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Tribological analysis of the surface of food gels

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ABSTRACT

The surface of intact food has a significant influence on its mouthfeel. However, such a surface has rarely been evaluated. In this study, we investigated the surface of food gels via tribological analysis. Agar gel, gellan gum gel, and xanthan/locust bean gum mixed gel were prepared and analyzed. A series of agar gels of different concentrations was initially studied. Although an increase in the torque resulted in an increase in the number of rotations, from 0.01/min to approximately 100/min, for each gel concentration, the rate of change observed for each gel was different. The harder the gel in the agar gelled, the more torque was needed for the movement to occur; however, the torque required was not completely in proportion to the hardness. Gels of identical hardness that were prepared using different gelling agents were also studied. Again, the rate at which the number of rotations changed with respect to torque was different for each gel. Our findings suggest that unique tribological information for gel surfaces can be identified via this new analysis and that this information might be related to mouthfeel.

1. Introduction

The texture of food has previously been investigated using measuring equipment, as well as sensory tests, to evaluate its quality or to develop new foods. In the evaluation of meat, measurements were performed using a texturometer and a Warner-Bratzler knife with a triangular cut-out (Węsierska, 2014). Using texture profile analysis, the hardness, adhesiveness, and cohesiveness of cooked sweet potatoes were evaluated (Truong, Walter, & Hamann, 1997). Rheological properties of gluten-free dough were evaluated using a dynamic viscoelastic test and a creep test (Korus, Witczak, Ziobro, & Juszczak, 2009). The viscosity of coating solutions applied to fruits and vegetables by dipping methods was also measured using a viscometer (Cisneros-Zevallos & Krochta, 2003). The yield stress of butter, cheese, and cream were measured using the vane method to investigate spreadability (Daubert, Tkachuk, & Truong, 1998). Numerous types of methods are used for various purposes.

Similar to rheological studies, tribological measurements have been recently adopted to analyze food. Chen and Stokes (2012) mentioned that tribology is emerging as a contributing discipline for understanding the oral processing of food, as well as texture and mouthfeel. Using agar gel, the influence of co-solute was investigated using tribological analysis (Fernández Farrés & Norton, 2015). Fat droplets in emulsion-filled gels reportedly affected rheological, tribological, and sensory properties (Liu, Stieger, van der Linden, & van de Velde, 2015). These reports only showed the tribological features of fluid or sheared gels, and not that of intact solid food, because the aim of the studies was to examine the texture of a food bolus in the latter part of mastication when tribological behavior is thought to be dominant. However, investigating the tribological features of intact solid food would be useful to study mouthfeel, for example surface smoothness and slipperiness, which are degrees to which the sample piece was perceived as smooth and slippery when evaluated prior to mastication (Gwartney, Larick, & Foegeding, 2004).

In this study, an attempt has been made to develop new analyses to evaluate the tribological features of intact solid food by adapting a tribological sensor that has previously only been used on liquid samples, and setting a reasonable normal force to ensure that samples were not destroyed during analysis (Fig. 1). Three types of gels were prepared using different gelling agents. The process by which the analysis worked to evaluate the tribological features of gel surfaces was confirmed.

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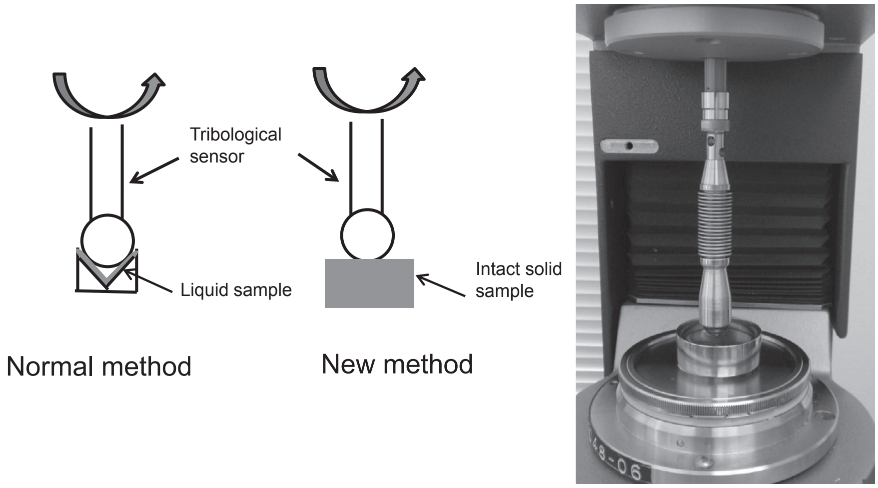

Fig. 1. New tribological analysis method. Normal method is to examine a liquid sample by placing the sample between the sensor and holder. New method is to examine the surface of an intact solid sample by establishing a contact between the sensor and sample with a reasonable normal force.

2. Materials and methods

2.1. Preparation of gel samples

To prepare the samples, 0.30, 0.50, 0.55, 0.70 or 1.0% (w/w) Agar (M–7, Ina food industry Co., Ltd) was added to water, mixed, heated in a water bath that was more than 90 °C for 5 min, poured in a dish (40 mm in diameter and 15 mm high), cooled at 23 °C for more than 6 h and was designated as 0.30%, 0.50%, 0.55%, 0.70% or 1.0% AG. Subsequently, 0.5% (w/w) native-type gellan gum (kelco LT100, San-Ei gen F. F. I. Co., Ltd.) was dissolved as AGs and was designated as "GG." 0.465% (w/w) Xanthan gum (Sanace NXG-S, San-Ei gen F. F. I. Co., Ltd.) and 0.465% (w/w) locust bean gum (Bistop D-30, San-Ei gen F. F. I. Co., Ltd.) (the total concentration of gelling agents was 0.93% (w/w)) were treated as AGs and the mixture was designated as XL. 0.55% AG, GG, and XL gels were selected so that the hardness of all gels was similar in preliminary experiments.

2.2. Texture profile analysis (TPA)

A Creepmeter RE2-33005B (Yamaden Co., Ltd., Japan) was used for measurements. With the exception of temperature, the test was performed in accordance with the method for testing foods for dysphagia (Ministry of Health, Labor and Welfare, 2009) under the following conditions: plunger, resin (20 mm in diameter); plunger movement, 10 mm/s; sample height, 15 mm; clearance, 5 mm; temperature, 23 °C; load cell, 20 N; compression cycles, two. The stress curves obtained were interpreted as follows: the maximum value during the first compression denotes the hardness, the ratio of the peak area of the second compression to the peak area of the first compression denotes the cohesiveness, and the peak area under the base line appearing after the first compression denotes the adhesiveness. The test was repeated five times.

2.3. Tribological analysis

A RheoStress 6000 instrument (Thermo Fisher Scientific, Inc., US) was used for the testing. Samples were placed as shown in Fig. 1. The test was performed to evaluate the number of rotations under the following conditions: sensor, tribological sensor made of stainless steel; normal force, 0.01–0.1 N (so as not to destroy the sample but to ensure certain contact with the surface); position of sensor, 1–2 mm depth from the sample surface; temperature, 23 °C; torque, 2–200 Nm. Unstable points at the early stage of low torque and the later stage of high torque were omitted. The test was repeated three times and averages are shown.

2.4. Statistical analysis

The hardness, cohesiveness, and adhesiveness obtained using TPA were evaluated using an analysis of variance (ANOVA; Tukey–Kramer HSD tests, JMP 8.0 software). The statistical significance level was set at $p < 0.05$.

3. Results and discussion

3.1. TPA of agar gels at different concentrations

The hardness, cohesiveness, and adhesiveness of 0.30%, 0.50%, 0.70%, and 1.0% AG are shown in Table 1. The hardness of the agar gels increased with agar concentration. The lowest hardness was 0.27×10^4 Pa for 0.30% AG, and the highest value was 3.1×10^4 Pa for 1.0% AG. The difference in hardness between agar gels was significant. Miura (2000) reported that the hardness of three types of agars, i.e., food, Japanese sweet, and culture grades, increased when the concentration of agar was in the range of 0.50%–1.75%.

The lowest cohesiveness was 0.19 in 0.70% and 1.0% AG, and the highest was 0.24 in 0.30% AG. Except for the difference in cohesiveness between 0.30% and 0.50% AG, and between 0.70% and 1.0% AG, the differences were significant. The cohesiveness of agar gels decreased slightly in relation to concentration. However, the cohesiveness of agar has previously been reported to increase slightly with concentration (Miura, 2000). The difference may be due to differences in sample preparation and measurement methods.

The adhesiveness of agar gels increased in correlation with the concentration of agar, similar to hardness. The lowest adhesiveness was 0.49×10^2 J/m^3 in 0.30% AG, and the highest was 12×10^2 J/m^3 in 1.0% AG. Except for differences in adhesiveness between 0.30% and 0.50% AG, and between 0.50% and 0.70% AG, the differences were significant. The adhesiveness of agar gels may be affected by hardness, because adhesiveness is equal to the energy required to pull the resin plunger out of the agar gel.