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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 by structure forming additives of different nature and without them. The correlation between 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. The absorbtion capability of the macaroni products and amount of adsorbed water has been determined. The micropore structure of these samples was characterized. The correlation between structures 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 fact, corn samples obtained higher energy of moisture sorption. The correlation between structural characteristics of the macaroni samples and their quality was shown.*

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

1. Introduction

One of the main tasks of food industry is to provide dietetic foods. Dietetic nutrition is an important factor and it plays an essential part in the complex treatment of different deseases. Dietetic food is a special food that differs from traditional food by chemical content and low caloric value.

Over years a number of metabolic deseases (in particular, celiac desease) has emerged in the population. The celiac – genetic desease involves intolerance to some proteins. The only effective and safe method of celiac treatment is strict dietary intervention during life time that excludes gluten. Gluten is a group of proteins that takes part in forming of wheat dough naming gliadine. Gliadine is an innocuous substance, but it causes allergy or recrudescence at people with genetic predelection for celiac desease [1].

Derived products from corn, rice and buckwheat are often used as gluten-free raw materials in the production of bread, pastries and macaroni products. Corn flour is the most relevant raw material to obtain macaroni products in Ukraine because corn does not contain gluten and it is one of the widely spread cereal crops on this territory. Corn contains higher amount of cellulose, polyunsaturated fatty acids of ω-3 and ω-6 groups, important for the organism, minerals such as ferrum, selenium, folic acid, tokoferol, biotine, β-carotene and others when compared with wheat [2].

Gluten-free macaroni products are not produced in Ukraine and they are provided by the import. The production of macaroni products is closely connected with the role of gluten in forming the structure of dough and ready products. Gluten-free flour does not contain proteins that form gluten, thus the making of macaroni products from corn flour raises some difficulties.

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

Most of the publications concerning the production of gluten-free macaroni products focus on their quality, providing little information about technology, in particular the colloidal processes in dough, kneading, drying processes and storage. For example, the European patent EP 0792109 B1 stipulates the 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 drying. This flour is mixed with water and formed one more time. Still this method has not come into common use obviously because of the additional preparing operations. Also, publications do not contain data on the main quality indexes of macaroni products.

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

Authors have developed macaroni products made from corn fine meal flour by using structure forming ingredients – xanthan gum, carboximethylcellulose (CMC) [6, 8], gelatin and dry egg white [7, 8], as well as without use 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 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 products and changes during its storage.

Determination of energy and forms of water bond in dough as well as investigation on 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 matter	8.9	9.1
Acidity, grade - after production - after 3 months	 3.2 3.9	 3.3 3.3
Fat content, % per dry matter	2.9	2.6

Structure forming additives

Structure forming additives of carbohydrate origin – xanthan gum - 0.7% of the weight of flour, carboximethyl cellulose – 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 to make macaroni samples without use 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 samples. All dough samples were prepared with moisture content 36% in the laboratory press MAKMA-M. Products had a short noodle shape.

Water bond forms

Forms of water bond were investigated by means of derivatograph Q-1000 in temperature interval 20 – 200ºC with speed of heating of samples 1g mass – 1.25°C/min. Authors have used the 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 changes (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 bond moisture (till 120°C). Osmotically bond moisture has low bonding energy although the mechanism of drying is related to the removal of water from macro- and microcappillars, releasing cappillars for migration of osmotically bound water; IV – adsorbically bound water (till 145°C) and V – chemically bound water (higher than 145°C).

Energy of activation

Energy of activation during water removal was determined due to the Arrenius formula by the obtained triangle, by the tangents of tip angle of hypotenuse that was created in coordinates lnΔt – 1/T: E = R·b/a, where 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 by 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 the authors have proved [15], the interaction in adsorbic layers (lateral interaction) takes place in case of $P/P_s > 0.3$. This interaction just determines the shape of adsorption isotherm in the segment of polimolecular water. Cappilar sweating in pores may appear at high pressure in porous adsorbents, so the water found is 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 and without use of structure forming additives [15].

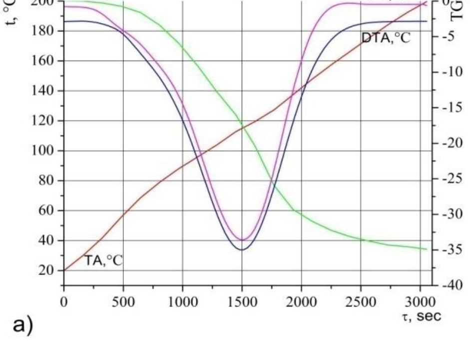
3. Results and discussion

Water bond forms

The derivatograms obtained of the samples under analysis are shown in figure 1.

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

The results show that a small amount of unbound water – 1.15-1.53% of overall moisture mass - is lost in I temperature interval in the wheat dough, for both 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.



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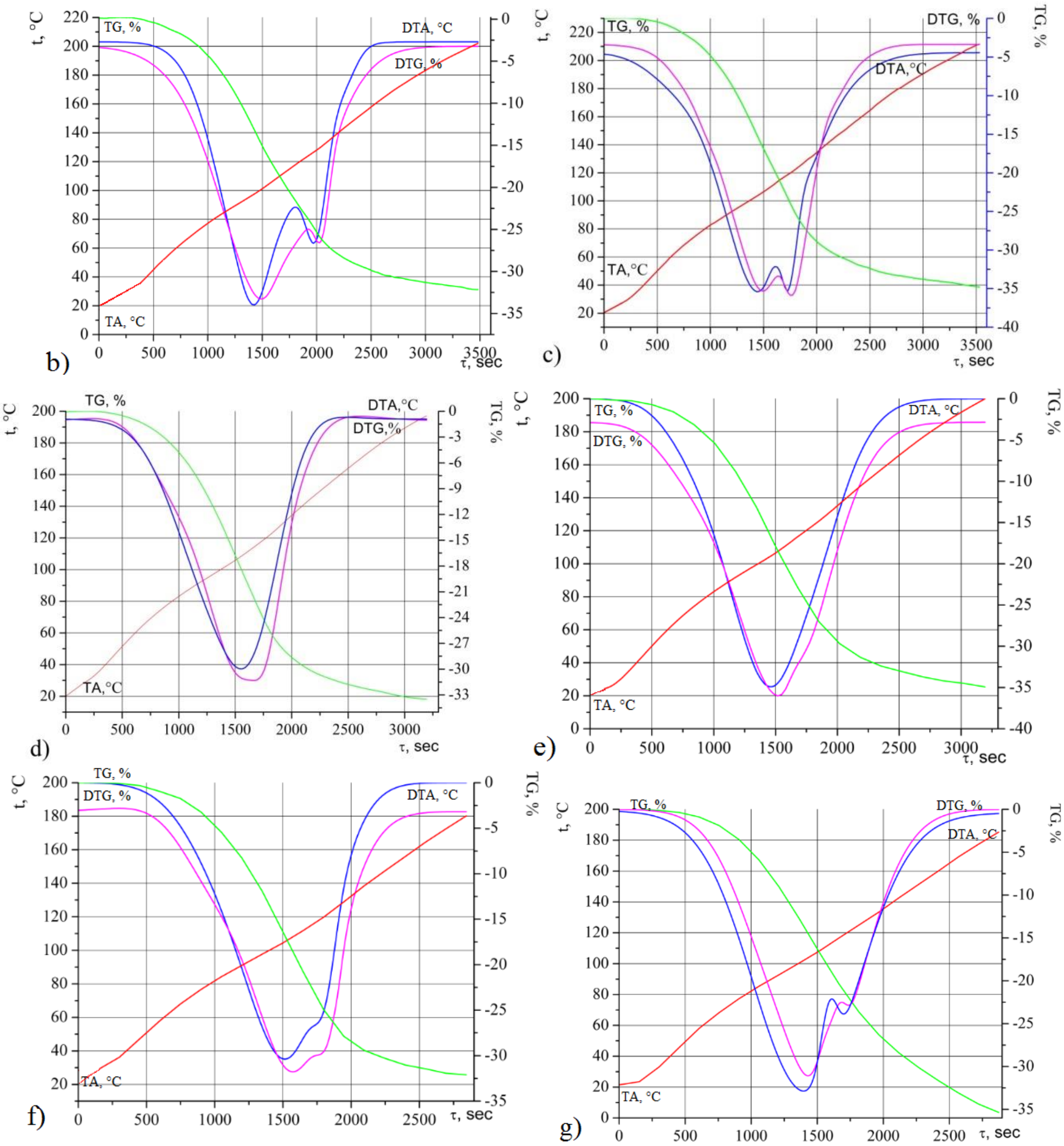


Fig. 1 – Derivatograms of macaroni dough samples made from flour: a) wheat; b) corn with addition of xanthan; c) corn with addition of CMC; d) corn with gelatin; e) corn with dry egg white; f) corn with addition of extruded flour; g) corn with part of scalded corn fine meal flour.

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 in this interval. With the increasing of temperature up to 110°C (II interval) the water from macro- and microcapillars removes from all dough samples. Amount of macro- and micro-cappillar water in 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 micro-cappillars 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.

The amount of osmotically bound moisture (III diapasone) in the corn dough samples is 20.36 – 28.04% of the total water amount. Most of this water is found in the dough with xanthan and DEW – approximately 4.0 – 2.0% of the total amount of `water respectively as compared to wheat dough sample. Water in CMC samples is almost the same as in the control sample, whereas in the gelatin sample it is lower than in the control sample, by 3.64% of the total amount of water.

The adsorbically bound moisture in samples of dough made from corn flour amounts to 18.49 – 23.13% of the total amount of water, a higher amount being determined in dough with additives of carbohydrate origin. The amount of adsorbically bound moisture in corn dough with additives is lower in all the samples approximately by 6.0 – 11.0% than in wheat dough – 29.23%. During heating over 145°C (V interval) water loss is caused by the start of the oxidation of organic elements and removal of chemically bound water, and further on by the destruction of material.

The amount of removed water in samples with structure forming additives of carbohydrate origin increases in this interval up to 8.21 – 9.07% of the overall water amount, as compared to 5.80% of the wheat dough, and the amount of removed moisture in the sample with protein structure forming additive decreases approximately by 1.0%.

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

Energy of activation

Energy of activation is higher – by 0.68 – 1.47kJ/mole in the samples with xanthan and CMC and by 3.13 – 3.87 kJ/mole in the samples with protein structure forming additives - as compared to wheat dough. Obviously, a high content of moisture of macro- and micro-cappillars (samples with protein structure forming additives) and amount of tighly bound water (samples with xanthan and CMC) has the most effect on the energy of activation for these systems.

The results of description of derivatograms of samples made from corn dough without structure forming additives are shown in table 3.

The data of table 3 show that the amount of unbound water in the dough sample which contains part of scalded corn flour is higher than in control sample – by 1.45% of the total water amount. The sample with extruded flour is 2 times lower than this previous amount.

The amount of moisture of macro- and micro-cappillars in the sample with extruded corn flour is 53.48 % of the total water amount. In dough with part of scalded flour this amount is not by much higher than in control sample – 41.60% as compared to 39.81% of the total water amount in wheat dough. The amount of osmotically bound water in the dough with 20% of extruded flour is less by 5.25% of the total water amount than in the control sample; and in the dough with part (10%) of scalded flour is insignificantly higher (by 0.83%). The amount of adsorbically bound water in the samples with use of extruded and scaled corn flour is lower by 6.32% and 8.77% of the total water amount than in the control sample. Obviously, during scalding of fine meal corn flour centers of micells get broken and Van der Waals' forces reduce [3]. Evidently, the same things take place during starch gelatinization of corn flour in the extrusion process. The energy of activation in corn macaroni dough samples without addition of structure forming ingredients is higher than in the dough samples made from wheat flour which has an energy of activation of 4.06 kJ/mol.

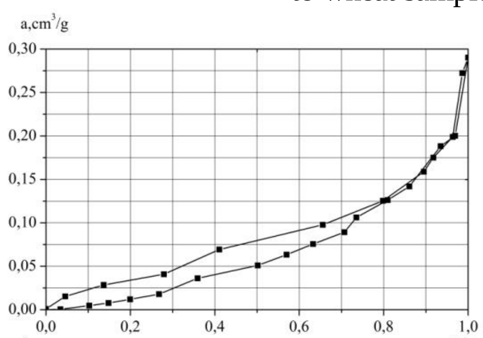
Table 3

Results of description of derivatograms of samples made from corn dough without use 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 extruded 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	

The moisture sorption-desorption isotherms of macaroni samples are shown in the fig. 2.
Data of moisture of monomolecular layer, polimolecular layer and hygroscopic moisture are given in the table 4 for the corn macaroni samples with addition of structure forming ingredients and in the table 6 - for the macaroni samples without addition of structure forming ingredients.
It was found that macaroni products made with use of structure forming ingredients of carbohydrate origin exert sorbtion capability that is marginally higher (table 5). The amount of adsorbed moisture is 101 – 102% for macaroni products with addition of CMC and xanthan gum as compared to the amount of adsorbed moisture of samples made from wheat flour. Nevertheless, the amount of moisture of monomolecular layer for the corn macaroni samples with xanthan gum and CMC is significantly higher (aproximately by 1.5 times) – 18.6% and 17.4% respectively of the overall water amount as compared to 12.4 % in wheat macaroni samples.
Thus, the amount of moisture of polymolecular layer by 0.5 – 1.5% and moisture of hygroscopic state approximately by 4.5% get reduced in the experimental samples when compared to the control sample. It stands for the increase 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 wheat samples and corn with additives of carbohydrates origin. The corn macaroni samples with use of dry egg white contain the lowest amount of adsorbed moisture – 88.0% when compared to its amount in wheat flour. It suggests less evident sorbing effect of these macaroni samples during storage. The macaroni samples with gelatin and dry egg white absorb higher amount of moisture of monomolecular layer by 1.4 and 1.2 times respectively when compared to the control sample. Thus, the amount of cappillar moisture reduces up to 83% when compared to wheat samples.



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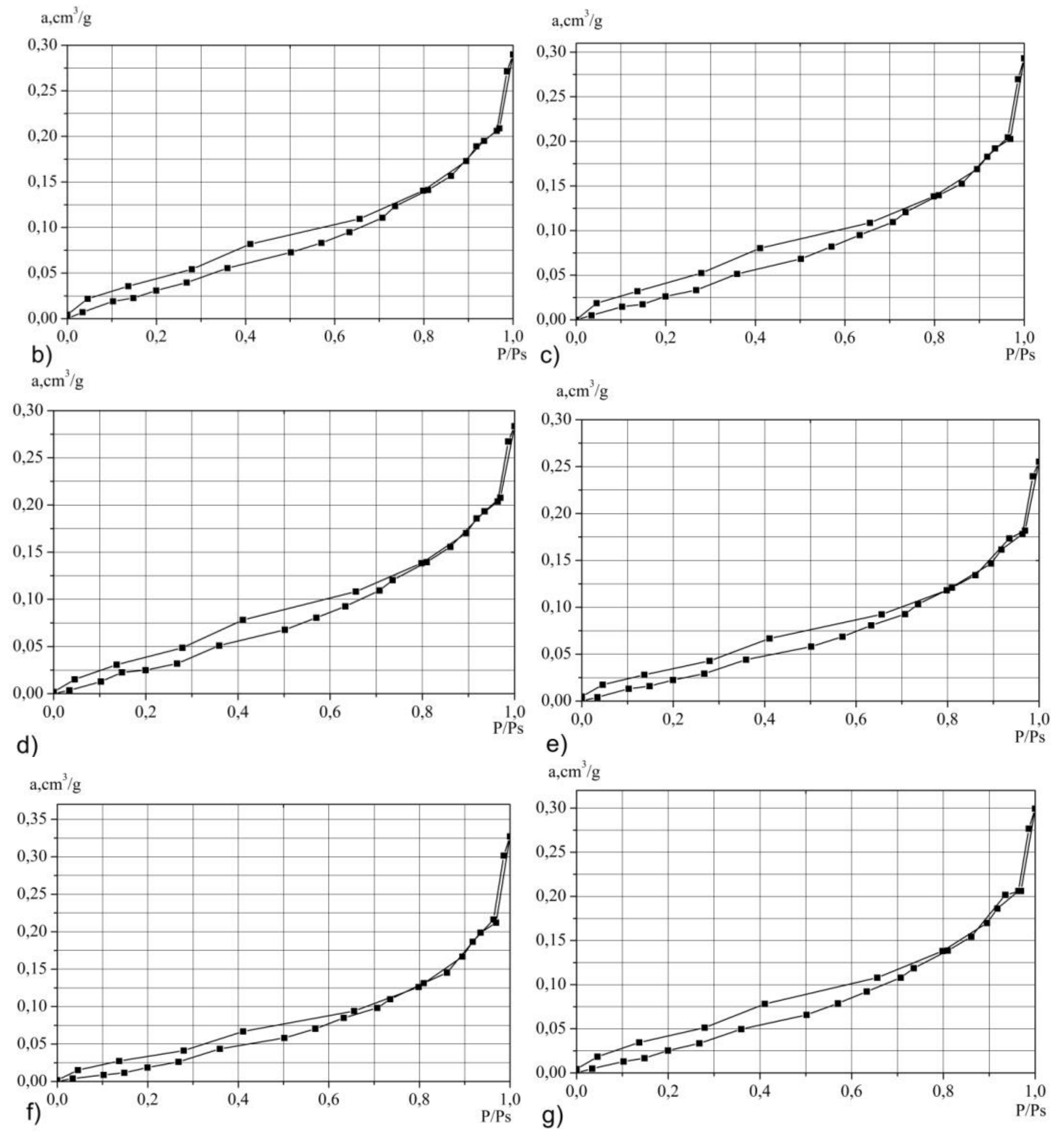

Fig. 2 – Isotherms of sorbtion-desorbtion of water in macaroni products made from flour a) wheat; b) corn with addition of xanthan gum; c) corn with addition of CMC; d) corn with gelatin; e) corn with dry egg white; f) corn with addition of extruded flour; g) corn with part of scalded fine meal corn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

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

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

The 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 use 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 an overall amount of adsorbed moisture that is slightly higher when compared to wheat sample. The amount of monomolecular layer's moisture of these samples is higher – 13.5 and 16.7 % of the total amount of adsorbed water in macaroni samples with extruded flour and part of scalded flour respectively. Amount of moisture of polymolecular adsorption in these samples is slightly reduced when compared to the control sample. Macaroni products with extruded flour also contain higher amount of hygroscopic state moisture – 66.4 % of overall water amount. Evidently, such results of amount of adsorbed water in the macaroni with extruded flour are associated with their more porous structure. 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 as compared to the control sample, which results in lowering the amount of moisture of monomolecular layer than in the other corn samples.

Table 6

Amount of adsorbed water in macaroni samples made without use 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 use 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

The energy of moisture sorption of these macaroni samples is higher – 4.62 kJ/mole. The samples that were obtained with addition of part scalded flour provide more fine-pored structure – contain pores of smaller diameter, while their square is maximum. Energy of moisture sorption for these macaroni samples is also high – 4.59 kJ/mole.

So, to summarize, the energy of moisture sorption and amount of the adsorbed water are both associated with the porous structure and square of pores.

The results of the previous experimental researches [8] show correlations between structural characteristics of the macaroni samples and their quality. As shown by our study, in the case of using structure forming additives in samples with smaller diameter pores and high energy of sorption, the best quality of macaroni is provided, in particular, both in terms of strength and passing of dry substances into the cooking water. For example, the macaroni samples with xanthan gum (0.7% of the weight of flour) and dry egg white (5.0% of the weight of flour) provide greater strength, while the passing of dry matters into the cooking water remains lower when compared to other samples – 9.8% and 11.8% of the dry matters respectively.

4. Conclusion

The results obtained show correlations between moisture of different bond forms in macaroni dough made from corn flour with and without use of different structure forming additives. It may determine both the rheology of 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 and without addition of structure forming ingredients was determined. The characteristics of microporous structure were shown, as well as their impact both on the energy of sorption and forms of moisture bond.

It was proven that the moisture of macro and micro-capillaries is prevalent in corn dough – 39.40 – 54.69% of overall water amount. This amount of moisture bond is bigger in the dough samples with gelatin and dry egg white. The osmotically bound moisture amounts to 18.75-28.04% of the total water amount, being mostly contained by the dough samples with xanthan and gelatin. Content of adsorbed bound moisture in dough samples made from corn flour amounts to 18.49 – 23.13% of total water amount, thus its bigger amount being determined in the dough samples with additives of carbohydrates origin. The increase in the moisture amount 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 in wheat samples. Macaroni samples with extruded corn flour are an exeption, where sorption capability is higher. Thus, corn gluten-free macaroni samples contain significantly higher amount of moisture of monomolecular layer – by 1.2 – 1.5 times, and, the energy of sorption is also higher. It may be explained by the microporous structure of gluten-free macaroni products which is characterized by smaller diameter of pores (excepting the samples with extruded flour), since the square of pores is higher.

This research might be considered a basis of developing regulatory documentation in view of producing gluten-free macaroni products from corn flour.

5. References

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