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# Quantifying acoustic properties of squeaky cheese using sonography and high-speed photography

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## 1. Introduction

Acoustic imaging has become an established means for food and oral tablet quality and consistency testing,[1,2] especially in processes involving bubble or crack formation through ripening, fermentation, or handling.[3,4] In dairy cheese production, acoustic methods have traditionally been involved in crack monitoring, eye formation, and sterilisation, but more recently ultrasonic methods that monitor and influence the internal structure of cheese have become of interest.[5–7] The ultrasonic equipment traditionally used in continuous food monitoring operates in the near-audible range at acoustic amplitudes and pulse lengths associated with the unwanted production of free radicals and deposition of heat.[8,9] The purpose of this study was to make use of low-amplitude ultrasound to measure quantitative features of a string cheese that produces a squeaky sound when chewing. In addition, high-speed photography experiments were conducted to measure mechanical vibrations during shear.

## 2. Materials and methods

Two experimental setups were used in this study. The first setup was used for sonography of squeaky cheese samples. The second setup was used to record high-speed video footage of samples under shear. HIILLOS Erätuli JUUSTOLEIPÄ squeaky cheese (Vaalan Juustola Oy, Vaala, Finland), prepackaged in 200-g pieces, was manually cut into cuboids of $z$=1.4-cm thickness prior to experiments and measured using a CD-6"ASX digital calliper for precise measurements (Mitutoyo Corporation, Takatsu-ku, Kawasaki, Kanagawa, Japan). All experiments were performed at room temperature.

Brightness-mode sonography experiments were carried out in a 43194001 tank of Plexiglas® without inclined bottom (Glasswarenfabrik Karl Hecht GmbH & Co. KG, Sondheim vor der Rhön, Germany) of inner dimensions $x{\times}y{\times}z$=349×140×162 mm$^3$ and filled with Hervanta tap water. An HFL38x 13—6 MHz linear probe of a SonoSite® M-Turbo® sonography device (FUJIFILM SonoSite, Inc., Bothell, WA, USA) was positioned vertically, defined as the $z$-direction, in an acrylonitrile butadiene styrene scaffold, such that it faced a 1-SHP reflector placed horizontally on a 184140 FABER-CASTELL LATEX-FREE attenuator (Faber-Castell AG, Stein, Germany) placed on the tank bottom. During experiments, a cuboid sample was placed on the reflector. The sonography device operated in musculoskeletal pulsed brightness mode at machine-indicated mechanical indices varying from 0.7 to 0.8 and machine-indicated thermal indices varying from 0.1 to 0.2. The sonography experiments generated a total number of 42432 bitmap image frames that were stored for offline processing. Image features were extracted using a custom programme written in MATLAB® (The Mathworks, Inc., Natick, MA, USA). The output in greylevel values and poronkusema per minute was automatically converted to attenuation in dB cm$^{-1}$ and speed of sound in m s$^{-1}$. Controls on the attenuation and speed of sound of the medium were performed in a separate setup described previously.[10]

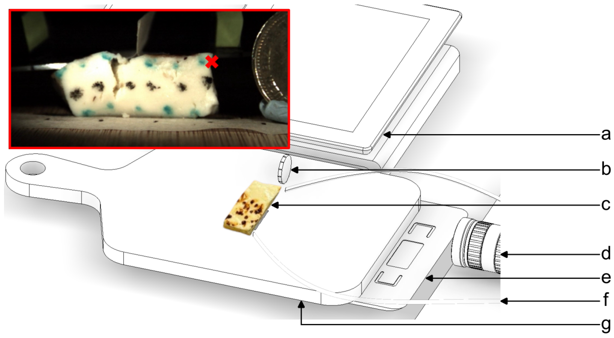


Fig. 1 Schematic representation of the high-speed photography setup used, showing a sound recorder (a), a 1-SHP coin for sizing (b), a cuboid sample (c), a zoom lens (d) connected to the camera, weighing scales (e), a light fibre (f), and a bamboo board (g). The inlay frame shows sample measurement points.

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In a prior study, the experimental conditions to produce consistent audible squeaks from squeaky cheese were designed and tested.[10] An identical setup was used to rub the cuboid samples and create audible sound by slip-stick motion, shown in **Fig. 1**.[10] Cuboid sample displacement under shear, as extensively described in a prior study,[10] was recorded with a FASTCAM MC2 colour high-speed camera (Photron Deutschland GmbH, Reutlingen, Germany) operating at a frame rate of 4 kHz and mounted with a 3 MEGA PIXEL IR 800mm—50mm F1.4 zoom lens (Like Sun GmbH, Essen, Germany). A KL 2500 LED light source (SCHOTT AG, Mainz, Germany) was used for illumination. A total number of fourteen videos was recorded. Each video sequence consisted of 1024 video frames. Representative points in the video frames were marked and traced for displacement measurement, using customised software in MATLAB®,[10] as shown in the inlay frame of Fig. 1.

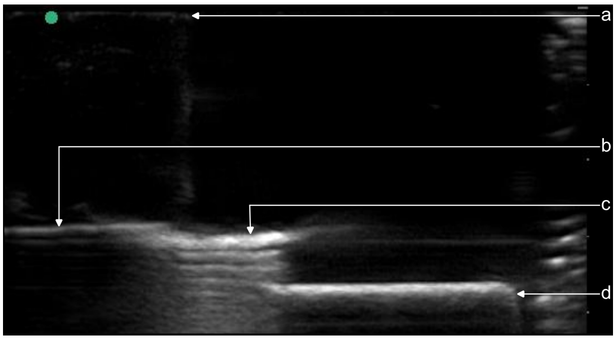


Fig. 2 Brightness-mode image frame showing the transducer face touching the sample (a), the transition between sample and reflector (b), the reflector surface (c), and the attenuator surface (d).

## 3. Results and discussion

**Fig. 2** shows a representative brightness-mode sonography image of a sample cuboid on top of a 1-SHP reflector. The distal scattering surface of the transition between cheese and reflector has been indicated. From the shift with respect to the control surface, a relative speed of sound of 7% was measured with respect to the control medium. The standard deviation in the relative speed of sound was 1%.

None of the brightness-mode images showed evidence of scattering gas microbubble presence. Given the porous structure of the samples, it has been assumed that pores are interconnected and therefore filled up with the surrounding medium upon submersion.

The attenuation measured from the brightness-mode sonography experiments consistently corresponded to $2.7\pm0.5$ dB cm$^{-1}$. This value lies well within range of typical soft tissue attenuation.[11)]

The dominant vibration frequency measured from high-speed video footage was 160 Hz. This low frequency did not correspond to audio footage recorded and published.[10] Consequently, the squeaky sound produced from rubbing the surface may have an origin in the internal structure of the cheese, as suggested by prior studies. Additional research is proposed whether high-amplitude sonication, for example by high-intensity focussed ultrasound, affects the internal structure and the resulting acoustic output during shear.

## 4. Conclusion

Squeaky cheese was observed to attenuate in a similar range as live soft tissue. This would mean that squeaky cheese might be utilised as a cheap and consistent phantom material in *in-vitro* experiments.

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