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COMPARATIVE ANALYSIS OF SELECTED PHYSICOCHEMICAL AND TEXTURAL PROPERTIES OF BREAD SUBSTITUTES

– Research paper –

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Abstract: In the present study, the physicochemical, textural and sensorial properties of crackerbread (made from rye, maize and wheat flour) and rice waffles, the most popular on the Polish market bread substitutes, were determined. It was shown that values of several mechanical properties of rice waffles, including ultimate fracture force, strain and stress differed significantly from that of crackerbread. Texture profile analysis showed that the highest hardness and springiness was exhibited by rice waffles with sesame seeds and wheat-rye, respectively. The concentration of salt was the lowest in rice bread with sunflower. The most acceptable was the rice bread with sea salt (8.26 in a 9-point scale) and overall consumer acceptance of crispbreads was highly correlated with sensory attribute of saltiness.

Keywords: bread substitute, crispbread, rice waffles, texture, sensory

INTRODUCTION

In recent years, the consumption of traditional bread has been decreased, whereas different types of crispbread classified into ready-to-eat snack products, have become more popular (Brennan et al., 2013). Bread consumption patterns differ widely within the Europe, but most countries have an average consumption of 50 kg of bread per person annually. The highest consumption levels are recorded in Bulgaria (approx. 95 kg), although the lowest is in UK (approx. 32 kg). In Poland, consumption of bread (per capita) declined to 47 kg in 2017 – half of the consumption recorded at the end of the 1990s. According to data reported by the Euromonitor International, sales of bread substitutes (crackerbread, breadsticks, rice waffles, biscuits, toast) will continue to grow in upcoming years (Euromonitor, 2018).

Many of these products are enriched with vitamins, minerals and additives such as sunflower, sesame, amaranth, making them a synonym of high nutritional and health value to some consumers (Jarosz, 2015). Besides, it is characterized by prolonged stability and convenient use. Additionally, crispbread is prepared in the process of extrusion, which ensures a prolonged stability and convenient use. Extrusion is a process that combines mixing, forming, texturizing and cooking of raw material into food product (Bordoloi and Ganguly, 2014). However, numerous studies have discussed the role of extrusion technology in altering the heat-labile vitamins, minerals, fiber or bioactive ingredients (Brennan et al., 2013). In addition, many of extruded food products are relatively abundant in sugar and salt, thus being regarded as energy dense but nutritionally poor foods exhibiting high glycemic index (GI) (Bator et al., 2014; Brennan et al., 2013). Moreover, research has also suggested that crispbread could be a considerable source of the acrylamide and 5-hydroxymethylfurfural in a modern diet (Michalak et al., 2016). These chemicals can be toxic, mutagenic and carcinogenic to humans (Capuano and Fogliano, 2011).

Extruded crispbread belongs to the group of products, for which their physical properties,

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including porosity and mechanical properties, are very important, because they form the texture of a product. These features are an essential factor influencing the consumer acceptability of a final product (Heiniö et al., 2016; Saeleaw and Schleining, 2011).
Taking into account the current popularity of crispbread, authors decided to test ten different crispbread products, the most popular on the Polish market, determining their selected physical, textural and chemical properties. In addition, their sensory properties and acceptability were analyzed. The obtained results will be useful to predict the nutritional value of commercially-available assortments of crispbreads.

MATERIALS AND METHODS

Bread samples

Commercial assortments of ready-to-eat bread substitutes (crispbread) available in the retail network in Lublin (Poland) in 2019 were used in this work. Seven assortments of crispbread known as crackerbread: rye-wheat (RW), rye-maize (RM), wheat-rye (WR), rye-maize-wheat (RMW), rye-spelled (RS), rye (R), rye-wheat-oat (RWO); and 3 assortments of rice waffles known as puffed rice cakes: rice with sunflower (RS'), rice with sesame seeds (RSS'), rice with sea salt (RSS"), were analyzed. The examined sample sets were prepared from three packets of each type of bread purchased in three different stores.

Physical analysis

Measurements of the true and apparent densities and porosity

The apparent (bulk) and true (material) densities were measured by a GeoPyc 1360 dry flow and an AccuPyc 1330 helium gas pycnometers, respectively. The parameters and procedures are described by Muszyński et al. (2016). Based on the measurements, porosity and specific pore volume were calculated. All measurements were performed in five replicates.

Moisture content and water activity

Moisture content and water activity (a_w) were determined on freshly unpacked bread slices. Moisture content was determined according to the Polish Standard (PN-84/A-8636). The a_w was measured using the Hygrometer 3 water activity meter (Rotronic, Switzerland) in six replicates for each bread type (Sołowiej et al., 2015).

Determination of sorption isotherms

The equilibrium moisture content of bread samples was determined at 20°C using the static gravimetric method according to the procedures and conditions described by Oniszczuk et al. (2015). The moisture adsorption data were fitted using Guggenheim-Anderson-De Boer (GAB) model with TableCurve 2D software (SYSTAT Software Inc, USA). The specific surface area a_{sp} of adsorbent was calculated according to Langmuir's model (Figura and Teixeira, 2007).

Water solubility index (WSI) and water absorption index (WAI)

WSI and WAI were measured using the centrifuge method according to procedure described by Rzedzicki et al. (2008). The measurements were taken in five replications.

Extruded crispbread strength analysis and calculations of mechanical parameters

The three-point bending test was performed to determine the mechanical properties of crispbread samples. Breads were loaded with the loading rate of 0.1 mm/s; the span length was set to 55 mm. Tests were performed on a TA.XT2i texture analyzer (Stable Micro System, UK). Crispbread structural properties (ultimate force, deflection at fracture, stiffness, and work to break) were determined from the force-displacement curves using Origin 2016 software (OriginLab, USA). Material properties of the crispbread samples (Young modulus of elasticity, ultimate strain, ultimate stress) were calculated using appropriate engineering beam-theory equations (Moore et al., 1990).

Volume of 100 g of bread

The measurement was carried out by means of millet seed displacement method (AACC, 2010) and was expressed in cm^3 of 100 g of crispbread.

Texture profile analysis (TPA)

Measurements were performed using a TA.XT2i texture analyzer. The samples cut from the middle part of the crispbread (cylindrical, 30 mm in diameter) were double compressed to 50% of deformation by a testing set (35 mm diameter) according to the protocol described by Michalak-Majewska et al. (2017). Crispbread samples were evaluated for hardness, fracturability, springiness and cohesiveness using Texture Expert software. Five measurements were carried out for each samples and average values were reported.

Cutting test
Measurements were performed applying the analyzer mentioned above. The crispbread samples were cut by a testing set (100 mm). The rate of penetration was 1 mm/s. There were three measurements for each treatment.

Chemical analysis
Water content, total titratable acidity and sodium chloride (NaCl) in crispbread samples were measured by reference method for analysis of bakery (PN-A-74108:1996; Serna-Saldivar, 2012).

Sensory analysis
Sensory evaluation of crispbread was carried out by scaling method, using a structured scale (Michalak-Majewska et al., 2020). The panelist group consisted of 25 untrained people (aged between 23 and 39-years old). Each sample of crispbread was served on a white plate and encoded with randomly assigned numbers. A nine-point scale was used to evaluation hardness, crispness, adhesiveness and saltiness. Rating scales were: hardness (1 = very soft; 9 = very hard), crispness (1 = non-crispy; 9 = very crispy), adhesiveness (1 = non-adhesive; 9 = very sticky), saltiness (1 = low saltiness; 9 = high saltiness). Furthermore, samples were evaluated for consumer acceptability (desirability) using a 9-point hedonic scale (1 = extremely disliked; 5 = neither liked nor disliked; 9 = extremely liked) (Meilgaard and Civille, 2007).

Statistical analysis
All results are expressed as means ± SD (standard deviation). To detect any significant difference between the groups, one-way analysis of variance (ANOVA) followed by Tukey's multiple comparison test was carried out. For all comparisons, the probability level of $P<0.05$ was considered statistically significant. The correlations were tested using Pearson linear correlation. All statistical analyses were carried out by means of Statistica 12 software (StatSoft, Poland).

RESULTS AND DISCUSSION

Physical and textural analysis
For the evaluation of mechanical properties three types of test were performed: TPA, cutting test and the three-point bending test. The bending test showed that the RW crispbread was described by the greatest ultimate force (36.3 N, Table 1). Moreover, this bread was characterized by the greatest work to break (along with WR and RS) and stiffness (along with RWO). However, its deflection until fracture was among the lowest values recorded. Young modulus was the highest for RWO and WR (exceeding 70 MPa). Opposite characteristics was observed for all types of rice waffles: RS', RSS' and RSS'' For this kind of crispbread, the lowest values of the ultimate force were recorded (just above 6 N for RS' and RSS'). Similarly, rice waffles were among those, for which the greatest deflection and the lowest work to break (total energy absorbed by the bread slice until fracture) was recorded. Also they were characterized by the lowest values of stiffness and Young modulus, describing their elastic properties (Table 1). Finally, the ultimate stress for rice waffles was significantly lower and ultimate strain was significantly higher than for other crispbreads. All above results allow to draw the conclusion, that rice waffles are less elastic and are characterized by lower mechanical endurance than rye crispbread.
Textural properties of crispbreads are presented in Table 2. The WR samples were characterized by the lowest hardness (58.6 N), springiness (0.45), cohesiveness (0.09) and the highest fracturability (0.49 N). The highest hardness and springiness was exhibited by RSS' (166.9 N) and RW (0.69), respectively. Cutting test showed the highest force to break for RS (71.2 N) and the lowest for RWO (20.5 N) and WR (22.1 N).
The rice waffles also differed from crackerbread in their structural characteristics, having the lowest apparent and true densities and the largest porosity and pore volumes among all samples (Table 3). Specific pore volume of RS', RSS' and RSS" was above 7.8 cm^3/g, which was over 2-fold larger than for crackerbread (3.6 cm^3/g for RM).
Van Hecke et al. (1995) showed that the organization of matter in the cell walls depends on ingredients and process conditions, which partially affects the overall mechanical characteristics of a product. In our study, correlation between the true density and ultimate stress was observed. For rice waffles, there was a positive correlation between true density and ultimate stress (Figure 1, left), while for the crackerbread, a negative correlation was found (Figure 1, right).

Table 1. The structural and material characteristic of crispbread determined during three-point bending tests.

Bread type	Ultimate force F_{max} (N)	Deflection x (mm)	Work for break W (mJ)	Stiffness S (N/mm)	Young modulus E (MPa)	Ultimate stress σ (MPa)	Ultimate strain ε (--)
RW	36.3 ± 3.0^{e}	1.15 ± 0.17^{a}	20.3 ± 3.9^{bc}	18.1 ± 2.7^{d}	23.6 ± 2.7^{b}	0.798 ± 0.065^{b}	0.019 ± 0.003^{a}
RM	23.5 ± 3.7^{d}	1.63 ± 0.16^{abc}	17.7 ± 2.4^{ab}	12.9 ± 1.2^{c}	38.2 ± 3.6^{c}	0.899 ± 0.141^{b}	0.021 ± 0.002^{a}
WR	14.0 ± 1.1^{b}	2.67 ± 0.30^{e}	24.9 ± 4.0^{c}	5.9 ± 0.4^{ab}	72.5 ± 5.3^{e}	1.331 ± 0.104^{c}	0.021 ± 0.002^{a}
RMW	13.9 ± 3.5^{b}	2.10 ± 0.33^{cde}	12.7 ± 3.6^{a}	4.4 ± 0.5^{a}	33.8 ± 4.0^{bc}	0.969 ± 0.241^{b}	0.019 ± 0.003^{a}
RS	22.8 ± 3.3^{d}	1.93 ± 0.13^{bcd}	19.8 ± 4.2^{bc}	7.8 ± 1.4^{b}	57.1 ± 10.4^{d}	1.546 ± 0.226^{c}	0.018 ± 0.001^{a}
R	16.6 ± 1.8^{bc}	1.11 ± 0.13^{a}	12.3 ± 3.2^{a}	13.6 ± 2.1^{c}	59.9 ± 9.1^{d}	0.768 ± 0.084^{b}	0.012 ± 0.001^{a}
RWO	20.8 ± 1.0^{cd}	1.44 ± 0.28^{ab}	18.6 ± 2.4^{abc}	17.3 ± 1.7^{d}	77.2 ± 7.6^{e}	0.934 ± 0.046^{b}	0.015 ± 0.003^{a}
RS’	6.77 ± 1.2^{a}	2.80 ± 0.99^{e}	11.1 ± 4.2^{a}	2.8 ± 0.6^{a}	2.4 ± 0.5^{a}	0.107 ± 0.020^{a}	0.057 ± 0.009^{bc}
RSS’	6.14 ± 1.3^{a}	2.51 ± 0.09^{de}	10.6 ± 1.4^{a}	2.8 ± 0.6^{a}	2.5 ± 0.5^{a}	0.103 ± 0.022^{a}	0.049 ± 0.002^{b}
RSS”	14.1 ± 1.0^{b}	2.27 ± 0.26^{de}	18.7 ± 3.3^{abc}	7.6 ± 1.2^{b}	1.9 ± 0.3^{a}	0.103 ± 0.007^{a}	0.068 ± 0.008^{c}

$^{a-e}$ Means with different letter superscript within the same column are significantly different ($p<0.05$)

Table 2. The textural properties of crispbreads – Texture Profile Analysis (TPA) and Cutting Test.

Bread type	Hardness (N)	Fracturability (N)	Springiness	Cohesiveness	Cutting test (N)
RW	73.9 ± 4.9^{a}	0.22 ± 0.03^{abc}	0.67 ± 0.04^{f}	0.21 ± 0.01^{c}	30.5 ± 3.5^{ab}
RM	102.1 ± 9.7^{b}	0.27 ± 0.02^{abc}	0.65 ± 0.05^{ef}	0.21 ± 0.01^{c}	40.4 ± 8.4^{bc}
WR	58.6 ± 4.3^{a}	0.49 ± 0.08^{d}	0.45 ± 0.02^{a}	0.09 ± 0.01^{a}	22.1 ± 2.5^{a}
RMW	64.9 ± 1.7^{a}	0.33 ± 0.02^{c}	0.57 ± 0.03^{cd}	0.15 ± 0.01^{b}	39.7 ± 4.2^{bc}
RS	116.1 ± 5.6^{b}	0.20 ± 0.03^{abc}	0.55 ± 0.02^{bcd}	0.22 ± 0.01^{c}	71.2 ± 4.9^{d}
R	153.3 ± 14.7^{cd}	0.31 ± 0.03^{c}	0.48 ± 0.02^{abc}	0.22 ± 0.01^{c}	42.7 ± 1.7^{bc}
RWO	145.5 ± 10.1^{cd}	0.25 ± 0.06^{abc}	0.59 ± 0.05^{de}	0.21 ± 0.01^{c}	20.5 ± 3.2^{a}
RS’	145.9 ± 9.6^{cd}	0.16 ± 0.03^{ab}	0.47 ± 0.03^{abc}	0.13 ± 0.02^{ab}	47.7 ± 7.6^{c}
RSS’	166.9 ± 16.6^{d}	0.30 ± 0.06^{bc}	0.63 ± 0.02^{def}	0.22 ± 0.01^{c}	41.6 ± 0.7^{bc}
RSS”	138.6 ± 4.7^{c}	0.14 ± 0.03^{a}	0.50 ± 0.03^{abc}	0.17 ± 0.02^{b}	51.6 ± 1.6^{c}

$^{a-f}$ Means with different letter superscript within the same column are significantly different ($p<0.05$)

Table 3. The water activity and structural characteristic of crispbread.

Bread type	Water activity a_w (--)	Water content (%)	True density (g/cm^3)	Apparent density (g/cm^3)	Porosity (%)	Specific pore volume (cm^3/g)	Bread volume (cm^3/100 g)
RW	0.328±0.003^{i}	7,744±0,031^{g}	1.290±0.030^{d}	0.283±0.014^{c}	78.00±1.23^{ab}	2.762±0.179^{bc}	1115,2±12,73^{d}
RM	0.227±0.003^{h}	6,685±0,017^{b}	1.163±0.046^{c}	0.221±0.011^{b}	80.99±1.12^{bc}	3.668±0.218^{c}	1201,2±1,80^{e}
WR	0.199±0.003^{g}	6,508±0,011^{a}	1.412±0.011^{ef}	0.236±0.004^{bc}	81.73±2.62^{bc}	3.446±0.134^{c}	1360,5±26,12^{h}
RMW	0.262±0.002^{f}	7,420±0,007^{f}	1.438±0.020^{ef}	0.282±0.016^{c}	80.39±0.85^{bc}	2.857±0.189^{c}	1219,5±1,86^{e}
RS	0.263±0.002^{f}	6,693±0,022^{b}	1.363±0.005^{de}	0.259±0.025^{bc}	80.99±1.87^{bc}	3.148±0.379^{c}	1037,5±0,83^{c}
R	0.294±0.001^{e}	6,994±0,022^{e}	1.541±0.008^{g}	0.492±0.011^{d}	68.09±0.92^{a}	1.386±0.050^{a}	820,3±4,28^{b}
RWO	0.316±0.001^{d}	6,897±0,014^{d}	1.463±0.017^{fg}	0.471±0.034^{d}	64.80±7.42^{a}	1.448±0.166^{ab}	548,7±7,74^{a}
RS’	0.170±0.002^{c}	6,810±0,040^{c}	0.757±0.037^{ab}	0.102±0.011^{a}	86.85±1.64^{c}	8.567±1.121^{d}	1307,1±18,90^{g}
RSS’	0.189±0.006^{b}	6,839±0,040^{cd}	0.683±0.040^{a}	0.098±0.008^{a}	85.58±1.91^{bc}	9.116±0.704^{d}	1262,2±19,79^{f}
RSS”	0.150±0.006^{a}	6,913±0,054^{d}	0.806±0.025^{b}	0.110±0.002^{a}	86.28±0.41^{c}	7.809±0.165^{d}	1550,9±16,22^{i}

$^{a-i}$ Means with different letter superscript within the same column are significantly different ($p<0.05$)

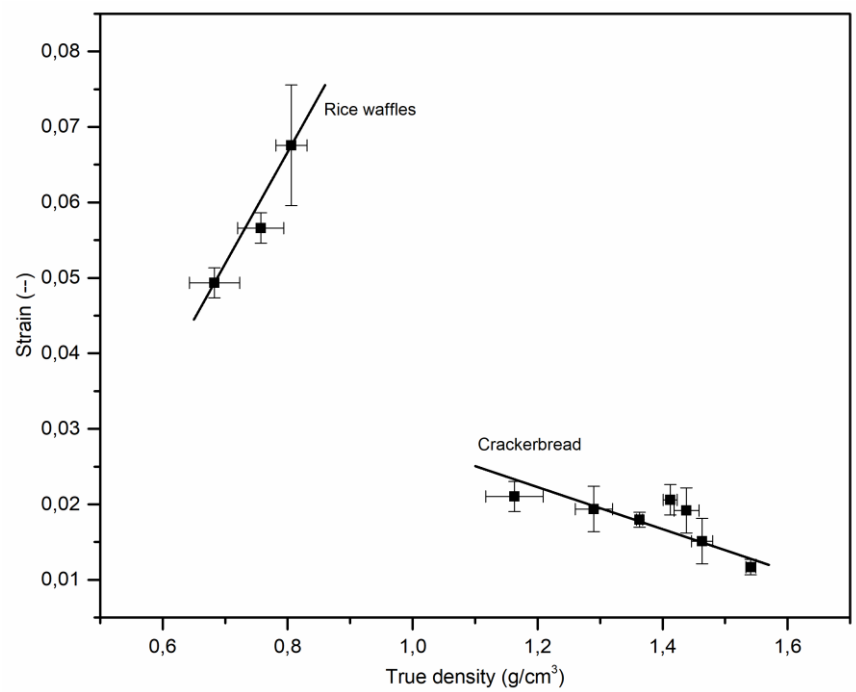


Figure 1. The difference between the true density-strain relation of rice waffles (on the left) and crackerbread (on the right).

Porosity, pore volume and bread volume are the primary criteria for evaluation of bread by consumers. Results of the present study indicated that crispbread volume was in wide range of 548.7 cm^3/100 g (RWO) to 1550.9 cm^3/100 g (RSS") (Table 3). Such differences may be caused by chemical composition of samples, and consequently different structure of extrudates. Samples of R and RWO crispbreads had the lowest volume of 100 g of bread, which was negatively correlated with its true and apparent density (r = -0.625 and r = -0.874, respectively).

Water content of crispbread observed in the present study was similar to that reported by Jakubczyk et al. (2015) and Rzedzicki et al. (2008) and it was within the range from 6.51% (WR) to 7.74% (RW) (Table 3). According to Polish Standard (PN-V-74030:2006) the rye crispbread should have a water content lower than 6%, and Graham crispbread - more than 7%. Results of the present study are slightly different, probably due to a multi type composition of raw materials, which have different proportions of corn, oats, and additives such as sunflower, sesame seeds and salt.

A transport of water is present in all systems where water activity has not reached its equilibrium state. This water transport may alter properties of a product, including mechanical and acoustic properties of crisp/crunchy products (Marzec et al., 2007; Roudaut et al., 1998; Świetlicka et al., 2015). Products with water activity below 0.5 are brittle and glassy at room temperature (Figura and Teixeira, 2007). In presented study, all crispbreads were characterized by water activity below this threshold value (Table 3). On the other hand, in starch-rich products, the anti-plasticizing effect of water could occur, leading to an increase of rigidity and brittleness (Enrione et al., 2007; Marzec and Lewicki, 2006). Further, extruded starch undergoes transitions from its amorphous to viscoelastic state, which lead to the increase of its -adsorption capacity (Fontanet et al., 1997; Van Hecke et al., 1995). In rye-rich products, as rye contains hydrophobic pentosans that also bind large amounts of water, the main ingredient responsible for the structure of rye bread is also starch (Marzec and Lewicki, 2006; Pomeranz et al., 1984). In our study, the negative correlation between water activity and ultimate force was observed (Table 1 and Table 3). However, the effect of water activity or density on Young modulus or the ultimate strain was indeterminate.

The relationship between relative humidity and equilibrium moisture content is given by isotherms (Figure 2). All sorption isotherms were of sigmoidal shape, typical for starch-based products (Marzec and Lewicki, 2006). The BET model gave the very good fit to the experimental data, and all coefficients of determination were above 0.98. The lowest R^2 was observed for rye-wheat RW bread (R^2=0.988, RME=0.74, Table 4). The monolayer moisture content u_m showed higher value in rice waffles compared to crackerbread. Comparing results of the water activity of monolayer calculated with BET model (Table 4) with the values of water

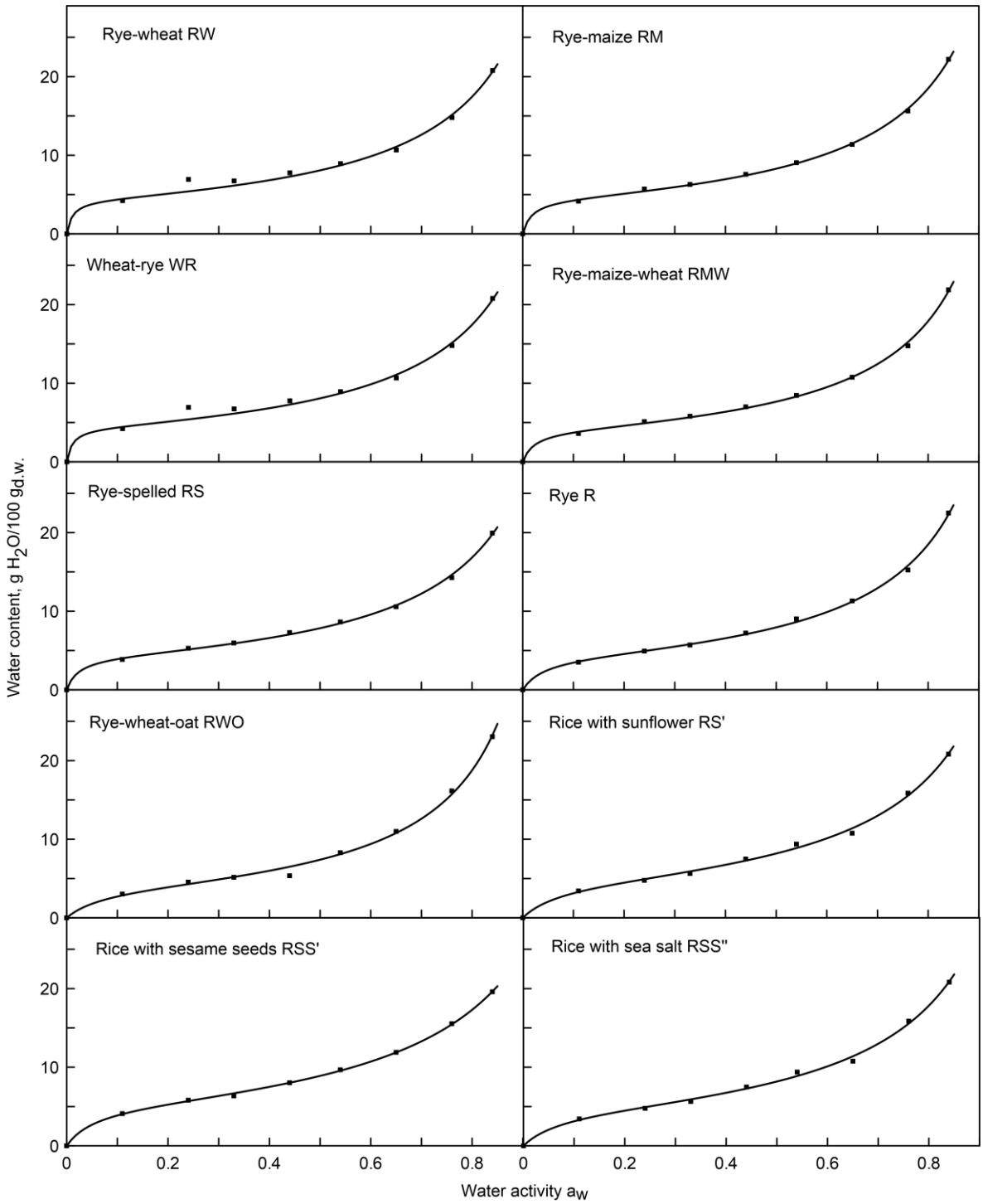


Figure 2. Sorption isotherms for different types of crispbread at 20°C approximated with the GAB model.

activity measured (Table 3), it can be seen that for rice waffles, measured water activities were lower than theoretical values of monolayer. This indicates that water has not formed a complete monolayer yet, extending waffles shelf-life and allowing them to retain their sensory properties and mechanical traits. Texture is also correlated with the u_m and the water content larger than u_m results in a decrease in crunchiness (Katz and Labuza, 1981; Świetlicka et al., 2015).

Determined values of BET constants for the rice waffles significantly differed than those for the crackerbread. The C constant is related to the sorption energies, while the k constant is related to multilayer sorption monolayer (Enrione et al., 2007). Lower values of both constants observed for rice waffles suggest that water molecules in this type of crispbread are characterized by a weaker bonding to active sorption sites of the matrix compared to the extruded rye crispbread (Table 4) (Enrione et al., 2007).

Previous research has shown that extrusion conditions such as barrel temperature above 130°C, pressure up to 200 bar, screw speed up to 150 rpm, have significant impact on the final product properties (Singh et al., 2007). Water absorption index (WAI) is a measure of starch gelatinization degree. The intensity of gelatinization depends on the extrusion process parameters and starch origin e.g. wheat starch does not lose its gel-forming capacity to the same degree as corn starch (PN-A-74105:1992). In the present study, WAI varied from 334% for RWO to above 500% (535% for RSS") (Table 5). There were no significant differences ($p > 0.05$) between the WAI of rice waffles with various additives - sunflower (RS'), sesame seeds (RSS') and sea salt (RSS") as well as R and RWO. Similar and high water binding capacity (495.06-609.72%) was also demonstrated for other assortments of crispbread (Rzedzicki et al., 2008). Higher WAI values indicate higher intensity of products thermal processing. WAI of products, for which such processing was not intense, changed from 110.7% (barley groats) to 174.6% (barley flakes) (Rzedzicki and Wirkijowska, 2008). WAI is greatly affected by degree of porosity or expansion of the extrudate; higher porosity and thinner cell walls in the extrudates lead to greater water absorption (Singh et al., 2007). This finding is in agreement with results of the present study (Table 1).

The water solubility index (WSI) measures the amount of soluble polysaccharide released from the starch after extrusion (Ding et al., 2006). Changes in water absorption of analyzed crispbread were always accompanied by changes in WSI. Products with high water absorption were characterized by lower value of WSI (Table 5). The WSI values were in the range from 39.27% (R) up to 48.16% for the WR (Table 5). Our observations also confirm the results of Marzec et al. (2007). The authors cast in doubt the nutritional value of this type of bread, due to its high solubility of dry matter, low protein content and dietary fiber. The WSI values of crispbread produced with the method of extrusion, are in contrast to those of traditional fermented bread, for which this parameters oscillated at low levels, up to 12% d.m. (Kasprzak and Rzedzicki, 2010; Rzedzicki and Kasprzak, 2009). This indicates low intensity of the process and slight degradation of biopolymers in that bread.

Table 4. The GAB equation parameters, the water activity of the monolayer and the surface area of adsorbent of crispbread stored at 20°C.

Bread type	GAB parameters			Model-fitting accuracy		Water activity a_w of monolayer	Surface area of adsorbent a_{ap} ($m^2/g_{d.m.}$)
	u_m	C	k	R^2	RME		
RW	4.33	99.97	0.94	0.988	0.74	0.097	152.1
RM	4.41	61.90	0.95	0.998	0.21	0.119	154.9
WR	4.03	46.11	0.97	0.998	0.26	0.132	141.6
RMW	4.40	64.93	0.95	0.997	0.38	0.116	154.6
RS	4.28	46.34	0.93	0.998	0.24	0.126	150.4
R	4.29	25.15	0.96	0.998	0.30	0.173	150.7
RWO	4.01	14.18	0.99	0.995	0.53	0.212	140.9
RS'	4.74	14.52	0.92	0.997	0.38	0.226	166.5
RSS'	5.55	13.09	0.84	0.995	0.45	0.256	195.4
RSS"	5.33	20.38	0.87	0.999	0.15	0.208	187.3

Table 5. Water solubility index (WSI) and water absorption index (WAI) in crispbread.

Bread type	WSI (% d.m.)	WAI (% d.m.)
RW	41.04 ± 0.58^{b}	412.81 ± 14.1^{b}
RM	$45.07 \pm 0.45^{e-f}$	428.02 ± 2.3^{b}
WR	48.16 ± 0.80^{g}	408.42 ± 46.3^{b}
RMW	45.65 ± 0.25^{f}	424.69 ± 20.9^{b}
RS	$44.03 \pm 0.15^{d-e}$	$465.55 \pm 1.2^{b-c}$
R	39.27 ± 0.19^{a}	336.6 ± 13.7^{a}
RWO	41.17 ± 0.04^{b}	334.73 ± 2.6^{a}
RS'	$42.98 \pm 0.24^{c-d}$	$518.94 \pm 15.6^{c-d}$
RSS'	$42.05 \pm 0.14^{b-c}$	534.90 ± 22.0^{d}
RSS"	$43.92 \pm 0.87^{d-e}$	535.64 ± 27.4^{d}

[a-f] Means with different letter superscript within the same column are significantly different ($p<0.05$)

A high content of soluble fractions of dry mass (like in crispbread) is characteristic of highly processed products, which are degraded by conditions of the technological process. During the intensive thermoplastic processing, a high-molecular polymers of starch and dietary fiber present in the raw material are decomposed to low-molecular water-soluble compounds (Singh et al., 2007). Upon consumption, such strongly degraded products are rapidly digested and absorbed, modifying the post-meal glycaemia. It was confirmed in medical research on humans, in which glycemic index (GI) values of the tested crispbread was defined in the ranged from 53 to 87 and 95 to 128 for puffed rice cakes. These products were classified into groups with medium and high GI (Bator et al., 2014; Kaur et al., 2016).

Chemical analysis

Acidity is another parameter of ready-to-eat bread substitute that has significant impact on its characteristic flavor. Standard wheat bread is characterized by generally low acidity, while rye bread and mixed one prepared using the sourdough, has higher acidity. Requirements for the total titratable acidity of bread formulated in Polish Standards (PN-A-74101:1993; PN- PN-A-74103:1993; A-74105:1992) indicate that the acidity of good quality rye bread should be at the level of 8-11º acidity degrees, mixed bread of 7-10 acidity degrees, and wheat bread of÷ 3-5 acidity degrees. In the present study, variations in the crispbread acidity were observed. The statistically lowest values were observed for RMW and RS breads, of 1.3 acidity degrees and 1.5 acidity degrees, respectively (Figure 3). The highest acidity (about 5 acidity degrees) was found in samples of rice breads: with sunflower (RS'), sesame seeds (RSS'), sea salt (RSS") and for rye-wheat-oat (RWO). Results similar to those values were given by Kudełka and Curyło (2014), who analyzed crispbread manufactured by leading Polish manufacturers and brands owned by supermarkets. In the case of bread produced from conventional ingredients, commercially available in Poland under the name of Breslau and Kaiser roll, whole meal rye bread, wheat bread, graham, spelled bread, the acidity was in the range from 1.2 (Kaiser roll) to 6.3 (spelled bread) acidity degrees (Rusinek-Prystupa et al., 2014). In the case of conventional bread, higher acidity may be a result of the presence of organic acids, formed during the fermentation - lactic acid and acetic acid (Decock and Cappelle, 2005). Study upon the sensory quality of soft and crisp rye bread indicated that acidity, besides ash and salt content, significantly affected the consumer acceptance of those kinds of bread (Heiniö et al., 1997).

Bakery products, and crispbread as well, have been identified as the main sources of salt in a diet. Salt is the ingredient that improves the taste and structure of bread shapes (flexibility). Furthermore, with the salt added, the bread crust gets better brown and becomes crispy (Michalak-Majewska et al., 2013).

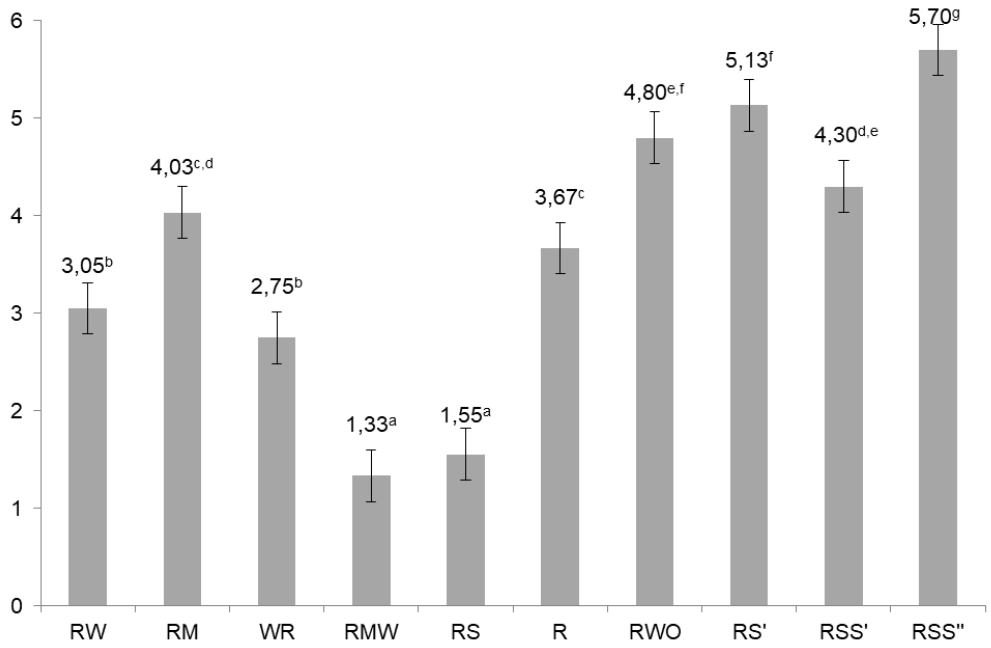


Figure 3. Crispbread acidity (acidity degrees).

In the present study, the lowest concentration of salt was 0.05 g per 100 g (equivalent of 20 mg of sodium per 100 g of bread) in RSS', whereas the highest concentration was 1.52 g per 100 g (equivalent of 608 mg of sodium per 100 g of bread) in RSS" (Figure 4).

Results of the present study are in general agreement with those reported by Heiniö et al. (1997) for crispbread with various ratios of wheat and rye. Whereas in another study (Kudełka and Curyło, 2014), irrespective of the type of the crispbread, the content of salt did not exceed 0.9%. According to recommendations of the World Health Organization (WHO), the maximum daily salt intake from all sources should not exceed 5 g, which is equal to 2 g of sodium (WHO, 2012). One of the important directions to reduce the amount of salt consumed with processed products may be reducing their portions. Putting a reliable information regarding the content of salt, sodium chloride or sodium in a specified amount of product (e.g. a slice) by manufacturer is useful for that purpose. Figure 4 shows the comparison of the content of sodium chloride in 100 g of crispbread determined analytically to the amount declared on the packaging by the manufacturer. This comparison shows a fairly good agreement of our results with those declared on the label. However, in most cases, the salt content determined analytically was higher by 4%, but the largest difference was observed for the RSS', in which the salt content declared at the label was five times lower than that determined analytically. It may be due to too low sensitivity of analytical method, especially for such low values of analyzed compound.

It should be noted that most of the analyzed samples of crispbread were characterized by a salt content comparable to that of conventional bread (calculated per 100 g). Regardless of the determination method (chloride- or sodium-based method), the sodium chloride contents of retail samples of 100 g breads ranged from 0.51 g to 1.8 g (Nigerian bread), from 1.0 g to 1.43 g (Portugal bread) and from 1.01 g to 1.82 g (European bread) (Nwanguma and Okorie, 2013; Quilez and Salas-Salvado, 2012; Plácido et al., 2012). This is especially important for people, who consider crispbread as a diet snack, regardless of the consumption volume. In this context, it should also be noted that both crispbread as well as puffed rice bread have high glycemic index, which is now considered more reliable than the caloric content of the product during the use in dieting. It is one of the reasons why this kind of meal is not suitable for diabetics or for those on a diet, because after eating one serving, we feel hunger in a short time again.

Sensory analysis

Sensory features of food products, in particular tastiness, are critical drivers of consumer perceptions of food quality and acceptance (Kaya, 2016). Flavor and texture of cereal foods are mostly formed during processing due to process-induced changes in the grain biopolymers and flavor-active compounds. In the present study, sensory evaluation of crispbread was carried out in a 9-point scale for: hardness, crispness, adhesiveness, and saltiness. Sensory scores for each of the breads are shown in Figure 5.

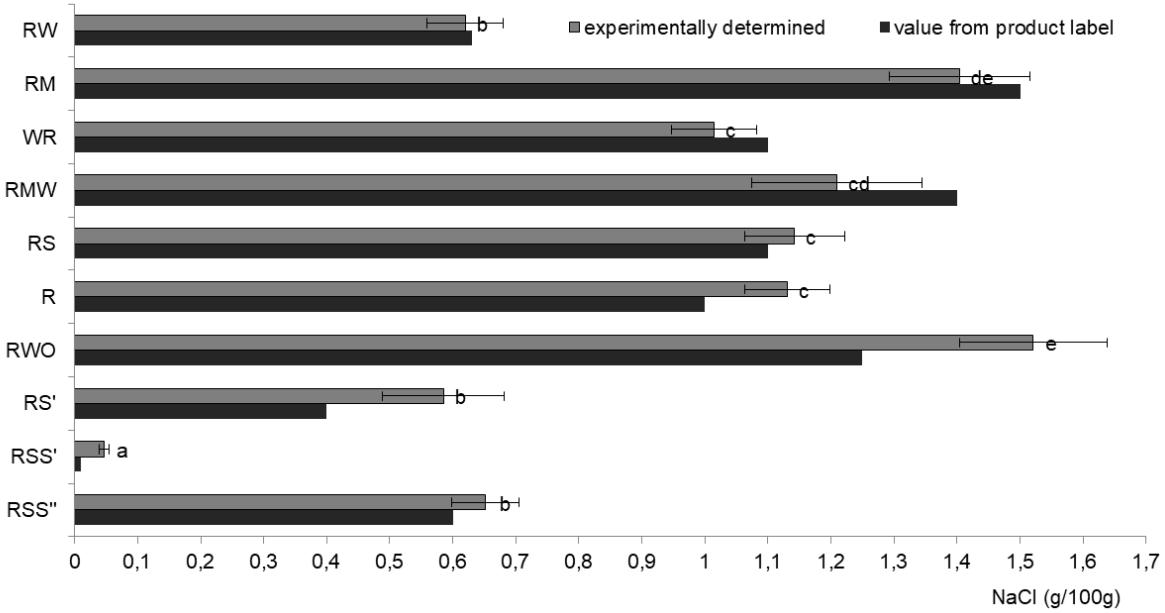
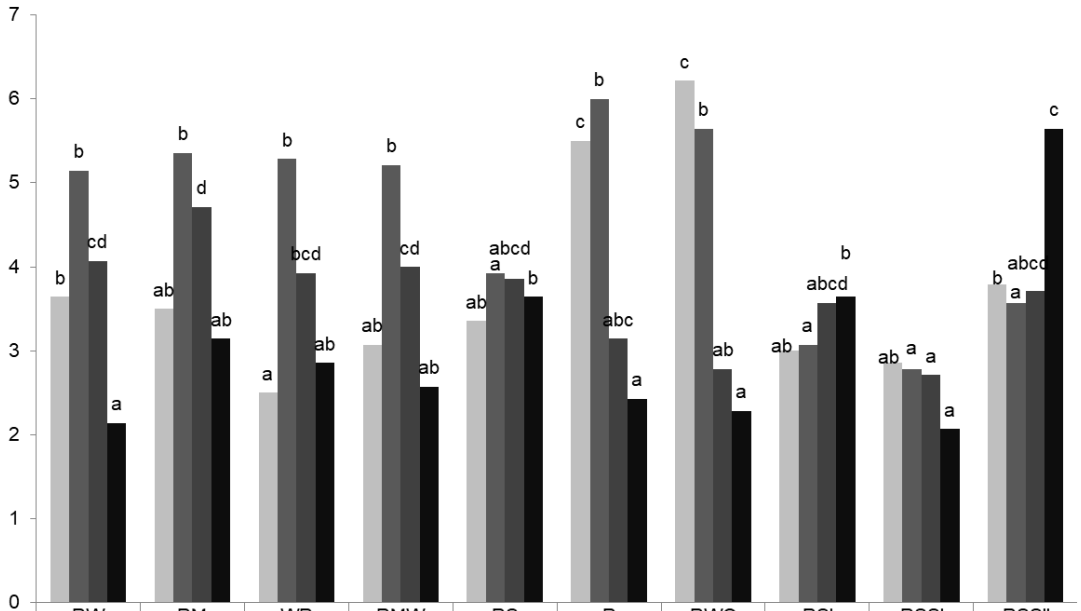


Figure 4. Comparison of the salt content (g/100 g) experimentally determined and given on the package label.



	RW	RM	WR	RMW	RS	R	RWO	RS'	RSS'	RSS"
hardness	3,64	3,50	2,50	3,07	3,36	5,50	6,21	3,00	2,86	3,79
crispness	5,14	5,36	5,29	5,21	3,93	6,00	5,64	3,07	2,79	3,57
adhesiveness	4,07	4,71	3,93	4,00	3,86	3,14	2,79	3,57	2,71	3,71
saltiness	2,14	3,14	2,86	2,57	3,64	2,43	2,29	3,64	2,07	5,64

Figure 5. Sensory evaluation results of crispbreads in 9--point scale.

The RWO and R samples scored the highest for overall hardness (6.21 and 5.5 on a 9-point scale, respectively). It was positively correlated with that parameter that was experimentally determined in TPA test (r = 0.44), Table 2. The results of sensory hardness perception observed in the other studies on extruded bread (Jakubczyk et al., 2015; March et al., 2007) were comparable to the results presented in our study. Maximum force evaluated by mechanical analysis presents the hardness of the products. It is often associated with the perception of the sensory hardness of extruded products.

There were no significant differences ($p > 0.05$) between crispness of the crackerbread samples containing rye, wheat, oat, regardless of the proportions of the components. Sensory analysis showed that panelists perceived the rice waffles (RS', RSS', RSS") as the least crispy. Generally, the loss of crispy texture by cereal-based products is associated with an increase in the water content of the material - mainly resulting from phase changes of carbohydrates (Marzec and Lewicki, 2006; Moore et al., 1990). However, in this case, these differences certainly are due to different structure of the rice bread caused by production conditions and properties of rice grain.

Regarding adhesiveness (the ability of bread to stuck to the palate, tongue, and teeth), the RM scored highest and the RSS' and RWO scored the lowest among all tested crackerbread samples. Adhesiveness described by panelists was positively correlated with water absorption index (WAI) (r = 0.602) determined experimentally (Figure 5, Table 5).

In nine types of bread, saltiness was recorded about 2.07, and as expected, rice waffles with addition of sea salt (RSS"), received the highest scores (5.64) (Figure 5). Heiniö et al. (1997) indicated that perceived saltiness of bread is influenced by both NaCl content and bread acidity. It is worth noticing that RSS" had the highest acidity value (Figure 3), which probably strengthened the perceptibility of saltiness by the panelists.

Crispbread is classified in the group of products, for which texture is the most important feature. The overall acceptability of this type of products is also determined by the intensity of taste, in which salty one seems to be the most important. In our study, samples of crispbread were evaluated for consumer acceptability (desirability) using a 9-point hedonic scale (1 - extremely disliked; 5 - neither liked nor disliked; 9 - extremely liked). Desirability is a degree of subjective acceptance of a specific sensation, its preference or "liking". Thus, the "range" of desirability also comprises the affective consumer assessment. In our study, the RWO was the lowest rated among all types of tested crispbread by panelists – it scored 3.34 points on a 9-point scale (Figure 6).

All the other samples, except rice waffles, received notes in the range of 4.64-6.31. The most acceptable was the rice with sea salt (RSS"), which scored 8.26 on a 9-point scale. This bread was also characterized by the lowest water activity (Table 3) and the lowest

fracturability (Table 2). It should be mentioned that overall consumer acceptance of crispbreads was highly correlated with sensory attribute - the saltiness (r = 0.74). Epidemiological studies indicated that salty taste preferences are linked to the country of residence. It was found that the strongest preferences for salty taste was found in Estonia, while the weakest in Cyprus and Italy (Ahrens, 2015).

Despite many expectations for a product, such as dietary values or convenience of meals preparing, sensory characteristics is the most important factor influencing the consumer's product acceptance.

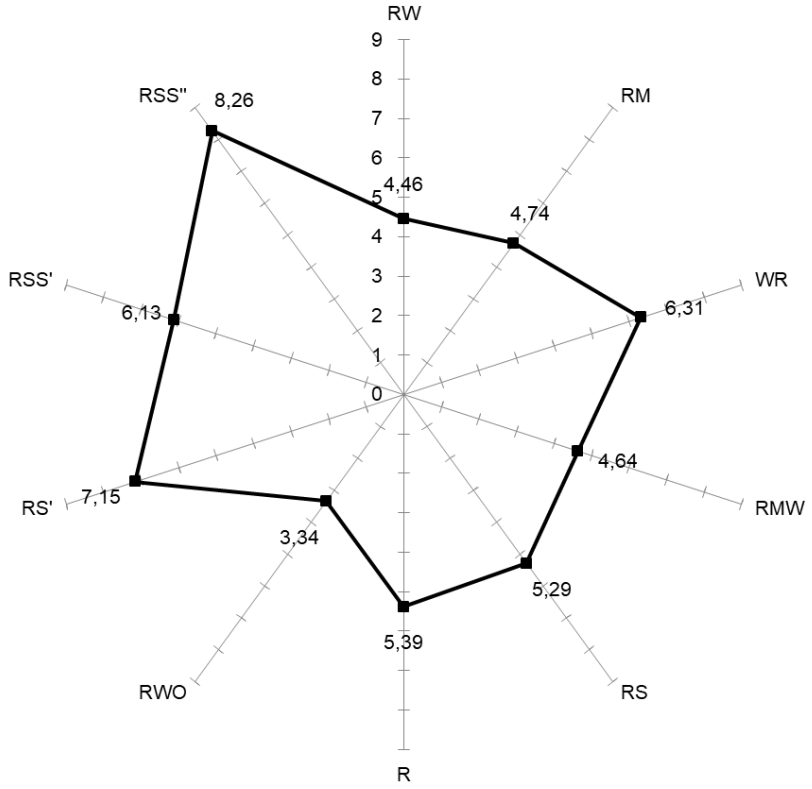


Figure 6. Values of sensory acceptance of crispbreads.

CONCLUSION

In the last several years, there has been a great interest in the bakery substitutes (crackerbread, breadsticks, rice waffles, biscuits, toasts) in Europe and the world. Opinions of dieticians and scientists in the context of the nutritional value of this type of assortment are increasingly sceptic (namely, it has low nutritional value, high glycemic index, it is a source of acrylamide and 5-hydroxymethylfurfural). Therefore, it can be expected that bread substitutes are the market segment, which will be an increasingly important research object in the upcoming years.

In this study, significant differences in the porosity and specific pore volume were observed among rice waffles and other samples of bread substitutes. Higher porosity leads to greater water absorption index (WAI) in the rye extrudates. The comparison of results of water activity measurements and theoretical equilibrium values of water monolayer calculated from BET model allowed to conclude that rice waffles are characterized by extended shelf-life that could allow them to retain their sensory properties and mechanical traits.

Taking into account the results of the texture analysis - the highest hardness and springiness was exhibited by rice waffles with sesame seeds and wheat-rye, respectively. Our analyses also showed a good agreement of salt content declared on the packaging label with analytical results. Concentration of salt was the lowest in rice bread with sunflower. The most acceptable was the rice bread with sea salt, which was also characterized by the lowest water activity and fracturability, but the highest content of salt. It should be mentioned that overall consumer acceptance of crispbreads was highly correlated with sensory attribute of saltiness (r = 0.74).

Conflict of interest
The authors declare no conflict of interest.

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