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Effects of protein-containing additives on pasta quality and biological value

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Abstract: The present work includes results on enrichment of pasta, a mass-consumption product, with protein. Meat products, legume (*Leguminosae* L.) flour and plant protein isolates were used as protein-containing additives. The content of protein and essential amino acids in the additives makes them promising for improving the biological value of pasta. We studied effects of the additives on raw gluten and wheat flour starch properties, pasta dough rheological characteristics, and finished product quality. As a result, the following optimal amounts of the additives were established: 15% by weight of flour for meat, 10% by weight of the mixture for pea and lentil flour as well as plant isolates, and 7.5% by weight of the mixture for soy flour. The enriching components added in pasta dough were found to have a positive effect on pasta quality. These increased protein content by 1.59–8.19%, biological value by 6–16%, utility coefficient of amino acid composition by 0.2–0.26, protein digestibility by pepsin by 11–24%, and daily protein intake level by 31.4–12.5%.

Keywords: Pasta, protein enrichment, biological value

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INTRODUCTION

Pasta is a mass-consumption product in Russia: more than 94% of the population uses it in their diets.

According to the current State Standard for pasta, high-grade and first-grade wheat flour can be used as basic raw material in the bread making industry. Protein content in pasta made from such flour is insignificant [1] and able to meet, on average, only 10.2–16.9% of daily protein requirement for adults [2]. However, the required protein level in a human body is a necessary condition for other nutrients to exert their biological functions. Moreover, it is not protein itself that is of significance but amino acids released in the gastrointestinal tract as a result of hydrolysis; it is amino acids that characterise the biological value of proteins.

In this research, we studied basic nutrients contents in pasta produced from bread flour that was obtained by milling common wheat grains grown in the central region of Russia. Thus, a maximum amount of protein did not exceed 11.1%, and scores of five out of eight essential amino acids were less than 90% [3].

Alternative raw materials as well as additives with higher content of protein and amino acids than that in wheat flour can be an effective way to increase the biological value of pasta. Those can be buckwheat processing products [4], egg products, including dry egg white [5, 6, 7], rye protein concentrate [8], mushroom powder [9], faba beans (*Vicia faba* L.) [10], soy protein concentrate [11], corn gluten [12], and even beef emulsion [13]. In some cases wheat flour is replaced with lupin (*Lupinus* L.) [12], defatted soy [9], kidney beans (*Phasedus vulgaris* L.) [12], whole grain amaranth, banana, and rice flours [12, 14, 15], etc.

As known, the human body assimilates proteins and carbohydrates effectively if their ratio is 1.4:1.45. In the case of pasta, the ratio of proteins to carbohydrates is 1:7. We took this fact into consideration when developing a new type of pasta with increased biological value and

Table 1. Characteristics of high-grade wheat flour samples for bread making

Parameters	Samples		
	no.1	no.2	no.3
Moisture content, %	10.60	10.80	13.00
Ash content, %	0.55	0.54	0.54
Acidity, °	2.00	2.00	2.20
Raw gluten content, %	28.80	29.50	29.50
GDI (gluten deformation index), units	100.00	77.50	80.00
Cohesion strength, N	4.10	3.10	5.50
Water-absorbing ability, %	200.70	183.00	198.00

when determining optimal amounts of protein-containing additives.

Since effectiveness of the latter directly depends on specific concentration of proteins, it is this parameter that was a key factor that we considered in choosing the additives. The additives would tend to reduce the content of gluten proteins which take part in product structure formation. Therefore, the more protein the additives contain, the lower amount of those is needed to provide pasta with this critical nutrient and ensure a high quality of the finished product.

The aim of this project was scientific and practical justification for the using of protein-containing additives of plant and animal origin to increase the biological value of pasta while maintaining/improving quality characteristics of the additives.

In this research we set the following tasks: to study effects of protein-containing additives on properties of raw gluten and wheat flour starch as texturizing agents, as well as their effects on rheological properties of pasta dough and quality characteristics of pasta, primarily on their organoleptic and cooking properties; to study effects of the enriching components added into pasta dough on protein content in pasta, biological value and amino acid balance of protein, utility coefficient of amino acid composition, protein digestibility by the proteolytic enzyme pepsin, and on daily protein intake level.

STUDY OBJECTS AND METHODS

Subjects of the research were wheat flour for bread making State Standard 52189-2003* (Table 1) as well as samples of pasta dough and finished pasta. We used the following enriching ingredients: meat products, namely chicken breasts and cooled B-grade veal meat (in amounts of 10% and 15% by weight of flour); legume flours, namely deodorized, low-fat soy flour (5%, 7.5% and 10% by weight of the mixture), pea and lentil flours (5% and 10% by weight of the mixture) in accordance with regulatory documents; and isolates of soy, pea, and corn proteins (in amounts of 5%, 10%, 15% and 20% by weight of the mixture). The isolates were produced by Dezhou Ruikang Food Co. (China), Cosucra Group (Belgium), and OOO Zvyaginki Krakhmalnyy Zavod (Russia), respectively. The corn isolate met the requirements of TU 9189-008-27291178-2005**. All the components contained protein with balanced amino acid composition (Table 2).

A traditional technology was used to produce high-protein pasta. The technology included the following steps: raw materials preparation, basic raw and enriching additives weighing-out, pasta dough kneading and pressing, pasta formation, cutting, pre-drying, putting on drying surfaces, final drying, stabilizing, and cooling. The additives were mixed with legume flours and plant protein isolates. In the case of meat additives, minced meat of at most 325 μm in size with formulation water quantity was introduced into pasta dough. To determine optimal amounts of the additives, we studied their effects on wheat gluten and starch characteristics, pasta dough rheological properties, and finished product quality.

To analyse the properties of raw wheat gluten, starch, and pasta dough, we applied ordinary techniques. The following devices were also used: a drying cabinet (Mogilev-Podolskiy Priborostroitel, Ukraine), a luxmeter 'Kvarts-21M' (Russia), a ST-1 texture analyser (mode 2 and 3) (OOO NPP Radius, Russia), and 'Amilotest' (mode 2) (OOO NPP Radius, Russia).

The rheological properties of pasta dough were determined by means of a device similar to a capillary viscometer, with a capillary length of 30 mm and a diameter of 3 mm.

Protein mass fraction in the additives and the finished pasta were determined by Nessler method [16] and Lowry method [17] (calibration curves were constructed using serum albumin). The amino acid composition of protein we determined by a liquid chromatography method with some modifications (Spackman method) using an amino acid analyser Chromaspek (USA). Essential amino acid scores (AAS), %, and coefficients of distinction amino acid scores (CDAAS), i.e. average values of essential amino acid scores redundancy in comparison to the lowest score value of an essential amino acid, were calculated as follows:

$$\mathrm{AAS} = \frac{\text{content of amino acid in 1 g of test protein}}{\text{content of the same amino acid in 1 g of reference protein}} \cdot 100, \quad (1)$$

$$\mathrm{CDAAS} = \frac{\sum_{i=1}^{N}(\mathrm{AAS_i} - \text{the lowest AAS})}{\mathrm{N}}, \quad (2)$$

where N is essential amino acids content, and AAS_i is amino acid score of the i-th amino acid, %.

To calculate biological value (BV), %, which is an indicator of protein quality, the following equation was used:

$$\mathrm{BV} = 100 - \mathrm{CDAAS}. \quad (3)$$

Utility coefficient (U), which characterises essential amino acid balance to the reference value, was found as follows:

$$\mathrm{U} = \mathrm{C_{min}} \frac{\sum \mathrm{M_{ri}}}{\sum \mathrm{M_i}}, \quad (4)$$

where C_{min} is the lowest amino acid score; M_{ri} is the content of the i-th essential amino acid that corresponds with the reference value, g/100 g protein; and M_i is the content of the i-th essential amino acid in the test pro-

* State Standard 52189-2003. 'Wheat flour. General technical specifications'.

Table 2. Amino acid composition and content of protein in additives

Parameter	Protein-containing additives							
	chicken	veal	legume flours			plant protein isolates		
			soy	pea	lentil	pea	corn	soy
Protein content, %	23.0 ± 0.1	22.3 ± 0.1	44.2 ± 0.1	24.25 ± 0.1	31.4 ± 0.1	90.9 ± 0.1	91.3 ± 0.1	92.5 ± 0.1
Amino acid content, mg/100 g product / Score, %:								
Isoleucine	916 / 100	1,148 / 129	1,807 / 102	1,407 / 145	1,291 / 103	4,190 / 115	4,510 / 123	4,440 / 120
Leucine	2,017 / 125	1,712 / 110	2,678 / 87	1,964 / 116	2,393 / 109	7,910 / 124	12,760 / 199	7,678 / 119
Valine	994 / 86	1,287 / 115	2,517 / 114	1,285 / 106	1,608 / 102	4,730 / 104	4,510 / 99	4,348 / 94
Lysine	1,879 / 149	1,918 / 156	2,195 / 90	1,619 / 121	2,178 / 126	7,000 / 140	2,770 / 55	5,920 / 116
Threonine	1,052 / 114	975 / 109	1,887 / 107	1,062 / 109	1,215 / 97	3,545 / 97	3,650 / 99	3,608 / 98
Methionine + Cysteine	918 / 133	805 / 103	1,062 / 69	648 / 76	652 / 59	2,090 / 67	2,050 / 64	2,312 / 71
Tryptophan	365 / 159	284 / 127	581 / 131	239 / 99	279 / 89	910 / 100	980 / 107	1,018 / 110
Phenylalanine + Tyrosine	1,274 / 92	1,680 / 125	3,891 / 147	2,196 / 151	2,603 / 138	8,640 / 158	7,260 / 133	8,500 / 153

Table 3. Amino acid scoring system recommended by FAO/WHO

Amino acid	Content in 1 g of ideal protein, mg
Isoleucine (Ileu)	40
Leucine (Leu)	70
Valine (Val)	50
Lysine (Lys)	55
Threonine (Thr)	40
Methionine (Met) + Cysteine (Cys)	35
Tryptophan (Trp)	10
Phenylalanine (Phe) + Tyrosine (Tyr)	60

duct, g/100 g protein.

We used the amino acid scoring system recommended by FAO/WHO Committee to compare content of each individual amino acid with that of the same amino acid in the ideal protein (Table 3). Unsettleable proteolytic products were an indicator of digestibility of the pasta proteins, with use of trichloroacetic acid (TCA) and Folin's reagent. The statistical analysis of the results was carried out by means of MS Excel and Statistica 6.0 programmes.

RESULTS AND DISCUSSION

We studied effects of the protein-containing additives on the quality characteristics of the pasta developed, such as sensory and cooking properties, properties of raw gluten and starch as basic texturizing agents, as well as rheological characteristics of the pasta dough (Tables 4 and 5, Fig. 1) [3]. Three control samples of wheat flour (Table 1) were used for the experiments.

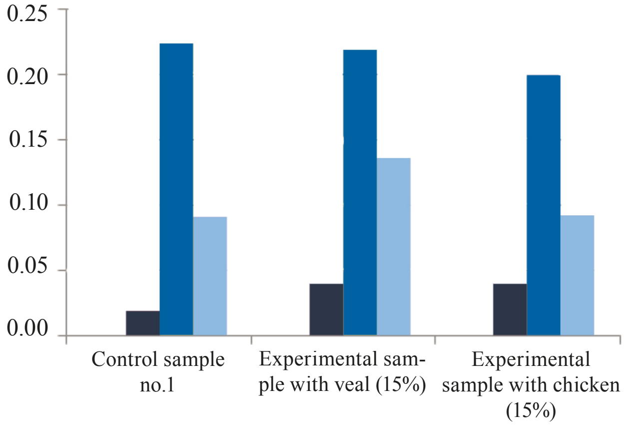
According to the results obtained, the following optimal amounts of the additives were established: 15% by weight of flour for the meat additives, 7.5% by weight of the mixture for soy flour, 10% by weight of the mixture for pea and lentil flours, as well as for the protein isolates of corn, pea, and soy. It was found that these amounts of the enriching components:

– improved consumption characteristics;

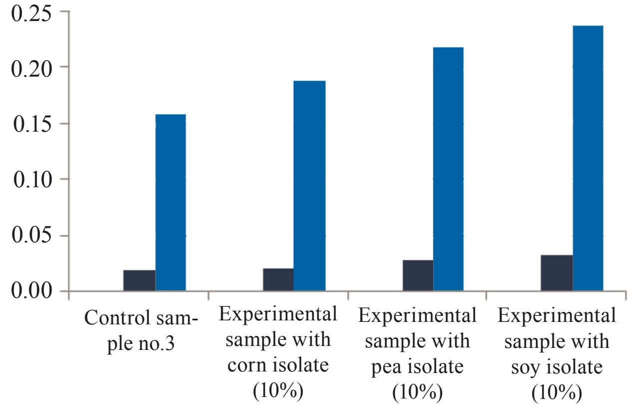
– improved wheat gluten elasticity (N_{el}^{GDI}) by 35; 2–10; and 12.5–22.5 units for meat additives, legume flours, and plant protein isolates respectively;

Table 4. Effects of protein-containing additives on properties of raw wheat gluten and starch

Pasta samples	Values						
	Raw gluten content, %	GDI, units	Cohesion strength of gluten, N	Water-absorbing ability of gluten, %	Gelatinization temperature of starch, °C	Temperature of maximum viscosity of starch gel, °C	Viscosity of starch gel at gelatinization temperature, N
Control sample no. 1	28.83 ± 0.1	100.0	4.1	200.7 ± 0.75	65.0	93.5	10.5 ± 0.1
Experimental samples with meat additives , % by weight of flour:							
Veal (15 %)	28.5 ± 0.1	65.0	4.0	212.5 ± 0.75	61.0	90.5	8.95 ± 0.1
CHicken (15 %)	28.6 ± 0.1	65.0	3.9	207.0 ± 0.75	62.0	91.0	9.23 ± 0.1
Control Sample no. 2	29.5 ± 0.1	77.5	3.1	183.0 ± 0.75	65.0	94.0	8.34 ± 0.1
Experimental samples with legume flours , % by weight of mixture:							
Soy flour (7,5 %)							
Lentil flour (10 %)							
Pea flour (10 %)							
Control sample no. 3	29.5 ± 0.1	80.0	5.5	198.0 ± 0.75	75.0	95.0	5.55 ± 0.1
Experimental samples with isolates of plant proteins, % by weight of mixture:							
Corn (10 %)	26.78 ± 0.1	72.5	7.7	184.0 ± 0.75	75.0	95.5	5.37 ± 0.1
Pea (10 %)	29.21 ± 0.1	57.5	5.9	165.3 ± 0.75	75.0	95.5	4.94 ± 0.1
Soy (10 %)	28.42 ± 0.1	67.5	6.9	166.7 ± 0.75	74.5	95.5	4.83 ± 0.1



(a)



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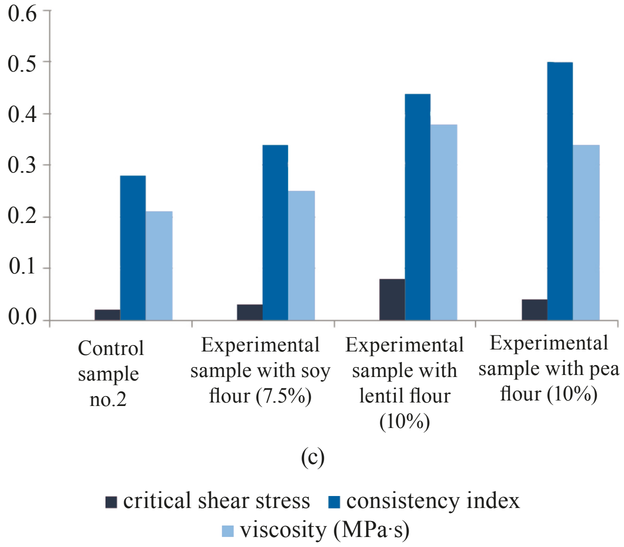

Fig. 1. Rheological properties of pasta with and without enriching additives: (a) meat; (b) plant protein isolates; (c) legume flours.

– increased the temperature of starch gel maximum viscosity by 0.5–1.5°C for legume flours and plant protein isolates (for meat additives, this parameter remained unaffected apparently due to a lower mass fraction of starch in the flour–water suspension);

– increased critical shear stress, a basic rheological characteristics of pasta dough, by a factor of 2; 1.5–4; and 1.1–1.7 for the additives from meat, legume flour, and plant protein isolates, respectively; and

– decreased dry matters passed into water, a key factor of cooking properties of pasta, by 1.93–2.29% for meat additives and by 1.6–2.22% for legume flours (in the samples with plant protein isolates the value did not exceed 0.4%).

It should be noted that one of causes of improved raw gluten elasticity and pasta dough rheological properties is interaction between protein substances of the additives and gluten proteins.

According to the research conducted by Chizhova in 1979, an equal distribution of molecular mass is of significance for forming an optimal gluten network. Thus, proteins with low/medium weight, which are soluble in water and salt solutions, can become an intermediate building material. Medvedev has proved that protein substances having lower molecular weight than wheat flour proteins interact with gluten proteins in dough and contribute to coagulation structure formation.

As known, the strength of intermolecular bonds, which determine gluten gel structure, directly depends on solubility of gluten proteins. To analyse the interaction of protein substances of the additives with gluten, we

Table 5. Effects of protein-containing additives on pasta quality

Pasta samples	Values			
	Titratable acidity, °	Shear strength, N	Weight ratio of dry pasta to cooked pasta	Dry matters passed into cooking water, %
Control sample no.1	2.0	4.30	2.10	9.66 ± 0.1
Experimental samples with meat additives:				
Veal (15%)	2.5	5.20	1.88	7.37 ± 0.1
Chicken (15%)	2.8	5.00	1.90	7.73 ± 0.1
Control sample no.2		2.96	1.83	6.20 ± 0.1
Experimental samples with legume flours:				
Soy (7,5%)	–	3.09	2.30	4.76 ± 0.1
Lentil (10%)	–	3.85	2.46	3.98 ± 0.1
Pea (10%)	–	3.61	2.46	4.21 ± 0.1
Control sample no.3	2.2	2.80	2.89	8.30 ± 0.1
Experimental samples with isolates of plant proteins:				
Corn (10%)	2.2	3.40	2.93	8.50 ± 0.1
Pea (10%)	2.2	3.70	2.94	8.60 ± 0.1
Soy (10%)	2.2	3.80	2.95	8.70 ± 0.1

studied their influence on the solubility of gluten in a polar solvent. In other words, we determined an amount of gluten protein which passed into the solvent from gluten, as the less proteins interact with each other, the more proteins pass into the solvent. 6M urea solution was used as a solvent since, as Medvedev found in 2004, in this case the type and amount of a protein-containing additive, rather than properties of gluten itself, had an effect on its solubility. An amount of protein passed into the polar solvent was determined by Lowry method. A graduation curve was constructed on serum albumin.

Optimal amounts of protein-containing additives in the pasta dough were found to reduce the passage of proteins from gluten into 6M urea solution. This fact proved the presence of strong bonds between molecules or aggregates of gluten proteins and the change in their structures. Moreover, the moving of dough inside an extruder barrel causes plastic deformation of particles and their sticking. As a result, interaction forces between proteins of gluten and those of the additives undergo increase (Fig. 2), which reduces the protein solubility.

As one can see from Table 5, the addition of plant isolates into dough impair the cooking properties of pasta, namely contribute to passage of dry substances into cooking water. Therefore, we studied qualitative characteristics of initial raw materials, above all mass fraction of raw wheat gluten, and their effects on the passage of dry substances into water during cooking. For that, three samples of wheat flour with different raw gluten content were used. According to the results of the experiment, the lower the raw gluten content is in flour, the greater amounts of dry matters pass into the cooking water.

The statistical analysis of the results showed a dependence of raw wheat gluten content and plant isolates amounts on the content of dry substances passing into water during the cooking process:

$$P_{d.m.} = y = 8{,}3(0.83 + 0.0133x_1)(1.53 - 0.02x_2), \quad (5)$$

where y is an amount of dry substances passed into the cooking water, %; x_1 is an amount of a plant isolate, % by weight of the mixture; x_2 is gluten content,%.

Table 6 gives the main quality characteristics of the protein in the enriched pasta. Analysis of the obtained data revealed:

The protein-containing additives, namely chicken and veal meats, pea, soy, and lentil flours, as well as corn, pea, and soy protein isolates, significantly increased protein content in the pasta – by 2.81, 3.08, 2.48, 1.59, 1.93, 7.49, 7.10, and 8.19% respectively.

Essential amino acids content in total amino acids was 29% for the samples with chicken and veal; 30, 29.2, and 31.3% for the samples with legume flours; and 35%, on average, for pasta with plant proteins isolates. It is a known fact that the amount of essential amino acids, including cysteine and tyrosine, should be 36% of total amino acid content for adults. The content of essential amino acids in the experimental samples was 4.1, 5.1, 4.3, 6.4, and 10.1% higher than in the control samples. Moreover, the content and scores of each essential amino acids, with some exceptions, had higher values than the control samples.

The biological value of protein in the samples with the additives was 6–16% higher than that in the control samples (except for corn protein isolate).

The utility coefficient of amino acid composition (whose theoretical value was 1) was 0.2–0.26 units higher in the experimental samples than that in the control samples.

100 g of the enriched pasta was able to meet 31.4–12.5% of daily protein requirement. That value for the control samples was 18–11%.

The protein digestibility of the enriched cooked pasta by pepsin was, on average, 11–24% higher than that of the control samples. One of the causes is balanced amino acid composition: proteins with a high biological value are digested and assimilated well. Another cause is an increased mass fractions of water-soluble and salt-soluble proteins in the pasta with protein-containing additives: albumins and globulins of both animal and plant origin are readily broken down by pepsin.

Since combined protein mixtures are considered to be quite effective in the development of a biologically valuable product, we calculated (by means of Microsoft Excel) a formulation of the pasta with mixtures of plant protein isolates in the amount of 10%. Thus, the following ratios of wheat flour to soy, pea, and corn isolates ensuring a high biological value of the finished pasta were established: 90:0:5:5 (BV = 73%), 90:3:3:4 (BV = 72%), 90:4:2:4 (BV = 72%), and 90:7:0:3 (BV = 72.5%). Furthermore, protein content in the pasta was 19.1–19.4%, essential amino acids content was, on average, 33.5% by total amino acids, and the utility coefficient was 0.69–0.70 units.

The experiments established that the combined protein mixtures enhanced the mechanical strength of dry pasta by 35.7–57.1% and the weight ratio of dry pasta to cooked pasta by 1.7–3.1%. Moreover, the value of dry matters passed into cooking water was virtually equal to that of the control sample. Thus, the combined protein mixtures allowed us to make qualitative pasta with higher biological value.

It should be noted that the duration of the drying process reduced for all samples with the protein-containing additives, except for pasta with soy flour. This might be due to an increased content of protein fractions whose molecular mass is lower than those of gluten proteins. They bind water mainly osmotically, and the binding is rather weak, so removing absorbent-bound water greatly reduces. The drying time of the pasta with soy flour, however, increased by 10 min compared to the control sample. This is due to the fact that soy contains lipids and a greater amount of dietary fibre (2.9 g per 100 g) forming strong bonds with water, the removal of which took longer than in the control sample [3].

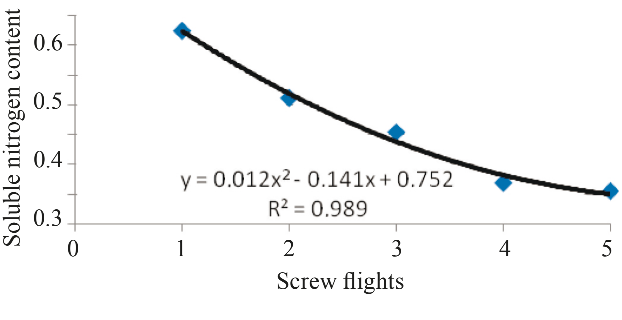

Fig. 2. Content of ammonium nitrogen passed into solution (in dough samples from different flights of the screw).

Table 6. Quality characteristics and composition of protein in pasta with protein-containing additives

Parameter	Pasta samples							
	control	chicken (15%)	veal (15%)	soy flour (7,5%)	pea flour (10%)	lentil flour (10%)	pea isolate (10%)	corn isolate (10%)
Protein, %	11.10	13.91	14.18	13.58	12.69	13.03	18.59	18.68
Daily value, %	18–11	22.6–13.6	23–14	22.1–13.3	20.6–12.5	21.2–12.8	30.2–18.2	30.4–18.3
Essential amino acids, %	2.69	3.53	3.82	3.58	3.30	3.52	5.52	6.21
Amino acid score, %							78	
isoleucine	65	66	71	74	75	75	85	91
leucine	71	72	77	75	83	80	75	135
valine	56	59	61	71	63	68	77	69
lysine	36	56	60	50	54	59	153	47
threonine	146	134	145	136	120	136	60	126
methionine + cysteine	54	64	66	61	56	66	97	60
thryptophan	97	109	103	110	102	100	108	105
phenylalanine + tyrosine	92	91	98	103	95	93		142
Essential amino acids, % by all amino acids	24.9	25.6	27.3	27.0	26.7	28.6	30.5	33.8
Biological value, %	59	75	75	65	73	74	68	51
Utility coefficient of amino acid composition, units	0.53	0.79	0.79	0.74	0.75	0.79	0.73	0.53
Coefficient of distinction amino acid score, %	41	25	25	35	27	26	32	49

As an example, Fig. 3 gives drying curves for semi-finished pasta (the control sample and the sample with pea protein isolate).

Statistical analysis of the experimental data resulted in a third-order equation describing the dependence of the drying time of the semi-finished pasta with the protein-containing additives on the protein content in it:
for the first stage of drying (at 55°C, until the moisture of 20%)

$$y = 0.012x^3 – 0.5587x^2 + 8.4295x – 38{,}452, \text{ and}$$

for the second stage (at 45°C, to the final moisture)

$$y = 0.0041x^3 – 0.1961x^2 + 3.0197x – 10.797,$$

where y is drying duration, min; and x is protein content in pasta, %.

The last step of the research included the evaluation of the novel pasta competitiveness. The integral index characterisng a product competitivenes, was higher than 1 for all the experimantal samples. The summery index reflecting the quality and nutritional value of the pasta with the protein additives, was 70% higher than that of the control sample (1.7 vs. 1.0).

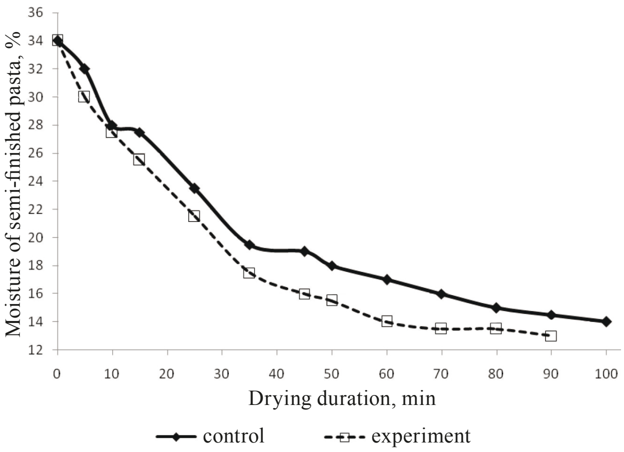

Fig. 3. Drying curves for semi-finished pasta.

CONCLUSION

In summary, the protein-containing components added into the pasta dough contribute to high quality formation of the finished product as well as the quality and quantity of protein substances in pasta made from bread flour. It should be noted that meat additives, pea and lentil flours, as well as soy isolate were the most effective to improve the biological value of the pasta. This characteristic in the developed pasta increased by 6–16% compared to the control samples. Additionally, the amino acid balance also improved. Consequently, the use of protein-rich pasta in the human diet will improve its nutritional value.

All new types of pasta enriched with protein-containing additives are supported by technical specifications and technological instructions. Pasta dough formulations are protected by the Patent of the Russian Federation.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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