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INFLUENCE OF WATER ACTIVITY ON TEXTURE OF CORN FLAKES*

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A b s t r a c t. Commercial corn flakes were equilibrated to different water activities and subjected to mechanical deformation. Breaking of corn flakes was done in a plastic tube in which flakes were piled one over another. Sounds emitted during breaking were detected by a piezoelectric accelerometer and recorded after amplification. Deformation curves were jagged and very irregular, and their course depended on the water activity of the material. Crispness of corn flakes was independent from water activity at a_w<0.3. At higher water activities crispness decreased fast and at a_w>0.639 that property was lost completely. An antiplasticizing effect of water on corn flakes was observed in the water activity range from 0.516 to 0.639. Acoustic activity of breaking corn flakes was also dependent on water activity. The energy of acoustic signal decreased at a_w>0.516. However, the number of acoustic events decreased abruptly in water activity range from 0.2 to 0.3. Crunchiness index was introduced, combining both mechanical and acoustic measures of crispness of the material. In the range of water activity from 0.3 to 0.5 the crunchiness index for corn flakes was constant. At lower water activities it decreased with increasing wetness of the material, but at higher water activities it was close to zero.

K e y w o r d s : breaking force, crispness index, acoustic emission, acoustic energy

INTRODUCTION

Texture is an important quality attribute for consumers as well as for producers. It affects eating habits, since the force which can be exerted by jaws and teeth is limited. Generally, tough products are not accepted. Texture is a property of sensory and psychophysical nature, and it depends on the chemical composition, structure

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and rheological properties of the material (Surówka 2002). Texture is a property created by many parameters and detected by human senses such as touch, eyesight and hearing, hence it is natural to analyse it by sensory tests. However, sensory tests are burdened with many deficiencies which are not encountered in instrumental methods. Instrumental methods overpass sensory tests by short time, lower cost and better reproducibility, and they are independent of the psycho-physiological condition of panellists (Surówka 2002).

Mechanical tests rely on deformation of the tested material with prescribed force and velocity. Changes exerted on the material by those variables are recorded and analysed. Interpretation of the relationship between force and deformation is difficult because of the complexity of the product morphology. Moreover, a sensory property can be differently described by panellists, as for example ,,crunchy" or ,,crispy" considering the same product (Peleg 1994).

Texture can be also assayed by acoustic emission, by analysing acoustic signals emitted during material deformation or biting (Marzec *et al.* 2005). The sound generated during biting of food is characteristic for crispy products. Hence, the aim of this work is to analyse the texture of corn flakes using instrumental methods, and to identify the relationship between the mechanical and acoustic properties of the product.

MATERIAL AND METHODS

Corn flakes were equilibrated to different water activities using desiccators with sulphuric acid and saturated salt solutions in the relative humidity range from 0 to 75% at 25^{o}C. Water activity of corn flakes was measured with Hygroscope DT 2 (Rotronic AG).

Corn flakes piled up one over another in a plastic tube with diameter of 20 mm (Fig. 1) were deformed by a ball type device with velocity of 1 mm s^{-1} in texture meter TA-XT2i (Stable Micro Systems).

The weight of corn flakes subjected to deformation was from 2 to 3 grams. Force and acoustic emission was recorded during the deformation test. Acoustic emission was detected by a contact method using piezoelectric accelerometer type 4381 (Brüel& Kjær). Acoustic signal was amplified by

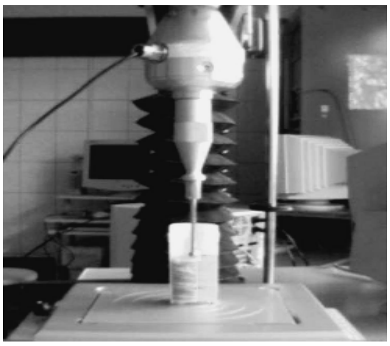


Fig. 1. Experimental stand for measurement of texture properties of corn flakes

40 dB and analysed in the frequency range from 0.01 Hz to 15 kHz. Acoustic signal recording was done for 10 seconds, but only 7 seconds was analysed. Breaking tests were repeated 10 times.

The crispness of the material was defined as the force of the first distinct break on the deformation curve of corn flakes. The hardness was described by the maximum force on the deformation curve (Fig. 2). The work of deformation was calculated as the area under the deformation curve (Marzec *et al.* 2005) taking 7 seconds as the time of crushing of corn flakes. The number of acoustic events was calculated using software developed by Ranachowski *et al.* (2005). The crispness index was calculated as the ratio of the number of acoustic events and the work of deformation (Marzec *et al.* 2005).

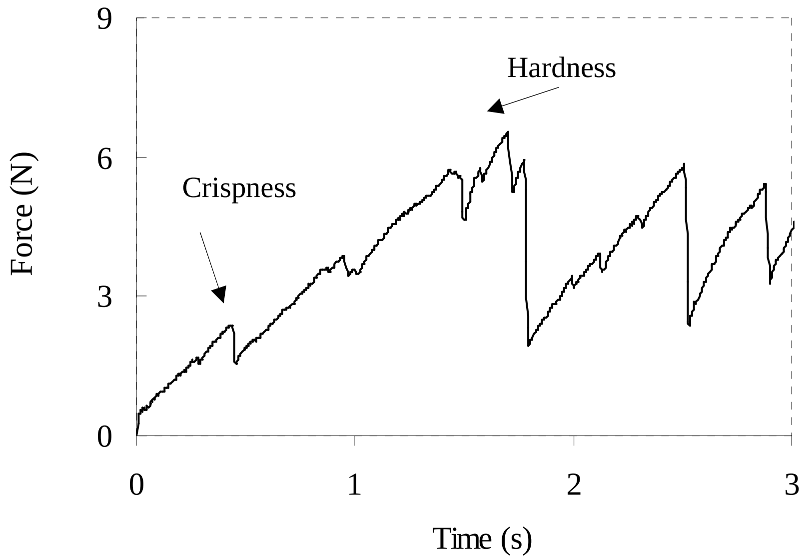


Fig. 2. Deformation curve of corn flakes at a_w = 0.21

RESULTS

Mechanical properties

Corn flakes, because of shape differences, surface irregularities and internal structure variability, are a very heterogeneous material for investigation. The flakes responded very individually to the applied force and broke continuously with increasing force. Hence, the deformation curve was jugged and very irregular. Moreover, each measurement for the same water activity yielded a different curve, and 10 repetitions resulted in 10 different jugged curves (Fig. 3). This illustrated very clearly the heterogeneity of the material under investigation.

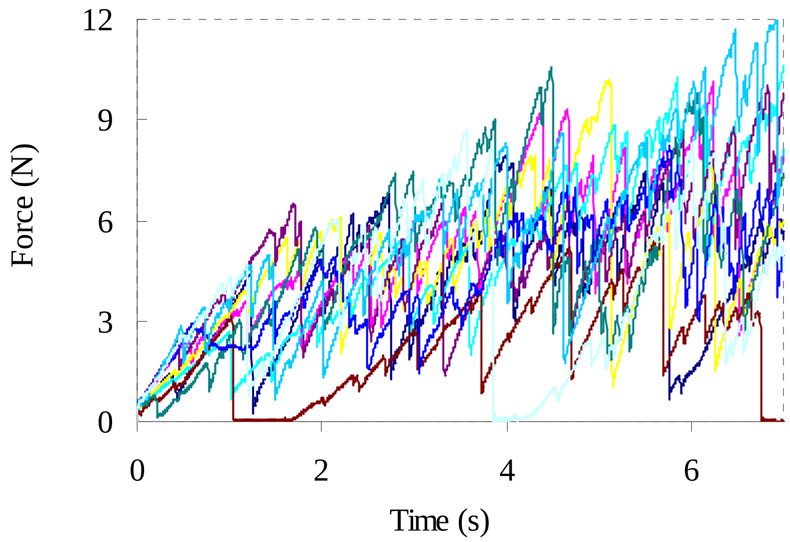


Fig. 3. Deformation curves for 10 samples of corn flakes a_w = 0.21

The crispness of corn flakes was dependent on water activity present in the material (Fig. 4). At water activities lower than 0.3, crispness was not affected by the wetness of the material. The average force of the first distinct break on the deformation curve was 4.93±0.57N. At water activities higher than 0.3, a decrease of the force was observed, and at a_w = 0.516 the crispness was equal to 3.00±0.18N. Further decrease of crispness was fast and at a_w>0.639 the deformation curves became smooth and no break preceding the maximum force was observed. Hence, there was no crispness detected as such according to the accepted definition. Crispness of cereal based products was investigated by Peleg (1994) who showed that 90% of that property was lost within a narrow water activity range from a_w = 0.47 to a_w = 0.65.

The hardness of corn flakes, which was twice as high as crispness, was not affected by water activity in the range from a_w = 0.015 to a_w = 0.516 and was equal to 11.00±0.59 (Fig. 5). Increase of water activity to 0.639 increased hardness substantially, and the average maximum force at that water activity was 47.57±9.20N. The increase of deformation force was probably caused by antiplasticizing effect of water. Further increase of material wetness caused its plasticization and decrease of deformation force.

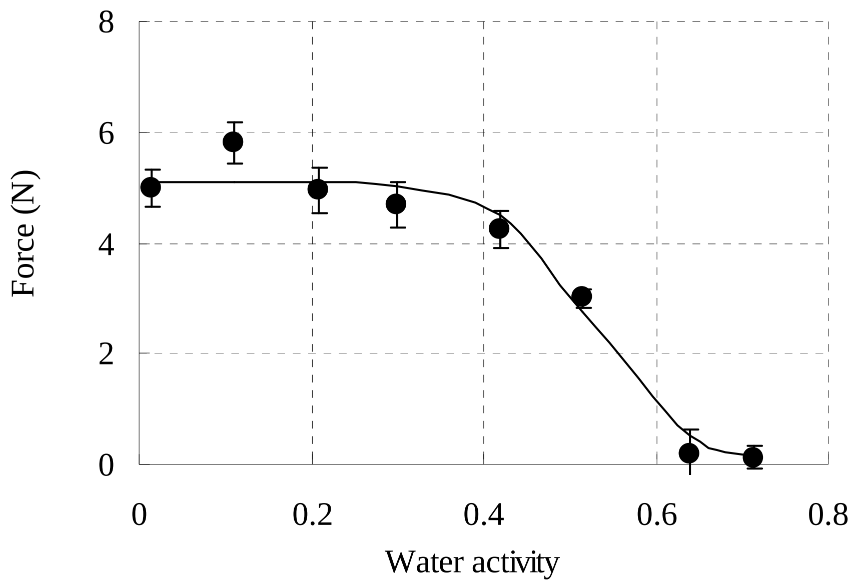


Fig. 4. Relationship between water activity and crispness of corn flakes

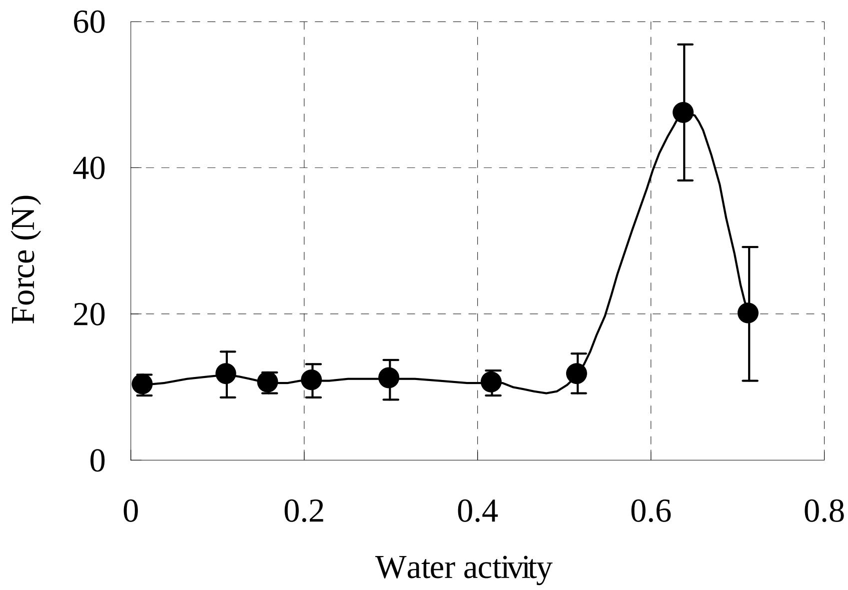


Fig. 5. Influence of water activity on hardness of corn flakes

Mechanical measurements made on corn flakes showed that the resistance of the investigated material was strongly influenced by water activity. Sorption of water by cereal-based flakes determines their mechanical properties. The structure of the material is either stiffened or plasticized due to interactions of water with the protein-starch matrix.

Influence of water on the texture of cereal-based products is documented in literature (Lewicki *et al.* 2003, Li *et al.* 1998, Marzec and Lewicki 2006, Wollny and Peleg 1994). The stiffening effect of water on the texture of crisp bread (crispness and hardness) was demonstrated by Marzec and Lewicki (2006). The loss of crispness is attributed to sorption of water and to phase change of carbohydrates from amorphous to crystalline state. Li *et al.* (1998) investigated the influence of water on the mechanical properties of cakes based on corn flour. It was shown that cakes were crisp at water activities lower than 0.4. Increase of water activity above 0.5 caused progressive loss of crispness.

Acoustic properties

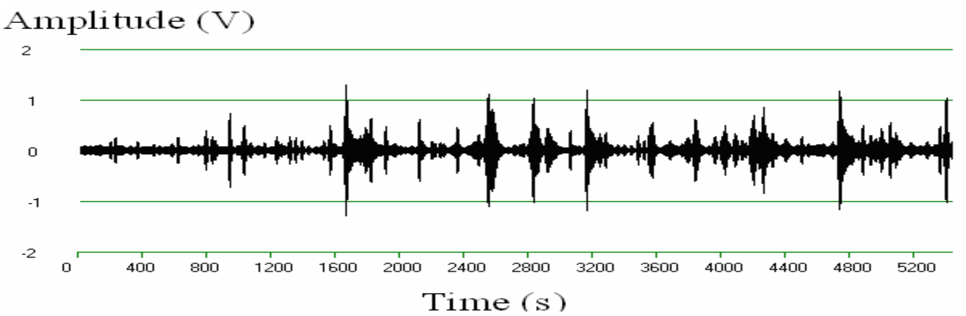
Amplitude-time characteristics of corn flakes showed that acoustic activity of the investigated material was affected by water activity (Fig. 6). There was no statistical difference in the energy of acoustic signal in the water activity range from $a_w = 0.015$ to $a_w = 0.516$. The energy of acoustic signal decreased at water activities higher than 0.516, and at water activity of 0.713 it was close to zero.

Acoustic wave is generated in a material during its deformation. It is affected by the size and distribution of air cells, cell wall thickness, structure defects and impurities (Alchakra *et al.* 1997). Frequency of generated waves is dependent on the size, shape and kind of deformed material (Wavers 1997) and is always affected by the way the material breaks and behalves under the applied stress.

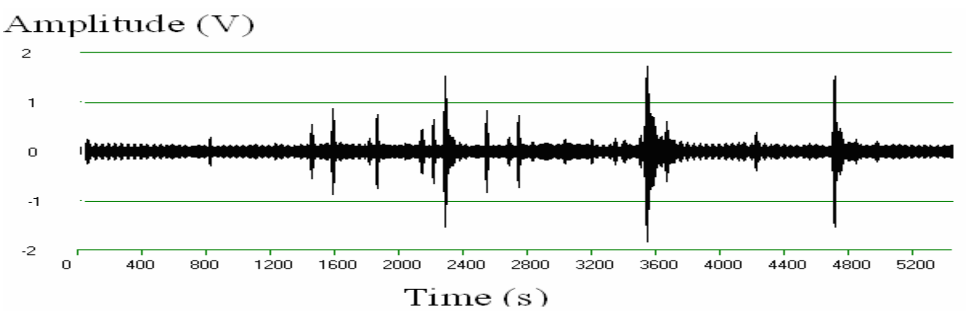
Frequency-time records are easily interpreted in the form of acoustograms. Acoustograms represent, in a graphical form, changes of the acoustic intensity of the material in relation to the frequency and time of deformation (Marzec *et al.* 2005). Acoustograms presented in Figure 7 show that the acoustic activity of corn flakes was dependent on water activity of the material. This observation is supporting previously discussed relationship between amplitude-time records and water activity.

Analysis of the acoustograms showed that corn flakes emitted sound in two frequency ranges. One range was at frequencies from 6 to 9 kHz and the second range was from 12.5 to 15 kHz. At water activities from $a_w = 0.015$ to $a_w = 0.516$ corn flakes emitted sound in both frequency ranges during the entire time of deformation. The intensity of emitted sound was a little lower at $a_w = 0.516$ than that recorded at $a_w = 0.015$. The difference was especially evident at the final stages of deformation, when most flakes were already broken and debris was filling

$a_w = 0.015$



$a_w = 0.516$



a_w=0.639

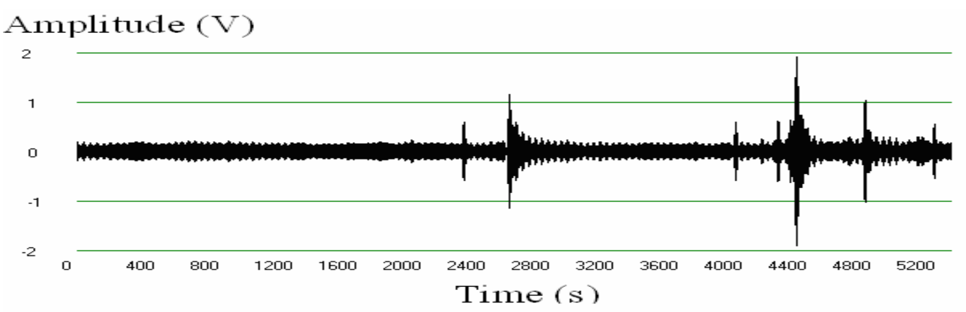


Fig. 6. Influence of water activity on amplitude-time characteristics of sounds emitted during deformation of corn flakes

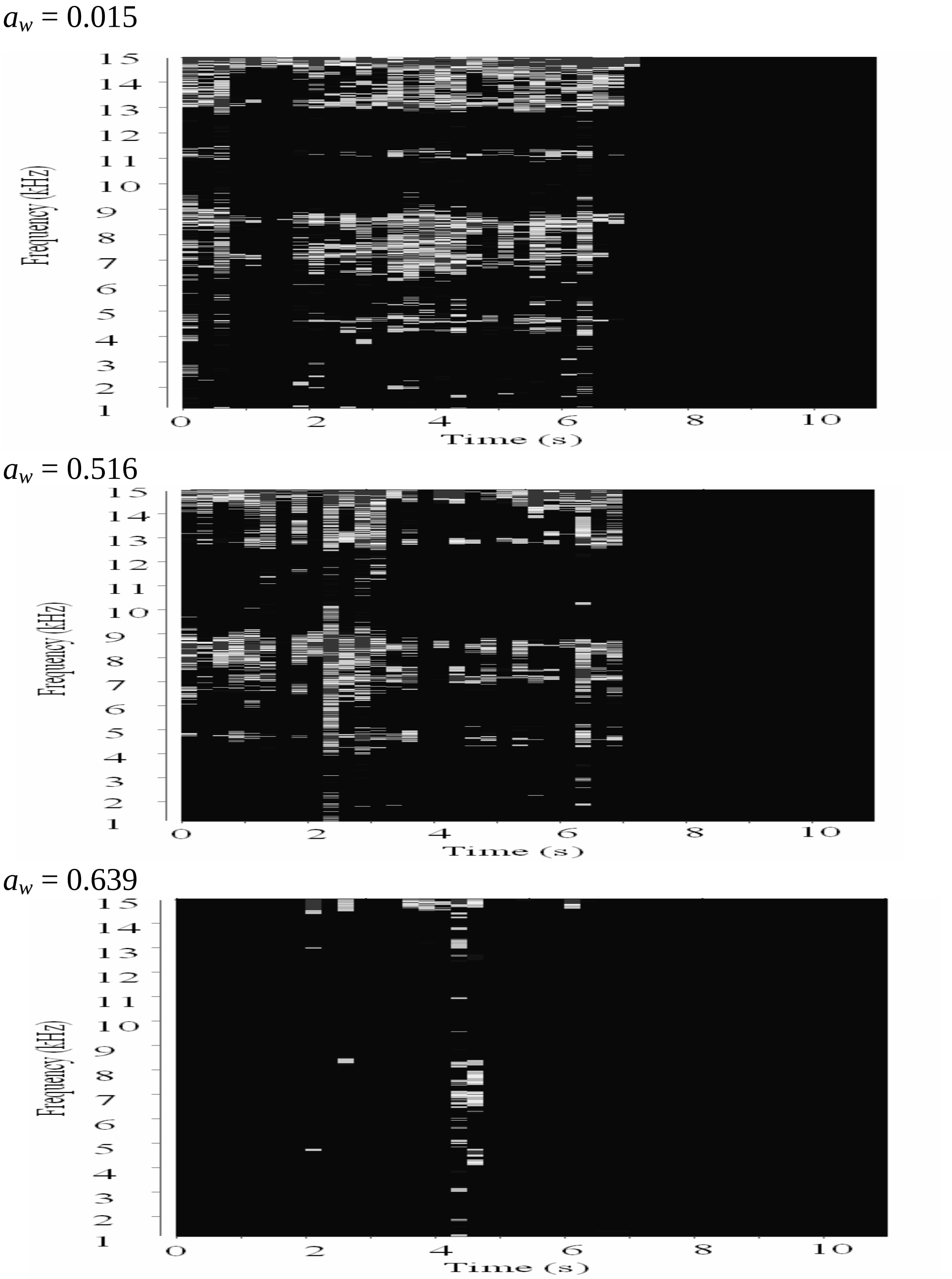


Fig. 7. Influence of water activity on acoustograms of corn flakes

empty spaces and undergoing compaction. At $a_w = 0.639$ a weak sound was still emitted at both frequency ranges, but corn flakes were silent for most of the deformation time. Most of the acoustic emission occurred between the 4th and 5th second of deformation. The acoustograms presented in Figure 7 show that the frequency ranges at which the sound was emitted were not dependent on water activity of corn flakes. However, the intensity of the emitted sound was affected by water activity in a specific fashion.

Analysis of amplitude-time records shows that they are composed of short dominant impulses with a similar amplitude and 100 μs duration. These impulses, following in quick succession, create a characteristic sound perceived by the consumer as crunchiness. The impulses were called acoustic emission events, and their analysis gave information about the number and maximum energy distribution within each event (Ranachowski *et al.* 2005).

In investigated corn flakes the number of acoustic events and intensity of emitted sound decreased with increase of water activity (Fig. 8).

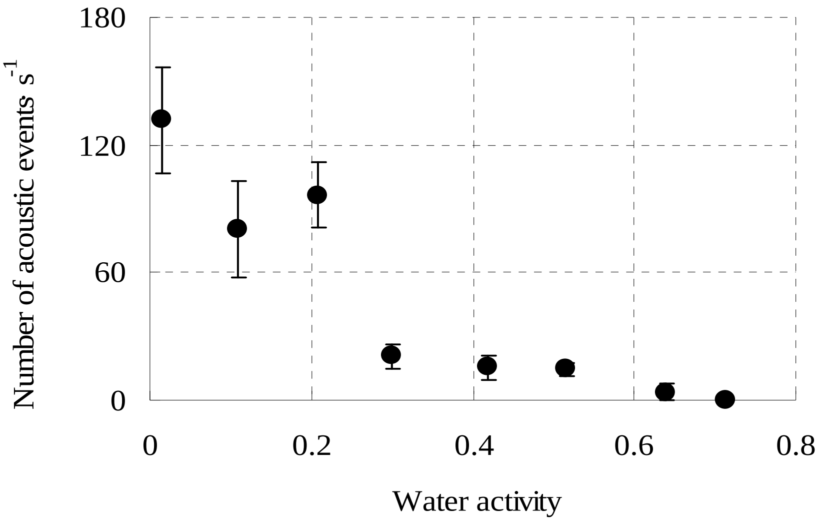


Fig. 8. Relationship between water activity and number of acoustic events generated during deformation of corn flakes

It is characteristic for corn flakes that the number of acoustic events changes abruptly in water activity range from 0.2 to 0.3. At low water activities, the number of acoustic events per second was between 80 and 130, but at water activity higher than 0.3 it was about 20 and gradually decreased to 0 with increasing wetness of the material. Lewicki *et al.* (2003) showed that the decrease of sound intensity in breakfast cereals, accompanying increase of water activity, is caused by variable distribution of stresses in dry and moistened materials. Sorption of water causes dissipation of elastic energy and reduces the possibility of brittle breaks (Poliszko *et al.* 1995). The number of acoustic events in biscuits was assayed by Chen *et al*. (2005) and was related to the crunchiness of the investigated material. The sound emitted by biscuits was detected by a microphone, amplified, and then analysed by an Acoustic Detector AED which, depending on the sound intensity, counted acoustic events of 250 ms duration. In this system of analysis, the time of acoustic event duration could be adjusted to the needs. Hence, products with different levels of crunchiness could be analysed. Chen *et al*. (2005) showed that analysis of the number of acoustic events was a sensitive method for the measurement of biscuits crunchiness.

Since sound is emitted during disintegration of the material, the crunchiness index was introduced as the ratio of the number of acoustic events to the work of deformation. The crunchiness index decreased fast with increasing water activity in the range of a_w 0.015-0.299 (Fig. 9). The decrease was about 100 crunchiness index units per unit of water activity. Then, in the range of a_w 0.299-0.516, the crunchiness index was constant at 4.35±0.53. At higher water activities, the crunchiness index was close to zero. The crunchiness index was calculated also for flat crispbread and crackers (Marzec *et al.* 2005, Marzec *et al.* 2006). It was shown that the crunchiness index was a good measure of water activity range at which a material was considered as crunchy. Moreover, it was shown that the crunchiness index was well correlated with sensory assessment of investigated material (Gondek and Marzec 2006).

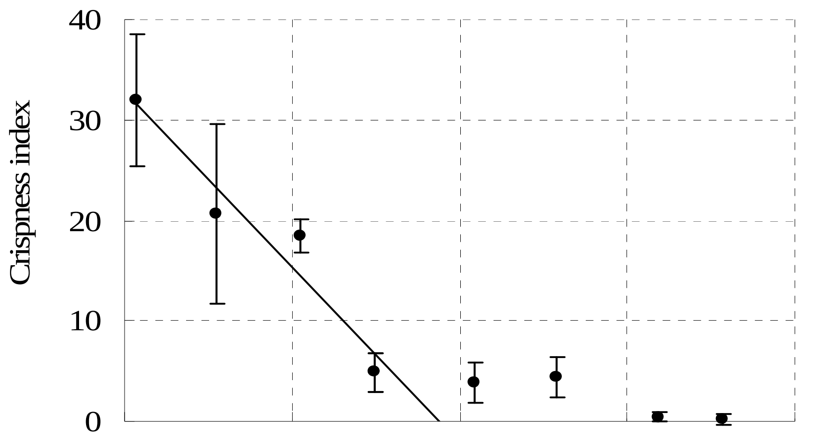


Fig. 9. Relationship between water activity and crispness index of corn flackes

CONCLUSIONS

1. Water activity substantially influences texture of corn flakes. Crunchiness and toughness measured mechanically were not affected by water activity up to 0.5. Further increase of water activity caused increased toughness, and above $a_w = 0.63$ a pronounced effect of plasticization was observed.

2. Analysis of sound emitted during corn flakes disintegration yielded different information about the crunchiness of the investigated material. Frequencies at which the sound was emitted were not dependent on water activity. The sound was emitted at two frequency ranges: 4-9 and 12-15 kHz. However, the intensity of emitted sound was very much influenced by water activity. Acoustic events of 100 μs duration abruptly changed between water activities of 02-0.3. A similar relationship between the crunchiness index and water activity was observed. Hence, acoustic measurements showed that sorbed water caused redistribution and relaxation of elastic stresses in the material, and those events were detected by sound analysis much faster in comparison with the mechanical measurements. It can be stated that analysis of sound emitted during food material disintegration is much more sensitive to changes caused in material structure by water sorption than analysis of mechanical tests.

REFERENCES

Alchakra W., Allaf K., Ville J., M., 1997. Acoustical emission technique applied to the characterisation of brittle materials. Applied Acoustics, 1, 53-69.

Chen J., Karllsson, Povey M. 2005. Acoustic envelope detector for crispness assessment of biscuits. Journal of Texture Studies., 2, 139-156.

Gondek E., Marzec A., 2006. Influence of water activity on sensory assessment of texture and general quality of crackers (in Polish). Inżynieria Rolnicza, 7(82), 181-187.

Lewicki P.P., Gondek E., Ranachowski Z., 2003. Influence of water activity on acoustic emission of breakfast cereals. Proceedings of the AMAS Course on Nondestructive Testing of Materials and Structures II. (eds. J. Deputat, Z. Ranachowski) Centre of Excellence for Advanced Materials and Structure, Warsaw, 93-109.

Li Y., Kloeppel K.M., Hsieh F. 1998. Texture of glassy corn cakes as a function of moisture content. Journal of Food Sci., 5, 869-871,

Marzec A., Borowiec M., Lewicki P.P. 2005. Crisp bread texture evaluation with application of acoustical method (in Polish). Żywność, Nauka, Technologia, Jakość, Kraków, Supl., 4(45), 75-84.

Marzec A., Lewicki P.P., 2006. Antiplasticization of cereal-based products by water. Part I. Extruded flat bread. J. Food Eng., 73. 1-8.

Marzec A., Lewicki P.P., Jakubczyk E., 2006. Quality of crackers assayed by acoustic measurements (in Polish). Żywność, Nauka, Technologia, Jakość, Kraków, (po recenzji).

Peleg M., 1994. A mathematical model of crunchiness crispness loss in breakfast cereals. J. Texture Studies., 25. 403-410.

Poliszko S., Klimek D., Moliński W., 1995. Acoustic emission activity of rehydrated corn extrudates. Properties of Water in Foods. (ed. Lewicki P.P.) Warsaw Agricultural University Press. 25-30.
Ranachowski Z., Gondek E., Lewicki P.P., Marzec A., 2005. Investigation of acoustic properties of compressed wheat bran flakes. Archives of Acoustic, 2, 255-265.
Surówka K. 2002. Food texture and methods of its study (in Polish). Przemysł Spożywczy, 10, 12-17.
Wavers M. 1997. Listening to the sound of materials acoustic emission for the analysis of material behaviour. NDT & International, 2, 99-106.
Wollny M., Peleg M. 1994. A model of moisture-induced plasticization of crunchy snack based on Fermi`s distribution function. J. Sci. Food and Agric., 64, 467-473.

WPŁYW AKTYWNOŚCI WODY NA WŁAŚCIWOŚCI TEKSTURALNE PŁATKÓW KUKURYDZIANYCH

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S t r e s z c z e n i e . Handlowe płatki kukurydziane były doprowadzone do różnych aktywności wody i poddane mechanicznemu niszczeniu. Płatki ułożone w kolumnę w plastikowej tubie były łamane za pomocą kulistego próbnika. Emisję akustyczną powstałą w wyniku niszczenia próbek rejestrowano za pomocą akcelerometru piezoelektrycznego i wzmacniano o 40 dB. Krzywe łamania były nieregularne i postrzępione, a ich przebieg zależał od aktywności wody materiału. Chrupkość płatków była niezależna od aktywności wody przy a_w<0,3. Przy wyższych aktywnościach wody chrupkość szybko malała i przy a_w>0,639 właściwość ta kompletnie zniknęła. Antyplastyfikujący wpływ wody był obserwowany w badanych płatkach w zakresie aktywności wody od 0,516 do 0,639. Aktywność akustyczna łamanych płatków również zależała od aktywności wody. Energia sygnału akustycznego obniżyła się przy a_w>0,516. Jednak liczba zdarzeń akustycznych uległa gwałtownemu obniżeniu w zakresie aktywności wody od 0,2 do 0,3. Wprowadzono współczynnik chrupkości łączący w sobie właściwości mechaniczne i akustyczne łamanego materiału. W zakresie aktywności wody od 0,3 do 0,5 współczynnik chrupkości płatków kukurydzianych był stały. Przy niższych aktywnościach wody ulegał on obniżeniu wraz ze zwiększającą się wilgotnością materiału. Natomiast przy wyższych aktywnościach wody był bliski zeru.

S ł o w a k l u c z o w e : płatki kukurydziane, aktywność wody, emisja akustyczna, współczynnik chrupkości, mechaniczne właściwości