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IMPLEMENTATION INSTRUCTIONS

OPPORTUNITIES FOR THE USE OF RYE IN POULTRY NUTRITION

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INTRODUCTION AND PURPOSE OF IMPLEMENTATION

Rye is a cereal with relatively low requirements regarding climate and soil conditions, and it is at the same time resistant to pests and fungal infection. For this reason, the cost of agronomic treatments during its cultivation are significantly lower in comparison to other cereal species. At the same time, the production potential of modern (hybrid) varieties of rye may exceed the productivity of other cereals, especially in the case of light soil cultivation. Therefore, the significance of the cultivation of modern rye varieties in domestic conditions is expected to increase, and a significant portion of the crops will be used not only for consumption but also for feed purposes.

Rye is traditionally considered to be a cereal with limited usefulness in poultry diets, especially in the diet of young, growing slaughter birds. According to the latest edition of the national 'Dietary guidelines and nutritional feed value for poultry' (*Zalecenia żywieniowe i wartość pokarmowa pasz dla drobiu*) of 2018, in young birds, that is up to 4 weeks old, rye should not be used as feed material at all. In older slaughter birds (4-18 weeks old), a maximum of 20 percent rye content is allowed in the feed but only if a proper selection of enzyme preparation is used at the same time. These limitations result from the high content of anti-nutritional substances, in particular some dietary fibre fractions, in rye grain. It should be noted, however, that as a result of many years of breeding work, the amounts of these undesirable rye components have been reduced to levels that are acceptable in practical poultry nutrition, which includes the nutrition of slaughter chicks. **Therefore, the purpose of the implementation is to use rye grain as a source of protein and energy in the nutrition of slaughter chicks, laying hens and geese.**

CHEMICAL COMPOSITION AND NUTRITION CHARACTERISTICS OF RYE GRAIN

Traditionally, rye grain is considered a typical bread grain with low nutritional usefulness for farm animals in comparison to other cereal species. Indeed, the breeding work on this species was largely aimed at its suitability for breadmaking. The significant limitations on the use of rye grain in poultry diet are commonly attributed to its possible negative impact on yield indicators, increased viscosity of the chyme, impeded flow of digesta and reduced digestibility of nutrients, diarrhoea, and an increased moisture content in the litter. This may finally have negative consequences for the health status and welfare of birds, especially in young slaughter chicks. However, in recent years, there are hybrid rye varieties introduced in the market, which are characterised not only by their improved agronomic characteristics, but also by a reduced content of anti-nutritional substances, first of all arabinoxylans.

In general, rye grain in poultry diet can be regarded as feed with moderate energy and protein content, characterised by a slightly lower content of general protein and metabolisable energy in comparison to wheat grain. Table 1. shows the average chemical composition and nutrient content of rye grain, based on tabular data. For comparison, rye grain of Brasetto hybrid variety, used in below described own research on slaughter chicks, laying hens and geese, contained 89.1 percent of dry weight; 9.23 percent of general protein; 0.81 percent of crude fat; 1.46 percent of crude fibre; 1.51 percent of crude ash; 0.119 percent of methionine; 0.297 percent of lysine; 0.263 percent of threonine and 10.97 MJ/kg of metabolisable energy. The studied rye grain exhibited relatively high content of soluble fractions of non-starch polysaccharides (NSP), which was reflected in the high viscosity of the aqueous extract of the same rye grain (Table 2).

An important feature to characterise the nutritional value of the feed material is digestibility of nutrients, including protein and exogenous amino acids. According to the

tabular data included in the 'Dietary guidelines and nutritional feed value for poultry' of 2018, the intestinal digestibility of specific exogenous amino acids in rye grain is lower by an average of a few percentage points in comparison to their digestibility in other cereals, which is 80 percent for lysine, 79 percent for methionine, 084 percent for cystine, 80 percent for threonine, 81 percent for tryptophan, 80 percent for arginine, 87 percent for isoleucine, 84 percent for leucine, and 83 percent for valine, respectively. The slightly lower digestibility of the rye grain amino acids in poultry is attributed to the presence of soluble NSP, in particular pentosans (arabinoxylans), in this feed material. Studies on laying hens indicate, however, that digestibility of specific exogenous amino acids in rye grain is variable and varies significantly between varieties of this cereal (Zuber et al., 2016). The Authors, having analysed 20 varieties of rye, concluded that digestibility of lysine is between 35-59 percent, of methionine between 57-75 percent, of threonine between 34-54 percent, and of tryptophan between 36-71 percent (Zuber et al., 2016).

As far as the nutrition of monogastric animals is concerned, especially where there are young broiler chicks, the most important problem related to the chemical composition of rye grain is its relatively high content of non-starch polysaccharides. It is therefore worthwhile to take a closer look at the structure and action of these anti-nutritional substances in the animals' digestive tract. Non-starch polysaccharides found in cereals include, above all, pentosans (xylans and arabinians) and beta-glucan. Rye grain is particularly abundant in arabinoxylans (AX) which, due to the lack of specific enzymes, are not digested in the digestive tract of monogastric animals. AX have a diverse structure depending on various factors, including cereal species and variety. These compounds may occur in the form of a single xylan chain or, on the other hand, a complex structure formed by a number of chains. The structural diversity of AX greatly affects their functional properties, particularly solubility, and largely determines the anti-nutritional effect of these compounds.

These polysaccharides, in particular their water-soluble fractions that form solutions (gels) with high water absorption properties, increase the viscosity of intestinal contents, which compromises the efficiency of digestion and absorption of nutrients. The effects of arabinoxylans described above may ultimately result in lowered yield indicators (weight gain, feed intake and feed conversion), particularly prevalent in young monogastric animals, including slaughter chicks. Young birds are particularly sensitive to high feed levels of AX as these compounds in young birds may cause intensive growth of harmful intestinal microflora. Numerous scientific studies have indicated, however, that the negative impact of AX on the digestive tract may be effectively reduced when the feed mixture is enriched with an enzyme preparation exhibiting xylanase activity and the ability to hydrolyse polysaccharide complexes.

INFORMATION ON THE RESULTS OF OWN RESEARCH

As part of the Biostrateg ENERGYFEED project at the National Research Institute of Animal Production (*Instytut Zootechniki – Państwowy Instytut Badawczy*, IZ PIB) on the nutrition of slaughter chicks and laying hens. The researchers adopted a hypothesis that the use of a feed enzyme exhibiting xylanase activity will introduce significant levels of rye of Brasetto hybrid variety into feed mixtures. The aim of the experiment was to determine the effects caused by the inclusion of rye grain in the feed mixture and the addition of xylanase to the yield indicators of broilers and laying hens. On the other hand, at the Agricultural University of Kraków, a study was carried out to determine the animal performance effects of the use of wheat in the nutrition of slaughter goslings and reproduction geese.

Methodological assumptions and results of studies on slaughter chicks

550 one-day-old Ross 308 slaughter chicks (roosters) with an initial weight of 41 g were used for the own research. The birds were kept in cages, on grid floor, in an experimental broiler building of the National Research Institute of Animal Production, located in Aleksandrowice, Poland. The experiment consisted of a 42-day-long rearing period (1-42 days of age), and the chicks were given a diet of isoprotein and isoenergy granular feed mixtures, which were either a starter feed mixture (1-21 days of age) or a grower-finisher feed mixture (22-42 days of age). The diets covered the birds' demand for nutrients and metabolisable energy. Two (5x2) factorial experimental design was used for introducing increasing amounts (0, 5, 10, 15 or 20 percent) of Brasetto hybrid rye into the experimental diets. A feed enzyme with xylanase activity was also introduced into the experimental diets (Ronozyme WX with a minimum xylanase activity of 1,000 FXU/g, in an amount of 200 mg/kg of feed). The experiments analysed the primary yield and growth indicators, the results of slaughter analysis, and the viscosity of intestinal contents.

Having analysed the obtained yield results, the researchers concluded that the tested hybrid variety of rye grain (Brasetto) had a statistically significant negative impact on the weight gain of birds when introduced into the feed mixture for the youngest chicks (1-21 days of age), although it did not affect feed intake or feed conversion (Table 3). In older chicks (22-42 days of age) as well as throughout the rearing period, no yield impact was observed relative to the levels of rye grain used in the diet (Tables 4 and 5). At this point, it should be noted that although the Brasetto rye variety used in the study was characterised by relatively high levels of both insoluble and soluble NSP fractions, this was not an obstacle to achieving very good final rearing indicators in all the experimental groups, including the groups fed the mixture with the highest levels of rye (15-20 percent). The results confirm that youngest chicks are the most sensitive to the content of non-starch polysaccharides (arabinoxylans) in their diet. During the first days of the chick's life, high NSP content may not only limit the digestibility of nutrients and the availability of energy in the feed, but it can also affect the development and impede the maturity of the digestive tract.

The yield results obtained during the studies support the use of the enzyme preparation (xylanase) as a feed additive in slaughter chicks that receive rye grain feed mixtures. In conclusion, the researchers observed a statistically significant positive effect of xylanase on weight gain and feed conversion in the starter period of rearing (Table 3). In older birds, the beneficial effect of the enzyme additive was less visible but remained within the range marking the improved feed conversion for the entire rearing period (Table 4). Importantly, during the first three weeks of rearing, a statistically significant interaction between the experimental factors was observed, where the addition of xylanase improved the chicks' weight gain, primarily when the diet contained a high proportion of rye. On the other hand, the levels of rye grain used for the diets and the addition of xylanase had no effect on the results of post-mortem analysis, that is slaughter yield, and they did not affect the share of the breast muscle, abdominal fat and selected organs in the carcass.

Table 6 shows the results of measurement of the viscosity of intestinal contents of the test chicks. The results indicate that this parameter is adversely affected by a high proportion of rye grain in the feed mixture, as it significantly increases the viscosity of the small intestine contents, in both the jejunum and the ileum. The addition of xylanase was found to significantly reduce this negative effect, and more importantly, a significant interaction was observed, as the introduction of xylanase into the diet containing 20 percent of rye, had a much greater effect on lowering the viscosity of intestinal contents than with a control diet (without rye grain).

Methodological assumptions and results of studies on laying hens

An experiment was conducted to determine how the introduction of different levels of rye grain into the feed mixture and the addition of xylanase to the feed affected the laying yield and quality in highly productive laying hens. 240 ISA Brown hens were used for the experiment. Laying hens, 25-50 weeks of age, were housed in cages on grid floor, and were fed ad libitum using complete isoprotein and isoenergy feed mixtures. The diets covered the hens' demand for all nutrients. 10 experimental groups were created. There were 12 replications in each group (cages with 2 hens each). As in the experiment, two (5x2) factorial experimental design was used for introducing increasing amounts (0, 10, 15, 20 or 25 percent) of Brasetto hybrid rye into the experimental diets. A feed enzyme with xylanase activity was also introduced into the experimental diets (Ronozyme WX with a minimum xylanase activity of 1,000 FXU/g, in an amount of 200 mg/kg of feed). The experiment investigated the yield indicators as well as the egg quality parameters.

The results of the experiment (Table 7) suggest that the introduction of rye grain into the feed mixture decreased the laying yield of the hens in a manner that was statistically significant. This effect was, however, relatively minor in percentage terms (the differences being no more than 2 percent), and all the experimental groups demonstrated very good laying indicators even where the proportion of rye grain in the feed was high.

Where 10-25 percent of rye grain was used in the feed mixture, this proportion of rye had no effect on most of the egg content quality parameters (amount of protein, Haugh units, sensory scores of boiled eggs) and the egg shell parameters (thickness, density, strength) (Table 8). It was found, however, that a growing proportion of rye in the diet causes a gradual decrease in the colour intensity of the egg yolk. The addition of the feed enzyme (xylanase) did not affect egg quality. Also, the study showed that the introduction of rye grain into the recipes of the feed mixtures had no effect on the organoleptic parameters (taste and odour) of boiled eggs.

The effect of soluble NSP was observed in the experiment as a significant increase in the viscosity of the food content of the small intestine and the jejunum in hens eating a diet that was 25 percent rye grain (Table 9). The addition of xylanase drastically reduced this effect and, at the same time, diminished the negative effect of NSP on the digestive processes.

Methodological assumptions and results of studies on slaughter geese

An experiment on 600 one-day-old, 95.3-gramme Zator goslings was conducted in Rząska, Poland, at the Research and Education Centre of the Faculty of Animal Science (*Wydział Hodowli i Biologii Zwierząt*) of the Hugon Kołłątaj Agricultural University (*Uniwersytet Rolniczy im. Hugona Kołłątaja*). The experiment consisted of a 14-week-long rearing period during which the birds were given a diet of isoprotein and isoenergy granular feed mixtures. The diets covered the birds' demand for nutrients and metabolisable energy. The rearing period was followed by a three-week period of grain fattening. The birds were housed on litter in a floor system. From 3 to 14 weeks of age, the birds had access to a pasture, and during the fattening period, they used open-air runs lined with straw. The following experimental design was used: the experimental diet was 40 percent rye grain of Brasetto hybrid variety, and subsequently, in the grain fattening period, the goslings were given a diet of whole grain oats, a one-to-one ratio of whole grain oats to Brasetto rye, and whole grain Brasetto rye.

The analysis of the production performance of slaughter goslings found that when experimental geese from 3 weeks of age were fed a diet of 40 percent Brasetto rye, this had a statistically significant adverse effect on the birds' body weight at 11 and 14 weeks of age

(Table 10). Statistically, the highest body weight at the end of the grain fattening period was found in oats-fed geese, regardless of their sex or type of feed mixtures used in the preceding rearing phase. Similar body weight (no statistically significant differences) was also found in the female geese receiving the oats and rye mixture, regardless of what feeding system was previously used in the group. Among all the male geese groups, the lowest statistically significant body weight was noted in the male geese that were fed a feed mixture containing 40 percent rye and just rye in the grain fattening period. To sum up, no negative effect of the use of rye between 3 and 14 weeks of rearing was observed in the geese if the subsequent fattening was based on oats. Furthermore, the male geese showed a more explicit response to the suggested experimental nutrition system.

Feed intake by growing Zator geese up to 3 weeks of age approximated 1650 g, whereas between 3 and 14 weeks of age, it approximated 19,750 g regardless of what feed mixture was given. There were, however, statistically significant differences in the intake of the cereals during the fattening period (Table 11). The lowest intake of grain was seen in both male and female geese eating a diet of hybrid rye. The consumption of oats and the oats and rye mixture was continuously similar, particularly in the groups that received the control mixture (without any rye) during the rearing period. Without a doubt, the lower intake of rye was partially caused by the characteristics of this cereal grain, which also had an impact on the level of weight gain achieved.

Methodological assumptions and results of studies on reproduction geese

The experiment was to determine how the selected reproductive indicators in geese are affected when a proportion of rye is introduced into the feed mixture. The experiment was performed on 240 Zator geese in the first and second breeding season. The geese were housed on litter and they had access to open-air runs lined with straw. The birds were fed ad libitum using isoprotein and isoenergy granular feed mixtures. The diets covered the geese's demand for all nutrients. 4 experimental groups were created with 10 replicates each. An increasing proportion of Brasetto hybrid rye (0, 20, 30 and 40 percent) was introduced into the experimental diets. Each pen housed six female geese and one male goose. Egg-laying yield and hatching results were evaluated individually.

The laying study of Zator geese showed statistically significant differences in the levels of egg production in the first (Table 12) and second (Table 13) laying season, in reproductive geese receiving control and hybrid rye-containing feeds, without strict correlation between the differences and the content of rye in the feed mixture. Among the experimental groups, the greatest number of eggs were laid by the geese eating a diet with 20 percent rye. No statistically significant differences in the egg weight were observed between the groups in the first and second breeding year.

The experiment demonstrated a variation in the amount of feed consumed by the geese in both the analysed laying seasons (Tables 12 and 13). Both in the first and second year of breeding, the lowest daily feed intake was seen in the geese eating the feed with 20 and 30 percent hybrid rye content.

Varied results were observed in the reproductive traits, including egg fertilization and hatchability of healthy chicks from fertilised eggs (Table 12 and 13). Statistically significant differences were demonstrated only in the group of younger geese, but these were not correlated with the increasing proportion of rye grain in the feed given to the birds. The best fertilisation and hatchability rates were observed in the group eating a diet with 20 and 30 percent rye content.

PRACTICAL RECOMMENDATIONS

The authors' own research suggests that under certain conditions, hybrid rye can be successfully used in poultry nutrition, which makes it a useful source of energy and protein. All the feed mixtures used must contain all the food nutrients in amounts to fully cover the hens' normal bodily demand and the demand during reproduction (Normy Żywienia Drobiu [*Poultry Nutrition Standards*], 2018). Some example feed mixture recipes with rye content are contrasted in Table 14. Recipes, however, will vary depending on the chemical composition of a given batch of rye and other feed materials used.

As a general rule, rye grain can be used in slaughter chicks in the grower-finisher period of rearing, where it is acceptable to have up to 15-20 percent of rye grain in the total feed mixture. In younger birds (1-21 days of age), the introduction of rye grain into the diet may have a negative impact on the yield indicators. It is also advisable to add an enzyme preparation (xylanase) into mixtures with rye content, due to the stabilising effect that xylanase has on the viscosity of the intestinal microflora contents and composition, and because of its ability to positively affect the yield indicators, especially in younger chicks.

In diets of laying hens, rye grain can be successfully used provided that its amount does not exceed 25 percent of the total feed mixture. By adding the enzyme preparation (xylanase) to the feed, the breeder can lower the viscosity of intestinal contents in birds eating feed mixtures with a high proportion of rye grain. The implementation should be carried out for laying hens in the first or second egg-laying cycle. Crumbles with 20-25 percent rye content can be used when hens are at least approx. 20 weeks old. Such mixtures can be used until the end of the laying period and they should be given on an ad libitum basis. During the rearing period of slaughter goslings, rye grain can be introduced into the feed mixture after 3 weeks of age. Under these circumstances, even a considerable proportion of rye is allowed in the diet, although when this proportion is in the higher range (up to 40 percent of the total feed mixture), it is recommended that the birds should have free access to silage or well-managed pastures. As for grain-based fattening, which usually takes place after a period of intense somatic growth of goslings (12-13 weeks of age) and lasts for about 3 weeks, the proportion of raw rye grain should not make up a major part of the total food ration. It is recommended that slaughter geese should have access to this cereal grain on an ad libitum basis.

In the diet of reproductive geese, the use of a feed mixture containing up to 20 percent of rye does not affect the performance of the group. If a higher proportion of this cereal grain is used in a complete feed (up to 40 percent), a slightly reduced laying performance can be expected, but there should be no significant negative effect on the remaining productivity and reproductive indicators. The implemented rye grain should be of good quality and it should, among other features, be free of mycotoxins. The content of the individual food nutrients in rye grain may vary, so a chemical analysis should be done before any batches are introduced into feed mixtures.

EXPECTED PRODUCTION AND ECONOMIC BENEFITS

- the possibility to partially replace corn, wheat and triticale grains with rye grain in formulations of feed mixtures for different species and technological groups of poultry. As a general rule, the price of protein, amino acids and other food nutrients in rye grain is lower compared to other cereal grain species, and therefore allows to reduce the cost of feed per unit of meat or eggs produced and improve the economic efficiency of the production.

Auxiliary literature

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Table 1. Chemical composition and nutrients of rye grain based on the national tabular data (g/kg).

	Source of data	
	Nutritional recommendations and nutritional value of feeds for poultry (2018)	Tables of chemical composition and nutritional value of national feeds (2010)
Metabolisable energy		
MJ/kg	10.30	12.2
Kcal/kg	2462	2915
General protein	94	91
Crude fat	14	14.6
Crude fibre	21	20.4
Nitrogen-free extract compounds	733	739
Crude ash	17	17.2
Lysine	3.6	3.9
Methionine	1.6	1.6
Methionine + cystine	3.7	3.8
Threonine	3.2	3.4
Tryptophan	0.9	0.7
Valine	4.4	4.6
Arginine	4.6	4.5
Isoleucine	3.1	3.2
Leucine	5.6	6.3
Calcium	0.7	
Total phosphorus	3.0	
Assimilable phosphorus	0.7	
Sodium	0.1	
Chlorine	0.3	

Table 2. Content of anti-nutritional constituents and viscosity of the aqueous solution of Brasetto rye grain and feed mixtures with an increasing proportion of rye (own studies)

	Feed mixtures (proportion of rye in %)					Rye grain
	0%	10%	15%	20%	25%	
Soluble NSP (% dry weight)	0.77	1.38	1.41	1.48	1.75	5.5
Insoluble NSP (% dry weight)	6.7	6.64	7.07	7.56	7.59	10.0
Total NSP (% dry weight)	7.48	8.02	8.47	9.04	9.34	15.50
Arabinoxylans (% dry weight)	3.34	3.58	3.82	4.02	4.08	8.55
Alkylresorcinols (mg/kg dry weight)	478	550	620	687	757	1.052
Simple sugars (% dry weight)						
Arabinose	1.54	1.65	1.75	1.81	1.88	3.02
Xylose	1.79	1.93	2.07	2.20	2.20	5.54
Mannose	0.67	0.36	0.52	0.52	0.57	0.67
Galactose	1.05	0.95	0.96	1.03	1.06	0.39
Glucose	2.56	2.84	3.03	3.29	3.40	5.87
Uronic acids (% dry weight)	1.23	1.10	1.16	1.13	1.02	0.30
Viscosity of aqueous solution (mPa x s)	1.02	1.32	1.46	1.60	1.94	9.47

Table 3. Effect of adding different proportions of rye grain to the feed mixture and effect of xylanase addition on the productive indicators in slaughter chicks during the starter period of rearing (1-21 days of age).

	Body weight gain (g)	Feed intake (g)	Feed conversion (g/g)
Proportion of rye in the diet (%):			
0	965 [a]	1280	1.33
5	933 [b]	1256	1.35
10	936 [b]	1256	1.34
15	949 [ab]	1268	1.34
20	928 [b]	1247	1.35
Addition of xylanase:			
-	930 [a]	1271	1.37 [a]
+	954 [b]	1252	1.31 [b]
SEM	4.25	6.39	0.007
P effect			
Rye	0.007	0.497	0.807
Xylanase	0.001	0.134	0.0001
Interaction	0.007	0.208	0.208

a, b – values marked with different letters differ significantly ($P \leq 0.05$)

Table 4. Effect of adding different proportions of rye grain to the feed mixture and effect of xylanase addition on the productive indicators in slaughter chicks during the grower-finisher period of rearing (22-42 days of age).

	Body weight gain (g)	Feed intake (g)	Feed conversion (g/g)
Proportion of rye in the diet (%):			
0	1950	3240	1.66
5	1956	3248	1.66
10	1959	3248	1.66
15	1950	3246	1.66
20	1925	3223	1.68
Addition of xylanase:			
-	1947	3240	1.66
+	1949	3242	1.66
SEM	9.88	17.0	0.06
P effect			
Rye	0.864	0.991	0.948
Xylanase	0.935	0.952	0.984
Interaction	0.991	0.972	0.872

Table 5. Effect of adding different proportions of rye grain to the feed mixture and effect of xylanase addition on the productive indicators in slaughter chicks during the entire rearing period (1-42 days of age).

	Body weight gain (g)	Feed intake (g)	Feed conversion (g/g)
Proportion of rye in the diet (%):			
0	2914	4509	1.55
5	2889	4503	1.56
10	2895	4499	1.55
15	2899	4510	1.56
20	2853	4467	1.57
Addition of xylanase:			
-	2877	4509	1.57 [a]
+	2903	4486	1.55 [b]
SEM	10.9	17.0	0.06
P effect			
Rye	0.503	0.944	0.692
Xylanase	0.261	0.537	0.015
Interaction	0.724	0.727	0.855

[a, b] – values marked with different letters differ significantly ($P \leq 0.05$)

Table 6. Effect of adding different proportions of rye grain to the feed mixture and effect of xylanase addition on viscosity of the small intestine contents in chicks.

	Viscosity of the contents of the jejunum (mPa x s)	Viscosity of the contents of the ileum (mPa x s)
Proportion of rye in the diet (%):		
0	1.56 [a]	1.56 [a]
20	3.26 [b]	3.21 [b]
Addition of xylanase:		
-	3.02 [b]	3.36 [b]
+	1.80 [a]	1.41 [a]
SEM	0.226	0.273
P effect		
Rye	<0.0001	<0.0001
Xylanase	<0.0001	<0.0001
Interaction	<0.0001	<0.0001

a, b – values marked with different letters differ significantly ($P \leq 0.05$)

Table 7. Effect of adding different proportions of rye grain to the feed mixture and effect of xylanase addition on the productive performance of laying hens between 26 to 50 weeks of age.

	Laying yield (%)	Weight of eggs laid in a day (g/hen)	Average egg weight (g)	Feed intake (g/hen/day)	Feed conversion (g/g)
Proportion of rye in the diet (%)					
0%	97.2[a]	58.7	60.4	120[ab]	2.04
10%	95.9[b]	57.7	60.2	120[ab]	2.08
15%	95.6[b]	58.2	60.9	121[a]	2.08
20%	96.0[b]	57.5	59.9	119[b]	2.07
25%	95.4[b]	57.6	60.4	119[b]	2.07
Addition of xylanase	NS	NS	NS	NS	NS
-	96.3	57.8	60.1	120	2.07
+	95.8	58.1	60.7	120	2.06
SEM	0.169	0.197	0.178	0.261	0.009
P effect					
Rye	*	NS	NS	*	NS
Xylanase	NS	NS	NS	NS	NS
Interaction	NS	NS	NS	*	NS

[a, b] – values marked with different letters differ significantly (P≤0.05)
NS – P>0.05; * – P<0.05

Table 8. Effect of adding different proportions of rye grain to the feed mixture and effect of xylanase addition on egg quality of laying hens at 50 weeks of age.

	Haugh units	Yolk colour (points)	Yolk ratio (%)	Eggshell thickness (mm)	Eggshell strength (N)
Proportion of rye in the diet (%)					
0%	89.8	2.58^{c}	25.6	0.393	47.8
10%	92.2	2.04^{b}	26.2	0.386	45.1
15%	90.1	1.38^{c}	26.3	0.379	47.0
20%	88.5	1.13^{c}	25.4	0.382	43.3
25%	89.2	1.08^{c}	25.8	0.371	43.9
Addition of xylanase					
-	90.2	1.85^{a}	25.8	0.384	44.6
+	89.7	1.43^{b}	26.0	0.381	46.2
SEM	0.472	0.079	0.142	0.003	0.896
P effect					
Rye	NS	*	NS	NS	NS
Xylanase	NS	*	NS	NS	NS
Interaction	NS	*	NS	NS	NS

$^{a, b}$ – values marked with different letters differ significantly ($P \leq 0.05$)
NS – $P > 0.05$; * – $P < 0.05$

Table 9. Effect of adding different proportions of rye grain to the feed mixture and effect of xylanase addition on viscosity of the intestinal contents in laying hens.

	Viscosity of the contents of the jejunum (mPa x s)	Viscosity of the contents of the ileum (mPa x s)
Proportion of rye in the diet (%):		
0	5.38 a	8.36 a
25	34.0 b	26.0 b
Addition of xylanase:		
-	18.0 b	26.8 b
+	11.4 a	7.63 a
SEM	0.235	0.250
Rye	*	*
Xylanase	*	*
Interaction	*	*

a, b – values marked with different letters differ significantly ($P \leq 0.05$)

* – $P < 0.05$

Table 10. Effect of different proportions of rye in the diet of slaughter goslings on average body weight at 8, 11, 14 and 17 weeks of age.

Week of age	Sex	Rye content (%) in the feed mixture during the second rearing period (from 3 to 14 weeks of age)						SEM
		0	0	0	40	40	40	
		Grain-based fattening (from 14 to 17 weeks of age)						
		Oats	Oats and rye (1:1)	Rye	Oats	Oats and rye (1:1)	Rye	
8	Males	3664	3656	3643	3615	3611	3640	22.8
	Females	3323	3366	3362	3225	3255	3258	19.1
11	Males	4554[a]	4549[a]	4569[a]	4337[b]	4363[b]	4350[b]	24.1
	Females	3992[a]	4014[a]	4012[a]	3840[b]	3859[b]	3846[b]	21.6
14	Males	5153[a]	5144[a]	5165[a]	4806[b]	4821[b]	4813[b]	29.9
	Females	4476[a]	4502[a]	4484[a]	4149[b]	4166[b]	4178[b]	25.0
17	Males	5575[a]	5339[b]	5211[b]	5627[a]	5300[b]	4951[c]	34.3
	Females	4825[a]	4807[a]	4550[b]	4762[a]	4672[ab]	4563[b]	26.8

a, b – values in the rows marked with different letters differ significantly ($P \leq 0.05$)

Table 11. Average cereal grain intake (g) during grain-based fattening in slaughter geese between 14 and 17 weeks of age.

Intake	Sex	Rye content (%) in the feed mixture during the second rearing period (from 3 to 14 weeks of age)						SEM
		0	0	0	40	40	40	
		Grain-based fattening (from 14 to 17 weeks of age)						
		Oats	Oats and rye (1:1)	Rye	Oats	Oats and rye (1:1)	Rye	
Daily	Males	339^{ab}	332^{bc}	294^{d}	347^{a}	320^{bc}	304^{d}	3.56
	Females	321^{abc}	322^{abc}	260^{e}	326^{ab}	312^{bc}	282^{d}	4.44
Total	Males	7112	6969	6176	7237	6719	6387	
	Females	6738	6771	5458	6842	6545	5923	

a, b – values in the rows marked with different letters differ significantly (P≤0.05)

Table 12. Effect of adding different proportions of rye grain to the feed mixture on the performance of reproductive geese during the first laying season.

	Laying rate (number of eggs in a season)	Average egg weight (g)	Feed intake (g/goose/day)	Egg fertilisation (%)	Hatchability from fertilised eggs (%)
Proportion of rye in the diet (%)					
0%	40.33^{a}	144.62	252.36^{b}	40.36^{c}	50.88^{b}
20%	39.35^{a}	145.52	239.29^{a}	68.92^{a}	64.01^{a}
30%	35.62^{b}	146.86	235.25^{a}	65.20^{ab}	68.26^{a}
40%	38.23^{ab}	144.28	252.00^{b}	52.26^{b}	52.25^{b}
SEM	0.58	0.57	1.99	1.90	1.95

a, b – values marked with different letters differ significantly ($P \leq 0.05$)

Table 13. Effect of adding different proportions of rye grain to the feed mixture on the performance of reproductive geese during the second laying season.

	Laying rate (number of eggs in a season)	Average egg weight (g)	Feed intake (g/goose/day)	Egg fertilisation (%)	Hatchability from fertilised eggs (%)
Proportion of rye in the diet (%)					
0%	45.17[a]	169.45	330.98[b]	58.43	54.69
20%	45.00[a]	168.85	311.95[a]	53.05	67.22
30%	37.67[b]	166.3	321.32[ab]	49.77	55.37
40%	37.13[b]	166.98	328.24[b]	62.76	60.61
SEM	0.99	0.67	2.39	2.26	2.52

a, b – values marked with different letters differ significantly ($P \leq 0.05$)

Table 14. Example feed mixture recipes for laying hens with rye content (%)

Specification	Species (technological group) of poultry					
						Geese
	Slaughter chicks (from 22 days of age)		**Laying hens**		**for slaughter (from 3 weeks of age)**	**for reproduction**
Rye grain	**10.00**	**15.00**	**15.00**	**20.00**	**40.00**	**20.00**
Corn	29.84	26.34	20.00	17.00	5.00	15.00
Wheat	20.00	18.00	31.16	28.86	16.30	30.24
Post-extraction soybean meal	30.40	30.50	20.**50**	20.50	25.40	16.70
Wheat bran	-	-	-	-	10.00	9.00
Rapeseed oil	6.00	6.40	2.10	2.40	-	-
Feed chalk	1.40	1.40	9.10	9.10	1.20	7.00
1–Ca phosphate	1.30	1.30	1.20	1.20	1.00	0.90
NaCl	0.30	0.30	0.30	0.30	-	-
L-lysine (78%)	0.17	0.17	0.03	0.03	-	-
DL–Met (99%)	0.23	0.23	0.11	0.11	-	-
L-Tre	0.06	0.06	-	-	-	-
Vitamin and mineral premix	0.50	0.50	0.50	0.50	1.10	0.90
Content of nutrients per 1 kg of feed mixture						
General protein	g	205		170	192	156
EM	MJ	13.10		11.55	10.10	10.20
Ca	g	8.10		36.0	7.30	28.30
Digestible P	g	4.10		3.75	4.30	3.90
Lysine	g	11.5		8.10	9.60	7.10
Methionine	g	5.25		3.60	3.80	3.00