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STRUCTURE ANALYSIS OF SELECTED CEREAL PRODUCTS IN THE ASPECT OF THEIR ACOUSTIC PROPERTIES

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Key words: cellular structure, acoustic emission, cereal products

The objective of the study was to analyse cellular structure of selected cereal products and its effect on acoustic emission generated during their breaking. Analyses were carried out for biscuits "A" and "B" and crackers. The structure of those products was determined by means of an electron scanning microscope FEI QUANTA 200 at 20x magnification, which enabled carrying out analyses in the natural form of products examined without their preliminary preparation. The cakes were subjected to a fracture test with a velocity of 50 mm/min in a testing machine coupled with an accelerometer registering acoustic emission (AE) in a frequency range of 0–15 kHz. Parameters of cellular structure were found to depend on the type of product. The structure of the material affected the acoustic emission generated during its breaking. Materials with smaller air pores generated sounds with a weaker acoustic energy. Large cellular spaces of the products caused a higher share of low-frequency sounds in the acoustic emission.

INTRODUCTION

We live in a society that has a wide choice of food products of various quality. Hence, consumer preferences have become the main criteria in their selection. The quality and acceptance of dried cereal products, due to their hygroscopicity, are determined by the content and manner of water binding. Their tenderness/crispness may be controlled with acoustic methods through measurement of a signal generated in the process of their damage. Acoustic emission of solid bodies is defined as a phenomenon of generation and propagation of an elastic wave as a result of a local, dynamic change in the structure of material. The source of the emission is an area of material or a structural element emitting the AE signal [Malecki & Opilski, 1994]. Registration and special processing of sounds enables analysing the cohesion of the structure examined and the course of its destruction [Luyten *et al.*, 2004]. Sound frequencies that best characterize crispy products fluctuate between 5 and 12.8 kHz and their measured range should reach, at least, the value of 12 kHz [Duizer, 2001]. Dried cereal products have been shown to emit sounds with the frequency ranging from 1 to 15 kHz. The quality of a generated acoustic signal is affected by production technology of material examined and its chemical composition [Marzec *et al.*, 2005]. Of great significance are also moisture content and structure of the material. Finding a relationship between structure of the material and other properties requires its quantitative description. Investigations carried out so far have demonstrated that structure is a typical trait of a given product, but highly labile [Konstankiewicz *et al.*, 2003].

The study was aimed at analysing cell structure of selected cereal products and its effect on acoustic emission generated during their breaking.

MATERIAL AND METHODS

The experimental material were biscuits "A" and "B" and crackers purchased at a local market (Table 1).

The products examined were of equal size, *i.e.* 64x48x4 ± 1 mm. Analyses were carried out directly from packages, at a room temperature. The samples were determined for water activity (a_w) in a Hygroskop DT 2 hygrometer by Rotronic (Table 1).

The structure of all cakes was determined by means of a scanning electron microscope FEI QUANTA 200 at 20x magnification which enabled carrying out analyses in the natural form of the material without its preliminary preparation. Cubicoid samples (5x5x10 mm) were cut out from the material. The microscopic pictures obtained were processed using filters in order to make the air cells convex and sharp. Next, Multi Scan: v13.11 CSS Scan software for Digital Image Analysis was used to determine areas 2x2 mm in size. Then, edges of pores were marked on the determined areas, thus fields were created that corresponded to area size of air cells. Plane sections of the structure enabled obtaining parameters and their distribution linked with cell size, *i.e.* area - A (mm^2), perimeter - L (mm) and Feret's diameters. Calculations were performed for: shape coefficient $\varphi = (4\pi A/L^2)$ and elongation factor as a ratio of Feret's diameters F_{max}/F_{min}. Analyses were carried out for 360 cells of each type of material.

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TABLE 1. Chemical composition of cakes declared by the producers and measured water activity.

Products	Protein (g/100 g)	Carbohydrates (g/100 g)	Fat (g/100 g)	Water activity
Biscuits "A"	8.5	75.3	9	0.16
Biscuits "B"	7.0	77.0	11	0.14
Crackers	7.7	63.5	23	0.20

A testing machine Zwick coupled with piezoelectric accelerometer registering acoustic emission (AE) was used to conduct tests of three-point breaking at a velocity of 50 mm/min. Acoustic emission generated as a result of material destruction was measured with type 4381V accelerometer (Brüel & Kjćr) with a frequency range of 0–15 kHz. The signal of acoustic emission was amplified to 40 dB in a line low-noise amplifier and saved in a PC computer using a sound card for analog-digital processing with sampling frequency of 44.1 kHz. The following descriptors of acoustic emission (AE) were analysed: spectral characteristics, the number of acoustic emission events, sound energy and coefficient of spectral characteristics inclination. Those parameters were determined with the use of appropriate computer software [Ranachowski, 2005].

A statistical analysis and distributions of values examined were carried out in Excel for Windows XP. In order to determine whether values of parameters examined represent the analyzed sample and whether they differ significantly, they were analyzed statistically with the use of an analysis of variance with repetitions at a significance level of $\alpha = 0.05$.

RESULTS AND DISCUSSION

The products examined slightly differed in water activity (Table 1), yet previous investigations demonstrated that in such a narrow a_w range the acoustic properties of cereal products did not change [Marzec *et al.*, 2007].

Acoustic emission of high intensity was registered in low and high frequencies individual for each product (Figure 1). Broken crackers generated sounds in a frequency range of 1–6 kHz and with a very low intensity in the band of 10–13 kHz, whereas biscuits "A" generated sounds between 1–8 kHz and 12–14 kHz, and biscuits "B" in the ranges of 1–7 kHz and 12–14 kHz (Figure 1). An inclination coefficient of spectral characteristics was determined as a quotient of signal energy in high-frequency band to signal energy in low-frequency band typical of individual products [Marzec *et al.*, 2007]. It provides information on the number of sounds emitted in high and low bands. In biscuits "A" and "B" the partition power spectrum slope was close to 1, which indicates that those products emit similar numbers of sounds with low and high frequencies. That coefficient reached the highest value for crackers (Table 2). In their case, emission of sounds with weaker intensity in high frequencies may result from a high content of fat (23%), which is likely to dampen sounds (Table 1). Of significance is also the structure of products (Photo 1). The obtained pictures of cakes differed in the number and size of air pores. Morphology of the products examined is heterogenous, typical of cakes, and results from their chemical composition and baking process. Biscuits "A" were characterised by more compact structure than the other products analysed, as well as by small air pores with thick walls densely packed in the structure. In biscuits "B" and crackers air pores of both large and small

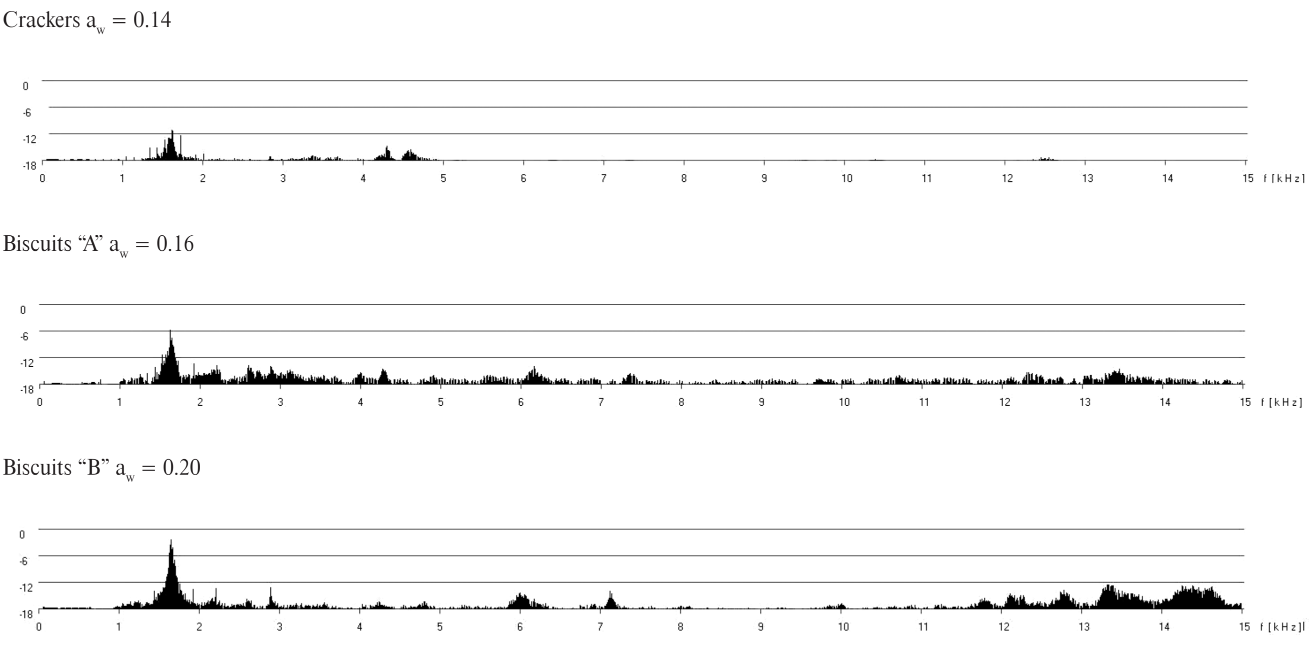
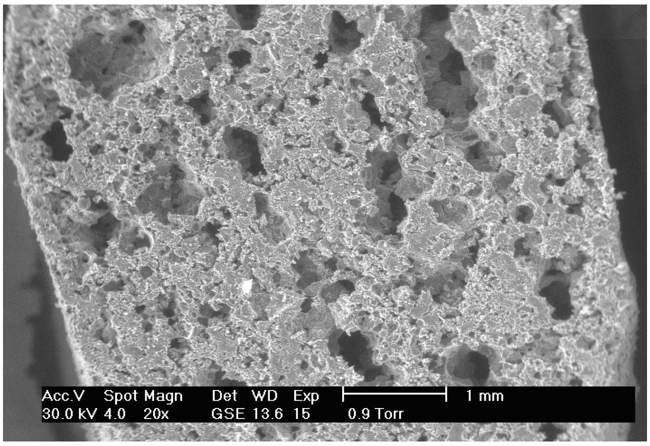


FIGURE 1. AE signal spectral characteristic of the material (x axis – sound frequency (kHz); y axis – sound intensity (dB)).

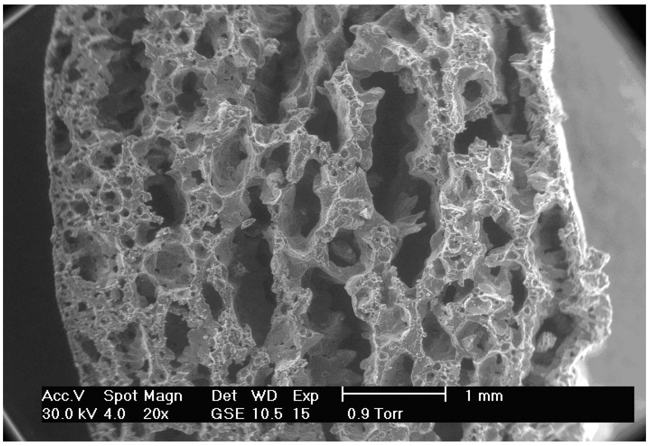
TABLE 2. Mean values of descriptors of acoustic emission of the materials examined.

Material	Partition power spectrum slope	Number of EA events (events no./s)	Acoustic emission signal energy (mV)
Biscuits “A”	0.85 ± 0.31	154 ± 54	117.32 ± 22.57
Biscuits “B”	0.99 ± 0.27	167 ± 78	316.00 ± 87.01
Crackers	0.04 ± 0.02	122 ± 51	202.10 ± 45.51

Biscuits “A” a_w = 0.16



Biscuits “B” a_w = 0.20



Crackers a_w = 0.14

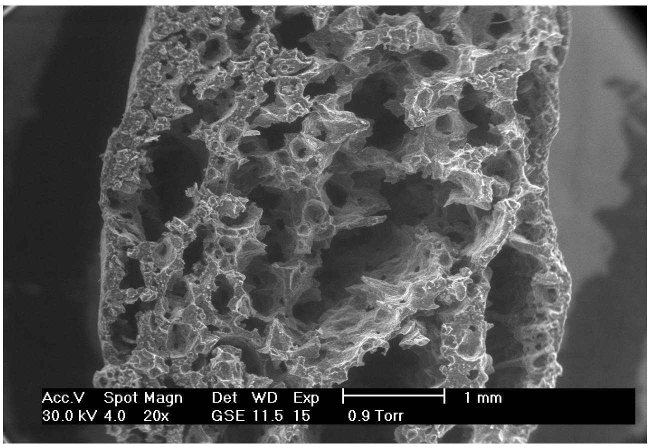


PHOTO 1. Microscopic picture of material structure.

sizes could be observed, they were flattened, in most cases ellipsoidal and with thin walls. Air pores occupied relatively large area and are deep. A structure of “pores in a pore” could be observed as well (Photo 1).

Volume, tone and frequency of sound emitted during deformation depend, among other things, on local characteristics of the material, its chemical composition and size of damaged elements that are subject to cracking [Luyten *et al.*, 2004].

The number of AE events of biscuits “B” was similar to the value reported for biscuits “A”, whereas AE energy was almost threefold higher (Table 2). In the case of crackers, the number of AE events turned out to be the lowest, whereas AE energy was twice as high as that of biscuits “A” (Table 2). The structure of biscuits “B” and crackers is more diversified in terms of the number of small and large air cells, as compared to the structure of biscuits “A” (Photo 1). It suggests that the energy of sound is significantly affected by material’s structure. Structure analysis of the biscuits and crackers examined indicates that the size and shape of pores are influenced by the type of product (Figures 3, 4 and 5), whereas elongation of cells is alike (Figure 6). Thus, further assays were carried out for parameters of cell size, *i.e.* area of their plane section and shape. A detailed analysis of area size distribution shows that the size of 87% of cells of biscuits “A” is 0.04 mm^2. In turn, biscuits “B” and crackers have *ca*. 90% of air pores with section area ranging from 0.04 to 0.12 mm^2 (Figure 2). Figure 3, depicting cumulative curves of the area size of cells on the surface of cakes, clearly shows that pores of biscuits “A” had the smallest area and their maximum size reached 0.60 mm^2,

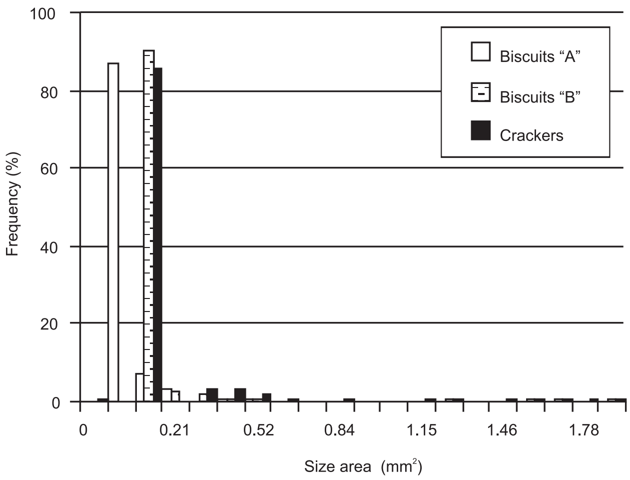


FIGURE 2. Distribution of area size of cells of the material examined.

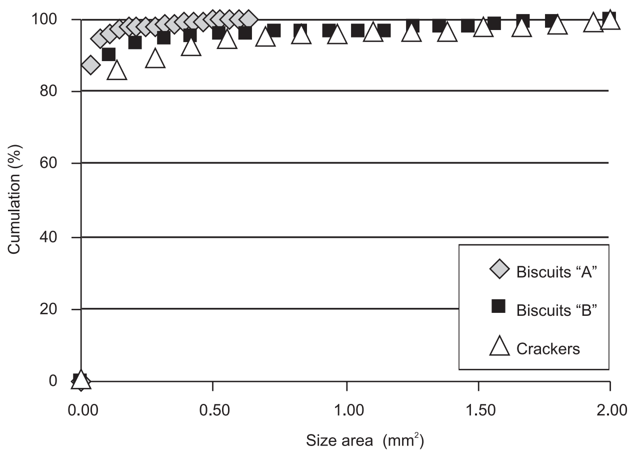


FIGURE 3. Cumulative curves of cell size area of the material examined.

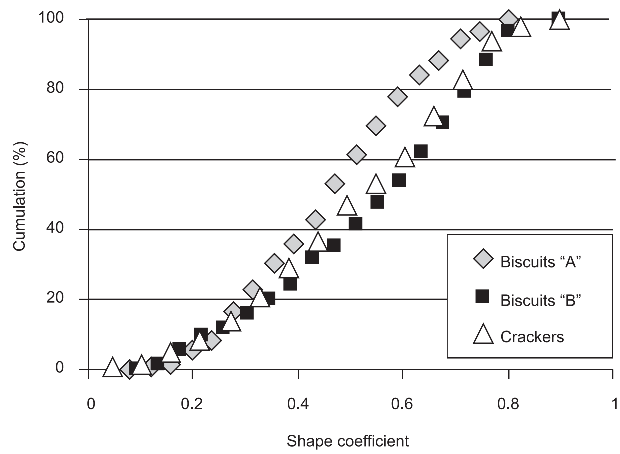


FIGURE 5. Cumulative curves of a shape coefficient of cell of the material examined.

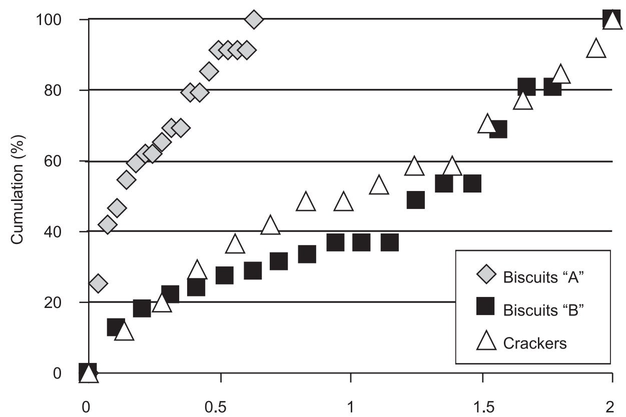


FIGURE 4. Cumulative curves of cell size area contribution in the material examined.

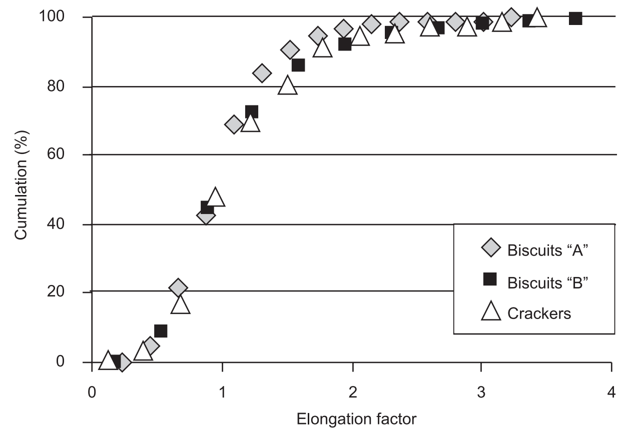


FIGURE 6. Cumulative curves of elongation factor of cells of the material examined.

whereas cells of the other materials were even 2 mm^2 in size. The contribution of cell size in the total section area was different for particular products examined. Although there was a high number of cells with small surface area, it turned out that only biscuits "A" were characterized by a higher contribution (by *ca*. 60%) of pores with surface area accounting for ≤0.20 mm^2 (Figure 4). It was observed that in biscuits "B" and crackers small cells (≤0.20 mm^2) constituted *ca*. 17% of the total surface area, whereas large pores (≥1.50 mm^2) constituted 70% of the surface. Cumulative curves of shape coefficient demonstrate that most of the cells of the analyzed products had a shape similar to elongated elipses, irrespective of the type of material, and that in 70% of biscuits "A" the shape coefficient equals 0.55, whereas in the case of biscuits "B" and crackers it accounts for 0.74 (Figure 5). It proves that damage of small cells evokes generation of sounds with poor acoustic energy. Biscuits "A" were characterised by a higher number of cells with small surface area, thicker walls and lower shape coefficient, which in turn caused a greater number of fragile cracklings, but with remarkably lower acoustic energy. Significantly lower values of AE events with high AE energy were observed for crackers. Such a behaviour results from their structure, *i.e.* from a relatively high number of pores with the greatest surface area (Table 1). Jaworska & Hoffaman [2005] investigated microstructure and carried out a sensory analysis of potato chips. They proved that photos of a sample evaluated in the sensory analysis as the most fragile indicated that it had: high porosity, high number of air pores and that fragments of its structure formed thin, delicate "walls".

CONCLUSIONS

1. Parameters of cell structure depend on the type of material.
2. The structure of products affects the acoustic emission generated during their breaking.
3. Materials with smaller air cells generate sounds with weaker acoustic energy. Large pores of products evoke a greater share of low-frequency sounds in the acoustic emission.

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ANALIZA STRUKTURY WYBRANYCH PRODUKTÓW ZBOŻOWYCH W ASPEKCIE ICH WŁAŚCIWOŚCI AKUSTYCZNYCH

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Celem pracy była analiza struktury komórkowej wybranych produktów zbożowych oraz jej wpływu na emisję akustyczną generowaną podczas ich łamania. Badania przeprowadzono na herbatnikach „A", „B" i krakersach. Określono strukturę ciastek za pomocą elektronowego mikroskopu skaningowego FEI QUANTA 200 przy powiększeniu 20x, który umożliwiał przeprowadzenie badań w stanie naturalnym, bez wstępnej preparacji materiału. Wykonano testy łamania ciastek z prędkością 50mm/min w maszynie wytrzymałościowej połączonej z akcelerometrem rejestrującym emisję akustyczną (EA) w zakresie częstotliwości 0–15 kHz. Parametry struktury komórkowej zależą od rodzaju produktu. Struktura materiału wpływa na emisję akustyczną generowaną podczas jego łamania. Materiały o mniejszych komorach powietrznych generują dźwięki o słabszej energii akustycznej. Duże przestrzenie komórkowe produktów powodują większy udział w emisji akustycznej dźwięków o niskich częstotliwościach.