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# Spatio-temporal gradients of dry matter content and fundamental material parameters of Gouda cheese

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ABSTRACT

In this research the spatio-temporal variability of the dry matter content and the fundamental parameters defining the material behaviour of Gouda cheese is described and quantified.

Spatio-temporal gradients existed for dry matter, for Young's modulus and for the residual Prony coefficient $G_\infty$. The gradients in Young's modulus and their changes during ripening were caused by the interplay between water and salt diffusion, water evaporation and proteolysis during ripening. The spatial distribution of $G_\infty$ was similar to that of Young's modulus. The effect of ripening on $G_\infty$ though was more complex and indicated that other factors than dry matter and proteolysis have an influence on $G_\infty$. Fracture stress was mainly influenced by the age of the cheese. The effect of ripening however did vary within a cheese block. Only a spatial gradient existed for the fracture strain.



## 1. Introduction

Cheese is an important part of the diet in many parts of the world. To suit the varied consumer needs different types of cheeses with varying textures are manufactured. A type of cheese that is consumed worldwide is Gouda. It is a cheese produced from pasteurized cows' milk acidified by a mesophilic starter culture containing several strains of lactic acid bacteria (CODEX STAN 266-1966, 2013; Van den Berg et al., 2004). Some major steps in the production process are characteristic for Gouda cheese, i.e. washing of the curd with hot water, moulding and pressing of the curd and salting in a brine solution (Gunasekaran and Ak, 2003).

A characterization of the rheological, textural and chemical attributes of different cheeses is needed to ensure their quality (Gunasekaran and Ak, 2003). Furthermore, a better understanding of the properties of cheese will contribute to a better insight in cheese production and processing. A broad variety of cheeses, including Gouda cheese, has been characterized by research of their chemical and structural properties (Messens et al., 1999, 2000; Luyten, 1988). The interplay between cheese structure and chemistry determines the fundamental material behaviour of the cheese. Consequently, cheese can also be characterized by defining this behaviour, which is described by several parameters such as Young's modulus, fracture stress and strain and Prony series representing the relaxation behaviour of cheese. The importance of these fundamental parameters is not only limited to the characterization of cheese. In recent years, the research on cheese has extended to the domain of numerical simulations, including simulations with finite elements (Goh et al., 2005; Lezzi et al., 2011; Mitsoulis and Hatzikiriakos, 2009). Such simulations require the fundamental parameters mentioned above to model the material behaviour of the cheese.

The influence of ripening on the chemical and structural properties of cheese has been studied by many researchers. For instance, the effect of cheese ripening on water and salt content (Simal et al., 2001), on water activity (Saurel et al., 2004) and on redox potential and pH (Abraham et al., 2007) has been examined. Changes in chemical composition and proteolysis during ripening have been examined for Picon Bejes-Tresviso blue cheese (Prieto et al., 2000), for Prato cheese (Cichoscki et al., 2002) and for Spanish goat cheese (Franco et al., 2003). Since the interplay between

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structure and chemistry determines the fundamental material behaviour, this behaviour will also be influenced by ripening. The influence of cheese ripening on Young's modulus has been described by Charalambides and Williams (1995), Noël et al. (1996) and Rinaldi et al. (2010). Noël et al. (1996), Visser (1991) and Rohm et al. (1992) examined the ripening effect on fracture stress and strain.

Besides a temporal variability in the properties of cheese caused by ripening, also a spatial variability exists. On a macroscopic level, numerous cheese varieties are heterogeneous in both chemical and structural properties due to their production process. The chemical variability of the water and sodium chloride content is described by Messens et al. (1999), Pajonk et al. (2003) and Simal et al. (2001). The volatile compounds in different zones of Stilton cheese were examined by Gkatzionis et al. (2009). Pachlova et al. (2012) included textural properties in their research by measuring the hardness of different cheese zones. Karoui and Dufour (2003) analyzed the differences in storage and loss modulus between the surface and the center of soft cheeses. As the fundamental cheese behaviour takes the chemical and structural properties into account, a spatial variability will also exist for the fundamental parameters. This was confirmed in previous research for Gouda cheese of 8 weeks old (Vandenberghe et al., 2014). To our knowledge no other research has been done on the spatial variability of the fundamental parameters in cheese.

It can be concluded that the information on the temporal and especially the spatial variability of fundamental parameters of cheese is limited. A better understanding of cheese requires additional research on both levels. Furthermore, no previous research has been done on the interaction between the temporal and spatial influence on cheese properties. However, this interaction is sometimes substantial and should therefore be considered to gain more insight in the processes that take place during cheese ripening. In addition, a better understanding of the heterogeneity of the fundamental cheese parameters, both spatial and temporal, is needed for further research that implements finite element modeling of cheese. It is necessary to take this heterogeneity into account to obtain realistic and valid material models.

## 2. Material and methods

When only small deformations are applied, the behaviour of Gouda cheese can be estimated by a linear viscoelastic material model (§2.1). The fundamental material parameters describing this behaviour were measured throughout the geometry of differently aged blocks of cheese (§2.2). Compression tests were used to determine Young's modulus, fractures stress and fracture strain (§2.3). Prony series coefficients were derived from stress relaxation experiments (§2.4). Simultaneously the dry matter content was also determined (§2.5).

### 2.1. Material model

Linear viscoelasticity is often modeled using the Generalized Maxwell model as described in Vandenberghe et al. (2014). This model consists of a Hookean spring which is connected in parallel with a series of viscous Maxwell elements. The relaxation behaviour of these elements is often represented by a Prony series expansion (Eq. (1)), where $\tau_i$ are time constants for $i = 1 \ldots n_G$ respectively. $G_\infty$ is the residual Prony coefficient, representing the material behaviour at an infinite relaxation time. The dimensionless constants $G_i$ and $G_\infty$ are normalized so that they add up to 1 (Eq. (2)).

$$G(t) = G_\infty + \sum_{i=1}^{n_G} G_i e^{(-t/\tau_i)} \quad (1)$$

$$G_\infty + \sum_{i=1}^{n_G} G_i = 1 \quad (2)$$

The material behaviour of cheese at fracture is described by the fracture stress and the fracture strain, i.e. the stress and strain at which a cheese sample fractures during compression.

### 2.2. Sample preparation

Gouda type cheeses of different ripening stages, produced in a small cheese company situated in Mol (Belgium), were examined. Each rectangular block of cheese was taken from the same batch and the blocks were stored under ideal ripening conditions at a temperature of 13 °C and a humidity of 85%. At different ripening stages, i.e. at 4, 8, 11 and 19 weeks old, one block was analyzed.

Three slices of cheese were taken out of the middle section of the blocks (M) and at the side section of the blocks (S) as shown in Fig. 1. Each set of 3 slices was considered to be the same (Vandenberghe et al., 2014).

Previous research showed that every cheese slice is symmetric around the middle line. Six samples were taken from every side of a slice (Fig. 2). The left side of the slices was used for compression tests. The samples at the right side were used for stress relaxation tests. Both sides were used to determine the dry matter content.

The samples used for the compression and stress relaxation tests were cylindrical with a diameter of 18 mm and a height of 27 mm (±0.5 mm), based on the standard ISO 17996 (2006). The samples were taken out of a block of cheese using a cylindrical tube. They were cut at the desired height with a wire cutting device. Every sample was stored 60 min at room temperature before measuring to allow temperature stabilization and sample relaxation after cutting.

### 2.3. Uniaxial compression tests

All measurements were performed using a Texture Analyser TA.XT2i (Stable Microsystems, UK) with a flat compression plate (diameter 7.5 cm). The samples were compressed at 0.83 mm/s till a strain of 80% was reached to determine Young's modulus and fracture stress and strain (ISO 17996, 2006).

Young's modulus, fracture stress and fracture strain were determined from the true stress and strain curves as described in Vandenberghe et al. (2014).

### 2.4. Stress relaxation tests

Stress relaxation tests were performed to determine the time-dependent behaviour of the visco-elastic material. The samples were compressed for 5 mm with a speed of 6 mm/s. This strain

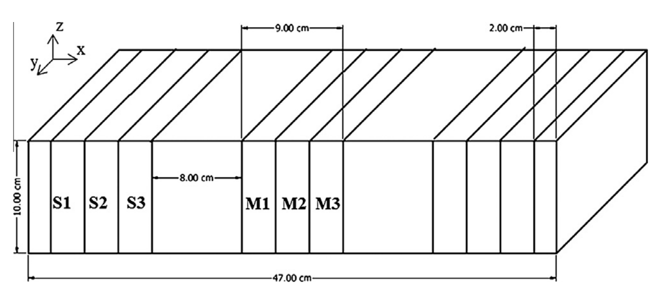


**Fig. 1.** Division of a cheese block in groups of slices.