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WATER BOND FORMS IN THE DOUGH AND SORBTION PROPERTIES OF GLUTEN-FREE MACARONI PRODUCTS MADE FROM CORN FLOUR

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Abstract:
Authors have developed macaroni products made from fine meal corn flour with usage of structure forming additives of different nature and without them. The correlation of water of different bond forms in macaroni dough with different structural forming additives and without them has been investigated. Results show that water of macro and microcapillaries is prevalent in the corn dough – 39.40 - 54.69 % of overall amount of water. Osmotically bound water amounts 18.75 – 28.04 %, adsorbically bound water -18.49 – 23.13 % of overall amount of water. Absorbtion capability of the macaroni products and amount of adsorbed water have been determined. The micropore structure of these samples was characterized. The correlation between structure of macaroni products, both amount of adsorbed moisture and energy of sorption were proven. The amount of monomolecular layer's moisture for gluten-free corn macaroni products is significantly higher – in 1.2 – 1.5 times – when compared to the wheat macaroni products. Due to this corn samples obtain higher energy of moisture sorption. The correlation between structural characteristics of the macaroni samples and its quality was shown.

Keywords: gluten-free macaroni products, water bond forms, absortion capability, structural characteristics, absorbtion energy.

1. Introduction

One of the main task of food industry is a providing of dietetic foods. Dietetic nutrition – important factor and essential part of the complex treatment of different deseases. Dietetic food is a special food that differs from traditional food by chemical content and low caloric value.
Last years number of metabolic deseases (in particular, celiac desease) grows across the population. Celiac – genetic desease that appears in intolerance for some proteins. The only one effective and safe method of celiac treatment is strict dietary intervention during life time that exclude gluten. Gluten is a group of protein that takes part in forming of wheat dough naming gliadine. Gliadine is an innocuous substance, but it causes allergy or recrudescence of this desease across people with genetic predielection to celiac desease [1].
Derived products of corn, rice and buckwheat are often used as gluten-free raw materials for producing of bread, pastries and macaroni products. The corn flour is the most relevant raw material for obtaining of macaroni products in Ukraine because corn does not contain a gluten and

is one of the widely spread cereal crops at this territory. Corn contains bigger amount of cellulose, polyunsaturated fatty acids of ω-3 and ω-6 groups, such important for the organism minerals as ferrum, selenium, folic acid, tokoferol, biotine, β-carotene and others when compared to the wheat [2].

Gluten-free macaroni products are not produced in Ukraine, and need of it is provided due to the import. Producing of macaroni products is closely connected with role of gluten in forming of structure of the dough and ready products. Gluten-free flour does not contain proteins that form gluten, so making of macaroni products from corn flour exerts some difficulties.

Some researchers believe that forming of structure of gluten-free macaroni products may be provided due to the gelatinization of starch of raw materials and usage of other structure forming additives [3].

Most of publications concerning producing of gluten-free macaroni products deal with its quality, while less information about technology, in particular colloidal processes in dough, kneading, drying processes and storage. For example, European patent EP 0792109 B1 claims method of production of corn macaroni products by means of additional operation of flour scalding [4]. According to this method corn flour is scalded completely or partially before kneading and is dryed. This flour is mixed with water and formed one more time. Although, this way did not come into common use evidently due to the additional preparing operations. Also, publication does not contain data of the main quality indexes of macaroni products.

Under the supervision of Lucia Padalino [5] investigation of the effect of different hydrocolloids on the chemical content and quality of gluten-free spaghetti made from corn and oat flour was carried out. The pectin, agar, carbulose, helan gum and other were used as structure forming additives. Results show that most of hydrocolloids increase quality of macaroni products and structural-mechanical properties of the dough. Since investigations of the technological processes are not presented in this paper.

Authors have developed macaroni products made from corn fine meal flour with using of structure forming ingredients – xanthan gum, carboximethylcellulose (CMC) [6, 8], gelatin and dry egg white [7, 8], as well as without usage of structure-forming ingredients – with addition of extruded corn fine meal flour [9, 10]. The dosage of structure forming additives, amount of added extruded or scalded flour that provide the best quality of products by strength, cooking properties in particular amount of dry matter passed into cooking water have been investigated.

Forms of water bonds in the dough determine the reological properties, kinetics of drying process and quality of macaroni products [11]. Microstructure effects on the quality indexes of macaroni products that, therefore, will have an impact on the sorption properties of the products and changes of it during storage.

Determination of the energy and forms of water bond in dough as well as investigation of the sorption properties of corn flour help to clarify the mechanism of influence of main raw materials and structure forming additives on the quality indexes and technological processes of its production and storage.

2. Matherials and methods

Flour

Corn fine meal flour and corn extruded flour were used (see *table 1*).

Table 1 - Quality indexes of the corn flour

Indexes	Samples of flour	
	Fine meal corn flour	Extruded corn flour
Coarseness, %		
>264 μ	7.0	48.6
>219≤264 μ	53.1	32.7
>195≤219 μ	28.3	18.7
>165≤195 μ	9.9	–
>115≤165 μ	0.8	–
<115 μ	0.9	–
Average diameter of the particles, μ	106.40	115.30
Homogenity of the particles, units of device.	0.59	0.66
Water absorption, %	260	320
Content of the carotene pigments, mg/100 g	0.339	0.733
Amount of amine nitrogen, mg % per 100g (proteolytic activity)	140	420
Autolytic activity, % per dry matters	8.9	9.1
Acidity, grade - after production - after 3 months	 3.2 3.9	 3.3 3.3
Fat content, % per dry matters	2.9	2.6

Structure forming additives

Structure forming additives of carbohydrate origin – xanthan gum - 0.7% of the weight of flour, carboximethylcellulose – 0.3% of the weight of flour were used. This dosage has been installed as optimal. Additives have been added in colloidal solutions.

Structure forming additives of protein origin – dry egg white (DEW) in disoxidated kind – 5% of the weight of flour, gelatin – in colloidal solution – 1 % of the weight of flour were used.

The extruded corn flour was used for making of macaroni samples without usage of structure forming additives (20 % of the weight of mix of corn fine meal flour and extruded flour). Scalding of part of flour – 10% of the total weight – was also used. Part of corn fine meal flour was replaced by the extruded corn flour.

Macaroni samples made from wheat baking flour were used like control sample.

All dough samples were prepared with moisture content 36% at the laboratory press MAKMA-M. Products had a short noodle shape.

Water bond forms

Forms of water bond were investigated by means of derivatograf Q-1000 in temperature interval 20 – 200ºC with speed of heating of samples 1g mass – 1,25°C/min.

Authors have used method of interpretation of derivatograms [12, 13], that helps to determine temperature intervals of different water bond forms due to the analysis of graph of temperature change (TA) and mass of the dough during heating (TG), and its derivates (DTA and DTG). By the dots of DTA curve knee we have marked V of main intervals: I – free moisture (temperature till 40…60°C), II – moisture of macro- and microcappillars (till 110°C), III – osmotically boned moisture (till 120°C). Osmotically boned moisture has low bonding energy although mechanism of the drying relates to removal of water from macro- and microcappillars, both and releasing of cappillars for migration of osmotically bound water; IV – adsorbically bound water (till 145ºC) and V – chemically bound water (higher than 145ºC).

Energy of activation

Energy of activation during water removal was determined due to the Arrenius formula by the obtained triangle, by the tangens of tip angle of hypotenuse that was created in coordinates lnΔt – 1/T: E = R·b/a, when R – universal gas constatnt 0.0083 kJ/moll·K; a – length of adjacent side of triangle (on axis 1/T), mm; b – length of opposite side (on axis lnΔt), mm [14].

Sorption properties

Sorption properties of dry macaroni samples were determined by means of vacuum-statistic method at the Mc-Ben apparatus [15]. The amount of water of monomolecular layer, polimolecular layer and capillary bound water (water of macro- and microcappillars) were determined by the obtained isotherms of sorption-desorption [15]. Determination of the amount was carried out taking into account knee points at adsorption graph in diapasons P/P_s 0.05…0.36; 0.36…0.74; 0.74…1.0 respectively. As authors prove [15], interaction in adsorbic layers (lateral interaction) takes place in case of $P/P_s > 0.3$. This interaction just determines shape of adsorption isotherm at segment of polimolecular water. Cappilar sweating in pores may appear at a high pressure in porous adsorbents, so water is found of hygroscopic state. Data of square, diameter, porous volume and energy of absorption have been obtained by means of isotherms processing for the macaroni products with usage of structure forming additives and without it [15].

3. Results and discussion

Water bond forms

Obtained derivatograms of the researched samples are presented in figure 1.

Results of description of derivatograms of samples made from corn dough with structure forming additives of carbohydrate and protein origin are presented in table 2.

Results show that small amount of unbound water – 1.15-1.53% of overall moisture mass - is lost in I temperature interval as for the wheat dough, both for the samples of dough made from corn flour with xanthan, gelatin and dry egg white. Thus, corn dough with CMC contains 4.48 % of overall unbound moisture content in half-ready product.

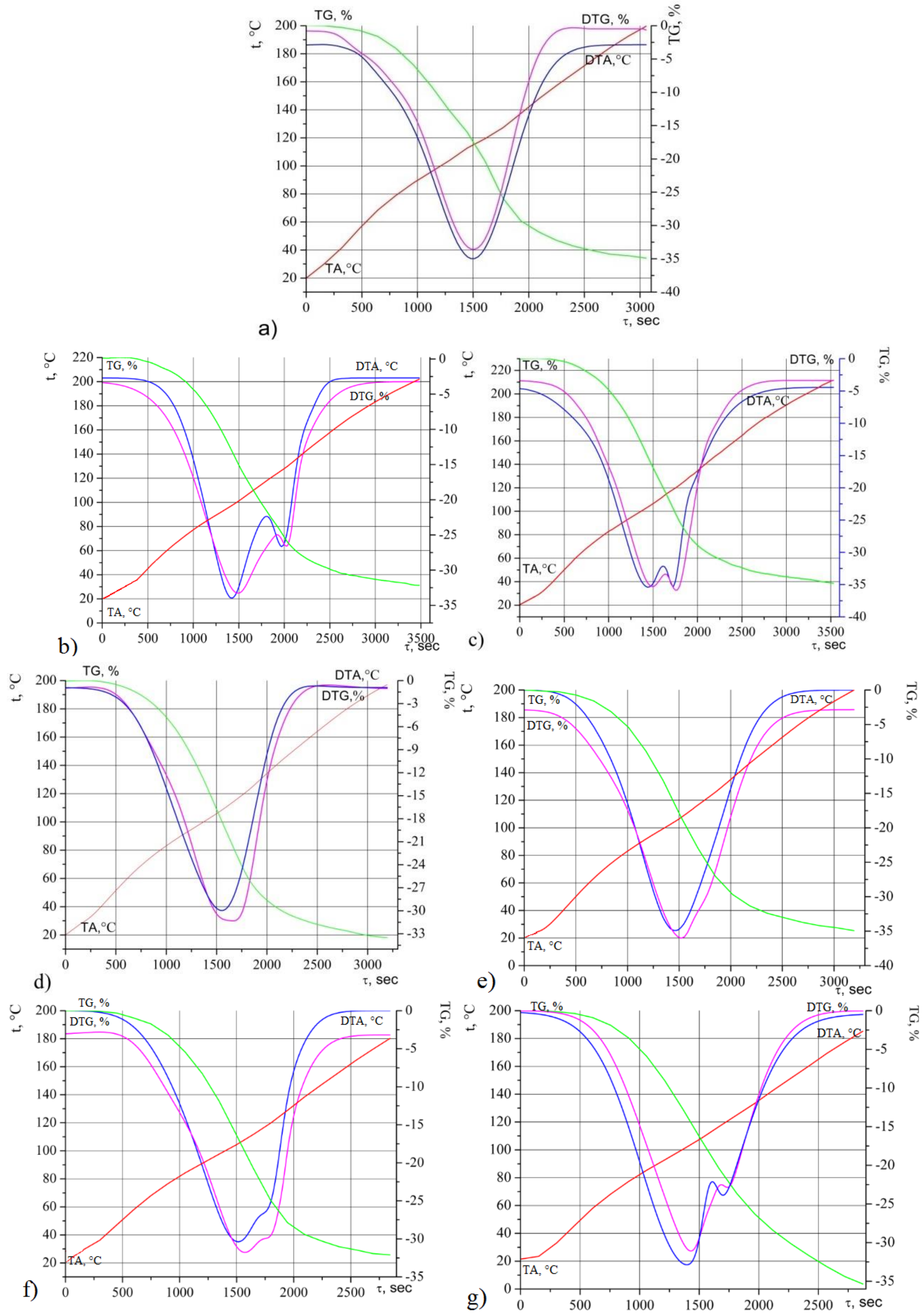

Fig. 1 – Derivatograms of macaroni dough samples made from the flour: a) wheat; b) corn with additiong of xanthan; c) corn with addition of CMC; d) corn with gelatin; e) corn with dry egg white; f) corn with addition of extruded flour; g) corn with part of scalded corn fine meal flour.

Table 2 – Results of description of derivatograms of samples made from corn dough with structure forming additives of carbohydrate and protein origin

Dough samples made from flour	Temperature interval, °C	Moisture loss, mg	Moisture loss, W, %		Energy of activation, kJ/mole
			% of sample mass	% of overall moisture mass	
Wheat (control)	I. 20-34	4.15	0.41	1.15	4.06
	II. 34-110	143.33	14.33	39.81	
	III. 110-120	86.42	8.64	24.00	
	IV. 120-145	105.21	10.52	29.23	
	V. 145-179	20.90	2.09	5.80	
Corn with xanthan gum (0.7 %)	I. 20-44	5.50	0.55	1.53	5.53
	II. 44-97	141.85	14.18	39.40	
	III. 97-118	100.94	10.09	28.04	
	IV. 118-140	79.06	7.91	21.96	
	V. 140-157	32.65	3.27	9.07	
Corn with CMC (0.3 %)	I. 20-60	16.12	1.61	4.48	4.74
	II. 60-100	145.07	14.51	40.30	
	III. 100-117	85.97	8.60	23.88	
	IV. 117-144	83.28	8.33	23.13	
	V. 144-177	29.55	2.96	8.21	
Corn with gelatin (1.0 %)	I. 20-42	5.16	0.52	1.43	7.93
	II. 42-105	196.89	19.69	54,69	
	III. 105-120	73.30	7.33	20,36	
	IV. 120-145	66.57	6.66	18,49	
	V. 145-177	18.07	1.81	5,02	
Corn with dry egg white (5.0 %)	I. 20-41	5.49	0.55	1,52	7.19
	II. 41-104	175.61	17.56	48,78	
	III. 104-120	93.84	9.38	26,07	
	IV. 120-145	68.60	6.86	19,05	
	V. 145-163	16.46	1.65	4,57	

All unbound water from big pores and meshes of these samples of dough is removed at this interval. With increasing of temperature till 110°C (II interval) the water from macro- and microcapillars removes from all samples of dough. Amount of macro- and microcappillar water for the wheat dough and corn dough samples with xanthan and CMC is almost the same – 39.81%, 39.40% and 40.30% of overall amount of water respectively. Weight percentage of water of macro- and microcappillars in corn dough with protein structure forming additives is slightly higher when compared to the other samples and amounts 54.69% in dough with gelatine and 48.78% in dough with DEW respectively.

Amount of osmotically bound moisture (III diapasone) in the corn dough samples is 20.36 – 28.04% of the total amount of water. At that most of this water is in dough with xanthan and DEW – higher approximately on 4.0 – 2.0% of the total amount of `water respectively comparing to the wheat dough sample. This water in samples with CMC is almost the same as in control sample, and in sample with gelatin is lower on 3.64% of the total amount of water than in control sample.

The adsorbically bound moisture in samples of dough from corn flour amounts 18.49 – 23.13% of the total amount of water, bigger amount of it is determined in dough with additives of carbohydrate origin. Amount of adsorbically boned moisture in corn dough with additives is lower for all samples approximately on 6.0 – 11.0% than for wheat dough – 29.23%. During heating over 145°C (V interval) the loss of water that is caused due to the start of oxidation of organic elements and removal of chemically bound water, further destruction of material. The amount of removed water from sample with structure forming additives of carbohydrate origin increases in this interval till 8.21 – 9.07% of the overall amount of water comparing to 5.80% of the wheat dough and amount of removed moisture from the sample with protein structure forming additive decreases approximately on 1.0%.

So, amount of moisture of macro- and microcappillars increases in the samples of dough with protein structure-forming additives, while osmotically boned moisture in sample with DEW increases on 2%. The amount of osmotically bound moisture (in case of xanthan usage) increases in the corn dough with carbohydrate structure-forming additives as well as chemically bound moisture.

Energy of activation

Energy of activation is some higher – on 0.68 – 1.47kJ/mole for the samples with xanthan and CMC and on 3.13 – 3.87 kJ/mole for the samples with protein structure forming additives - comparing to the wheat dough. Obviously, high content of moisture of macro- and microcappillars (samples with protein structure forming additives) and amount of tighly bound water (samples with xanthan and CMC) have the most effect to the energy of activation for these systems.

Results of description of derivatograms of samples made from corn dough without structure forming additives are presented in table 3.

Data of table 3 show that amount of unbound water for the sample of dough that contains part of scalded corn flour is higher than in control sample – 1.45% from the total amount of water. Sample with extruded flour this amount in 2 times lower.

Amount of moisture of macro- and microcappillars for sample with extruded corn flour is 53.48 % of the total amount of water. In dough with part of scalded flour this amount is not by much than in control sample – 41.60% comparing to 39.81% from the total amount of water for the wheat dough. Amount of osmotically bound water in the dough with 20% of extruded flour is less on 5.25% of the total amount of water than in control sample; and in the dough with part (10%) of scalded flour is insignificantly higher (on 0.83%).

Amount of adsorbically bound water in the samples with usage of extruded and scaled corn flour is lower on 6.32% and 8.77% of the total amount of water respectively than in control sample. Obviously, during scalding of fine meal corn flour centers of micells destruct and Van der Waals' forces reduce [3]. Evidently, the same things take place during gelatinization of starch of the corn flour in exdtrusion process.

Energy of activation in the corn macaroni dough samples without addition of structure forming ingredients is higher than in the dough samples made from the wheat flour that has energy of activation 4.06 kJ/mol.

Table 3 – Results of description of derivatograms of samples made from corn dough without usage of structure forming additives

Dough samples made from flour	Temperature interval, °C	Moisture loss, mg	Moisture loss, W, %		Energy of activation, kJ/mole
			% of sample mass	% of overall moisture mass	
Wheat (control)	I. 20-34	4.15	0.41	1.15	4.06
	II. 34-110	143.33	14.33	39.81	
	III. 110-120	86.42	8.64	24.00	
	IV. 120-145	105.21	10.52	29.23	
	V. 145-179	20.90	2.09	5.80	
Corn with estruded corn flour (20%)	I. 20-36	2.53	0.25	0.70	6.61
	II. 36-106	192.54	19.25	53.48	
	III. 106-116	67.51	6.75	18.75	
	IV. 116-143	82.47	8.25	22.91	
	V. 143-160	14.95	1.50	4.15	
Corn with part (10 %) of scalded corn flour	I. 20-35	5.20	0.52	1.45	8.48
	II. 35-103	149.76	14.98	41.60	
	III. 103-119	89.39	8.94	24.83	
	IV. 119-139	73.67	7.37	20.46	
	V. 139-159	41.98	4.20	11.66	

Obtained moisture sorption-desorption isotherms of macaroni samples are presented in fig. 2.

Data of moisture of monomolecular layer, polimolecular layer and hygroscopic moisture are given in table 4 for the corn macaroni samples with addition of structure forming ingredients and in table 6 - for the macaroni samples without addition of structure forming ingredients.

It was found that macaroni products made with usage of structure forming ingredients of carbohydrate origin exert sorbtion capability that is marginally higher (table 5). Amount of adsorbed moisture is 101 – 102% for macaroni products with addition of CMC and xanthan gum compared to the amount of adsorbed moisture of samples from the wheat flour. Nevertheless, the amount of moisture of monomolecular layer for the corn macaroni samples with xanthan gum and CMC is significantly higher (aproximately in 1.5 times) – 18.6% and 17.4% respectively of overall amount of water compared to 12.4 % for the wheat macaroni samples.

Thus, amount of moisture of polymolecular layer on 0.5 – 1.5% and moisture of hygroscopic state approximately on 4.5% reduce in experimental samples when compared to control sample. It suggests increasing of energy of moisture bond in the samples with structure forming additives.

Macaroni samples with structure forming additives of protein origin have slightly reduced sorbtion capability when compared to the wheat samples and corn with additives of carbohydrates origin. The corn macaroni samples with usage of dry egg white contain lowest amount of adsorbed moisture – 88.0% when compared to its amount in the wheat flour. It suggests less evident sorbing effect of these macaroni samples during storage. Macaroni samples with gelatin and dry egg white absorb bigger amount of moisture of monomolecular layer in 1.4 and 1.2 times respectively when compared to the control sample. Thus, amount of cappillar moisture reduces till 83% when compared to the wheat samples.

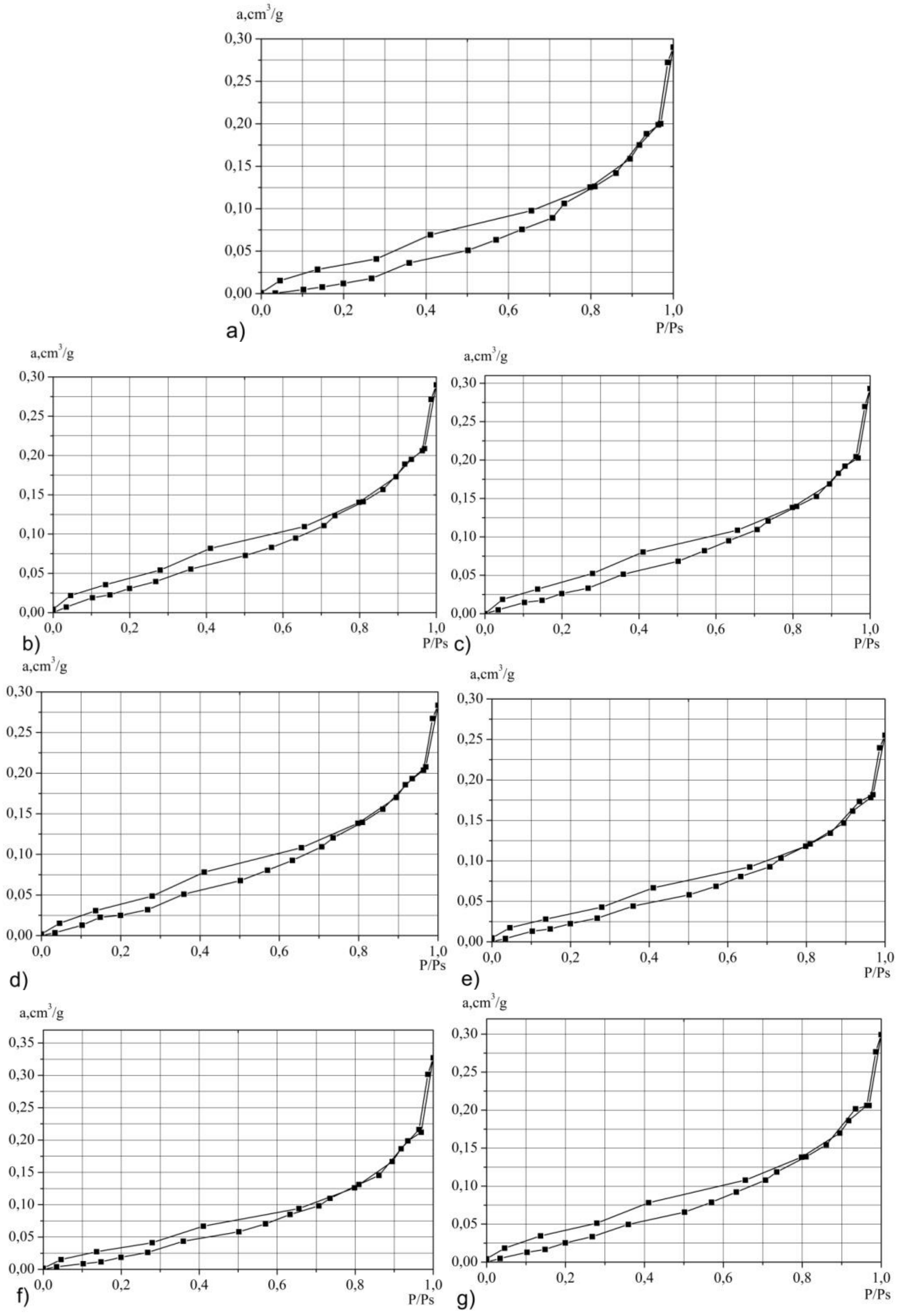

Fig. 2 – Isotherms of sorbtion-desorbtion of water by macaroni products made from the flour a) wheat; b) corn with addition of xanthan gum; c) corn with addition of CMC; d) corn with gelatin; e) corn with dry egg white; f) corn with addition of extruded flour; g) corn with part of scalded fine meal corn flour.

Due to adsorbtion-desorbtion curves analysis the structural characteristics of the macaroni samples with structure forming additives were calculated by means of equation BET [15] (see table 5). Results suggest that in case of equal micropore volumes corn macaroni samples with xanthan gum and CMC have less diameter of pores, and, respectively, bigger square of pores approximately in 1.4 times when compared to the wheat samples. It exerts as an increasing of amount of adsorbed moisture of monomolecular layer both energy of moisture bond in 1.4 times.

Macaroni samples with gelatin and dry egg white have slightly reduced volume of pore, while diameter of them is also less but square is bigger. Due to this energy of moisture sorption is higher – 4.26 and 4.76 kJ/mole when compared to 3.41% kJ/mole for the wheat samples.

Overall amount of adsorbed moisture in macaroni sample with extruded flour without addition of structure forming ingredients is evidently higher when compared to other samples – 113% of control sample (table 6).

Table 4 - Effect of different structure forming additives on the adsorbed moisture content in the gluten-free macaroni products

Macaroni samples made from	Amount of adsorbed moisture										
	Monomolecular layer (p/p_S =0 - 0,36 g/g)			Polymolecular layer (p/p_S = 0,36 - 0,74 g/g)			Hygroscopic state (p/p_S = 0,74-1,0 g/g)			total	
	a, g/g DS	% tof the control	% of the total amount of water	a, g/g DS	% tof the control	% of the total amount of water	a, g/g DS	% of the control	% of the total amount of water	a, g/g DS	% of the control
Wheat flour (control sample)	0.036	100	12.4	0.071	100	24.1	0.184	100	63.5	0.290	100
Corn with xanthan (0.7%)	0.055	153	18.6	0.067	97	22.6	0.174	94	58.8	0.296	102
Corn with CMC (0.3%)	0.051	142	17.4	0.069	99	23.6	0.173	94	59.0	0.293	101
Corn with gelatine (1.0%)	0.051	141	18.0	0.070	99	24.7	0.163	89	57.4	0.284	98
Corn with DEW (5.0%)	0.044	122	17.0	0.060	84	23.5	0.151	83	59.2	0.255	88

Table 5 - Structural characteristics of the macaroni samples with usage of structure forming additives

Macaroni samples	Square of pores, S, m^2/g	Volume of pores, Vs, cm^3/g	Diameter of pores, D, 10^{-10} m	Sorbing energy, kJ/mole
Wheat (control, no additives)	110	0.29	105	3.41
Corn with xanthan (0.7%)	149	0.29	77	4.92
Corn with CMC (0.3 %)	151	0.29	78	4.59
Corn with gelatine (1.0 %)	139	0.28	81	4.26
Corn with DEW (5.0 %)	139	0.26	75	4.76

Macaroni products made from the part of scalded corn fine meal flour contain overall amount of adsorbed moisture that is slightly higher when compared to the wheat sample. Amount of monomolecular layer's moisture for these samples is higher

– 13.5 and 16.7 % of the total amount of adsorbed water for macaroni samples with extruded flour and part of scalded flour respectively. Amount of moisture of polymolecular adsorption for these samples is slightly reduced when compared to the control sample. Macaroni products with extruded flour also contain bigger amount of hygroscopic state moisture – 66.4 % of overall amount of water. Evidently, such meanings of amount of adsorbed water for the macaroni with extruded flour is associated with their more porous structure.

Table 6 - Amount of adsorbed water by macaroni samples made without usage of structure forming additives

Macaroni samples made by	Amount of adsorbed water										
	Monomolecular layer (p/p_S =0 - 0,36 g/g)			Polymolecular layer (p/p_S = 0,36 - 0,74 g/g)			Hygroscopic state (p/p_S = 0,74-1,0 g/g)			total	
	a, g/g DS	% of the control	% of the total quantity of water	a, g/g DS	% of the control	% of the total quantity of water	a, g/g DS	% of the control	% of the total quantity of water	a, g/g DS	% of the control
Wheat flour (control, no additives)	0.036	100	12.4	0.070	100	24.1	0.184	100	63.5	0.290	100
Corn with extruded flour (20%)	0.044	121	13.5	0.066	94	20.2	0.217	118	66.4	0.327	113
Corn with part of scalded flour (10%)	0.050	137	16.7	0.069	98	23.1	0.180	98	60.2	0.299	103

Table 7 - Structural characteristic of macaroni samples made without usage of structure forming additives

Macaroni samples made from	Square of pores, S, m^2/g	Volume of pores, Vs, cm^3/g	Diameter of pores, D, 10^{-10} m	Sorbing energy, kJ/moll
Wheat flour (control, no additives)	110	0.29	105	3.41
Corn with extruded flour (20 %)	115	0.33	115	4.62
Corn with part of scalded flour (10 %)	156	0.30	77	4.59

As can be seen from the table 6 corn macaroni samples with extruded flour provide the maximal volume and diameter of pores – $0.33 cm^3/g$ and $115 \cdot 10^{-10}$m respectively. Nevertheless, square of pores is slightly increased compared to the control sample, which results in lowering the amount of moisture of monomolecular layer than in other corn samples. The energy of moisture sorption for these macaroni samples is higher – 4.62 kJ/mole. Samples that were obtained with addition of part scalded flour provides more fine-pored structure – contain pores of smallest diameter, while square of it is maximum. Energy of moisture sorption for these macaroni samples is also high – 4.59 kJ/mole.

So, to summarize, energy of moisture sorption and amount of the adsorbed water are associated both with its porous structure and square of pores.
The results of previous experimental researches [8] show correlation between structural characteristics of the macaroni samples and its quality. As shown by our study, in case of usage of structure forming additives samples with smallest diameter of pores and high energy of sorption provides the best quality of macaroni, in particular, both for strength and pass of dry substances into the cooking water. For example, macaroni samples with xanthan gum (0.7% of the weight of flour) and dry egg white (5.0% of the weight of flour) provides bigger strength, while pass of dry matters into the cooking water remains lowest when compared to other samples – 9.8% and 11.8% of the dry matters respectively.

4. Conclusion

Obtained results show the correlation of moisture of different bond forms in macaroni dough made from corn flour with usage of different structure forming additives and without. It may determine both rheology of the dough and mechanism of drying process of macaroni products. On the ground of analysis of sorption-desorption curves the sorbtion capability of gluten-free macaroni products made from corn flour with addition of structure forming ingredients and without of it was determined. The characteristic of microporous structure was shown, as well as its impact both on the energy of sorption and forms of moisture bond.
It was proven that the moisture of macro and microcapillaries is prevalent in corn dough – 39.40 – 54.69% of overall amount of water. Amount of this moisture bond is bigger in dough samples with gelatin and dry egg white. Osmotically bound moisture amounts 18.75-28.04% of the total amount of water, which are mostly contained in dough samples with xanthan and gelatin. Content of adsorbed bound moisture in dough samples made from corn flour amounts 18.49 – 23.13% of total amount of water, thus bigger amount of it is determined in dough samples with additives of carbohydrates origin. Increasing of amount of moisture of macro and microcapillaries and lower content of adsorbed bound water in dough made from corn flour obviously will provide fastening of drying of corn macaroni products.
Total amount of adsorbed moisture in macaroni products made from corn flour is slightly changed from this index for the wheat samples. Macaroni samples with extruded corn flour is an exeption, where sorption capability is higher. Thus, corn gluten-free macaroni samples contain significantly higher amount of moisture of monomolecular layer – in 1.2 – 1.5 times, and, energy of sorption is also higher. It may be explained due to the microporous structure of gluten-free macaroni products which is characterized by smaller diameter of pores (except of samples with extruded flour), since square of pores is higher.
This research is taken as a basic of developing of regulatory documentation for producing of the gluten-free macaroni products from corn flour.

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