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Production, Chemical Composition and Nutritive Value of Oat Grain Fed to Fattening Geese

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The documented history of goose breeding in Poland dates back to the 18th century, with significant development of this branch of agricultural production a century later, when more than 3.5 million of live birds were sold annually at the Warsaw Commodities Exchange (Kruczek, 2011). Several native regional goose varieties and breeds developed in the past centuries and were included in the genetic resources conservation programme in 1999 (Krupiński, 2008). Conservative flocks were gathered in the Waterfowl Genetic Resources Station in Dworzyska, a unit of the National Research Institute of Animal Production in Kraków, Kołuda Wielka Experimental Station.

Goose breeding and farming intensified in Poland after WW2, and, in particular, after 1962, as the possibility to export goose meat appeared. In those days, White Italian chicks were purchased in Denmark and brought to Poland, to the National Research Institute of Animal Production, Experimental Station in Kołuda Wielka. Breeding work was started, which produced a new native goose breed. Soon, the plant grew into the only goose breeding farm and goose breeding centre in Poland, assuming full responsibility for improving the birds' domestic population. The forerunners of goose studies in Poland and authors of the very first academic and popular science papers were the then head of the Experimental Station in Kołuda Wielka, Associate Professor Kazimierz Bieliński, PhD and his wife, Krystyna Bielińska, PhD. Soon the Station's less senior academic researchers followed in their footsteps, supervised by Halina Bielińska, PhD, as well as staff from other research and breeding centres. In 1993, geese bred in Kołuda Wielka started to be known as "Gęś Biała Kołudzka" (White Kołuda Goose), a name approved by the Commission for Breeding Material Recognition of the Ministry of Agriculture, Forestry and Food Economy (Badowski, 2013). In 2001, the Patent Office of the Republic of Poland registered the trademark of *Biała Kołudzka® Goose* as exclusive right no. 159835 (Patent Office of the Republic of Poland, 2001). The genetic improvement programme for the White Kołuda® goose covers two strains: The W-33 male strain and the W-11 female strain. In the male strain, breeding work is aimed at improving meat traits, while in the female strain efforts are made to improve laying characteristics (MRiRW, 2013). In recognition of the scientific achievements and significant breeding progress in works on White Kołuda® Geese, in 2012 the Minister of Agriculture and Rural Development authorised the Polish National Poultry Council – Chamber of Commerce in Warsaw to maintain herdbooks for White Kołuda® Geese, strains W-33 and W-11, thus acknowledging White Kołuda® Goose to be a separate breed of Polish native geese (MRiRW, 2012). In 2015, the National Research Institute of Animal Production, Kołuda Wielka Experimental Station registered the White Kołuda® Goose trademark in 28 European Union Member States and in Japan (Herbut, 2016). Currently, about 98% of the goose population in Poland derives its genotype from the White Kołuda goose from the breeding farm at the National Research Institute of Animal Production, Kołuda Wielka Experimental Station.

Poland has been valued as a producer of geese for years, with the 'young Polish oat goose' often being referred to as a distinctive mark and one of the best export products of the Polish agriculture. Table 1 shows the biggest fattening goose producers.

Table 1. Fattening goose producers in the world in 2013 (Leszczyńska, 2015)

Country	Production of fattening geese (tons)
World, total, incl.:	2,698,322
China	2,557,098
Egypt	32,907
Hungary	26,441
Taiwan	19,550
Poland	18,405
Madagascar	12,603
other	31,318

China is by far and away the major producer and consumer of fattening geese, which is understandable given the country's population. In 2012, the world's leading exporter of fresh and frozen goose and guineafowl meat were: Hungary (18,272 t), Poland (16,145 t), China (11,921 t), Malaysia (1,194 t), Germany (1,155 t) and France (381 t). As shown by the data above, while China is the tycoon of goose meat production, Europe has grown into the lead exporter. World slaughter geese export totalled 50,654 tons, of which 36,652 was European export. Around 68% of global export was from Hungary and Poland (Leszczyńska, 2015).

Oat as the Polish speciality in fattening geese production

The trade name 'oat goose' derives from the fact that in the last three weeks of the fattening period, i.e. from week 15 to the end of week 17 of life, fattening geese are fed only with oats and water. The right to use the 'young Polish oat goose' shared trademark is vested in the Polish National Poultry Council – Chamber of Commerce in Warsaw and in companies holding the relevant authorisations (KRD-IG, 2006). Because of its specific chemical composition, the oat, which is rich in fat, is digested and builds into the goose's tissues, thus increasing the taste of its meat and fat, as well as feather quality (Majewska, 2011; Brzóska et al., 2017). The meat is dark-coloured, similar to wildlife birds' flesh, and is low in fat compared to other poultry species. Fat is deposited subcutaneously and in abdominal muscles (pads in posterior abdominal cavity). The fat of oat geese is rich in mono- and polyunsaturated fatty acids and contains conjugated linoleic acid (CLA), known for its excellent health properties, which is not present e.g. in broiler meat (Czarnewicz-Kamińska, 2011). CLA is obtained from grass and grass forage, the main source of goose feed from spring to autumn. In humans polyunsaturated acids are precursors for substances which have hormone-like activity and are the determinants of health. With a favourable climate, Poland is a significant producer of oat grains fed to horses and slaughter geese (Tab. 2).

Table 2. Sown, harvest and crop areas of oat around the world in 2013 (GUS, 2015)

Country	Sown area (thous. ha)	Grain harvest (thous. tons)	Oat crop (dt/ha)
World	9780	23881	24.4
incl.:			
Russia	2998	4932	16.5
Canada	1107	3888	35.1
Australia	699	1124	16.0
Poland[1)]	434	1190	27.4
Spain	432	965	22.3
USA	417	1016	24.4
[1)] *in 2014*	479	1459	30.5

In Hungary and China, slaughter geese and ducks are primarily fed with maize and sorghum grains. The largest recipient of Polish goose meat is Germany, which purchases 95% of all exported slaughter geese. On Saint Martin's Day (November), the patron saint of German protestants, relatives gather in the family house around a table on which goose meat is served, a tradition known for 250-300 years. Although the consumption of goose meat in Poland has been growing systematically owing to a far-reaching promotional campaign, it remains low and equals c.a. 300 g per capita per year. The consumption growth trend is estimated to continue in the oncoming years. Therefore, more extensive research should be conducted on the economic aspects of slaughter goose production in connection with raising the quality of goose meat. Selective studies on increasing the share of breast and leg meat in carcass weight are equally justified.

There are two types of common oat grain, the yellow-coloured hulled common oat (*Avena sativa* L.) and naked oat (*Avena nuda* L.). In recent years, brown common oat has been grown. Research shows that despite differences in colour, these varieties have the same average protein content. The difference is that brown oat contains more hull and crude fibre and less starch (Biel et al., 2006, 2010). In Poland there are 42 hulled oat varieties approved for cultivation, among which is one brown cultivar. A considerable diversity was reported among different oat varieties grown in the same conditions in terms of crude protein content (from 115 to 141 g/kg of grain). The Hetman, Bachmat and Rajtar cultivars have proved to have the highest crude protein content (Brzóska et al., 2017). As protein demand of geese between the age of 15 and 17 weeks is 14% of the feed ratio, oat cultivars with crude protein content close to 14% should be preferred in goose fattening.

Chemical composition and nutritive value of oat grain

The chemical composition of oat grain is the outcome of a number of factors, including genetic and environmental ones, such as the type and water content of soil, its amelioration (in particular, with nitrogen), seeding density and insolation (Michalski et al., 1999; Givens et al., 2004; Podolska et al., 2009; Tobiasz-Salach et al., 2010; Sułek, 2003; Koziara, 2004; Hebda and Micek, 2007; Sykut-Domańska, 2012). Variations in amino-acid composition of oats depending on agricultural engineering factors were described by Ralcewicz and Knapowski (2006). Szymczyk and Hanczakowski (2006) in turn tested the effect of naked oat on fatty acid profile in rats, taking into account the high content and composition of fatty acids in naked oat. Oat grain has a very specific chemical composition and nutritive value of proteins, fat and fibres (Majewska, 2006; Brzóska et al., 2017). Although the content of crude protein in oat grain (12-14%) is similar to other cereals, its nutritive value is higher. The content of essential amino acids in oat fed to poultry equals 43.7 g/kg, compared to 38.3 g/kg in wheat grain (water content 12%) (Smulikowska and Rutkowski, 2005). Despite these obvious advantages, with crude fibre content of 11-16%, oat cannot be used as the primary cereal component of compound feeds for poultry and young swine, except for geese, whose extended caecum allows them to digest a considerable amount of fibre. Czarnota (2006) proved that hulled oat can be successfully fed to poultry in a proportion not exceeding 10% of diet, whereas in the case of laying hens it works best when crushed. Sokół and Fabijańska (2006) pointed to lower digestibility and energy content of hulled oats. The energy value of naked grain is the same or higher than that of maize grain. The *Poultry Feeding Recommendations* (Smulikowska and Rutkowski, 2005) read that common oat grain contains 4.7 g/kg of lysine and 1.9 g/kg of methionine, compared to 2.5 and 1.9 g/kg in maize. Sokół and Fabijańska (2006) showed that the content of lysine, methionine, arginine, tryptophan and valine in grains of 8 yellow hulled oat varieties equalled 4.64; 1.87; 7.3; 1.28 and 6.09 respectively. Oat grain can be successfully used in goose fattening, no matter how insufficiently the fitness of individual cultivars for use in feeding geese has been examined. An analysis of literature shows that individual oat varieties differ significantly in protein and amino-acid content (Brzóska et al., 2017). There are 26 common oat varieties and 5 varieties of naked oat registered in the National List of Varieties of Agricultural Plant Species (COBORU, 2017). Table 3 contains the chemical composition of oat as presented by Smulikowska and Rutkowski (2005) and by Brzóska et al. (2017), while Table 4 lists coefficients of protein, fat and n-free extractive digestibility in oat according to data included in the *Poultry Feeding Recommendations* (Smulikowska and Rutkowski, 2005).

Table 3. Chemical composition of 1 kg hulled oat in poultry feed value tables (Smulikowska and Rutkowski, 2005) and in hulled and naked oats (Brzóska et al., 2017)

Nutrients (g/kg)	Smulikowska *and* Rutkowski (2005)	Brzóska *et al.* (2017)		
		yellow oat	*brown oat*	*naked oat*
Dry matter	880.0	880.0	880.0	880.0
Crude protein	118.0	115.3	115.2	129.2
Metabolizable energy (MJ)	11.75	9.28	8.84	12.21
Crude fat				
Crude fibre	41.0	37.8	37.0	63.1
Crude ash	89.0	88.1	103.7	34.9
Starch	31.0	20.3	23.1	20.3
Calcium	393.0	393.8	374.5	438.0
Phosphorus	0.7	0.6	0.6	0.8
Lysine	3.7	3.5	3.5	3.6
Methionine	4.6	4.64	4.75	5.21
Methionine + Cystine	1.9	1.87	1.85	2.06
Threonine	4.5	4.83	5.11	5.35
Tryptophan				
Isoleucine	4.0	4.15	4.23	4.53
Leucine	1.5	1.28	1.43	1.47
Valine	4.7	4.3	4.2	4.7
Histidine	8.3	8.6	8.8	9.6
Arginine	6.1	6.09	6.13	6.78
	2.5	2.5	2.4	2.7
	7.4	7.6	7.4	8.3

Research by Biel at al. (2006) assessed the quality of grain of different oat types based on chemical composition. Comparison of 6 selected naked oat strains with reference varieties (Polar and Akt) and with the hulled Chwat variety led to the following conclusions:

– naked oat was characterised by c.a. 20% higher protein content, low content of crude fibre and fat content higher by over 66% compared to common oat;

– the lower content of crude fibre and structural fibre fractions in naked oat varieties made it fit for use in feeding monogastric animals;

– the protein in naked oat is characterised by a favourable essential amino acid composition, which ranks it among the top cereals.

In addition, research by Biel at al. (2010) specified the chemical composition and protein quality in brown- and yellow-hulled oat. Study material consisted of grains of two yellow oat varieties (Deresz and Bohun) and four brown-hulled oat strains from the Danko plant breeding company in Choryń. Significant differences were shown between brown and yellow oat in terms of protein, n-free extractives and acid detergent lignin (ADL). Brown-hulled oat contained considerably more crude protein, while yellow-hulled oat was richer in n-free extractives and in ADL. There were no significant differences between the amino-acid composition and nutritive value of protein. Experiments by Gąsiorowska et al. aimed at testing the influence of the seed output on the accumulation of phosphorus, potassium and calcium in naked and hulled oat grains. Naked oat proved to contain more phosphorus and calcium and less potassium compared to hulled oat. The accumulation of minerals in oat grain was largely determined, next to genetic factors, by weather conditions in the vegetative period and seeding density. The biggest content of phosphorus and potassium in oat grain was obtained for the lowest seeding density (300 grains per 1m^2) while the largest content of calcium was obtained for average seeding density (500 grains per 1m^2). The impact of habitat, soil and weather in the vegetation period on fat yield per the cultivated area, fat content and fatty acid composition in the grains of naked and hulled oat genotypes was also examined (Pisulewska et al., 2011). The research was carried out in 3 habitats in Podkarpackie Voivodeship with the use of 1 variety and 2 strains of each of the two oat types. It was proved that diversified soil and weather conditions had a significant impact on oat fat yield per area, similar to the distribution of precipitation in the vegetation period; the varieties and strains examined differed significantly in yield and fat content. Naked oat grain was in general by 32% richer in fat, with considerable differences in fatty acid profile between individual oat types. The fat present in hulled oat grains contained in turn less mono-unsaturated and more poly-unsaturated fatty acids. Naked oat (strain STH 7505) had the biggest content of oleic (41.54%) and the lowest content of linolenic acid (1.00%), while naked grains of the Krezus cultivar were characterised by the smallest content of oleic (37.05%) and the biggest content of linoleic (40.71%) and linolenic (1.39%) acids. Other research showed the effect of feed particle size on alimentary tract of poultry, in particular, on the size of stomach (Carré, 2000), health of birds and agility and activity of the intestinal epithelium (Ferket, 2000; Engberg et al., 2002. 2004; Bjerrum et al., 2005; Amerah et al., 2007).

Digestibility of crude protein and amino acids in oat

After the method of digestibility assessment in the entire alimentary track was objected, as certain bacterial digestive processes occur in caeca, i.e. outside of the section of the alimentary tract responsible for absorption of the products of digestion, a proposal was made to determine amino-acid digestibility in the small intestine, taking into consideration 'exogenous' excretion of amino acids (Ravindran and Bryden, 1999). The content of endogenous proteins depends on the quantity of the forage consumed and its chemical composition, including digestibility, content of fibre and non-starch polysaccharides, ileal contents viscosity and presence of anti-nutritive factors (Angkanaporn et al., 1997). The new digestibility determination method was given the name 'standardised ileal digestibility (SID)'. Although apparent ileal digestibility (AID) does not include exogenous excretion of amino acids, the method is frequently used to estimate ileal digestibility of proteins and amino acids in poultry and pigs. Apparent digestibility is minimally higher than true digestibility. Based on digestibility examination in birds of different age, fed with cereal forages, ileal digestibility of carbohydrates and amino acids in waterfowl is assumed to be lower than in slaughter chickens and turkeys (Kluth and Rodehutscord, 2006). In their research, Jamroz et al. (2004) showed that the difference in forage digestibility in individual poultry species, including geese, compared to chickens and ducks, may be due to differences in their alimentary tract anatomy, in particular, relative length of the small intestine, the proportion of which to metabolic body weight ($MC^{0,75}$) is higher in broiler chickens than in ducks. The nutrition system used for breeding and fattening geese is based on feedingstuffs that are balanced in terms of the amino-acid and energy demand of the birds, with granules being used as the exclusive forage, in particular in the first 4-5 weeks of life. In the available literature there is no information on digestibility of amino-acids contained in the feed ratio within the final breeding phase, when only whole, crushed and ground oat is fed to the birds. Amino-acid digestibility in geese depends on a number of factors, such as the birds' age, feed ratio content, grain type and composition of the feed ratio (Jamroz et al., 2001; 2004).

Chicken studies have shown that digestibility of amino acids in 8 feed materials increased with broilers' age, which may have been due to the extension of the small intestine absorbing surface in growing chickens or increasing effectiveness of the enzyme system (Huang et al., 2005). In comparative studies on growing poultry species, average amino-acid digestibility in chickens equalled 70% and grew to 73% between the age of 15-42 days, compared to 43-61% in ducks and 63% in geese (Jamroz et al., 2002). Amino-acid digestibility in poultry is assumed to be limited by anti-nutritive substances in the diet, such as fibre, tannins and protease inhibitors (Fan and Sauer, 1999). The coefficients of digestibility of the main three nutrients in goose diet are presented in the study by Smulikowska and

Rutkowski (2005). Available literature provides no results of tests on the influence of the physical form of oat grain on the apparent or true amino-acid digestibility in geese.

Table 4. Coefficients of oat grain nutrient digestibility (Smulikowska and Rutkowski, 2005)

Nutrients	*Hulled oat*	*Naked oat*
Crude protein	0.75	0.83
Crude fat	0.86	0.74
N-free extractives	0.75	0.89

Jamroz et al. (2004) examined the ileal and post-ileal fermentation of cereal carbohydrates in chickens and ducks. In other research on broilers, ducks and geese, the same authors made an attempt to determine true and apparent digestibility of feed ratios containing maize, wheat, barley and rye, disregarding oat grains (Jamroz et al.,1996). Follow-up experiments focused on the development of alimentary tract in poultry and ileal digestibility of fibre and amino acids in young chickens, ducks and geese at the age of 42 days (Jamroz et al., 2001). This study showed, in turn, that in 3 cases, ileal digestibility of amino acids in geese was higher and in 1 case lower (threonine) than showed in previous research by Jamroz et al. (2001).

An attempt to explain the effect of the physical form of feed ratio and time of the matter transport through the gastrointestinal tract on ileal digestibility of amino acids in geese fed exclusively with oat was made by Kłopotek in his PhD dissertation (2016). In older birds the motility and food traverse through the alimentary tract is slower, making the food more exposed to hydrolytic activity of digestive enzymes, while due to larger absorbing surface of the small intestine, ileal digestibility of amino acids is higher, a fact confirmed in poultry fed with feeds of animal origin (Shires at al., 1987). More light on digestive processes in poultry, including geese, has been shed by the digestibility results reported by Jamroz et al. (2001). A considerable amount of amino acids, probably contained in cell walls, is digested by bacteria outside of the small intestine, i.e. in caecum, whereas cellulose digestion rate is very low, between 0.2 and 0.4% (Jamroz et al., 1992). Kłopotek (2016) showed in his studies that ground oat grain fed to geese highly significantly improved, while crushed oat grain highly significantly deteriorated (compared to whole oat), the digestibility of proteins and amino acids, whereas the time of transport of food containing different physical forms of oat through the alimentary tract was the longest in geese fed with whole oats. In geese fed with ground oat, the time of food transport through the alimentary tract was more than twice shorter. The results point to reliance between the fragmentation, feed transport duration and digestibility of forage in geese. Previous research showed that differences in digestibility in different poultry species result from differences in the development of the birds' alimentary tract, its anatomy and morphology (Jamroz et al., 2004). In the process of oat crushing its endosperm gets crushed, too, which should improve access of water and digestive juices to the grain. Research showed, however, that the process did not increase amino-acid digestibility. It cannot be excluded that by crushing cereal grains, including oat, endosperm compaction increase is obtained, making the grain less vulnerable to hydrolytic activity of digestive juices. Nonetheless, the above did not affect the weight of the stomach, whose muscular part exceeds several times the glandular part both in terms of weight and volume.

Table 5. Apparent ileal and faecal digestibility of major essential amino acids in young geese, from diets containing barley and wheat grain (Jamroz et al., 2001), compared to fattening geese fed whole oat grain only (Kłopotek, 2016)

Amino acids	*Faecal digestibility*	*Ileal digestibility*	
	Jamroz *et al.* (2001)	Jamroz *et al.* (2001)	Kłopotek (2016)
Lysine	85.5	40.8	55.8
Methionine	87.1	51.6	66.6
Cystine	77.2	47.0	56.7
Threonine	78.6	49.6	43.7

High faecal digestibility is the outcome of bacterial decomposition of nutrients, including non-starch polysaccharides, in the large intestine, which is quite extended in waterfowl. Opinions concerning the digestibility of different physical forms of oat grains in geese are unequivocal. Grain grinding appears to be more effective. The smashing of grains into numerous particles causes the removal and crushing of seed coat, as a result of which the surface of grain exposure to digestive enzymes grows several times, as showed in studies by Arroyo et al. (2013 ab). The present study showed that ground oat grain in geese was characterised by the highest ileal digestibility of proteins and amino acids, highly significantly higher than the digestibility of the same ingredients in geese fed with whole and crushed grain, with the shortest duration of transport of ground grain through the birds' alimentary tract. In the study, however, there was an additional factor that may have interfered with assessment of the influence of the form of oat grain on protein and amino-acid digestibility. This major factor with influence on the digestibility of nutrients, including amino acids, which has not been taken into account in scientific research is the feed ratio intake. Oat grinding has been proved to significantly reduce the amount of grains consumed by geese compared to whole grains; the same difference is observed between crushed and whole grains. This means that the amount of digestive juices secreted per the specified weight of grains fed to the birds (assuming a certain length of the small intestine) is considerably higher for ground grain consumed in smaller amounts. This might have provoked a more intense proteolytic hydrolysis of protein in ground oat and better absorption of peptides and amino acids in the small intestine, which showed in the research in higher coefficients of apparent ileal digestibility of amino acids, despite the significantly shorter duration of transport of food through the alimentary tract. Grain grinding through its fragmentation, including fragmentation of the seed coat, may reduce the time of it staying in caeca. The notion is not yet fully understood, as we do not know whether the alimentary tract of geese or, more broadly, waterfowl, contains an inner system of food segregation into fibrous matter, transported to caeca, and non-fibrous matter, i.e. mainly starch fractions not digested in the small intestine, including non-starch polysaccharides. The notion, although interesting from the scientific perspective, would require different patterns of feeding experiences and operational preparation of the birds in order to assess digestibility within different sections of the alimentary tract in geese. As part of research on protein and amino-acid digestibility in slaughter geese, it has been observed that digestibility is substantially higher in geese than in ganders, with highly significant interaction between the physical form of grain and the birds' sex. In the available literature there is no information on the above, and the relationship cannot be reasonably explained in light of the research conducted.

Conclusions

Given the substantial diversity of individual oat varieties in terms of protein and amino-acid content and the demand for protein and amino acids in fattening 'oat geese' aged between 15 and 17 weeks, varieties with a 14% crude protein content in grain should be preferred in cultivation of oats for goose feeding, while varieties with lower protein content should be avoided. Although digestibility of whole oat grains is lower than digestibility of ground grains, smashing substantially reduces grain intake and the time of its retention in the alimentary tract, thus causing no improvement in the growth and musculature of geese.

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PRODUCTION, CHEMICAL COMPOSITION AND NUTRITIVE VALUE OF OAT GRAIN FED TO FATTENING GEESE

Summary

In Poland, geese for fattening are specifically fed common (hulled) oat grain from 15 to 17 weeks of age. This review article discusses global production of fattening geese as well as oat cultivation, harvests and yields. The nutrient content, including the energy value and amino acid level in oat grain are presented according to feed value tables, as is the nutrient content in yellow hulled oat, brown hulled oat, and naked oat. Research results are shown for digestibility of nutrients and ileal digestibility of lysine, methionine, cystine and threonine in oat grain fed to geese in the finishing period. It was found that out of the three forms of oats (ground, crushed, whole), whole grains are the best form to be used in oat fattening. Feeding geese with ground oat, despite the highest ileal digestibility, reduces its intake and thus has an effect on body weight at 17 weeks of age. It is concluded that fattening geese should be fed with whole grain of oat varieties that contain around 14% crude protein.

Key words: composition, nutritive value, oats, geese