Acoustic Properties of Crunchy Products

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Introduction

Texture is a complex quality attribute and consist of preferred and disliked features. One of the preferred texture features is crispness, which is always associated with fresh and healthy food. The lack of expected crunchiness is understood by consumers as quality failure. Combination of mechanical and acoustic measurements suggests that the results can be highly correlated with consumer’s texture perception. However the number of publications considering this problem is rather small.
Introduction

The significance of the sound in food quality evaluation was recognized in the early 60’s. Drake (1963, 1965) analyzed sounds accompanying disintegration of different brittle products, and found that the results differ in amplitude and frequency. Thereafter Kapur (1971), Vickers and Bourne (1976), Lee et al. (1988), Poliszko (1995), Tesh et al. (1996), Roudaut et al. (1998), Liu and Tan (1999), Duizer (2001) and Lewicki et al. (2002, 2003) analyzed acoustic characteristics of crunchy foods, and showed that acoustic emission can be a good measure of crispness. Moreover it was shown that acoustic emission is strongly dependent on water content of the food and soggy products are practically silent.
Methods

Samples of flat extruded wheat, rye, corn-buckwheat and corn-rice bread with dimensions 120x54x7mm, crackers with dimensions 48x40x5mm, corn flakes and potato chips were stored in desiccators at 25°C at prescribed relative humidities of air. Sponge-cake and biscuits were taken directly from packages for analysis.

Water activity ($a_w$) of all samples was measured with Hygroskop DT 2 (Rotronic) with the accuracy ± 0.001, at 25°C.
Methods

Samples of flat extruded bread and crackers were subjected to three-point breaking process done in a Zwick 1445 Machine. Loading was done with the cross-head speed 20 mm/min. Corn flakes and potato chips were piled one over the other and pressed with a ball in Texturometer TA XT2i/25 (Stable Micro Systems) at ball speed 60 mm/min.
Methods

Acoustic emission (AE) signals generated during breaking of the samples were registered with a specially designed accelerometric sensor, which was mounted near the lower end of the upper head of loading machine to achieve an acoustic contact with the sample. The accelerometer was capable to register the AE signals at the frequency range from 0.1 Hz to 14 kHz.
The AE signals were transmitted from the sensor to a 20 dB low-noise amplifier and finally registered using 44.1 kHz sampling sound card placed in a PC computer. A special uniformity test, including 0.5 mm pencil HB break, was applied to keep sensitivity control of the AE signal. Registered AE signal was processed with a discret Fourier transform in the range 0.1–15 kHz split into 11 Hz sequences.
Fig. 1. Sample in the Zwick loading machine
Data analysis

Energy of the AE signal

\[ E = \sum_{m=1}^{N} v(mT_1) \]

V(t) - time dependent session of the AE signal,

T_{1} - time delay between the consecutive executions of taking a sample,

v(mT_{1}) - amplitude of voltage registered by the AE sensor,

m - consecutive number of a signal sample.

T - time of signal registration,

N - number of signal samples.
Results

$a_w = 0.041$

Fig. 2. Relationship between amplitude and time for flat extruded wheat bread broken at different water activities
Results

$aw = 0.037$

$aw = 0.330$

$aw = 0.408$

$aw = 0.530$

$aw = 0.750$

Fig. 3. Relationship between amplitude and time for flat extruded rye bread broken at different water activities
Fig. 4. Relationship between amplitude and time for crackers broken at different water activities.
$a_w = 0.035$

$aw = 0.088$

$aw = 0.345$

$aw = 0.591$

$aw = 0.761$

Fig. 5. Relationship between amplitude and time for potato chips
Fig. 6. Relationship between amplitude and time for corn flakes
Flat extruded corn-buckwheat bread $a_w = 0.304$

Flat extruded corn-rice bread $a_w = 0.281$

Low-calorie biscuits $a_w = 0.180$

Full fat biscuits $a_w = 0.191$

Sponge-cake $a_w = 0.560$

Fig. 7. Commercial products
Fig. 8. Influence of water activity on energy of acoustic emission during breaking of flat extruded wheat and rye bread.

Results
Results

Fig. 9. Influence of water activity on energy of acoustic emission during breaking of flat extruded breads.
Results

Fig. 10. Influence of water activity on energy of acoustic emission during breaking of crackers.
Flat extruded corn-rice bread $a_w = 0.281$

Flat extruded corn-buckwheat bread $a_w = 0.304$

Flat extruded wheat bread $a_w = 0.462$

Flat extruded rye bread $a_w = 0.408$

Fig.11. Spectral characteristics of commercial products
Crackers, $a_w = 0.413$

Sponge-cake $a_w = 0.560$

Low-calorie biscuits, $a_w = 0.180$

Full fat biscuits, $a_w = 0.191$

Fig. 12. Spectral characteristics of commercial products
Fig. 16. Spectral density of the AE signal generated by crackers at different water activities

- $a_w = 0.011$
- $a_w = 0.308$
- $a_w = 0.518$
- $a_w = 0.617$
Fig. Spectral characteristics of the AE signal generated by potato chips at different water activities
Fig. 5. Spectral density of the AE signal generated by corn flakes at different water activities

\[ a_w = 0.159 \]
\[ a_w = 0.516 \]
\[ a_w = 0.209 \]
\[ a_w = 0.639 \]
Acoustic activity of flat extruded wheat bread recorded during bending-breaking test

$a_w = 0.462$

$a_w = 0.730$
Acoustic activity of flat extruded rye bread recorded during bending-breaking test

\[ a_w = 0.408 \]

\[ a_w = 0.730 \]
Acoustic activity of flat extruded corn-rice bread recorded during bending-breaking test at $a_w=0.244$

Acoustic activity of flat extruded corn-buckwheat bread recorded during bending-breaking test at $a_w=0.244$
Acoustic activity of corn flakes recorded during bending-breaking test

\[ a_w = 0.015 \]

\[ a_w = 0.159 \]

Acoustic activity of corn flakes recorded during bending-breaking test
Acoustic activity of potato chips recorded during bending-breaking test

\[ a_w = 0.088 \]

\[ a_w = 0.438 \]
Acoustic activity of crackers recorded during bending-breaking test
Acoustic activity of biscuits recorded during bending-breaking test

Low-calorie $a_w = 0.180$

Full fat $a_w = 0.191$
Sponge-cake, $a_w = 0.560$
Relationship between partition power spectrum and water activity of flat extruded bread
Relationship between partition power spectrum and water activity of corn flakes and potato chips.
Effect of water activity on spectral density of the AE signal generated by flat extruded wheat bread
Effect of water activity on spectral density of the AE signal generated by flat extruded rye bread
Flat extruded corn-rice bread

Flat extruded corn-buckwheat bread
Conclusions

1. Acoustic emission generated during disintegration of food is its characteristic feature
2. Energy of acoustic signal is strongly related to water activity of material
3. AE signal is generated at the same frequencies independently on water activity