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THE ADAPTATION OF PANCREATIC SECRETION AND METABOLISM IN ANIMALS WITH DIFFERENT DIGESTION TYPE TO CHANGES IN DIETARY PROTEIN INGREDIENTS

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Abstract

The adaptation of the pancreas to diet composition is still a matter of discussion. The methodical difficulties related to the sampling of pure pancreatic juice resulted in the scarce and discrepant published data on the alterations of exocrine pancreatic secretion in response to changes in diet composition (A.D. Sineshchekov, 1965; P.P. Berdnikov, 1990; Ts.Zh. Batoev, 2001; A. Huget et al., 2006; V.I. Fisinin et al., 2017; K. Liu et al., 2018); the effects of individual dietary ingredients on the pancreatic secretion were not scrutinized to date. We present a comparative study on the alterations of exocrine pancreatic function in response to the change in dietary protein source (substitution of sunflower cake for soybean cake or meal) with the use of similar methodology for animals with different digestion type; this approach can reveal both specific and common patterns in the respective adaptive reactions. The study was performed on 18 laying hens (*Gallus gallus domesticus* L.; cross Hisex White) at 10-12 months of age including 3 hens with chronic fistulae of main pancreatic duct inserted according to the method of Ts.Zh. Batoev (2001), and on 9 piglets (*Sus scrofa domesticus* L.; hybrid of Danish Landrace and Danish Yorkshire breeds) at 5 months of age and 45-55 kg of live bodyweight including 3 intact piglets, 3 piglets with cannulated pancreatic duct, and 3 piglets with ileal cannulae. It was found that the most responsive enzymatic activity in chicken is lipase: in hens fed diet with sunflower cake the basal (preprandial) level of lipase activity was significantly higher by 37.7 % in compare to diet with soybean meal, postprandial lipase activity in 90 min after feeding higher by 46.6 %; in 150 min after feeding higher by 93.7 % ($p < 0.05$). The shift from soybean meal to sunflower cake resulted in the significant increase in crude fat digestibility by 3.5 % ($p < 0.05$). This shift was also found to increase the postprandial protease activity though similar response of crude protein digestibility was not found. To the contrary, the same shift in diet composition in pigs resulted in the significant decrease in postprandial protease activity by 43.8 % ($p < 0.05$); no alterations were found in the digestibility of crude protein probably due to the presence of trypsin inhibitor(s) in soybean meal. Regardless of the similar total volumes of pancreatic juice secreted in pigs during the sampling period with different dietary protein sources the dynamics of the postprandial pancreatic secretion substantially differed with these sources both in the complex-reflex and neurohumoral regulative phases. The exocrine pancreatic function in chicken was considerably more strenuous in compare to pigs: the relative (per 1 kg of live bodyweight) volume of pancreatic juice secreted in chicken was 2.2-fold higher, total amylase activity secreted was 94-fold higher, protease activity 145-fold higher, lipase activity 17-fold higher in compare to pigs. The tryptic activity in blood serum in chicken was 7-fold higher in compare to pigs evidencing higher metabolic intensity. Therefore, when changing the dietary ingredients the functional peculiarities of the adaptation of pancreatic

secretion to these shifts in the productive animals with different digestion type should be taken into account since exocrine pancreatic function and feed digestibility are correlated and can, in turn, jointly affect the productive performance.

Keywords: pancreas, exocrine pancreatic function, chicken, pigs, activities of digestive enzymes in blood serum

The adaptation of the pancreas to the diet composition in animals is still a matter of discussion. There is an opinion about parallel changes in the enzymatic activity in pancreatic juice. According to the parallel secretion hypothesis, the activity of pancreatic enzymes changes in the same proportions, regardless of the food components [1]. Such results were obtained in cannulated dogs that constantly lost pancreatic juice, in which the ability of the pancreas to adapt the enzymatic composition of the secret to the nature of the food was significantly impaired [2]. Such an imbalance occurs in diseases of the digestive system, as well as in the case of excess intake of nutrients, in particular fats [2]. However, there is a large amount of experimental data indicating the ability of the pancreas to change the enzymatic activity and juice production depending on the composition of the consumed food [3-6]; it is also described for birds [7-11]. Evidence of adaptation of the digestive glands to the quality of food was obtained using modern methods in the process of synthesis, transport, and isolation of zymogenic granules at the level of both individual acinar cells and acinuses of topographically different parts of the gland [12-14]. Currently, more and more attention is paid to molecular genetic approaches in the study of secretory function of the pancreas [15], and although these methods are not widely used in the study of pancreas adaptation to food quality, the few obtained results are consistent with biochemical data [16, 17]. The experiments on animals fitted with a cannula, which allows taking samples of pancreatic juice in vivo during the experiments and sending it to the intestine, are of particular interest. It should be noted that due to methodological difficulties in obtaining pure pancreatic juice, the available data on the adaptation of the secretory function of farm animals are few and contradictory [18, 19]. In the last century, the academician Pavlov developed a method for studying pancreatic juice in dogs and obtained experimental data on the adaptation of pancreatic secretion to bread, milk, and meat, which became the basis of the physiology of the digestive system [3]. Later, the adaptation of pancreatic secretion to various feeds and additives was studied in farm animals [7-9, 20], but the effect of certain feed ingredients on pancreatic secretion was not studied.

This paper describes for the first time quantitative changes in the secretory function of the pancreas when replacing one of the components of the diet. In addition, due to the use of similar methods for the study of pancreatic secretion (experiments on fistulated individuals), indicators were compared in animals with different types of digestion, which allowed us to identify both peculiar and general patterns of adaptive responses of the pancreas.

Our goal was to study, in a comparative aspect, the adaptation mechanisms of the digestive system of mammals and birds to diets with different protein ingredients.

Techniques. The study was performed on chickens (*Gallus gallus* L.) of Leghorn breed egg cross Hisex White aged 10-12 months with chronic pancreatic duct fistulas (3 birds), intact chickens (15 birds), piglets (*Sus scrofa domesticus* L.) cross between Danish Landrace and the Danish Yorkshire aged 5 months, the live weight of 45-55 kg (3 piglets with the cannulated pancreatic duct, 3 piglets with ileal cannulae, and 3 intact piglets).

To obtain "pure" pancreatic juice from a bird, a surgical operation was performed in the chronic experiment [7]. The essence of this operation was to create an isolated segment of the duodenum and transplant the main pancreatic duct into it, implanting two L-shaped fistulas and forming an external anastomosis making it possible to return the pancreatic juice to the duodenum if necessary. The piglets were operated according to the technique of Tkachyov [21]. From the duodenum, a 4-5-cm-long segment was cut out, into which the pancreatic duct flows, and a Y-shaped cannula was implanted (in an isolated segment of the intestine and the main intestine), allowing the pancreatic juice to return to the duodenum during the period outside the experiments.

Physiological experiments on poultry were performed using the method developed earlier [8]. The authors used PK-1 feed (All-Russian Research and Technological Poultry Institute RAS) with different protein ingredients. At least 3 experiments were performed on each bird to study digestion in each accounting period. Physiological experiments on piglets were started in the morning on an empty stomach after a 14-hour fast. The piglets were placed in a special machine in which they were kept for 3.5 hours. To collect pancreatic juice, a microtube was attached to the fistula through a special rubber adapter. In the first 30 minutes, the juice was collected after fast, then the pigs were given 500 g ($^1/_3$ of the daily norm) of compound feed (SK-4, Institute of Animal Physiology, Biochemistry and Nutrition, Russia) (as per Feeding norms and diets for agricultural animals. Handbook. Moscow, 2003), and the secretion was collected every 30 minutes for 180 minutes.

A Smith-Roe method in a modification for determining high enzyme activity [7] was applied for amylase analysis, proteolytic activity was assessed by Gammersten's hydrolysis of purified casein with colorimetric control (KFK-3, Zagorsk Optical and Mechanical Plant, Russia, $\lambda = 450$ nm) [7]. Lipolytic activity was assessed using a Sinnowa BS3000P biochemical analyzers (SINNOWA Medical Science & Technology Co., Ltd, China) and Screen Master LIHD113 (Hospitex Diagnostics S. r. L., Italy) with a set of veterinary diagnostic reagents for determining blood concentration of animal lipase (DIAKON-VET, Russia).

Blood of chickens was samples from the axillary vein, in pigs from the tail vein before feeding. Freshly prepared sodium citrate solution was added to the test tubes, the blood was centrifuged for 5 minutes at 5,000 rpm, and the resulting plasma was examined using a SINNOWA BS3000P flow biochemical semi-automatic analyzer (SINNOWA Medical Science & Technology Co., Ltd, China) using biochemical kits (DIAKON-VET, Russia). The activity of amylase and lipase was studied on a Chem Well 2900 (T) device (Awareness Technology, Inc., USA) using appropriate reagent kits (Human GmbH, Germany). Trypsin activity was evaluated using a semi-automatic biochemical analyzer Sinnowa BS-3000P (SINNOWA Medical Science & Technology Co., Ltd, China) [22].

Digestion trials of the digestibility of nutrients in the diet were performed by generally accepted methods (Methods of scientific and industrial research on poultry feeding. Molecular genetic methods for determining intestinal microflora. Sergiev Posad, 2013).

Statistical analysis was performed by ANOVA method (Statistica 10.0 software, StatSoft, Inc. USA; Microsoft Excel). The mean value (M) and standard errors of the means (±SEM) were calculated for the enzyme activity indicators. The reliability of differences was determined by Student's t-criterion, considering them statistically significant at $p < 0.05$.

Results. Table 1 describes the experiment design.

1. Design of the experiment on replacing dietary soybean cake/meal → sunflower cake in animals with different types of digestion

Investigation stage	Group (period)	Feed features
Hissex White Laying hens (*Gallus gallus* L.)		
Study of the pancreas secretory function	Control	Main diet (MD) with soybean cake (19.8%)
	Test	MD with sunflower cake (21.0%)
Study of the digestibility of feed nutrients	Control	MD with soybean cake (19.8%)
	Test	MD with sunflower cake (21.0%)
Determination of blood biochemical parameters	Control	MD with soybean cake (19.8%)
	Test	MD with sunflower cake (21.0%)
Crossbred (Danish Landrace and the Danish Yorkshire) piglets (*Sus scrofa domesticus* L.)		
Study of the pancreas secretory function	Control	MD with soybean meal (18.5%)
	Test	MD with sunflower cake (22.5%)
Study of the digestibility of feed nutrients	Control	MD with soybean meal (18.5%)
	Test	MD with sunflower cake (22.5%)
Determination of blood biochemical parameters	Control	MD with soybean meal (18.5%)
	Test	MD with sunflower cake (22.5%)

The composition and characteristics of the used main diets are shown in Tables 2 and 3

2. Composition (%) and quality indicators of diets for Hissex White laying hens (*Gallus gallus* L.)

Ingredient, indicator	Combined feed	
	control (feed 1)	test (feed 2)
Wheat	58.225	55.781
Sunflower cake	5.000	21.026
Soybean cake	19.784	8.912
Limestone (36%)	9.137	9.045
Soybean oil	1.936	3.026
Wheat bran	3.847	Absent
Monocalcium phosphate	1.149	1.233
Table salt	0.250	0.250
Lysine (98%)	0.073	0.214
Sodium sulphate	0.205	0.182
Feed methionine (98%)	0.214	0.151
Premix	0.180	0.180
In 100 g of feed:		
exchange energy, kcal	270.00	270.00
raw fiber, g	4.89	5.92
raw protein, g	16.70	17.20
raw fat, g	6.72	8.12
lysine, g	0.73	0.80
methionine, g	0.44	0.45
calcium, g	4.78	4.61
total phosphorus, g	0.89	0.90

3. Composition (%) and quality indicators of diets for crossbred piglets (*Sus scrofa domesticus* L.)

Ingredient, indicator	Combined feed	
	control (feed 3)	test (feed 4)
Wheat	50	47.4
Barley	11.84	11.2
Wheat bran	15	14.2
Soybean meal SP (42%)	18.55	Absent
Sunflower cake	Absent	22.5
Sunflower oil	1.45	1.0
Chalk	1.13	1.0
Tricalcium phosphate	0.79	0.7
Table salt	0.24	0.24
Lysine	Absent	0.22
Threonine	Absent	0.11
Premix KS-4-1	1	1.0
Total	100.0	100.0
1 kg of concentrate feed contains:		
energy feed units (EFU)	1.28	1.28
exchange energy, MJ,	12.8	12.8
net energy, MJ	9.5	9.5
dry matter, g	911.6	914.5
raw protein, g	170.5	170.0
raw fat, g	34.8	44.1
linoleic acid $C_{18:2}$, %	1.78	1.78
α- linolenic acid, %	0.19	0.19
raw fiber, g	50.4	99.0
crude ash, g	51.8	65.1
nitrogen-free extractives (NFE), g	638	683
lysine, g	7.8	7.8
methionine + cystine, g	5.60	6.22
threonine, g	5.9	5.9
calcium, g	7.53	7.50
total phosphorus, g	6.11	6.08

In the experiment on laying hens, concentrate feed was prepared in such a way that feed 1 had the prevalence of soybean cake and feed 2 — of sunflower cake. The analysis showed that feed 2 contained more raw fat (1.4%) and fiber (1.0%) than feed 1. In the study of the secretory pancreatic function in chickens (Fig. 1), we revealed an increase in lipolytic activity by 33.8% ($p < 0.05$) when replacing feed 1 with feed 2, which seems to be due to the quality of fat in sunflower cake [23], as well as an increase in the amount of raw fat in the experiment relative to the control. Protease activity increased by 28.1% ($p \geq 0.05$) as a result of changes in protein quality and a slight increase in the proportion of raw protein in the feed (by 0.5%), as well as the content of amino acids, which in total exceeded that in the control by 0.33%. From these re-

sults, it follows that the secretory function of the pancreas is adapted to the quality of the consumed feed.

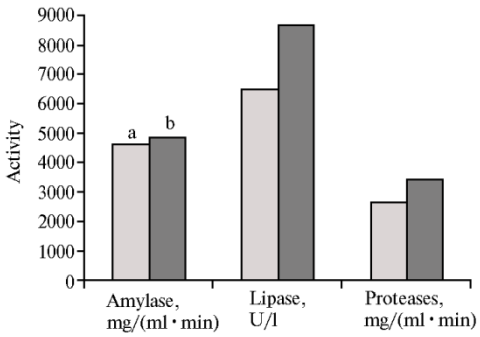

Fig. 1. Activity of pancreatic enzymes in laying Hissex White hens (*Gallus gallus* L.) depending on dietary protein ingredients: a — feed 1, b — feed 2 (n = 20, lab test on fistulated poultry; see Table 2 for the composition of diets, the values of protease activity increased by 10 times).

To understand the mechanisms of adaptation of pancreatic enzyme production to the changing composition of the diet, we studied the dynamics of the pancreas secretory function of chickens (Fig. 2).

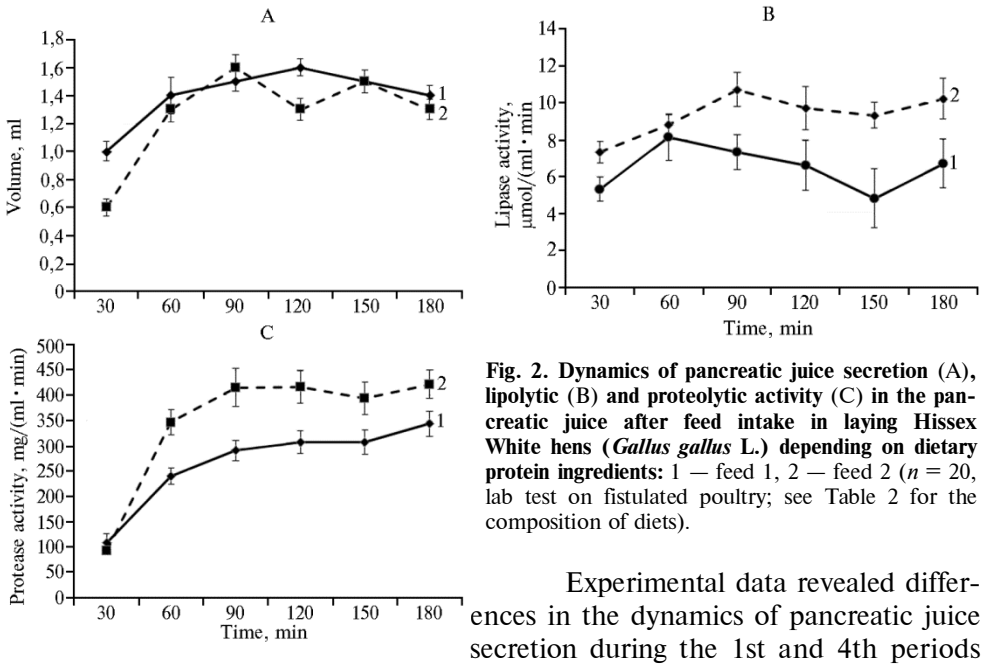

Fig. 2. Dynamics of pancreatic juice secretion (A), **lipolytic** (B) **and proteolytic activity** (C) **in the pancreatic juice after feed intake in laying Hissex White hens (*Gallus gallus* L.) depending on dietary protein ingredients:** 1 — feed 1, 2 — feed 2 (n = 20, lab test on fistulated poultry; see Table 2 for the composition of diets).

Experimental data revealed differences in the dynamics of pancreatic juice secretion during the 1st and 4th periods of the experiment depending on the diets (see Fig. 2, A), which is associated with the complex reflex and neurochemical phases of regulation of the external secretory function of the pancreas [7, 8].

The changes were the most apparent in the activity of lipase (see Fig. 2, B): the increase in the 1st period (before feeding) was by 37.7% ($p < 0.05$), in the 90th min by 46.6% ($p < 0.05$) when using sunflower cake, and in the 150th min by 93.7%. The difference in the basal activity of enzymes when using different protein supplements indicates a long-term adaptation to feed 2, which causes increased lipolytic activity. The main difference in the dynamics is that the intensive growth of lipase activity in the presence of sunflower cake in the feed continued until the 90th min of the experiment, and then its value remained until the end of the experiment.

The dynamics of proteolytic activity in chicken pancreatic juice when replacing soybean meal with sunflower meal in the diet (see Fig. 2, C) had no fundamental differences, but the curve of enzyme activity was higher in using dietary sunflower cake. If feeding activity parameters were not significantly different, in the 60th, 90th and 120th minutes of the experiment, the activity of proteases when

adding the sunflower meal was significantly higher than indicators for the diet with soybean meal. The first 30-60 minutes of the postprandial period correspond to the complex reflex phase of regulation of pancreatic secretion, which is determined by both conditional and unconditional reflexes (due to the presence of taste receptors in the oral cavity of chickens) [24-26], and from the 90th minute by hormonal factors that also affect the secretory function of the pancreas [27].

The digestibility of feed nutrients is associated with chicken pancreas secretory function (Table 4).

4. Digestibility and utilization of feed nutrients in laying Hissex White hens (*Gallus gallus* L.) depending on dietary protein ingredients (M±SEM, n = 10, lab test on intact poultry)

Diet	Digestibility, %				Availability, %		Utilization, %		
	protein	dry matter	fat	fiber	Ca	P	N	lysine	methionine
Feed 1	88.3±0.43	73.0±0.73	90.1±0.67	24.1±2.42	62.8±2.90	27.3±3.51	55.5±1.94	90.0±1.16	95.1±0.32
Feed 2	86.9±0.46	71.5±0.86	93.6±0.58*	11.8±2.74*	64.2±2.82	32.3±4.06	51.9±1.87	90.9±0.25	93.7±0.28

N o t e. Feed 1 — control, feed 2 — test. See Table 2 for diet compositions.
* Difference from the control is statistically significant at $p < 0.05$.

Analysis of the digestibility and availability of feed nutrients shows that replacing soybean meal with sunflower worsens the digestibility of fiber by 12.3% ($p < 0.05$), feed dry matter by 1.5%, protein by 1.4%, and methionine by 1.4%. In feed 2, raw fat was digested 3.5% better ($p < 0.05$) than in feed 1, which is consistent with the lipolytic activity of pancreatic juice (see Fig. 2).

5. Blood biochemical parameters of laying Hissex White hens (*Gallus gallus* L.) depending on dietary protein ingredients (M±SEM, n = 15, lab test on intact poultry)

Indicator	Control (feed 1)	Test (feed 2)	To control, %
Trypsin, U/l	154±16.8	105±10.8*	–31.8
Amylase, U/l	166±9.3	202±27.8	+21.7
Lipase, U/l	38±2.5	32±2.2	–15.8
Total protein, g/l	23.5±1.40	38.6±3.40*	+64.2
Uric acid, μmol/l	95±10.3	109±14.9	+14.7
Glucose, mmol/l	2.8±0.58	4.1±0.91	+46.4
Alkaline phosphatase, U/l	853±85.0	503±81.1*	–41.0
Cholesterol, mmol/l	2.6±0.70	3.9±0.90	+50.0
Triglycerides, mmol/l	5.6±1.63	8.7±2.76	+55.3

N o t e. See Table 2 for diet compositions.
* Difference from the control is statistically significant at $p < 0.05$.

Biochemical study of blood of laying hens (Table 5) revealed significant changes in indicators related to protein metabolism. The trypsin activity during experiment decreased by 31.8% ($p < 0.05$). In the case of a control diet with soybean cake, the activity of trypsin in the blood was high. The transition of poultry to a diet similar in the protein level, but with a different ingredient composition (replacing soybean cake with sunflower cake) led to a decrease in trypsin activity in the blood, apparently due to an increase in the activity of common proteases in the intestine [28]. It may be due to the presence of chlorogenic acid in sunflower oil cake that inhibits trypsin and lipase [23]. The total protein content in the control was lower than optimal, which is probably due to a deficit of full-fledged proteins and limiting amino acids in the diet. It is no accident that in the experiment, the use of concentrated feed caused an increase (within the margin of error) in the uric acid indicator and an increase in the total protein content in the blood by 64.2% ($p < 0.05$), which corresponds to its normal physiological value for laying hens. A decrease in alkaline phosphatase activity by 41.0% ($p < 0.05$) indicates a change in liver function, which produces this enzyme that hydrolyzes phosphorus bonds.

In the diets of experimental piglets, the used concentrate feed varied in raw fat and fiber content: in feed 4, compared to feed 3, the content of these components was higher by 9.3 and 21.1%, respectively; the diets did not differ in the amount of raw protein. The composition of limiting amino acids and their content also did not differ significantly due to adjustments using different amounts of synthetic amino acids. The excess of methionine and cystine in feed 4 (even without adding synthetic methionine to feed) was due to their increased content in sunflower cake.

6. Pancreatic secretory function of 5-month-old crossbred (Danish Landrace and Danish Yorkshire) piglets (*Sus scrofa domesticus* L.) depending on feed composition (M±SEM, n = 3, lab test on fistulated animals)

Indicator	Control (feed 3)	Test (feed 4)
Amount of pancreatic juice per experiment, ml	139,5±1,50	134,9±7,16
Enzyme activity in 1 ml juice:		
amylase, mg/(ml · min)	1564±267,0	1800±92
lipase, μmol/(ml · min)	14,8±1,01	15,1±1,16
proteases, mg /(ml · min)	88,1±9,92	49,6±6,04*

N o t e. See Table 3 for diet compositions.
* Difference from the control is statistically significant at $p < 0.05$.

The study of the pancreas secretory function of piglets (Table 6) showed that when replacing soybean protein with sunflower, the lipase activity did not change, although the fat content in this feed was 9.3% higher compared to the control diet. Perhaps the reason is the presence of chlorogenic acid in sunflower cake, which serves as an inhibitor of trypsin and lipase. We found no significant differences in amylase activity. The number of proteases decreased by 43.7% in the experimental period with the same content of protein and amino acids in compound feeds 3 and 4. Therefore, in piglets (as in chickens), the secretory function of pancreas adapts to the feed quality. We compared the dynamics of pancreatic juice release and enzyme activity after feeding by analyzing the mechanisms of the pancreas adaptation to the new feed (Fig. 3, A, B).

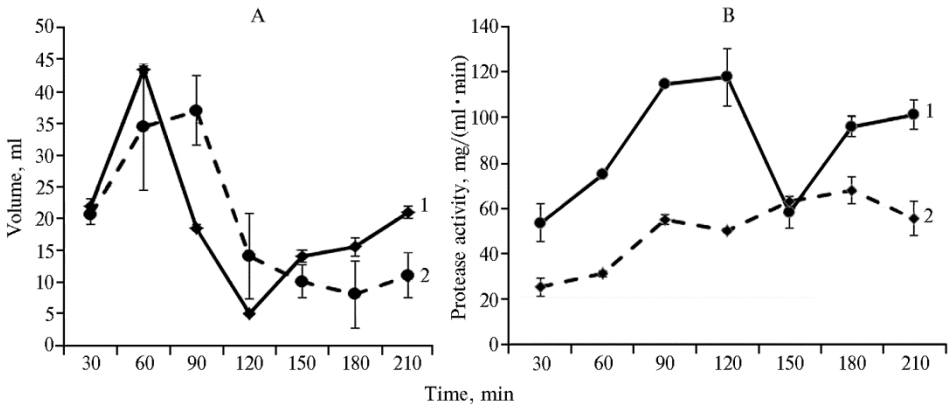

Fig. 3. Dynamics of pancreatic juice secretion (A) **and proteolytic activity** (B) **in pancreatic juice after feed intake in 5-month-old crossbred (Danish Landrace and Danish Yorkshire) piglets (*Sus scrofa domesticus* L.) depending on feed composition:** 1 — feed 3, 2 — feed 4 (n = 20, **lab test on** fistulated animals; see Table 3 for diet compositions 3).

The data indicate (see Fig. 3, A) that in piglets in the first 30 minutes after receiving the feed, the secretion of pancreatic juice increased by 2.0 and 1.3 times when using soybean or sunflower components in the diet, respectively. Further on, by the 90th minute of the experiment in the version with soybean meal, the amount of pancreatic juice decreased to the initial value, with sunflower cake – continued to increase to the 90th minute of the experiment and became 2 times higher compared

to the previous period. From the 120th to 210th minute of the experiment, an increase in secretions in the first period was observed; in the second period (when adding sunflower cake in the diet), significant changes in the amount of secretions were not observed. Therefore, despite similar gross amounts of pancreatic juice for the experiment, in variants with different protein feed ingredients, the dynamics of secretions after food intake differed significantly in the complex-reflex and neurohumoral phases of pancreatic function regulation.

Since there were significant changes in the activity of proteases, the authors analyzed the dynamics of this indicator in the postprandial period with different sources of protein in the feed of piglets (see Fig. 3, B). Proteolytic activity in the control (feed 3) increased in the postprandial phase of digestion up to the 120th minute of the experiment, followed by a decline and a new rise, typical for the neurochemical phase of regulation of pancreatic secretion. When using sunflower cake in the diet of piglets, the dynamics of protease activity was characterized by a 2.2-fold increase within 60 minutes after feeding (as in the control), but since the basal level of activity was 2 times lower, the value of this indicator in the postprandial period significantly differed at all points of the curve, except for the 150th minute (intersection of graphs). Therefore, in piglets, when replacing one protein component in the diet with another, the pancreas reacts by changing the predominantly proteolytic activity, which indicates that the secretory function of the pancreas is adapted to the feed quality.

No significant changes in the dynamics of amylase and lipase activity were observed in piglets after replacing the protein component of the feed.

Thus, the replacement of soybean meal with sunflower meal in the diet of piglets is reflected in the dynamics of pancreatic juice release and protease activity in the postprandial period of digestion, which indicates the adaptation of the pancreas to individual feed components with the same content of raw protein in concentrate feeds. The study of visceral organs in weaning pigs using common and low-oligosaccharide soybean meal revealed no differences [29]. At the same time, molecular genetic methods lead to the conclusion that the content of fats and carbohydrates in the diet of pigs significantly affects gene expression [30]. Therefore, the use of cannulated animals to study the adaptation of pancreatic secretion has a perspective.

When replacing soybean meal with sunflower meal, neither visible nor ileal digestibility of protein was significantly changed (Table 7), although the ileal method is considered the most objective when assessing the availability of nutrients in the diet [31]. Even with a higher content of fiber and fat in the second diet (experiment), there was a significant increase in their digestibility, by 11.7 and 28.7%, respectively ($p < 0.05$). At the same time, ash and nitrogen-free extractives were digested worse.

7. Digestibility and utilization of feed nutrients in 5-month-old crossbred (Danish Landrace and Danish Yorkshire) piglets (*Sus scrofa domesticus* L.) depending on feed composition ($M \pm$SEM, $n = 10$)

Diet	Digestibility, %								
	Pv	P	DM	OM	Fib	F	A	NFE	GE
Control	78.42±0.90	75.4±1.89	78.3±0.25	80.4±0.24	36.7±0.78	61.2±0.50	43.0±0.75	88.1±0.19	79.6±0.32
Test	81.21±1.87	77.0±2.12	77.1±0.32	80.0±0.47	41.0±0.56*	78.8±1.82*	37.6±0.80*	87.3±0.54	78.4±0.64

N o t e. Pv — protein (visible digestibility), Pi — protein (ileal digestibility), DM — dry matter, OM — organic matter, Fib — fiber, F — fat, A — ash, NFE — nitrogen-free extractives, GE — gross energy. See Table 3 for the composition of the diets.

* Differences from the indicator for feed 3 (control) are statistically significant at $p < 0.05$.

Biochemical studies have not revealed significant changes in the activity of digestive blood enzymes and biochemical parameters in piglets when using various protein supplements in the diet (Table 8).

8. Blood biochemical parameters of 5-month-old crossbred (Danish Landrace and Danish Yorkshire) piglets (*Sus scrofa domesticus* L.) depending on feed composition (M±SEM, n = 10)

Indicator	Control (feed 3)	Test (feed 4)
Trypsin, U/l	690±56.0	620±34.1
Amylase, U/l	179.5±83.9	141.7±32.7
Lipase, U/l	51.0±12.75	76.5±22.08
Total protein, g/l	57.03±2.59	62.2±2.24
Urea, mmol/l	4.3±0.29	5.2±0.45
Alanine aminotransferase, U/l	89.6±9.94	71.8±10.1
Aspartate aminotransferase, U/l	70.2±12.9	57.5±7.67

N o t e. See Table 3 for the composition of the diets.

Since the digestive systems of birds and mammals differ morphologically and functionally, the biological mechanisms of feed adaptation are not the same. For the first time in world practice, we have undertaken a comparative study of the features of such adaptation to changes in the protein component of the diet when replacing soybean meal with sunflower meal on fistulated animals.

The research showed that the amount of pancreatic juice during the experiment (per 1 kg of live weight) was almost 2.2 times higher in chickens than in piglets. Amylase activity, when used feed 1 for chickens, was 4,620±253.1, in piglets 1,564±267.0 mg/(ml· min), which in absolute values is almost 3 times lower than in chickens. When using feed 2, the amylase activity in chickens increases to 4,855±290.0, and in piglets to 1,800±92.0 mg/(ml· min).

The lipolytic activity of pancreatic juice in piglets in absolute values was higher than that in chickens by almost 2 times and amounted to 14.8±1.01 and 6.5±0.51, respectively, when the control feed was fed, and 15.1±1.16 and 8.7±0.62 mmol/(ml· min) when replacing the protein component (soybean cake/meal → sunflower cake). However, per 1 kg of live weight, the ratio of lipolytic activity in chickens and piglets was 17:1.

Protein hydrolysis in chickens was more intense. The activity of proteases in animals receiving the control feed was 3 times higher in chickens than in piglets – 267±17.9 vs 88.1±9.92 mg/(ml· min). Sunflower meal increased protease activity in chickens to 342±61.3 mg/(ml· min) but decreased it in pigs to 49.6±6.04 mg/(ml· min). Taking in mind that the digestibility of raw protein does not change significantly, one can assume the presence of trypsin inhibitors in soybean meal, which increases the activity of proteases. This assumption is confirmed in the works of Tarasenko [31], indicating higher availability of amino acids in sunflower meal (25.4%) compared to soybean. Our data are also partially consistent with the results of comparative studies of the physical and chemical properties and enzymatic activity of pancreatic juice in different animals [32].

The activity of digestive enzymes in the blood plasma of animals with different types of digestion significantly differed in trypsin: as calculated per 1 kg of live weight, the activity was 100 U/l in chickens and 14 U/l in pigs. Consequently, the metabolic processes in chickens are more intense than in pigs, and the trypsin activity index (trypsin activity/live weight) can serve as a criterion for evaluating the activity of metabolism.

It is known that the provision of feed is the most expensive area in the livestock economy, but the largest reserves are hidden here [20]. Knowledge of the biological effects of feed ingredients forms the basis for the formation of balanced diets for farm animals. The data obtained in this paper characterize the main digestive and nutrition-related metabolic processes comprehensively. This approach makes it possible to interpret the results of the study in both theoretical and practical aspects.

Thus, the data of the original experiments carried out on fistulated animals

allow drawing the following conclusions. A distinctive feature of the exocrine function of the pancreas of birds is its high intensity: the amount of pancreatic juice per unit of live weight in chickens is 2.2 times higher than in pigs, the amylase activity is 94 times higher, protease activity 145 times higher, and lipase 17 times higher. The trypsin activity index in the blood plasma of chickens is significantly (7 times) higher than in pigs, which indicates increased metabolism. Adaptation of pancreatic secretion in chickens when replacing soybean meal with sunflower meal is characterized by an increase in lipase activity in pancreatic juice by 33.8%. In this case, significant differences are observed in the basal and postprandial period 60 minutes after feeding. As a result, the raw fat digestibility increases by 3.5% in feeding sunflower cake. In pigs, when replacing soybean meal with sunflower meal, the external secretory function of the pancreas reacts by 43.8% reducing the proteolytic activity. At the same time, the digestibility of raw protein does not change due to the presence of a trypsin inhibitor in soybean meal. In animals, regardless of the type of digestion, the adaptation of pancreatic secretion occurs in the case of non-parallel changes in the enzymatic activity in response to qualitative changes in feed ingredients.

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