduce but not completely inhibit moisture migration and softening, whereas formulation to match water and salt activity of sausage and cheese virtually eliminated moisture migration and softening.

1. Introduction

Specialty sausage products that contain pieces of natural cheese often show a defect called "cold melt" during storage. Cold melt is a textural change where the cheese takes on a melted appearance (soft and runny) without the addition of heat. Migration of water and/or salt from the sausage into the cheese, due to thermodynamic imbalance, could potentially disrupt the protein matrix, resulting in a softer texture. The thermodynamic imbalance between the cheese and sausage provides the driving force for a change in composition; however, it is the kinetic aspect of the migration that determines the shelf life of the product. The speed at which migration takes place is determined by factors and conditions inherent to the product, its formulation, and its storage conditions. Changes to the cheese-in-sausage product due to migration can be stopped by either eliminating the thermodynamic driving force, slowing the kinetics to a point where the changes are negligible, or both.

Diffusion between components in multi-domain food systems during storage can result in a loss of product quality, whether through texture, flavor, or microbiology safety. Overall, this migration over time has been studied less comprehensively than mass transfer during food processes such as baking, drying, or rehydration. As a result, the shelf life of these products is still often determined by potentially long and laborious storage tests as opposed to predictive models (Bourlieu et al., 2008). Often, diffusion is coupled with a change in structure to the component the species is migrating through that affects the diffusion rate through the food material (Aguilera, 2000). This complicates the use of predictive models as they may not be able to forecast structural changes that may accompany mass transfer and lead to dramatic changes in diffusion rates (Ghosh et al., 2005).

The diffusion of salt (NaCl) and water in cheese has been studied during brining (Geurts et al., 1974; Guinee and Fox, 1983; Luna and Chavez, 1992). When cheese is put in a brine solution, there is a net movement of Na^+ and Cl^- ions from the brine into the cheese and water out of the cheese into the brine as a result of the osmotic pressure difference. The NaCl molecules must travel an indirect route to bypass obstructing protein strands and fat globules against the outward migration of water. The result is an impeded diffusion process, which means that NaCl and H_2O molecules move in response to their respective concentration gradients, but their diffusion rates are much lower than those in pure solution due to the impeding factors such as structure and hydrophilic constituents (Guinee and Fox, 2004). Geurts et al. (1974) used the term "pseudo-diffusion coefficient" to describe the movement of NaCl in cheese moisture since the value of the observed coefficient depended on the net effect of many interfering factors. These physical impeding factors also apply to other food systems; for example, Roca et al. (2006) showed that moisture diffusivity in sponge cake was significantly impacted by the initial porosity of the cake, with decreasing porosity lowering the diffusivity.

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Using a Fickian model for diffusion, the pseudo-diffusion coefficient, or effective diffusivity, of salt during brining is typically $2.3 \times 10^{-10}\,m^2/s$ and can range from 1.1×10^{-10} to $5.2 \times 10^{-10}\,m^2/s$ depending on cheese composition and brining conditions, as compared to $1.1 \times 10^{-9}\,m^2/s$ for NaCl in pure H_2O at 12.5 °C (Guinee and Fox, 2004). Small molecules may interact with each other or with larger macromolecules in the system, such as proteins. Consequently, the mobility of the diffusing molecule changes unpredictably, even in dilute solutions. Each mechanism is difficult to study independently; therefore, the whole process is described by Fick's law, a phenomenological law that only describes the experimental observations (Geurts et al., 1974). The effective diffusivity is also a function of the concentrations of the migrating species. When using data from moisture migration through chocolate and confectionery coatings, Antunes and Antunes (2000) showed that models where the diffusion coefficient is dependent on the moisture concentration gave a better prediction of the data than when the diffusion coefficient was independent of moisture content.

Salt uptake during brining is sometimes accompanied by an increase in moisture content in the vicinity of the cheese-brine interface, especially in weak brines (<10% w/v NaCl). Such an effect is associated with the "soft rind" defect and swelling in cheese and is attributed to a salting-in of the protein matrix in low percentage NaCl brines which results in increased protein solubility (Geurts et al., 1972).

The strength of the protein matrix primarily dictates the firmness of cheese (Lucey et al., 2003). Diffusion of salt into cheese also changes the strength of interactions between protein molecules by screening charged groups, which reduces electrostatic repulsion but also lessens the number of plus–minus interactions between protein molecules. The impact of salt diffusion on the properties of the cheese matrix depends on factors such as salt concentration, pH, moisture content, temperature, and calcium concentration (Lucey et al., 2003).

Increasing the moisture content or increasing the ratio of moisture to protein in cheese weakens the rigidity of the cheese as the volume fraction of the protein decreases (Walstra and van Vliet, 1982). When the protein is hydrated and swollen, the cheese is soft (Lelievre, 1977).

One method for reducing water and salt migration into cheese is to reduce the driving force or difference in chemical potential. Eliminating the driving force can be accomplished through careful formulation of all components of a multi-component system (Bourlieu et al, 2008).

Another method is to kinetically slow or stop the migration with a physical barrier, whether it be tightening the protein matrix of the cheese or including an edible film. Lipid and lipid emulsion films provide a moisture barrier that can help prevent moisture migration in low- and intermediate-moisture foods over time because the nonpolar attributes of the lipids do not interact with the polar water molecules (Shellhammer and Krochta, 1997). Crystalline lipids provide a better barrier to moisture transfer than do liquid lipids. Edible films may have limited effectiveness at preventing moisture migration at high relative humidities and water activities (Greener-Donhowe and Fennema, 1993).

In this study, model cheese and sausage systems were prepared with differing levels of moisture content, salt content, and fat-to-protein ratio and the softening of the cheese during storage was monitored as a function of moisture content, salt content, and water activity. Approaches to inhibit or prevent cheese softening were also tested.

2. Materials and methods

An experimental design was set up to determine the effects of water content, salt content, and fat-to-protein ratio on softening of cheese-in-sausage. The composition of the sausage was changed (rather than the cheese) because sausage makes up approximately 80% of the specialty meat product and exerts it effect on the cheese. High and low values of water content (55% and 65%), salt content (1.5% and 2.5%), and fat-to-protein ratio (1.15 and 2.15) in the sausage were studied in a 2^3 full-factorial design. These values were chosen based on what is considered to be extreme high and low end-points for use in smoked sausages. A center point of 60% moisture, 2% salt, and 1.65 fat-to-protein ratio was used. To test the effects of salt versus water, a sausage with high salt content and lower water activity was also formulated.

2.1. Sausage manufacture

Sausages were formulated according to the experimental design with a base formula containing lean beef, lean pork, pork fat, added water, and salt, as well as 1.1% sucrose, 0.20% cure mix, and 0.04% erythorbate (Table 1). The full 2^3 factorial design plus center point was done in triplicate with Cheddar cheese. A smaller 2^2 factorial design was done with Swiss cheese, with water and salt content as the two changing factors. The same levels were used; therefore, the same formulas applied. The Swiss cheese experiments were run in duplicate, with the same center point conditions run once.

The sausages were made on benchtop units for grinding, mixing, and stuffing in a 7.16 cm diameter moisture impermeable fibrous casing. A Hobart mixer with a hook attachment was used for the mixing. The sausages were cooked in a smokehouse set to steam cook at 79.5 °C until the center temperature of the sausage reached 74 F. They were cooled quickly in a cold shower until the temperature was below 29.5 F and stored at 4.5 F. Initial moisture content, water activity, and salt content of the cheese and sausages were measured along with the initial firmness (described later) of the cheese.

The cheese was obtained from the Babcock Hall Dairy Plant in Madison, WI. Composition of the Cheddar cheese was approximately 37% moisture, 31% protein, 31% fat, and 1% salts and acids with a water activity of 0.965. The Swiss cheese had a composition of approximately 39% moisture, 31% protein, 29% fat, and 1% salts and acids with a water activity of 0.97. The Swiss cheese had a slightly higher pH (5.4) than the Cheddar (5.1).

2.2. Storage study

To prepare the samples for storage, a 16 cm long section of the 7.16 cm diameter sausage was cut length-wise to give a long, flat surface. A block of cheese was cut 16 cm long, 7.16 cm wide and at least 5 cm tall. The flat surface of the sausage was placed on the

Table 1
Levels used for sausages in the factorial design and resulting measured water activity

Condition	% Moisture	% Salt	Fat to protein ratio	Water activity
1	55	1.5	1.15	0.976
2	55	1.5	2.15	0.977
3	55	2.5	1.15	0.971
4	55	2.5	2.15	0.972
5	60	2.0	1.65	0.979
6	65	1.5	1.15	0.983
7	65	1.5	2.15	0.984
8	65	2.5	1.15	0.978
9	65	2.5	2.15	0.981
High salt content	55	3.4	1.15	0.960
Thermodynamically balanced[a]	55	1.5	2.15	0.966

The initial water activity of the Cheddar cheese was 0.965. The initial water activity of the Swiss cheese was 0.97. Both cheeses had an initial salt content of approximately 1%.

[a] Sucrose added to sausage to modify water activity.