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Yield, grain quality and potential use of triticale in Poland

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Abstract. Several cereal species are grown in Europe, but wheat and maize have the largest acreage, followed by barley, oats and rye. Due to breeding improvements, cereal cultivars produce high grain yields. Improvement of cereals within a species and breeding of new cultivars is one of the main methods to improve yield and grain quality. However, the creation of interspecific hybrids, in which new types with better characteristics are obtained through introgression and genetic selection, is also worthy of attention. The interspecific hybrids of cereals are not very popular, but triticale is the cereal that has gained the most popularity and is of increasing interest to farmers in Europe. It is the result of the hybridisation of wheat and rye. Having many beneficial properties, its cultivation should be popularised. The aim of this paper was to review scientific research concerning possibilities of increasing the acreage under cultivation of this cereal, taking into consideration its agronomic requirements and grain quality, as well as the potential of grain utilisation for food and fodder purposes.

Keywords: Triticale, nutritional value, agronomic requirements, cultivar, feed value, amino acid profile, energetic use of grain

INTRODUCTION

Cereals occupy a significant area in Poland, estimated at 75% of all arable land. In recent years, in terms of acreage under cereal cultivation in the EU, Poland ranked second, and in terms of grain production – third. Moreover, in the period 2018–2019, the share of total cereals in global agricultural production was 15–16%, and in crop production – about 33% (Augustyńska, Czułowska, 2021). Harvested grain is of strategic importance for human nutrition. This applies both to the direct use of grains for food, but also for the production of animal feed. Populations of poultry have increased significantly in recent years (CSO, 2019). The production of feed for these animals covers a significant amount of the grain produced in Poland. Considerations of feed use and the better value of triticale grains have led to a significant increase in the area under this cereal. The determinant of production of particular grains in Poland is their adaptation to climatic and soil conditions and the demand for them on the market, which in turn, results from possible strategies for its disposal (food, fodder, industrial). The possibility to use produced grains for various purposes significantly facilitates their sale. From the farmers' point of view, production costs and labour input are also important. These factors affect farmers' interest in growing a given cereal, which translates into the scale of cultivation in the country and grain production. A new cereal, namely triticale, was gradually introduced to cultivation in Poland at the beginning of the 1990s. This resulted from the fact that farmers were accustomed to cereals grown earlier, mainly rye. Gradually, farmers were persuaded to cultivate triticale, whose share in the total area under cereal crops increased from 5.6% at the end of the 1990s, to 10.7% in 2005, and in the period of the next five years it increased to the level of 12.3%. At present, it accounts for 17% of the total area under cereals (Figure 1). This was done at the expense of reducing the acreage of rye, which has a lower feed value (Jaśkiewicz, Sułek, 2017). The development of breeding new varieties that achieve higher yields brings with it the possibility of further increases in grain yield per hectare. This gives an opportunity for exports of grain outside Poland or to increase its use for food or energy purposes. According to the latest data, 4.3 million tonnes of triticale grain was harvested in 2019, which was slightly below the average of the last three years (4.4 million tonnes in 2016–2018). The cultivation of this cereal involves mainly the winter form, which occupies about 89–85% of the total sown area, with the remaining 11–15% by spring varieties. Increased interest among farmers in the winter form of triticale has resulted in an increased number

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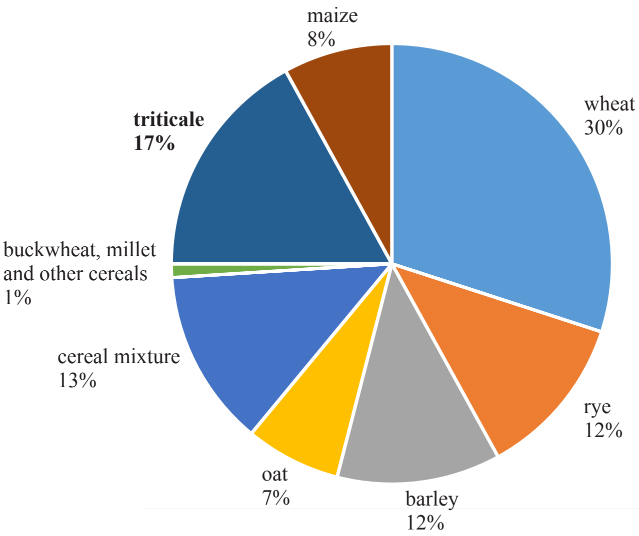

Figure 1. Percentage of individual cereals in the cultivation structure in Poland (own study based on Central Statistical Office, 2019).

of these varieties (46) compared to spring varieties (16) entered in the national register of the Research Centre for Cultivar Testing (COBORU). Winter varieties yield better than spring ones. The protein content in grains of winter varieties is also higher by 2–4%, which translates into a higher protein yield per hectare (Table 1).

Table 1. Comparison of grain protein content and protein yield per hectare of different cereal species (Różewicz, 2019).

Cereal species	Form	Protein content of grains [%]	Protein yield [kg ha^{-1}]
Triticale	spring	11.6	291.2
	winter	15.2	498.5
Wheat	spring	13.8	434.5
	winter	12.2	516.0
Rye	winter	9.7	233.5
Barley	spring	11.4	336.3
	winter	11.6	438.5
Maize		10.9	652.6
Oats		12.2	407.0

The aim of the work is to review the knowledge of the importance of cultivating triticale in Poland and the possibility of using its grain for food, fodder and energy purposes

CULTIVATION AND PRODUCTION OF TRITICALE IN POLAND

Triticale is a cereal species that has both spring and winter forms. In the national register of the Research Centre for Cultivar Testing in Poland (COBORU, 2019), 16 spring and 46 winter cultivars of triticale are listed. These cultivars are characterised by high yield, disease resistance and have the highest predisposition for cultivation in Poland. Poland is the leader in triticale grain production among the European Union countries. In total, in 2017, the world produced 15.5 million t, including 5.3 million t in Poland. Large producers of triticale are also: Germany 2.3 million t, France and Belarus about 1.6 million t each. (FAOSTAT, 2019). The cultivated area and the production of triticale grain place Poland as a leader in the production of triticale grains. Polish breeders of new triticale cultivars have made a very large contribution to the breeding progress of triticale. Polish triticale cultivars are also valued abroad and account for 70–80% of triticale cultivation area in the world (Jaśkiewicz, 2016a). Triticale currently plays a very important role in the total production and species structure of cereal grains, as its cultivation has largely replaced the cultivation of rye. Thanks to the involvement of breeders of this cereal species, as well as scientists involved in the improvement of its agrotechnology and the transfer of knowledge to practical growers, it has resulted in its economic importance, mainly for use as feed grains. The annual harvest of triticale grains in Poland is used in 85% for feeding by various animal species (Jaśkiewicz, 2017). Certified seed represents a cost for the agricultural producer. According to the Central Statistical Office in Poland (CSO, 2019), triticale seeds saw the highest increase in sales by 8.2%. The area under triticale cultivation has been systematically increasing in recent years. It is a fodder cereal which, with the increased demand for its grains, will be cultivated on an increasing area. Among factors predisposing further growth of triticale cultivation are its soil requirements. It yields well and is recommended for cultivation on soils unsuitable for growing wheat, but too good for rye. Triticale yields quite well under conditions of cereal monoculture but requires, however, a plough system of cultivation (Jaśkiewicz, Jasińska, 2018). Another advantage of spreading triticale cultivation in Poland is the high demand for fodder grains and the formation of a stable market where demand and supply will balance each other. This is favoured by a small, though systematic increase in poultry production, accompanied by a constant fluctuation in the stock of pigs. These two species have the greatest influence on the demand for grains from feed companies. Increased demand from the feed industry and the occurrence of droughts have resulted in a steady increase in the price of feed grains in recent years (CSO, 2019).

Individual growing seasons can be characterised by high yield variability, which is related to agroclimatic conditions, as well as to changes in farming intensity. The occurrence of drought is the main factor limiting triticale yield, regardless of the tillage treatments applied (Jaśkiewicz, 2016b). Rainfall deficiencies and droughts cause higher yield losses of spring cultivars of triticale. The period of development stages from earing to wax maturity of grains is particularly critical. Rainfall deficiency in this period may cause yield losses of 10–20%, while in the periods of sowing-wax maturity and sowing-harvest by 12–16 and 10–14%, respectively (Kalbarczyk, 2008). The areas in the south-eastern part of Pomerania are the most threatened by rainfall deficit in the critical period of spring triticale. Production volume of grain determines its unit price and economic usefulness for fodder. The higher the harvest, the cheaper the grain, which positively affects the economics of poultry production (Koreleski, 1992).

The grain yield obtained depends on soil conditions but also on the cultivar. The results of a study by Noworolnik and Jaśkiewicz (2018) showed that different cultivars grown on poorer soils responded with different degrees of yield reduction. Individual triticale cultivars also show different responses to the tillage system. According to a study by Jaśkiewicz and Jasińska (2018), under reduced and plough tillage, the cultivars Cerber and Alekto yielded higher than Fredro. With optimal rainfall, higher grain yields of winter triticale are obtained with plough tillage. Grain yield was then 15% higher than that under reduced tillage. Similarly, in spring triticale cultivars, a higher yield is obtained under ploughing cultivation. Then, fertilisation in the amount of 70 kg N ha^{-1} is sufficient to obtain a high yield, however weather conditions and adequate precipitation are important (Jaśkiewicz, 2021). Cultivation in a crop rotation with a smaller share of cereals ensures higher yield of triticale compared to winter triticale yields under monoculture (Jaśkiewicz et al., 2018).

Soil and climatic conditions and regional traditions determine the specialisation of production. The areas of central, eastern and northern Poland are dominated by rye, cereal mixtures and maize. The greatest concentration of triticale cultivation and the largest share in domestic triticale production are in Wielkopolska and Kujawy and in the central and eastern part of Poland. The large scale and acreage of triticale cultivation and production in these regions is associated with numerous animal populations (Jaśkiewicz, 2016a), including the occurrence of large-scale poultry farms. Studies by Jaśkiewicz et al. (2019) also indicate a significant share in the national production of triticale grains of the areas of Wielkopolskie voivodeship and central and eastern parts of Poland.

Triticale makes it possible to produce more fodder protein per hectare of area than do other cereal species. Winter cultivars have a higher protein content in grains and a higher yield (Table 1). Therefore, they are grown on a larger area. Under certain weather conditions and proper crop management practices, especially as far as fertilisation is concerned, it is possible to obtain very good results in the production of spring triticale grains as well. Knapowski et al. (2010) applying diversified nitrogen fertilisation (80 or 120 kg ha^{-1}) and foliar zinc fertilisation obtained an average protein yield of spring triticale within the range of 555–750 kg ha^{-1}. A three-year experience of the authors quoted showed that in favourable years protein yield could be as high as 896 kg ha^{-1} with 120 kg ha^{-1} N application and foliar zinc fertilisation in the amount of 0.3 kg ha^{-1}.

Triticale protein is characterised by a very good amino acid profile. Compared to wheat, it contains more lysine, as well as many other important amino acids (Table 2).

Table 2. Amino acid profile of grain protein of individual cereals [g/16 g N] (Biel et al., 2020).

Amino acid	Wheat	Triticale	Barley	Hulled oats	Naked oats
Lysine	1.89	2.56	3.59	2.73	2.76
Methionine + Cysteine	2.77	3.43	3.11	4.08	3.66
Methionine	1.29	1.55	1.63	1.34	1.26
Cysteine	1.48	1.88	1.48	2.74	2.40
Threonine	2.25	2.99	3.10	2.46	2.59
Isoleucine	2.39	3.51	3.10	2.32	2.49
Tryptophan	1.02	0.90	1.23	1.15	1.18
Valine	3.30	4.71	4.45	3.20	3.31
Leucine	5.82	6.35	6.31	5.26	5.25
Histidine	1.90	1.99	2.11	1.74	1.76
Phenylalanine +Tyrosine	5.77	7.43	7.45	5.88	5.92
Phenylalanine	3.69	4.44	4.97	3.62	3.57
Tyrosine	2.09	2.99	2.48	2.26	2.35
Arginine	4.19	5.41	4.41	5.79	5.32
Aspartic acid	4.67	6.27	5.93	7.37	7.02
Serine	3.61	3.88	4.23	3.86	3.38
Glutamic acid	33.12	29.42	24.83	19.12	18.24
Proline	7.29	8.59	9.26	4.54	4.01
Glycine	3.36	3.91	3.99	3.81	3.93
Alanine	2.58	3.85	3.82	3.51	3.72

NUTRITIONAL AND FEED VALUE OF TRITICALE GRAINS

Triticale is a cereal with high yield potential. In 2018, in Poland an average yield of 31.7 dt ha^{-1} was obtained and the overall grain harvest of this cereal was 4.1 million tonnes (CSO, 2019). The high supply of grains and its lower price than that of feed wheat or maize, predisposes the use of triticale for poultry feed purposes economically, but also in terms of feed value. Triticale has the same metabolic energy content as wheat. The main source of energy is starch, whose content in triticale grains is 50–85%. Such a big variation in the content of this compound results from the influence of many factors, among others, the varietal (genetic) factor and weather conditions during the vegetation and the applied cultivation technology. The crude fat content, which like the other nutrients, depends on the genotype (Table 3), is 0.86–1.98% (Langó et al., 2017).

Different triticale cultivars have different protein content in grains and give different yields of total protein (Jaśkiewicz, 2017). The maximum content of this component can be as high as 20% in some triticale cultivars (Elangovan et al., 2011). Achremowicz et al. (2014) indicate a proportional relationship between starch content and protein content in grains. There is always 5–6 times more starch than protein. In addition to the total protein content, the amino acid profile, and in particular the content of essential amino acids, is an important indicator of feed value. The protein amino acid profile in winter triticale is a genetically determined (Jaśkiewicz, Szczepanek, 2018). Another factor influencing feed value are the applied crop management treatments and weather conditions. The ratio of exogenous amino acids in the protein of triticale grains and their nutritional value (EAAI) are higher when intensive technology is applied (when high rates of NPK fertilization and intensive chemical plant protection are used). Jaśkiewicz and Szczepanek (2018) show that cultivar has an influence on protein amino acid profile. The authors also pointed out the great importance of adequate rainfall and water resources in the soil, as they cause an increase in the content of almost all essential amino acids (except valine). Considerable variability in the years of the study was observed for the amount of precipitation and the amino acid composition of the protein and, according to the cited authors, was particularly true of tyrosine.

The main amino acid limiting the quality of protein in triticale grains is lysine. Its increase in the amino acid profile of protein, as well as other essential amino acids (phenylalanine, histidine, arginine) under the influence of an adequate amount of precipitation in the Woltario cultivar was found by Brzozowska et al. (2009). This amino acid showed high variability among years and cultivars, but a weak response to agricultural practices-related factors (production technology and percentage of cereals in the crop rotation) was observed. The amino acid composition of grain protein is affected by crop management techniques, including sowing density, as well as weather conditions (Stankiewicz, 2005). Therefore, the amino acid profile of triticale grain protein of the same cultivar may differ in particular years (Table 4-5). Results obtained by Siegert et al. (2017) showed the effect of nitrogen fertilisation on

Table 3. Chemical composition of triticale grains of various cultivars [% dry matter] (Alijošius et al., 2016).

Cultivar	Crude protein	Crude fat	Crude fiber	Nitrogen free extract	Ash
Adverdo	9.81 ef	1.07 d	1.51 b	75.69	1.63 a
Grenado	10.17 de	1.18 c	1.02 e	76.33	1.43 f
Remiko	9.45 f	1.17 c	1.02 e	77.51	1.33 g
Sequenz	10.40 d	1.37 a	1.61 a	74.53	1.55 c
SU Agendus	11.89 b	1.34 b	1.39 c	73.26	1.58 b
SW Talentro	12.51 a	1.01 e	1.37 d	73.11	1.51 d
Toledo	11.31 c	1.17 c	1.38 cd	76.64	1.45 e

Means in the same column with different letters are significantly different at $P < 0.05$

Table 4. The content of exogenous amino acids (g kg^{-1}) in winter triticale grains of the Pizarro and Pigmej cultivar depending on the year of harvest (Jaśkiewicz, 2018).

Year of harvest	Threonine	Valine	Isoleucine	Leucine	Phenylalanine	Histidine	Lysine	Arginine	Methionine	Tryptophan	Sum
2011	3.84 a	5.01 a	4.07 a	7.69 a	5.47 a	2.83 a	3.95 a	5.44 a	2.29 a	1.13 a	41.82 a
2014	3.54 b	4.95 b	3.63 b	7.08 b	5.07 b	2.58 b	3.45 b	5.07 b	2.05 b	1.05 b	38.51 b

Means with different letters are significantly different at $P < 0.05$

Table 5. Content of endogenous amino acids (g kg^{-1}) in winter triticale grains of the Pizarro and Pigmy cultivar depending on the year of harvest (Jaśkiewicz, 2018).

Year of harvest	Serine	Aspartic acid	Glutamic acid	Proline	Glycine	Alaninie	Tyrosine	Cysteine	Sum
2011	5.54 a	8.10 a	31.65 a	10.86 a	4.75 a	4.89 a	3.06 a	2.25 a	71.10 a
2014	5.23 b	6.74 b	28.44 b	10.23 b	4.69 b	4.30 b	1.93 b	1.89 b	63.45 b

Means with different letters are significantly different at $P < 0.05$

the amino acid composition of triticale grain protein, but also the effect on amino acid digestibility for laying hens. Research by Muhova and Dobreva, (2020) also showed the effect of preceding crop and fertilisation on the amino acid composition of triticale grain protein, especially for lysine and methionine.

The nutritional value of grain is also determined by the content of macro- and microelements. The results of a study by Brzozowska (2006) concerning the content of macroelements in dry matter of winter triticale grains, indicate a dependence of the content of calcium, phosphorus, potassium and magnesium on weather conditions during the vegetation season. The content of nitrogen, phosphorus and potassium in grains increased with a decrease in precipitation, which in June and July amounted only to 49.4% of the mean sum over the multi-year period, and the mean temperature in those months was higher by 0.7 and 2.4 ^{o}C. In contrast, Gibczyńska et al. (2016) point to a varietal factor that differentiated potassium content in triticale grains. The cited authors point to the influence of the triticale cultivation system on mineral nutrient composition. Grains from the organic system had higher iron, zinc, manganese and copper contents by several percent, compared to those from the conventional system. The applied mineral fertilisation also influenced the content of mineral components in grains. Kozera et al. (2015) found that the rate of 120 kg N ha^{-1} considerably decreased the magnesium content and increased the concentration of manganese in spring triticale grains, compared to the rate of 80 kg N ha^{-1}. The authors also indicated a similar relationship for zinc. A more effective way of increasing the zinc concentration in grains was foliar application of zinc at the rate of 0.3 kg Zn ha^{-1}, than soil fertilization.

Cereal grains contain substances that reduce nutrient utilisation or negatively affect digestive processes and growth rates in poultry. Anti-nutritional compounds include: non-starch polysaccharides, alkylresorcinols and digestive enzyme inhibitors. According to Yin et al. (2001), the variable nutritional value of cereals is mainly due to the presence of non-starch polysaccharides (NSP) contained in cell walls. The water-soluble fraction of non-starch polysaccharides increases the viscosity of the intestinal digestive contents, which hinders the diffusion of digestive enzymes, thus decreasing nutrient absorption. Arabinoxylans in particular should be mentioned here, which have a high water absorption capacity, forming a viscous fraction in the intestines (Boros, 2015). The arabinoxylan fraction includes pentosans, whose content in triticale grains is similar to wheat, while much lower compared to rye grains (Boros, 2015).

Alkylresorcinols in the human diet are considered to be health promoting compounds. However, in animal nutrition, including poultry, they have an anti-nutritional effect. Triticale grains contain less alkylresorcinols compared to rye, with a comparable content of these compounds with wheat grains (Boros, 2015). The content of alkylresorcinols is determined by genetic factors. The study of Skrzypek et al. (2007) shows that the level of alkylresorcinols in grains of triticale hybrid lines varies, regardless of their content in parental forms. Jaśkiewicz and Szczepanek (2016) point to the influence of factors such as mean air temperature and the sum of precipitation at particular stages of plant growth on the content of alkylresorcinols. The results of long-term studies of the cited authors showed that the increase in the concentration of alkylresorcinols is favoured by low temperature in May and April. On the other hand, a shortage of precipitation in the period of tillering and the beginning of stem shooting (March and April) and earing (June) causes a decrease in alkylresorcinols content in grains. Also, cultivar and cultivation technology affect alkylresorcinol content (Table 6).

Table 6. Alkylresorcinol content (mg kg^{-1}) in winter triticale grains depending on the harvest year, production technology and cultivar (Jaśkiewicz, Szczepanek, 2016).

Year of harvest	Production technology		Cultivar		Average
	Integrated	Intensive	Pizarro	Pigmej	
2011	287 b	316 ab	277 b	326 ab	302 b
2014	327 ab	356 a	325 ab	358 a	342 a

Values with different letters are significantly different at P < 0.05

Trypsin inhibitors are also an anti-nutritional factor contained in triticale grains. They are located mainly in the endosperm and embryo of the grains. Their antinutritional action consists in the formation of solid complexes with proteolytic enzymes secreted by the organism, forming inactive bonds with them. This worsens the digestibility of protein, so that it is not used effectively by the body. Studies by Makarska et al. (1999) show that the content of trypsin inhibitors in triticale grains depends on weather conditions during vegetation. The authors believe that this is related to a decrease in the weight of a thousand grains and worse grain filling, and an increase in the concentration of the inhibitors themselves.

A problem in cereal cultivation is the occurrence of infestation with mycotoxin-producing fungi of the genus *Fusarium*. The mycotoxin content has a negative impact on the quality and feed value of the grains. If the mycotoxin content standards are exceeded, the grains are disqualified as feed material. The permissible levels for mycotoxin content in feed grains are:
ochratoxin A 0.25 mg kg^{-1},
aflatoxin B1 – cereals 0.02 mg kg^{-1}, maize 0.05 mg kg^{-1},
zearalenone 2 mg kg^{-1},
deoxynivalenol 8 mg kg^{-1}.

As Gagiu (2018) points out, the problem of increased mycotoxin production in triticale grains may be a future challenge in the context of climate change. Góral et al. (2016) evaluating *Fusarium r*esistance in 32 winter triticale and 34 winter wheat cultivars found a 9% lower infection rate in triticale (28% for wheat, 19.2% for triticale). Mycotoxin contents were different in both compared cereal species. The mean deoxynivalenol (DON) content in wheat was 11.65 mg kg^{-1} and was lower than in triticale, 14.12 mg kg^{-1}. The mean content of nivalenol was similar in both cereals: wheat 4.13 mg kg^{-1} and triticale 5.19 mg kg^{-1}. The zearalenone content in grains was 0.60 mg kg^{-1} for wheat and 0.66 mg kg^{-1} for triticale.

POSSIBILITY OF FOOD USE OF THE GRAINS

The significant supply of triticale grains and, at the same time, their lower price compared to wheat, predisposes their use for food purposes. Interest in the food use of triticale is growing, although it is still not as high as the use of wheat (Langó et al., 2017). Attempts have therefore been made to replace wheat flour with triticale flour. However, a hindrance is the protein in the grains, which is mainly located in the outer endosperm layer, which is removed during milling of the grains together with the aleurone layer and the fruit and seed coat (Jaśkiewicz, 2010). The gluten content in protein decreases, which significantly impairs the quality of baked bread. Therefore, it is more beneficial to bake mixed wheat-rye bread (Gambuś, 1995). It is also possible to bake mixed bread from flours of other cereals in combination with triticale flour. Triticale-oat bread is rich in fibre (Fraś et al., 2018). An alternative direction is to use triticale to make crispbread. It is produced by extrusion from triticale grains in a twin-screw extruder, which allows obtaining an attractive bread in terms of sensory and nutritional characteristics (Obuchowski et al., 2015). National studies have shown that most cultivars of both spring and winter triticale have desirable quality and high suitability for the extrusion process and crispbread production (Obuchowski et al., 2010).

It is possible to completely replace wheat flour in the recipe of wafer leaves with triticale flour, but the most favourable recipe variant is to use both flours in the proportion of 35% wheat flour and 65% triticale flour (Sucharzewska, Nebesny; 2000).

Triticale flour can also be used in the production of biscuits. Trials carried out so far have shown that triticale can be a good alternative, replacing wheat flour as an ingredient for biscuit production (León et al., 1996; Arizmendi-Cotero et al., 2020). The high activity of endogenous alpha-amylase in triticale grain, results in sweeter tasting biscuits baked with its flour (Arizmendi-Cotero et al., 2020). This offers the chance to obtain a product with the desired taste and at the same time with a reduced sugar content compared to traditional wheat biscuits. It is also possible to use triticale flour in the production of crackers. Both those made from wheat flour and those made from triticale flour are similar in crunchiness and taste (Pérez et al., 2003). An impediment to the wider use of triticale grains for food purposes is the wide variation in quality. Significant differences can be observed between cultivars. There is a clear need to classify cultivated cultivars in terms of suitability. The identification of cultivars that meet market needs in terms of high quality should significantly increase the use of triticale in the baking industry. The high starch content of triticale grains means that pure starch extract can be extracted for industrial use. It is widely used mainly in the food industry (as a thickener), but also in the pharmaceutical industry (as an envelope component and filler for drugs and pharmaceutical products) or in the textile industry (stiffening and starching of textiles). Due to the high starch content and alpha-amylase activity, attempts were made to use triticale grains as a raw material for the fermentation industry. This was especially true for the use of grains as malt for brewing and distilling. However, the results obtained did not confirm the usability of triticale grains for these purposes (Achremowicz et al., 2015).

EFFECTIVENESS OF USING TRITICALE IN FEED FOR POULTRY AND PIGS

Studies on the possibility of using triticale in broiler chicken feeding have been carried out for decades and do not give unequivocal answers as to the maximum share of this cereal in the mixture and its influence on rearing indices and carcass quality. Some research results showed that triticale can be the only cereal in mixtures, because with the use of enzymatic preparations it does not cause decrease of birds production results (Matyka, Rubaj, 2004; Józefiak et al., 2007). According to Zarghi and Golian (2009), the introduction of triticale to the corn-soybean mixture in the amount of 40% does not negatively affect the final body weight of broilers and feed consumption per unit weight gain. The study by Osek et al. (2010) shows that the use of triticale in feed for broiler chickens as a substitute for wheat or maize decreases the cost of bird feeding, but has a negative effect on bird production results (body weight). However, the authors found a significant improvement in the fatty acid profile in a health-promoting direction, when feed based on wheat and triticale or triticale alone, was used. A study by Widodo et al. (2015) showed that broiler chickens fed some triticale cultivars (Bogong, Jackie and Tobruk) performed better than birds fed wheat-based feed. In contrast, Elangovan et al. (2011) used high-yielding triticale cultivars containing more than 20% protein in grains for broiler chickens. In the conclusions of their research, they stated that triticale of the cultivars H55, H128, H431 and H261 has the same feed value as wheat, because no differences in the production results of birds were found. According to the cited authors, these triticale cultivars can be used in the amount of 40% of the mixture composition without the use of enzymatic preparations due to the lower content of non-starch polysaccharides. Good effects in the use of triticale grains as fodder may be obtained in feeding of laying hens. In this case, triticale grains may be used as a partial substitute for wheat and maize. The maximum proportion of triticale grains in the feed for laying hens is 20% (30% after enzyme treatment) during rearing. However, during the laying period up, triticale grain share increases up to 40% of the feed share (Smulikowska, Rutkowski, 2018). According to Grozina et al. (2018), triticale grains can be used at up to 30% of the mixture without any negative effect on laying performance. However, an increased share of these grains in the mixture up to 45% results in decreasing of laying performance (by 1.4%) and increased feed consumption in kg per kg of eggs laid (by 2.2%). Triticale can also be used in the feeding of other domestic poultry species. When investigating the possibility of replacing maize grains with this cereal in duck feeding, no differences in production results were found (Arroyo et al., 2014). The results of this study confirm the effect of the varietal factor on the feed suitability of different cultivars of triticale. Grains of this cereal are also used in feeding turkeys in the amount of up to 10% (20% when using an enzyme preparation) in the period up to 4 weeks of age. Older birds can be fed feed with 20% (40% after enzyme preparation) triticale in the feed (Smulikowska, Rutkowski, 2018). The use of triticale in turkey feed has no negative effect on growth rate, slaughter performance, and at the same time has a positive effect on the economic results of fattening (Konca et al., 2012). The use of 35–50% triticale in grover and finisher feeds for these birds does not negatively affect turkey production performance (Zarghi et al., 2010). Triticale is also a valuable feed component for pheasants, but it can also be a separate additive to reduce the use of complete feed for these birds, without negatively affecting bird growth (Kokoszyński et al., 2018a). The use of whole grain triticale for pheasants has beneficial effects on meat sensory characteristics (Kokoszyński et al., 2018b). Triticale can be a component of feed as administered as a separate supplement for Japanese quail. Replacing wheat with triticale does not negatively affect the meat characteristics of these birds (Konca, Beyzİ, 2013). The results of the study indicate that the feed value of triticale for poultry is influenced by the predominance of wheat genome over rye. The predominance of the wheat genome in some triticale cultivars affects the reduction of anti-nutrients, especially in hexaploid triticale cultivars, and may increase the use of this cereal in poultry (Boros, 1999).

The lower content of anti-nutrients in triticale grains compared to rye offers the possibility of increasing the share in feed formulations. However, it is still necessary to determine the maximum proportion that can be used without impairing the production performance of poultry and pigs. For pigs, this cereal can be used in the feeding of most production groups (piglets, fatteners, sows) together with barley. National research has shown that triticale can be used in mixtures for fattening pigs in the amount of 50% of cereal middlings and the rest can be barley (Tywończuk et al., 1994) Triticale outperforms cereals such as barley and rye in terms of nutrient digestibility in pigs (Schemmer et al., 2020). A maximum of 40% triticale grains is recommended in feed for young pigs (Khimich et al., 2018)

USE OF TRITICALE GRAINS FOR ENERGY PRODUCTION

Currently, there is no problem with selling triticale grains, however, the problem may be grains that do not meet the quality requirements for use in animal feed (especially in terms of mycotoxin content). Such examples are grains infested by diseases and pests during the storage process and sprouting grains (Żabiński et al., 2011). Żabiński et al. (2012) showed that sprouted grains have lower heat of combustion values. However, in order not to waste the raw material grains, it is worth to eventually use it for energy purpose to produce bioethanol. Compared to products derived from crude oil, bioethanol is a more environmentally friendly fuel because its exhaust exhibits less toxicity compared to the exhaust produced by gasoline and diesel fuel (Hryniewicz, 2008). Ethanol can be used as a fuel on its own or in the form of an additive to gasoline, increasing its quality. One of the criteria of raw materials for this purpose is a high activity of endogenous alpha-amylase, of which triticale grains contain an increased amount. This enzyme causes decomposition of starch to monosaccharides, which positively influences fermentation processes. Higher content of alpha-amylase in triticale grains in comparison to rye grains, makes the mash ferment faster. The advantage of using triticale mash in comparison with rye mash is lower viscosity, which solves part of technological problems consisting in difficult mash mixing and incomplete starch hydrolysis (Dynkowska, Boros, 2009). This results in a higher ethanol production efficiency from ha of triticale cultivation, which is 1160 l of ethanol, a higher value by 26% than from the same area of rye cultivation (Jaśkiewicz, 2010). The efficiency of the process of bioethanol production from triticale depends not only on the starch content in the grains, but also on the application of an appropriate method. The method of non-pressure liquefaction of starch is more advantageous than the method of simultaneous hydrolysis and fermentation (Gumienna et al., 2008). It is possible to improve the efficiency of the process of bioethanol production from triticale also by appropriate selection of cultivars and crop management techniques (Obuchowski et al, 2008; Jaśkiewicz, 2010). Triticale grains can also be burned. However, the efficiency of this process is much lower in triticale than in rye (Kaszkowiak et al., 2013).

CONCLUSIONS

The cultivation and use of triticale grains are currently focused on the feed purposes. It provides an adequate supply of fodder grains, necessary for poultry and swine nutrition. Taking into account a significant influence of genetic (varietal) factor on the fodder value of grains, it is necessary to recommend for cultivation cultivars with a higher fodder value (higher protein content and more favourable amino acid profile and lower content of anti-nutritive substances). Further breeding work within this cereal species should take into account increasing the fodder value of grains. The crop management techniques for triticale should aim at increasing fodder quality of triticale grains, especially in the aspects of cultivar selection and fertilization. Food and industrial utilization is not practiced on a large scale. There is a potential to develop those types of triticale grain utilization, especially because the improvement of quantity and quality of gluten proteins in grains may increase their utilization in baking. Triticale grains may also find application in energy production and provide feedstock for efficient bioethanol production.

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