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EFFECT OF WATER ACTIVITY ON MECHANICAL PROPERTIES OF DRY CEREAL PRODUCTS*

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A b s t r a c t. The aim of this work was to determine the effect of water activity on the mechanical properties of cracker and corn-rye bread. Bread and cracker were stored at water activities in the range of 0-0.8. The mechanical properties were measured by three-point loading bending test. Water activity significantly influences mechanical properties of cellular snacks. At low water activities product is crisp and brittle. The highest values of ultimate stress and deformability modulus were determined for crackers at $a_w = 0.306$ and for corn-rye bread at $a_w = 0.538$. Increase of water activity above these values caused softening and flowability of snacks.

K e y w o r d s: crackers, crunchy bread, rheology, water activity

INTRODUCTION

Many cereal snack foods are cellular, brittle and crisp, and these textural characteristics contribute to the high popularity of these products. Texture is an important sensory attribute for many cereal-based foods.

The crispness is associated with pleasing textural contact and with freshness and quality, its loss is a major cause of consumer rejection. Most low moisture baked and extruded products, such as breakfast cereals, wafers, biscuits and snacks, have a crispy texture. If the moisture of these products increases, due to

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water sorption from the atmosphere or by mass transport from neighboring components, it results in a soggy, soft texture [10].

Water is a constituent of food which affects food stability, quality and physical properties. Water activity – a_w [15] - a parameter representing the 'water availability' in material, is defined as the ratio of vapour partial pressure of water in food to the vapour partial pressure of pure water at the same temperature and total pressure. Water influences the rheological properties of food in liquid and solid state alike. In solid foods, water affects their response to force. Increasing water content can lead to plasticizing or antiplasticizing effects [7]. The plasticization of polymer chains facilitates deformation, and brittle material becomes more soft and flowable and losses crispness. The antiplasticizing effect is not well understood until now.

Katz and Labuza [4] have described the texture of snack foods such as crackers and chips as a function of water activity. They determined that baked saltine crackers, popcorn, and fried potato chips lost crispness when water activity exceeded 0.35 to 0.50 depending on the product. A slight decrease in crispness of breakfast cereal occurred at $a_w < 0.5$. Thereafter, a rapid decrease of crispness was observed until $a_w = 0.8$, at which the product lost its brittleness completely [14]. Force-deformation curves for an uniaxial compression test were recorded for crackers at various water activity values (a_w = 0.14-0.80) [6]. The curves became smoother and the maximum force decreased with the increase in water activity.

Roudaut *et al*. [12] studied texture properties of crispy bread as a function of water content using the compression test. They observed plasticizing effects of water between 3 and 9%; then, up to 11%, there was an apparent hardening of the material. Beyond 11% of water content, the apparent stiffness modules decreased and softening effect of water became dominant. In some cases, the antiplasticizing effect is observed. Adsorbed water adds some strength to the material and reduces its brittleness. Marzec [8] reported that failure stress of flat wheat and rye bread increased as moisture was adsorbed and reached the peak at an a_w range between 0.5 and 0.6. Baked and extruded cereal products are generally in the glassy state since cooking is accompanied by the disappearance of most crystalline structures of native starch. Cereal products stored above their glass transition temperature undergo changes which are manifested, among others, by alternations of mechanical properties. Cellular products may densify and their mechanical strength can increase [13].

Brittle and crunchy foods are known to have very irregular and irreproducible force-deformation relationships [11]. This seems to be due to the non-uniformity in internal structure and surface characteristics of this type of cellular materials. Kim and Okos [5] investigated the mechanical properties of crackers using a 3-point loading beam bending technique. The coefficient of variance in that measurement of mechanical parameters was found between 12.8% and 47.8%.

This is not particular for cookies and crackers since Gormley [2] also reported 24-39% variation of the fracture force measured for five brands of cream crackers. For Dutch crispbakes, Mohamed *et al.*, [9] found the coefficients of variation being 16.8%, 48.4% and 53.7% for the breaking force, fracture rate and the ratio of fracture work to the total work, respectively.

The aim of this work was to determine the effect of water activity on the mechanical properties of cereal-based snacks.

MATERIAL AND METHODS

Crackers with a water activity a_w = 0.413 and corn-rye crisp bread (a_w = 0.281) were materials purchased in a local market. The snacks were parallelepipeds: cracker with 63 x 48 mm base and 5 mm thickness, crisp bread with 120 x 54 mm base and 8 mm thickness. Samples were equilibrated over saturated salt solutions to water activity in the range from 0.01 to 0.80 at 22°C. Water activity was measured with the use of Hygroskop DT (Rotronic) with an accuracy of ±0.001

The mechanical properties were measured by three-point loading bending test. Samples were placed on two supporting parallel bars situated 40 mm (crackers) or 52 mm (crisp bread) apart. A loading bar connected with the crosshead of Zwick Machine 1445 (ZWICK GmbH) was used to deform samples to the moment of their breaking. The bending test for crackers was done with a loading bar velocity of 60 mm min^{-1} and for crisp bread – 20 mm min^{-1}. The measurements were repeated 7 times. Force versus time deformation curves were recorded, analyzed, and some mechanical indices were calculated:

The ultimate stress σ_f was calculated as follows:

$$\sigma_f = \frac{3FL}{2bt^2} \tag{1}$$

where: L – distance between the supports (m), F – force (N), b – width of the sample (m), t – thickness of the sample (m).

The deformability modulus E_B was calculated as follows:

$$E_B = \left(\frac{dF}{dt}\right) \cdot \left(\frac{L^3}{4vbt^3}\right) \tag{2}$$

where: dF/dt – initial slope of the compression curve (straight part of the force–time curve), v – velocity of loading bar (m s^{-1}).

The work of bending was calculated as the area under the force–time bending curve multiplied by crosshead velocity m s^{-1}.

RESULTS AND DISCUSSION

The effects of water activity on the mechanical properties of cracker and corn-rye bread are demonstrated in Figures 1a, 1b, and 2a, 2b. The figures show the force versus time for different water activity values in the range of a_w 0-0.8. The low water activity results in jaggedness of the force-time curves. It is strongly evident for crackers at water activity in the range of 0.011 to 0.306 (Fig. 1a) and for corn-rye bread at an a_w range 0.283-0.458 (Fig. 2a).

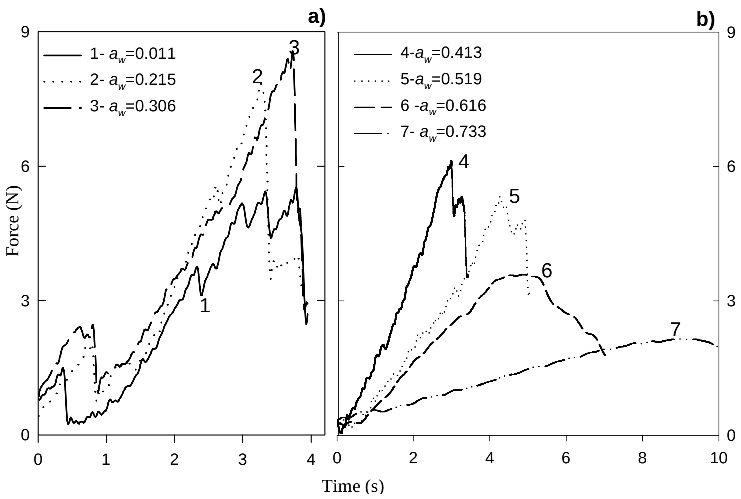

Fig. 1. Effect of water activity on bending curves of crackers

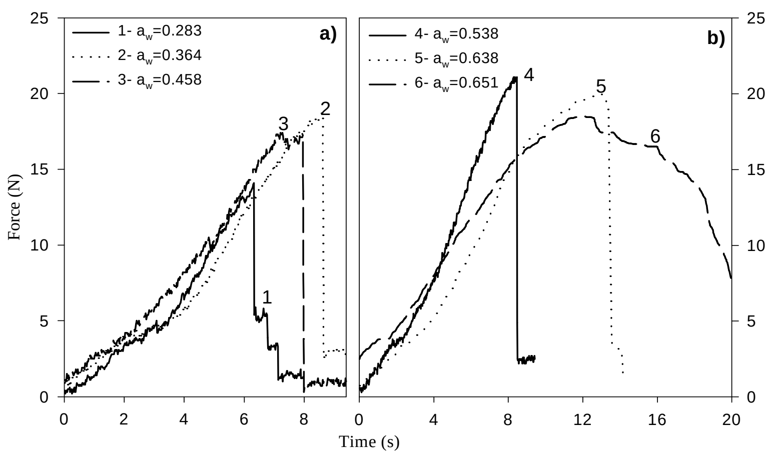

Fig. 2. Effect of water activity on bending curves of corn-rye bread

The first breaking peak occurred after 0.4, 0.8 and 0.6 s of the bending test at water activities of 0.011, 0.215, and 0.306, respectively. The first breaking peak for the bread is far less evident than that observed during the bending test of crackers. Further increase in water activity of cracker and bread leads to smoothing of the force-time relationship, and the breaking peak is not observed at the early stages of the test. At high water activity for corn-rye bread at $a_w > 0.651$ and for cracker at $a_w > 0.519$ the breaking is not longer observed. Samples flow under the applied force.

The appearance of the first breaking peak at the beginning of the test after 0.4-0.8 s and the characteristic jaggedness of the force-time curves indicate that at low water activities snacks behave as crisp, brittle materials. The increase in water activity results in smoothing of deformation curves, which indicates that less micro-breaking events occur. Hence, it can be inferred that water plasticizes air cell walls in cellular materials.

The average and standard deviation values for ultimate stress at different water activities is presented on Figure 3 and 4 for cracker and corn-rye bread, respectively. The ultimate stress generally describes the fracture strength of products. The ultimate stress of cracker and corn-rye bread is related to water activity. The increase of water activity of cracker from 0.011 to 0.306 yielded an increase of ultimate stress by more than 32%. A similar increase in ultimate stress is observed for corn-rye bread but in the range of water activity from 0.283 to 0.538.

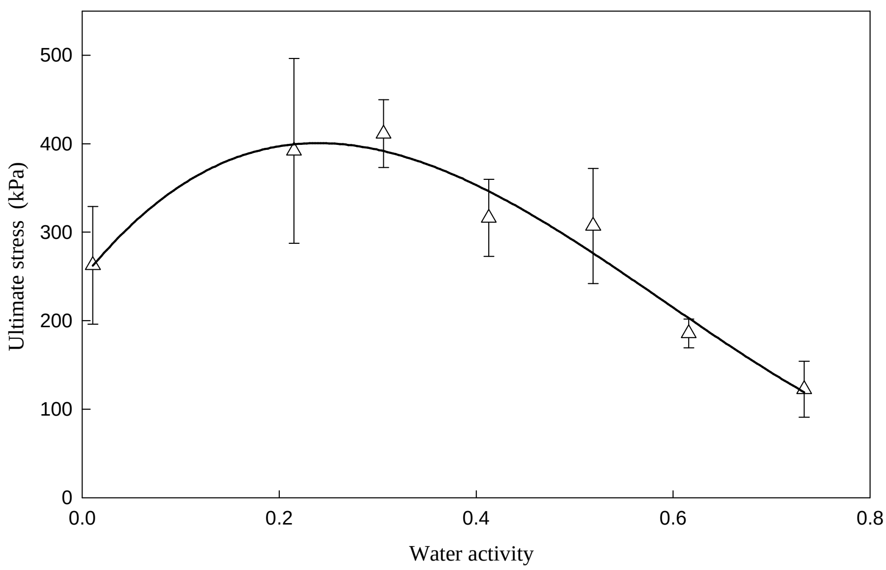

Fig. 3. Effect of water activity on ultimate stress of crackers

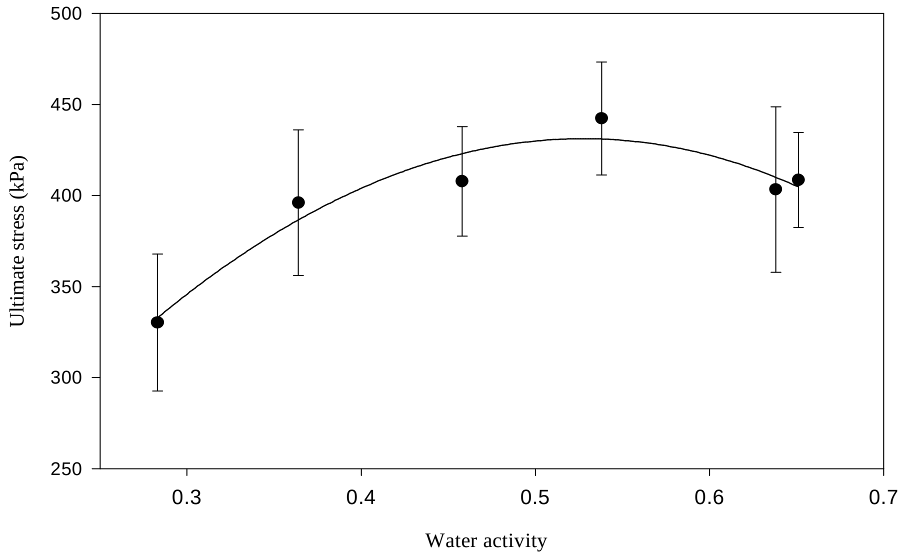

Fig. 4. Effect of water activity on ultimate stress of corn-rye bread

The fracture strength is the highest at water activity 0.306 for crackers and for corn-rye bread at $a_w = 0.503$. The increase of water activity to 0.733 for crackers decreases ultimate stress over 3 times. The ultimate stress of corn-rye bread decreased by some 12% (which is within the experimental error) caused by an increase of a_w from 0.538 to 0.651.

Numerous authors studying different types of crisp foods found that as the water activity increases the crispness decreases with simultaneous hardening of the material. Harris and Peleg [3], Duizer and Campanella [1] defined hardness as the force required to bite the sample. The ultimate stress measured in this work characterizes the strength fracture which can be taken as the measure of hardness. The increase of water activity to 0.306 for crackers and to 0.458 for corn-rye bread was accompanied by an increase of ultimate stress. Adsorption of water added some strength to the investigated materials, and reduced their brittleness.

The increase in strength as the water activity increases was explained by Harris and Peleg [3] as a result of partial plasticiziation of air cell wall material which increases the cohesion and hence the toughness of a product structure. At very low water activity, the structure of cellular products collapses rapidly and its destroyed elements offer no resistance to deformation. On the other hand, partial plasticization is accompanied by toughening because moistened structure does not disintegrate so easily.

The effect of water activity on the deformability modulus of crackers is similar to that obtained for the ultimate stress (Fig. 5). The effect of water activity on the deformability modulus of corn-rye bread is presented in Figure 6 and is similar to that for ultimate stress. Differences in the deformability modulus of corn-rye bread observed in the range of water activity from 0.283 to 0.538 are statistically insignificant. Moreover, as the water activity increased from 0.538 to 0.651, the deformability modulus decreased by about 25%.

The relationship between the work of bending and water activity for crackers (Fig. 7) differed substantially from that for corn-rye bread (Fig. 8). The increase of water activity of crackers caused the increase of the bending work and the value of work reached its maximum at $a_w = 0.306$, and after that the work decreased. Nicholls *et al*. [10] reported that the area under the force-deformation curves is associated with toughness (i.e., the absorbed energy). The gradual increase in bending work of corn-rye bread is related to the increase of water activity. The values of work increased 3 fold in the range of water activity from 0.283 to 0.651.

Seymour and Hamann [16] showed that as the water activity increases, the force level and mechanical work required to break the sample increases. The results correlated strongly and inversely with crispness of the material assayed by sensory panel. The relationship between work of bending and water activity for crackers is substantially different than that for corn-rye bread. At low water activities the work increases and reaches its maximum at $a_w = 0.306$. Further increase of water activity slightly decreases work of bending.

At high water activities samples of corn-rye bread required much more energy to bend. Fibres of extruded bread lose brittleness and the increase of water activity adds some resistance to deformation. The bending curves of corn-rye bread show that time to reach peak force at high water activities is far longer than that at low water activities. However, there is not much difference in the force reached (Fig. 3). On the other hand, the time to reach peak force at high water activities of crackers is also longer than that for low water activities, but force reached at high a_w is much smaller than that at low a_w. This can be explained by differences in the microstructure of the products investigated and in the chemical composition of snacks. Corn-rye bread contains resistant cellulose fibres, crackers contain fat which can be an important factor influencing mechanical behaviour of the material. Fat may behave as a lubricant at high water activities and reduce the friction between surfaces, which results in low strength.

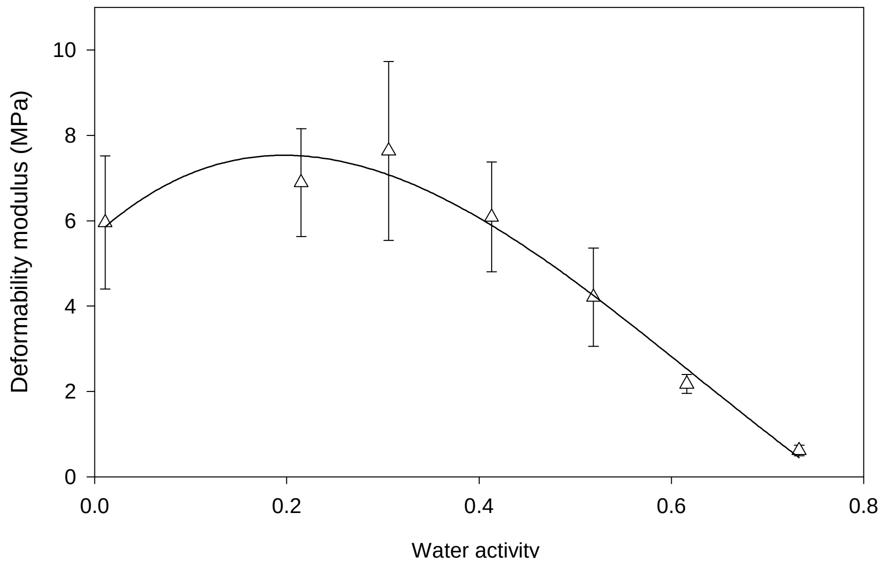

Fig. 5. Effect of water activity on deformability modulus of crackers

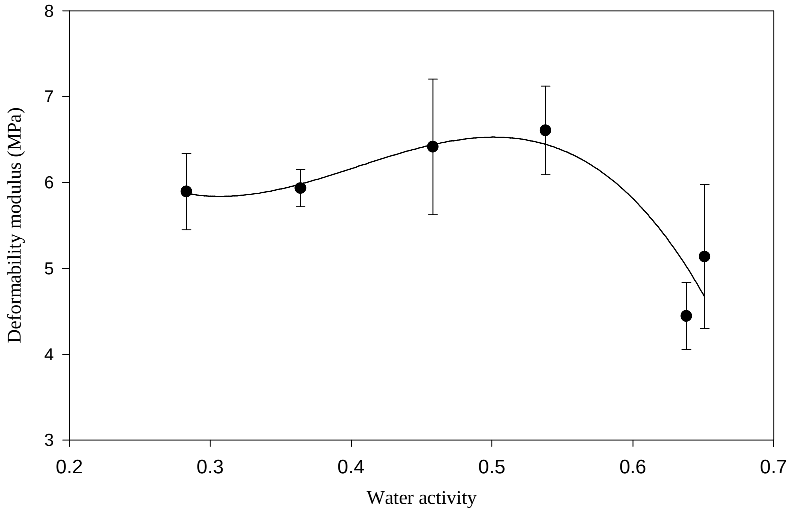

Fig. 6. Effect of water activity on deformability modulus of corn-rye bread

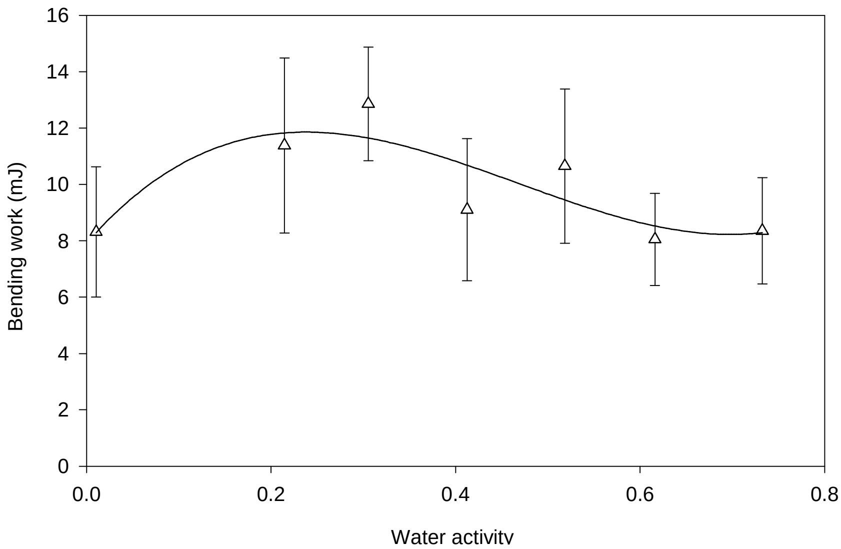

Fig. 7. Effect of water activity on bending work of crackers

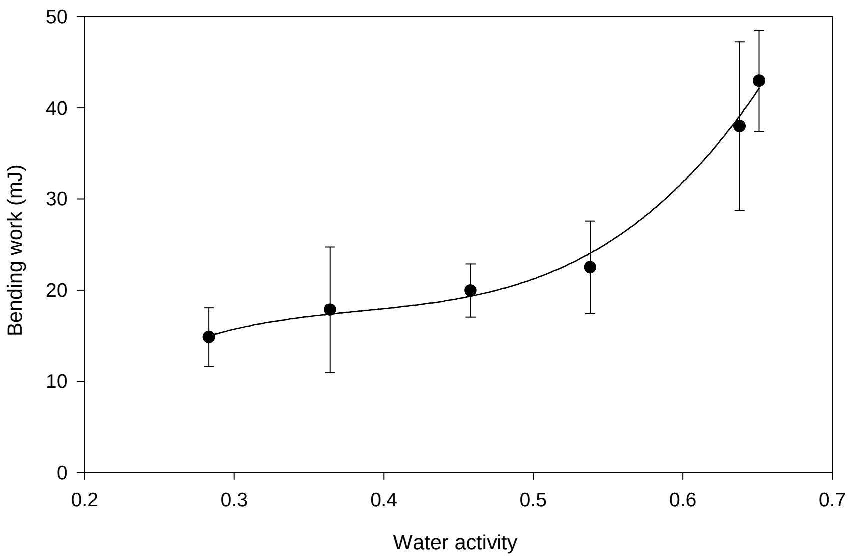

Fig. 8. Effect of water activity on bending work of corn-rye bread

CONCLUSIONS

The changes of water activity influence and are responsible for the mechanical properties of crackers and corn-rye bread. At low water activities during bending test, the first breaking peak was observed for crackers, which characterizes the crisp and brittle behaviour of these snacks. The first breaking peak was far less evident during bending of corn-rye bread than for crackers. It seems that differences in the structure of snacks can play an important role in the formation of a more crispy texture. The highest values of ultimate stress and deformability modulus were determined for crackers at $a_w = 0.306$ and for corn-rye bread at $a_w = 0.538$. Increase of water activity above these values caused softening and fowability of snacks. The extruded corn-rye bread has higher resistance to deformation than crackers, probably due to differences in the microstructure and chemical composition.

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WPŁYW AKTYWNOŚCI WODY NA WŁAŚCIWOŚCI MECHANICZNE SUCHYCH PRODUKTÓW ZBOŻOWYCH

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Streszczenie. Celem pracy było określenie wpływu aktywności wody na właściwości mechaniczne krakersów i chrupkiego pieczywa kukurydziano-ryżowego. Próbki były przechowywane w zakresie aktywności od 0 do 0,8. Właściwości mechaniczne określano na podstawie trójpunktowego testu łamania. Stwierdzono, że niskie aktywności wody mają wpływ na chrupkość i kruchość. Najwyższe wartości parametrów mechanicznych: naprężenia końcowego i modułu sztywności uzyskano dla krakersów przy a_w = 0,306, zaś dla chleba chrupkiego a_w = 0,538. Przy aktywnościach wody powyżej tych wartości materiał stawał się plastyczny i zaczynał płynąć pod wpływem przyłożonej siły.

Słowa kluczowe: krakersy, pieczywo chrupkie, reologia, aktywność wody