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Characteristics of *Tritordeum* and evaluation of its potential for cultivation in Poland, with considerations for the nutritional and fodder value of the grains

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Abstract. After triticale, *Tritordeum* is the second cereal obtained by means of hybridization. As a new type of cereal, it can be introduced in the long term into cultivation in Polish conditions after conducting scientific research. However, it is necessary to identify its requirements regarding climate, soil conditions as well as agricultural engineering. Since this cereal has a high nutritional value, it may be successfully used in the production of food products with increased nutritional value. At the same time, the grains have a good fodder value, therefore they can also be used for the production of feed for livestock. In this work, a description of *Tritordeum* and an assessment of the cultivation potential of this crop in Poland are undertaken, with considerations for its nutritional and fodder value, based on the scientific literature.

Keywords: ×*Tritordeum*, cultivation, grain quality

INTRODUCTION

Cereals belong to the most important crops, the grains of which constitute the foundation of human nutrition and the raw material for the production of animal feed. They are of great economic importance. Currently, six main cereals are grown in Poland (wheat, maize, triticale, barley, oats and rye). Cereal farming provides new cereal cultivars, characterized by high yield potential. The creative breeding of new cultivars of major cereal species involves the creation of new genotypes within the same species. Another option for improvement is the creation of new types of cereals through hybridization. Hybridization leads to introgression, that is, the flow of genes from the gene pool of one species into the gene pool of another. Triticale was obtained this way, which is currently the cereal of the greatest importance for fodder production in Poland. *Tritordeum*, in turn, is a lesser-known cereal, which has not been cultivated in Poland so far. It is a cereal obtained by means of hybridization, whose parent forms are durum wheat and a wild form of barley. Both the parent plants, as well as the obtained hybrid, are best adapted to the warm and relatively dry climate of the Mediterranean area, however, due to the ongoing climate changes, it is also possible to grow it in Poland. *Tritordeum* grains are characterized by a very high nutritional value, which is linked to the lack of allergenic proteins, as well as an increased content of lutein. The main purpose of cultivating *Tritordeum* is to use it as food, however, the grains of this cereal has a very good fodder value and may be widely used in animal nutrition.

The aim of this work is to describe and assess the possibility of introducing *Tritordeum* cultivation in Poland as a new cereal, taking into account the directions of its use, based on a review of scientific literature.

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THE HISTORY OF BREEDING AND CHARACTERISTICS OF *TRITORDEUM*

Hybridization, is the crossing of two separate species. In this way, by means of introgression, a new species is created as a combination of new genes of both parent plants. This process often occurs spontaneously, without human intervention. In this way, common wheat and durum were obtained. However, triticale, which is now widely cultivated in Poland as a fodder cereal, was obtained purposefully, by means of controlled hybridization. A lesser-known species is *Tritordeum* created by means of the hybridization of durum wheat (*Triticum durum*) and wild barley (*Hordeum chilense* Roem) (Martin and Sanchez-Mongelaguna, 1981). The development of *Tritordeum* began in the late 1970s, when scientists from the Institute of Sustainable Agriculture (IAS) of the Consejo Superior de Investigaciones Científicas (CSIC) in Córdoba began working on the creation of a new cereal. Initially, various combinations

were tested, including cultivated forms of barley and common wheat, which did not lead to any results (www.tritordeum.com). Ultimately, the maternal form of barley (*Hordeum chilense*) was successfully used, the ears of which were castrated by removing the still immature thecae, and then pollen was obtained from the paternal form of durum wheat (*Triticum durum*). In this process, different varieties of both barley and wheat were used, hence the great genetic diversity of the obtained *Tritordeum* and its diverse response to growing conditions. According to Słowik (2018), 103 maternal lines of barley and 80 paternal lines of durum wheat from an international seed bank were used. The lines of the barley used in the breeding process of *Tritordeum* came from Chile and Argentina, while the selected forms of wheat were from various continents and thus various areas with varied climatic and soil conditions. Due to a large number of varieties of both parent plants, numerous combinations were obtained, however, 250 of the obtained baselines of *Tritordeum* were selected for the next stage of breeding. The name of the newly created cereal is a combination of the Latin names of the parent plants. The prefix is derived from *Triticum durum* (durum wheat), whereas the latter part of the word stems from *Hordeum chilense* (wild barley). Thus, the new plant is currently called *Tritordeum*. After 30 years of breeding and research work, Agrasys placed *Tritordeum* on the market in April 2013. Due to the fact that in the breeding of *Tritordeum* the hybridization technique was used, this cereal is not included in the category of genetically modified organisms (GMOs). *Tritordeum*, the newly obtained cereal species, is characterized by desirable nutritional properties. It contains 10 times more lutein in grains than common wheat, which imparts highly beneficial, health-promoting properties to it. Lutein, as an important carotenoid, is part of the macula of the eye, protecting the eye and ensuring its proper functioning. On average, *Tritordeum* contains 5.2 times more carotenoids than durum wheat, which suggests that the species has great potential to become functional food (Atienza et al., 2007; Montesano et al., 2020). Moreover, the most remarkable result of this work is the degree of lutein esterification found in *Tritordeum*, which is high in comparison to durum wheat. Another advantageous aspect is also the absence of D chromosomes, which bear genes responsible for the production of immunogenic peptides, in the genotype of hexaploid forms of the new crop. This makes *Tritordeum* better tolerable by gluten-intolerant people. The octoploid form already has D chromosomes (AABBDDHH) in its genome. Apart from the content of allergenic proteins, the octoploid forms produce lower yields than the hexaploid ones. Therefore, it should be anticipated that in the future, the hexaploid varieties of *Tritordeum* will be of greater importance and they will be cultivated on a larger scale.

The current direction in the improvement of the varieties and lines of *Tritordeum* is the resistance to fungal diseases. The results of the studies by Martinek et al. (2003) showed that this cereal is characterized by resistance to powdery mildew, leaf rust, and septoria leaf and ear blotch, similar to wheat. However, the authors also found a higher degree of *Tritordeum* resistance to mildew in plants sown in autumn, and lower in plants sown in spring. The reverse relationship was true for ear septoria blotch, as spring-sown plants showed a higher degree of resistance than those from autumn sowing. As determined by Rubiales et al. (1991), the resistance of *Tritordeum* to rust is related to the inheritance of relevant genes from the wild form of barley.

Depending on the sowing date, *Tritordeum* enters the earring stage in the second decade of May (in the case of autumn sowing) or in the first decade of June (spring sowing). Plants reach a height of 0.7–1.02 m. The research by Martinek et al. (2003) demonstrated that plants from winter sowing reached a greater height than those from spring sowing. The full maturity phase takes place in the first or second decade of July.

THE POSSIBILITY OF GROWING *TRITORDEUM* IN THE CONDITIONS OF THE POLISH CLIMATE

So far, the cultivation of certain types of cereals in Poland, due to the occurrence of low temperatures and periods of severe frosts in winter, has proved to be ineffective. Currently, the simulations of temperature rise and climate warming in Poland have been positively verified. In the long-term perspective of 1971–2000, the temperate cool region in Poland was found to have decreased from 37 to 3%, with an increase in the area of the temperate warm region from 62 to 75% and the emergence of a warm region with an area of 22%, which, according to forecasts, may increase to even 94% (Ziernicka-Wojtaszek, 2009). The extension of the growing season and the possibility of growing thermophilic plants are positive effects of the temperature rise (Kopeć, 2013). However, it is also associated with the potentially more frequent occurrence of drought periods, which negatively affects the yield of cereals, especially spring ones (Wójcik et al., 2019). In this context, introducing new cereal species into cultivation in Poland may be beneficial. Increasing the diversity of cereal species should have a positive impact on the supply of grains on the market, while simultaneously securing the needs of both the food and fodder production sectors. In this context, the possibility of introducing *Tritordeum* into cultivation seems a potentially good option. So far, there are no results of scientific research into the possibility of growing this cereal under Polish climate conditions, nor is its yield potential in our soil conditions known. This can be based on research results obtained under climatic conditions similar to those in Poland. Although *Tritordeum* is considered to be a thermophilic cereal and is cultivated as a spring plant, it can also be sown as a winter crop under favourable conditions. Martinek et al. (2003) established that in

the case of autumn sowing the plants exhibited a good degree of winterhardiness and yielded much better than those sown as spring crops. This may have been due to the mild winter and favourable conditions of vernalization and water supply, which contributed to doubling the grain yield. The yield from the plants sown in spring was 1.4–2.44 t ha^{-1}, with a yield of 2.04–3.92 t ha^{-1} for winter-sown ones. This yield may be higher, as other research results have shown yields in the range of 4 to 5.5 t ha^{-1} (Vaquero et al., 2018). Thus, there exists a possibility of cultivating *Tritordeum* in Poland, especially in the south-west and south-east part of the country. According to the results obtained by Stoyanov (2015), there is a large variation in the winterhardiness of individual *Tritordeum* lines within the range of winterhardiness (from 40–100% of sowings). Therefore, it is possible to conduct purposive breeding work and select appropriate genotypes for cultivation under Polish climatic conditions, also taking into account their regional variation. Lima-Brito et al. (2006) established that higher yields of *Tritordeum* in the case of autumn sowing, predispose its winter forms for cultivation in central European countries. The authors also point out that autumn-sown crops mature uniformly and there are no problems with determining the optimum harvest date. Currently, the worldwide cultivation area of *Tritordeum* is 13,000 hectares, with 450 hectares in Spain, followed by Italy with 440 hectares, and Turkey with 250 hectares (www.worldbakers.com). Despite a lower grain yield than that of wheat or triticale, *Tritordeum* produces a comparable or even higher yield under drought conditions (Villegas et al., 2010). This is due to the fact that *Tritordeum* is more efficient in using limited water resources than wheat (Martın et al., 1999). This is confirmed by the study of Küçük et al. (2018) who, when growing *Tritordeum* under drought conditions, obtained a lower yield, but the yield reduction was much lower than in wheat. The authors also established that individual cultivars and lines responded with varying degrees of yield reduction, which is associated with a drop of the weight of one thousand grains in these cultivars. At the same time, according to the cited authors, drought causes an increase in the protein content of the grains.

Currently, there are no cultivated varieties of *Tritordeum* entered in the register of the Central Centre for Testing Varieties of Crops, as there are in the Community Catalogue of Varieties of Agricultural Plants (CCA). This is due to the fact that the exclusive rights to the obtained *Tritordeum* varieties are owned by Agrasys, which has two varieties registered at the Community Plant Variety Office (CPVO):

– AUCAN – as the first stabilized and registered variety in 2010;
– BULEL registered in 2015.

Further 12 genetic lines are candidates for variety registration and are currently undergoing field trials (Nightingale, 2018). Agrasys, which provides seed grains of the varieties, ensures control of the supply chain and full traceability of the products of this cereal throughout the production chain which includes control of the seed grains for cultivation, grains for milling and baking flour.

Due to legal restrictions on licensing and difficulties in obtaining seed grains, *Tritordeum* is currently unknown to growers in Poland. For this reason, farmers do not cultivate this cereal on their own, relying on the cultivation of previously known cereal species and extensive knowledge of the agricultural engineering applicable to them. Introducing a new cereal into cultivation, especially on a larger scale, is considered risky by them. Further limitations are the lack of national studies on the agricultural engineering and fertilisation requirements of *Tritordeum*. It is therefore necessary to undertake such work and to implement its results in agricultural practice through dissemination instructions and implementation, as well as training in the scope of cultivation. This is currently the subject of research at the Institute of Soil Science and Plant Cultivation – State Research Institute in Puławy, whose aim is to verify the yield of both registered *Tritordeum* cultivars (Aucan, Bulel) under different soil conditions and different sowing time (autumn and spring). The research results will be published and will contribute to the dissemination of knowledge on the possibility of cultivating *Tritordeum* in Poland. Another limitation is also the current lack of market and the problem with the management of the harvested grains. They cannot be used as seed grains, and currently there are no companies interested in their purchase for baking and fodder purposes. In Europe, certified organic cultivation covers approximately 50% of the *Tritordeum* production area (www.worldbakers.com). The number of companies licensed in Europe to process *Tritordeum* grains into flour increased from 9 in 2015 to 13 in 2016. There exist wider prospects of developing further certified plantations and mills which process these grains. Over the period of 2016–2017, an increase in the number of *Tritordeum* grain processing plants was observed in France, Switzerland and currently it is also observed in Germany. Three years ago, *Tritordeum* was grown only in Spain, Italy and Portugal. Since the 2015/2016 season, it has also been grown in France and Turkey (www.worldbakers.com). In Poland, the increase in market interest and demand for grains will probably rise along with disseminating knowledge about the nutritional value of these grains, as well as their popularisation. Many consumers in Poland are not even aware of the existence of a new cereal like *Tritordeum* and the nutritional value of its grains. The good fodder value of grains and a significant livestock headcount may also contribute to increasing the interest in the cultivation of *Tritordeum* in Poland. Due to the certified production system, *Tritordeum* products may appear on the Polish market by being imported from countries where this cereal is grown and processed, and by establishing cooperation with the Agrasys company and recreating the production chain in

Poland with regard to the cooperation with growers and mills that will obtain a licence from the company to process *Tritordeum*.

NUTRITIONAL AND TECHNOLOGICAL VALUE OF THE GRAINS

The main direction of cultivating and growing *Tritordeum* is the use of its grains for food. It is used for the production of: cookies, breakfast cereals, biscuits, cereal bars, as well as pasta, pizza and beer. The research by Zdaniewicz et al. (2020) demonstrated that *Tritordeum* might be used in the brewing industry. The use of the grains of this cereal in various proportions (from 10% to 100%) did not cause any technological difficulties at consecutive stages of beer production. Bakers compare the bread made from *Tritordeum* flour to standard bread made from wheat. However, they conclude that it has different rheological, nutritional and organoleptic properties. This cereal contains gluten, but the quality of the gluten differs from that of other cereals. The water absorption of *Tritordeum* flour may amount to 60–80% of its weight, which allows baking products with a closed or open crumb structure. Alvarez et al. (1995) analysed the properties of bread baked from the flour of eight hexaploid *Tritordeum* lines together with the properties of one variety of bread wheat. They indicate that in general *Tritordeum* flour has a similar quality to bread wheat, although its rheological and baking properties were slightly inferior. The authors observed differences in the quality of *Tritordeum* flour related to the varietal factor, which, in their opinion, indicates the possibility of isolating varieties with the desired quality characteristics. The research by Sillero et al. (1997) showed that *Tritordeum* possesses a higher protein content than wheat. Both forms of *Tritordeum*, both hexaploid and octoploid, exhibited higher values of the SDS sedimentation coefficient than durum and common wheat. In the research by Martinek et al. (2003), the sedimentation coefficient for *Tritordeum* amounted to 44.3–57.3, whilst its higher value was found in the grains obtained from autumn sowing. A higher protein content in *Tritordeum* grains than in common wheat is beneficial from a nutritional point of view. In addition, protein has a higher digestibility, which is linked to the lower content of gliadins which cause celiac disease and gluten allergy. Alvarez et al. (1999) report that further improvement of the value of *Tritordeum* in terms of lower gliadin content is feasible. The authors discovered six loci responsible for the production of prolamins, which are located on the H chromosome. Genetic variation within this trait in the hexaploid *Tritordeum* lines may be the basis for further cultivation of this plant with a view to achieving better quality grains. The studies by Martinek et al. (2003) demonstrated that the gluten index is significantly lower in *Tritordeum* than in wheat (Table 1). However, *Tritordeum* grains contains significantly more wet gluten. The authors also investigated the baking properties of *Tritordeum* flour; however, the loaf volume was lower than in the case of wheat bread. *Tritordeum* grains contain more oleic acid than wheat and other monounsaturated fatty acids, which help in reducing the risk of cardiovascular diseases. It also contains more fibre than wheat, which has a beneficial effect for health (Erlandsson, 2010).

FODDER VALUE AND THE POSSIBILITY OF USING *TRITORDEUM* GRAINS FOR FODDER PURPOSES

In terms of protein content, *Tritordeum* significantly exceeds wheat and barley. The protein content ranges from 17 to 21% in *Tritordeum* grains (Martinek et al., 2003) compared to 10.5–14% in wheat (Woźniak and Makarski,

Table 1. Porównanie wartości technologicznej ziarna *Tritordeum* w różnych terminach siewu z ziarnem pszenicy (Martinek et al., 2003).

Trait	Harvest year	Spring sowing			Autumn sowing		
		Tritordeum	Spring wheat		*Tritordeum*	Winter wheat	
			Sandra	Saxana		Astela	Brea
Falling number [s]	2000	118	88	122	214	166	148
	2001	185	192	215	225	245	261
Sedimentation index [ml]	2000	54.4	82	87	57.3	42	61
	2001	44.3	55	64	55.2	40	57
Wet gluten content [%]	2000	43	31	27	41.5	23.6	28.0
	2001	38	25	24	37.3	21.2	24.2
Gluten index	2000	46	96	99	46	86	90
Water absorption [ml]	2000	56.8	56.2	59	57.7	50.6	56.0
Dough stability [min]	2000	2.7	9.6	9.0	1.7	1.5	4.5
Dough softening [BU]	2000	107	60	50	103	100	90
Bread volume [cm^3]	2000	260	350	443	-	-	-
Thousand grain weight [g]	1999	37.6	43.2	42.7	-	45.1	43.0
	2000	28.7	30.7	32.7	33.1	40.1	43.4
	2001	38.8	45.7	44.8	40.3	41.4	44.6

Table 2. Yield and protein content of cereals dependent on sowing date (Martinek et al., 2003).

Trait	Harvest year	Spring sowing			Autumn sowing		
		Tritordeum	Spring wheat		*Tritordeum*	Winter wheat	
			Sandra	Saxana		Astella	Brea
Yield [t ha^{-1}]	2000	1.48	6.25	6.41	2.04	9.27	7.45
	2001	2.44	6.89	7.02	3.92	8.26	6.74
Protein content	1999	17.6	13.4	13.8	-	9.5	12.5
	2000	21.2	15.7	14.6	19.8	10.8	12.0
	2001	17.7	13.2	13.0	18.6	9.7	11.8
Lysine content [mg g^{-1} grain dm]	1999	5.4	6.0	6.2	-	5.47	5.64
	2000	5.7	4.0	3.9	-	3.71	3.68
Cysteine content [mg g^{-1} grain dm]	1999	5.8	2.3	2.3	6.2	3.27	1.54
	2000	6.8	3.4	3.3	5.4	3.31	3.22

2013), 10–12% in barley (Noworolnik and Leszczyńska, 2018) and 12–16 in triticale (Jaśkiewicz, 2014). Cubero et al. (1986) demonstrated that the grains of *Tritordeum* varieties may contain up to 25% of protein. On the other hand, Küçük et al. (2018) found varying protein content in the grains of *Tritordeum* from individual varieties and lines of this cereal, respectively: Aucan 19.5%, HT-444 18.1%, Bulel 16.8% and HT460 16.2%. Similarly to other types of cereals, the protein content depends, however, on many factors, including mainly the genetic factor and agricultural engineering (e.g., nitrogen fertilization). In turn, Martinek et al. (2003) demonstrated that the sowing date (spring or autumn) has little impact on the protein content. The same *Tritordeum* varieties sown in autumn or spring had a similar protein content, whilst in one year (2000) in winter sowing, a higher content of this component in the grains, was recorded. The research by Montesano et al. (2020) shows that the protein content is related to a genetic factor. The authors determined the protein content in various *Tritordeum* lines to be in the range of 12.4–15.9%. This protein additionally has a more beneficial amino acid composition, because it contains a slightly lower amount of lysine compared to wheat, but significantly more cysteine (Table 2).

Tritordeum, apart from macronutrients, also contains a valuable ingredient, namely carotenoids, especially lutein, of which these grains contain ten times more than the grains of wheat. Its overall content in proportion to the total amount of carotenoids is 86% and is followed by zeaxanthin at 7%. There is a relatively small amount of α- and β-carotene – respectively: 0.5% and 0.3% of the total amount of carotenoids (Paznocht et al., 2018). Because of this, the application of *Tritordeum* varieties as a fodder component introduces this compound into the bodies of animals and through this process, it is deposited in tissues as well as in products such as eggs, therefore increasing their health-beneficial value for humans (Mattera et al., 2020).

Phenolic compounds can also be found in cereal grains. They have a beneficial effect which exhibits antioxidant properties, which involve eliminating reactive oxygen species, blocking free radicals, inhibiting enzymes from the oxidase group, as well as supporting enzymes that exhibit antioxidant properties and chelating metal ions (Parus, 2013). The introduction of such products into the diet of broiler chickens also demonstrates a beneficial effect. A reduction in the lipid oxidation and cholesterol levels is observed, along with a simultaneous increase in the presence of beneficial fatty acids (Starčević et al., 2014). According to Eliášová and Paznocht (2017) *Tritordeum* has a similar concentration of phenolic compounds and antioxidant activity to wheat grains. However, the authors concluded that the breeding line HT 439 possesses a negligibly higher content of these compounds. In the profile of phenolic acids, the cinnamic acid predominates, followed by gentianic acid, ferulic acid, protocatechuic acid, p-coumaric acid, sinapic acid, syringic acid, vanillic acid, gallic acid, p-hydroxybenzoic acid, caffeic acid and chlorogenic acid (Montesano et al., 2020).

The fodder value of *Tritordeum* grains may also be enhanced by applying appropriate fertilisation. Applying selenium fertilization results in an enhancement of selenium concentration in the grains and its subsequent use in the feed for laying hens, generating higher selenium concentrations in eggs (Tufarelli et al., 2016).

While these grains can be also used for fodder purposes for various animal species, they are currently still not widely available on the market due to licensed production involving the usage of the grains primarily for human food purposes.

Currently, there is no research data available concerning the content of anti-nutritional components in *Tritordeum* grains, which is of significant importance in restricting the possibility of using these grains and their participation in compound fodder for particular age and production groups and poultry breeds or other livestock species. Neither do the Polish Poultry Feeding Standards contain specific information on restrictions concerning the use of these grains. It is therefore necessary to conduct national research in this respect.

SUMMARY AND CONCLUSION

Tritordeum being a newly developed cereal is at the stage of testing and genetic stabilisation of new varieties of this species. According to the very limited number of crop management studies carried out, there is a potential for a more widespread cultivation of this plant in Europe, as well as in Poland. Because of the restrictions on the marketing of the seed material of this cereal as a result of legal and licensing restrictions, this cereal is not widely cultivated and research results are very limited. However, according to the available documentation, it appears that this cereal has great potential and could be widely cultivated and used in the future. Its fodder value and yield potential may contribute to the widespread cultivation of this crop. Nevertheless, it is fundamental to carry out research, especially national research, concerning the possibility of cultivating individual varieties in the climatic conditions of our country (Poland), appropriate agricultural engineering and the exploitation of the fodder value of this cereal, especially in poultry feeding. Since Poland is a significant producer of poultry in the European Union, appropriate fodder supply is of great significance in guaranteeing the economics of production. As demonstrated by the results of research, *Tritordeum* has a relatively stable yield during drought conditions and a good fodder value. The elevated lutein concentration in the grains of this cereal predisposes it for use in poultry feeding, particularly in the feeding of laying hens, the eggs of which will contain a higher content of this health-promoting compound in the yolk.

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