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Durum wheat – crop cultivation strategies, importance and possible uses of grain

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Abstract. Durum wheat grains are in demand on the international market because they exhibit exceptional quality traits, which make them suitable for use in the pasta industry. Most Polish pasta producers import the necessary raw material from other countries (e.g. Italy). However, it is also possible to grow durum wheat under the conditions of Poland, as cultivars that can be successfully cultivated under these climatic conditions, as well as those that can overwinter successfully, have already been grown. When compared with the common wheat, durum wheat performs much better in terms of yellow pigments, gluten, glassiness and grain hardness. Under Poland's conditions, it yields lower than common wheat, but the grain reaches a higher price. It should be stated that durum wheat is an important cereal, whose grain is used mainly for pasta and semolina production. The aim of this study is to characterise the method cultivation, cultivation possibilities, and usage of durum wheat grains.

Keywords: durum wheat, quality, yields, cultivation

INTRODUCTION

Wheat is the cereal that is grown on the largest area. The main reason for this is the chemical composition of the grain and its technological value. The most important species are common wheat (*T. vulgare*) and durum wheat (*T. durum*). The majority of the cultivation area, as much as 90%, is occupied by common wheat cultivars, while the remaining 8–10% are mainly durum wheat crops (Manzano, 2007; Cacak-Pietrzak, 2008). The world cultivation area of this wheat species is 16 million hectares, from which about 30–37 million tons of grain are obtained (Lindon et al., 2014; Taylor and Koo, 2015). In the European Union countries, the production of durum wheat is estimated at 2.6% of the total cereal grain production (Fig. 1),which ultimately amounts to 7.78 million tonnes. The largest area of durum wheat cultivation and grain production is mainly in geographical areas with dry and warm climates. The global harvest is about 5–8% of the total wheat harvest, which is 13 million ha, and the grain harvest was about 37 million tonnes in 2017 (Zawadzki, 2017). These include the Middle East and North African countries, India, the Great Pre-African Plains, and in Europe – the Mediterranean countries. The Mediterranean region produces about 60% of the world's durum wheat production (Morancho, 2000). Such a significant regionalisation and concentration of wheat cultivation is related to its climatic and soil requirements. *Triticum durum* is a steppe plant, and its cultivation is best carried out on brown soils, in hot and dry Mediterranean zones. Cold climate and short periods of favourable thermal and climatic conditions caused lack of interest in cultivation of this cereal in Poland. It was caused by its low overall performance and the risk of low yields. Achieving a satisfactory yield of durum wheat grain requires ripening in conditions of rain-free weather and high temperature. A critical moment is the period of the month preceding the harvest, when plants require a total of at least 250 hours of sunny weather (Royo, 1998). Such favourable conditions are found in the Mediterranean basin. However, the increasing climatic changes, which can also be observed in Poland, make it possible to grow durum wheat and extend its area of cultivation in the long perspective. In the period 1971–2000, there was a decrease in the area of moderately cold region in Poland from 37 to 3%, with an increase in the area of moderately warm region from 62 to 75%. Also, a warm region covering 22% of Poland appeared, which is expected to increase to even 94% (Ziernicka-Wojtaszek, 2009). A positive effect of the temperature increase is the extension of the growing season and the possibility of growing thermophilic plants (Kopeć, 2013). However, it is also connected with the potentially more frequent occurrence of drought periods, which negatively affects the

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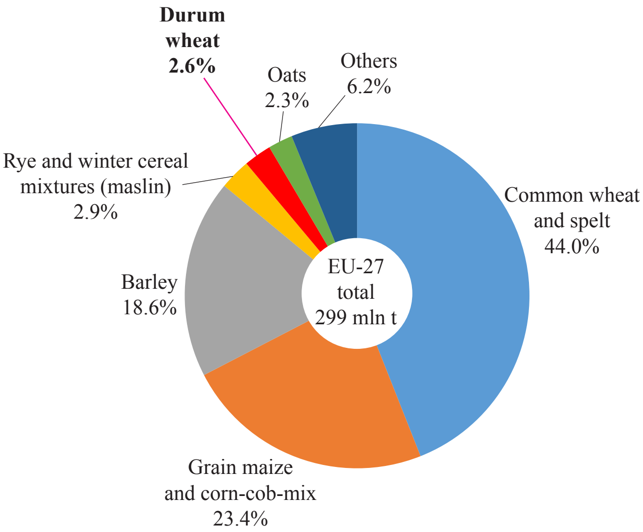


Figure 1. Percentage share of individual types of cereals in the total grain production in the European Union countries (Eurostat, 2019).

yields of cereals, especially spring crops (Wójcik et al., 2019). In this context, the introduction of new cereal species to cultivation in Poland, including durum wheat, may be beneficial.

The aim of the paper is to review the scientific literature concerning the latest scientific achievements in the field of durum wheat, taking into account the importance of crop management and its impact on grain quality, as well as the breeding of new cultivars and possibilities of their cultivation in Poland.

TRAITS OF DURUM WHEAT

The original region of tetraploid wheat cultivation, the so-called Fertile Crescent region covering Egypt through Palestine and Syria to Mesopotamia, marked the beginning of farming of this cereal. It was in this region, about 12,000 years ago in the Fertile Crescent, that the first form of naked wheat – *Triticum turgidum* ssp. *dicoccoides*, appeared. Its cultivation was popular with the people of that time, due to the ease of threshing grains from its ears (Zohary et al., 2012). The migration and relocation of people caused a large spread of the cultivation area of this plant. Further cultivation of the emmer wheat in its area of origin caused the development of a new species of durum wheat (*Triticum turgidum* ssp. *durum*) (Zohary et al., 2012). Its advantages, apart from having naked grains, included a higher yield and bigger grain size. For these reasons, it has gained popularity and has been the main cultivated form of tetraploid wheat for a very long period of time (Zohary et al., 2012).

Durum wheat differs from widely-grown common wheat (*Triticum aestivum* L.) by its many morphological traits and the quality and intended use of the grains. Durum wheat plants are blue-green, dark green, yellow-green or purple after emergence. They do not trail during the tillering stage. Ears are dark green, filled or empty. Blade length is 40–160 cm. Tillering amounts to 1, 2 to 3 shoots per plant. They develop blue-green, dark green, yellow-green, bare or mossy leaves, 16–35 cm long and 0,7 to 1,1 cm wide. Durum wheat ears are straight, 5 to 13 cm long. The spikelet is usually strong. The spikelets in the ears are multiflowered, with 2–5 grains. Bones: from short to very long (7–23 cm), they are rough or smooth in touch. Durum wheat grains are short, round to long and narrow. In most cases, they are glassy. Usually this type of wheat does not shed grains before harvesting.

Originally, *durum* wheats were very tall and reached an average height of 150 cm, so lodging was a constant problem under rainy conditions. Nowadays, the problem of lodging has been solved by breeding short-strawed cultivars and, in the case of cultivars with higher growth strength, by using retardants. By shortening the internodes, these retardants ensure lower plant height, compactness of the canopy, and its resistance to lodging (Delchev, 2012).

In this wheat species, a higher protein content is genetically determined. However, nitrogen fertilisation is also a factor that modifies this parameter. Nowadays, in breeding programs aimed at genetic improvement of new durum wheat cultivars, the selection process is based on modern scientific methods using QTL markers and genes (Blanco et al., 2006)

A particularly valued product made from durum wheat grain is semolina. According to Bojarczuk (2006), the protein content of semolina is on average 1% lower than that of the whole grain. Both the protein content and the colour of semolina are important quality traits of durum wheat (Clarke et al., 2000).

The characteristic trait of this *durum* wheat is the glassiness of its grains. It determines quality in a significant way. The literature states that the glassiness of grains is correlated with the protein content, grain hardness and structural and mechanical properties of the endosperm. It depends on how both the protein particles and the starch in the endosperm are packed. Starch of this type of wheat is distinguished by large, regular grains of equal size (Gąsiorowski and Obuchowski, 1977; Bojarczuk, 2006). More glassy grains are more technologically useful as they give more porridge and less flour. The milling industry requires hard and glassy grains to produce good quality semolina. Glassy grains enable the production of coarse-grained semolina, which has low water absorption. This trait is desirable in the production of pasta, as pasta made from this raw material is characterised by a lower degree of shrinkage (Bojarczuk, 2006).

In addition to the abovementioned traits, durum wheat has different proportions of individual protein fractions than common wheat. The proportion of gliadin proteins is higher at the expense of the higher molecular weight fraction of glutenine proteins. This has an impact on the specific rheological properties of the dough: it is more malleable and less elastic. The middle endosperm of durum wheat cultivars generally exhibits low activity of oxidative enzymes and low content of ring amino acids available for the Maillard's reaction (Obuchowski et al., 2007).

HISTORICAL BACKGROUND AND NEW BREEDING TRENDS FOR DURUM WHEAT CULTIVARS

In Poland, rye has always taken a significant area of cereal cultivation. Due to the cold climate and weak soils, wheat cultivation was much less popular, whereas common wheat played a dominant role. The cultivation of durum wheat in Poland was initiated after World War I by Stefan Lewicki (Szwed-Urbaś, 1993). At that time, the first Polish spring cultivar of durum wheat, called Puławska Twarda, was grown. After World War II, there were two cultivars in use (Hela and Puławska Twarda). However, they were withdrawn from cultivation due to low yields. Taking into account the soil and climatic conditions of Poland, Plant Breeding Smolice intensified the work on winter forms of durum wheat and bred a winter-hard cultivar called Komnata. The cultivar Komnata was entered in the National Register of Varieties in 2009. This cultivar has wintering genes that had not been found in this wheat species before. It was the first durum wheat to winter in Poland, which was extremely important due to climatic conditions, in particular during the winter period with negative temperatures. The cultivation of durum wheat in winter period in regions with more severe winters (e.g. Poland) must take into account that its effective cultivation requires adaptation to climatic conditions in order to obtain high and stable yields while maintaining high technological parameters of grains. Currently, four winter cultivars (Ceres, SM Eris, SM Metis, SM Tetyda) and one spring (SMH87) are entered into the Register of the Research Centre for Cultivar Testing. All of these cultivars are the result of the work of HR Smolice. In Europe, most of the durum wheat under cultivation is of spring type. Only in Hungary the winter durum wheat cultivars are preferred (Becke and Barabas, 1981). The results of the experiments showed that winter cultivars (Minaret Group, Tiszadur Group, Novodur Group and Betadur Group) yield by about 15–30% less than winter cultivars of common wheat (Becke et al., 2000). The research conducted in Hungary shows that the production of winter forms is much more profitable.

Nowadays, apart from the criterion of high yield, grain quality is also important. This is particularly important in the case of durum wheat, which is intended for food use. To this end, genetic research is carried out to analyse the influence of individual genes and their variants on quality traits. Molecular identification of genes and their effects, provides the basis for targeted breeding of quality lines. Studies carried out by Pogna et al. (1990) have shown that γ-42 and γ-45 gliadins are merely genetic quality markers, while allelic variability for low molecular weight gluten subunits (LMW) encoded in the Glu-B3 locus affects the SDS sedimentation index and gluten properties. It was also found that two alleles of Gli-A2 gene responsible for encoding α-gliadins have different effects on gluten quality. However, gluten is a protein which has an allergenic effect and therefore, currently a significant number of people have to exclude cereal products from their diet. A new trend is the attempt to reduce this protein by genetic modification of plants through targeted selection. As indicated by Graziano et al. (2019), individual durum wheat cultivars have different gluten contents. The results of the 2-year field cultivation of durum wheat by the quoted authors showed a higher amount of gluten proteins, amino acids and immunogenic peptides in Cappella than in Saragolla. This indicates genetic diversity in this respect in both cultivars, but the authors also emphasize the influence of weather conditions, especially of rainfall, during the growing season. Sestili et al. (2019), while analyzing the effect of GW2 gene transcription in durum wheat cultivar Svevo, found that it increases starch content in grains by 10–40%, their width by 4–13%, and surface area by 3–5%. According to the authors, the results of the study indicate a probable influence of the GW2 gene on cell wall development, which suggests a role in the regulation of cell division in wheat grains and their final size.

Another very important breeding strategy is plant resistance to diseases, which is particularly in cereals that are highly economically important group of crops. The most harmful are fungi of the genus *Fusarium* (FHB), which, apart from infesting the plants and lowering the yield, cause mycotoxin contamination of grain. This is particularly important in the context of using durum wheat grains for human consumption. One of the most important aims of breeding is therefore to produce cultivars with the highest possible degree of resistance to *Fusarium* infection. However, as Steiner et al. indicate (2019), the resistance breeding for fusarium ear blight of durum wheat is limited due to low genetic variability in modern cultivars and difficulties in identifying the genes responsible for this trait. The authors assessed the international collection of 228 genotyped durum wheat cultivars in terms of *Fusarium* resistance and found correlations between the Fhb1 genes present on the B chromosome. Further work carried out by the authors using genetic analysis contributed to the development of lines with increased resistance to ear blight. There are also genes responsible for the resistance to leaf rust in durum wheat, which can be used for resistance selection against this disease (Aoun et al., 2019). Similarly, Ouaja et al. (2020) point to the possibility of resistance selection of durum wheat against leaf septoria leaf blotch.

Due to the very long history and tradition of durum wheat cultivation and breeding and its great importance today, it has become necessary to preserve its genetic resources (Martínez-Moreno et al., 2020). The genetic diversity of the species is important due to the interaction between genotype and environment. It gives an opportunity to adapt to new conditions through natural selection, but it is also of great importance for the breeding of new cultivars for a specific purpose by humans. In order to preserve genetic resources, global seed banks are being set up to store the seeds of old cultivars, including durum wheat. In Poland, this role is played by the National Centre of Plant Genetic Resources.

IMPORTANCE AND USE OF DURUM WHEAT

Due to its high quality, durum wheat commands high prices and is sought after on the international market. Durum wheat, compared to common wheat, is characterized by a more favourable nutritional and technological value of grains in terms of the content of pro-health yellow pigments (lutein), gluten, glassiness and hardness of endosperm and has a lighter and thinner coat (Rachoń, 1997; Ciołek and Makarska, 2004; Makowska and Obuchowski, 2004; Rachoń and Kulpa, 2004).

In Poland, durum wheat yields less than common wheat, yet the high price induces growers to start working on the breeding and cultivation of this species (Gontarz, 2006; Rachoń et al., 2002; Szwed-Urbaś and Segit, 1995). The research conducted in the conditions of our country (Rachoń, 2001; Szwed-Urbas et al., 2004; Woźniak et al., 2005) shows that durum wheat grain yields are at the level of 65–82% of those of spring common wheat. Many authors (Rachoń and Szumiło, 2002; Woźniak, 2005) indicate that in terms of quality (protein content, gluten amount, etc.), Polish durum wheat lines are comparable to foreign cultivars.

A higher price for durum wheat grain may suggest that cultivation of this species will be profitable in Poland. Currently, Polish pasta factories have to import grain or semolina from America, Asia or Europe to obtain high quality raw material. Breeding Polish cultivars of durum wheat gives farmers an opportunity to make production profitable.

Durum wheat, due to its properties (hard endosperm, high glassiness and pigment content) is used for pasta production. Pasta made from durum wheat is characterised by a smooth, translucent surface, glassy fracture, golden amber colour, specific taste and smell both before and after boiling. Currently in Poland about 3 kg of pasta is consumed per person per year, and an upward trend is observed. In other countries, this indicator is much higher (Italy 28 kg, Switzerland 9.8 kg, USA 9 kg, Greece 8.7 kg, Sweden 8 kg, France 7.5 kg, Germany 6.8 kg per person) (Eurostat, 2019).

AGROTECHNOLOGY AS A FACTOR INFLUENCING THE YIELD AND QUALITY OF DURUM WHEAT GRAINS

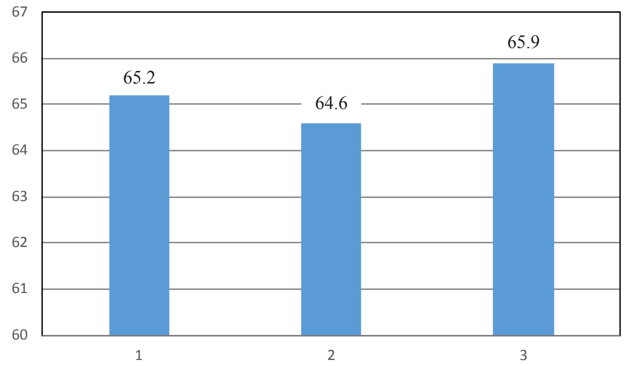
Grain yield and its technological value depend both on genetic characteristics of a given cultivar, habitat conditions and agrotechnology. The genetic potential of high-yielding durum wheat and its quality can only be revealed under appropriate environmental conditions (Mohammadi et al., 2020a). According to Mohammadi et al. (2020b), individual factors have a different effect on durum wheat yield, with agrotechnical and environmental factors accounting for 81.9%, followed by an interaction between genotype and environment of 5.2% and genotype itself of only 2.1%. The amount of nitrogen fertilization rate and the date of its application had a significant effect on the yield of wheat grain. Large rates of nitrogen increase grain yield and protein content in grains, but adversely affect their quality. According to the available literature, the optimal rate of nitrogen for durum wheat ranges from 80 to 120 kg N ha^{-1}. According to Rachoń et al. (2002), the differentiated level of durum wheat fertilization significantly influenced grain yield. The author states that with an increase in the dose of nitrogen from 90 to 180 kg N ha^{-1}, there was a statistically significant decrease in grain yield by 0.32 t ha^{-1}. It was caused by the increased plant lodging as well as a smaller 1000 grain weight. In the study by Woźniak (2006), increasing the nitrogen rate from 90 to 140 kg N ha^{-1} did not significantly increase the yield of durum wheat grain. The only statistically significant differences were found in the number of ears per area unit (Table 1). The quality of durum wheat grain is affected not only by the nitrogen rate level but also by the date of its application. The application of nitrogen in the later stages of wheat development is more effective in increasing the protein content in grain than its application in the early stages (Wuest and Cassman, 1992; Kelly, 1995; Ottman et al., 2000; Podolska and Wyzińska, 2013).

Podolska and Wyzińska (2013) found that both the rate and the manner of nitrogen application significantly influenced the quality characteristics of durum wheat grain and flour of Komnata cultivar (Table 2). The authors found that

Table 1. Grain yield and yield components of durum wheat line LGR 896/23 (Woźniak, 2006).

Nitrogen fertilizer rate [kg N ha^{-1}]	Grain yield [t ha^{-1}]	Number of ears per m^2	Grain weight per ear	Number of grains per ear
90	3.91 a	377 a	44.3 a	28.6 a
140	3.98 a	408 b	44.0 a	26.5 a

The values marked with the same letters in the columns do not differ significantly (p = 0.05)



1 – 50% of the rate in the start of growing season + 50% of the rate in the stem formation stage,
2 – 40% of the rate in the start of growing season + 40% f the rate in the stem formation stage + 20% of the rate in the earing stage,
3 – 40% of the rate in the start of growing season + 30% of the rate in the stem formation stage + 20% of the rate in the earing phase + 10% of the rate in full maturity stage

Figure 2: Weight of 1000 grain [g] of durum wheat cultivar depending on nitrogen rate distribution (Podolska and Wyzińska, 2013).

the application of nitrogen in rates of 160 kg N ha^{-1} resulted in the highest 1000 grain weight. The highest value of this trait was also found when nitrogen was applied four times (Fig. 2). The authors also showed that at the rate of 160 kg N ha^{-1} and 200 kg N ha^{-1} (year 2009), the grains were characterized by the highest glassiness. Fourfold application of nitrogen during growing season caused an increase in grain vitreous aspect ratio by 6% compared to twofold application of this element. Spychaj et al. (2010) report that the variability of vitreous aspect of grain of Komnata cultivar varies with study years and range from 49 to 87%. Such a high variability of this trait may indicate its low stability.

Table 2. Selected quality characteristics of Komnata durum wheat depending on nitrogen rate (Podolska and Wyzińska, 2013).

Nitrogen rate [kg N ha^{-1}]	Year of harvest	1000 grain weight [g]	glassiness [%]	Protein content [g kg^{-1}]	Falling number [s]
80	2008	66.5	29.3	137	198.0
	2009	54.2	56.0	168	62.7
120	2008	62.8	32.6	153	189.0
	2009	54.3	69.3	171	62.3
160	2008	67.2	47.3	152	144.0
	2009	54.4	64.0	470	62.3
200	2008	64.3	46.7	164	159.0
	2009	53.5	67.3	171	62.3

Protein and gluten contents are very important criteria for assessing wheat quality. The protein content of durum wheat can be 9–18% d.m. and is usually higher than that of common wheat (Szwed-Urbaś, 1993; Rachoń and Kulpa, 2004; Rachoń and Szumiło, 2006). Semolina obtained from durum wheat should contain at least 13% protein. Otherwise, the pasta obtained from it will be crumbly and brittle (Obuchowski, 2000). In the study by Ciołek and Makarska (2004), a significant increase in protein and gluten contents was found after applying increased nitrogen fertilization (180 kg N ha^{-1}). Podolska and Wyzińska (2013) also proved the effect of the size and distribution of nitrogen rate on protein content in grains. In both years of the study (2008, 2009), the highest protein content was found in treatments where 200 kg N ha^{-1} was applied. It should be emphasized that the protein content in wheat grain is shaped by the weather conditions (moderate precipitation and appropriate temperature) in the years of cultivation (Obuchowski, 2000; Rachoń and Szumiło, 2006; Spychaj et al., 2010). The protein concentration in spring wheat grains of the Puławska Twarda cultivar ranged from 15.3 to 17.5% (Rachoń and Szumiło, 2006). Makarska and Szwed-Urbaś (2005) prove that the protein content of spring line of durum wheat is in the range of 12.5–14.4%. In a study by Rachoń and Woźniak (2020), over a 10-year period, the average protein content of durum wheat grains was 15.4%, being 1.3% higher compared to common wheat. According to a study by Bobryk-Mamcarz (2019), the protein content varies in years (Table 3)

Table 3. Total protein content in wheat grains [%] (Bobryk-Mamcarz, 2019).

Variety	Years			Mean
	2015	2016	2017	
T. durum 'SMH87'	15.4	14.5	14.8	14.9
T. durum 'Floradur'	14.4	14.0	15.3	14.5

A very important indicator of cereal grain quality is the falling number, which is an indicator of alpha-amylase activity. The low values of this parameter indicate sprouting of the grain and it is therefore of little use as a raw material for the production of pasta products. Weather conditions have the biggest influence on the value of this parameter, so it is variable in years. The best raw material for the production of pasta is when the falling number is 350–450 s. Spychaj et al. (2010) state that the falling number of the Komnata cultivar, depending on the years, varied between 332–402 s. In the studies of Podolska and Wyzińska (2013), the value of this index differed throughout the years and was at a very low level of 62.3–198 s. Also, the variability of this parameter in the years was observed by Szumiło et al. (2010), where it ranged between 153–207 s.

Table 4. Grain yield [t ha^{-1}] depending on the dose of nitrogen (Jarecki et al., 2013).

Dose of nitrogen [kg ha^{-1}]	Cultivar	2009	2010	2011	Mean
90	Durobonus	4.00	3.90	4.30	4.10
	Duroflavus	4.10	4.00	4.40	4.13
150	Durobonus	4.30	4.40	4.50	4.43
	Duroflavus	4.60	4.40	4.60	4.50

Table 5. Effect of sowing density on grain yield, yield components and total protein content in durum wheat grain (Panasiewicz et al., 2009).

Sowing density [grains m^{-2}]	Grain yield [kg ha^{-1}]	Number of ears	Number of grains per ear	1000 grain weight [g]	Total protein [% d.m.]
200	4.67	348	28.6	48.3	16.3
350	4.45	376	28.3	47.3	16.4
500	3.68	397	27.5	45.7	16.7
650	3.69	431	27.9	44.7	16.5
$NIR_{0,05}$	0.39	39.2	1.05	1.31	ns

ns – not significant

The basic distinguishing feature of semolina determining the quality of pasta, is the content of natural pigments present in wheat, belonging to the group of carotenoids and xanthophylls. The higher their content, the more lively and lighter the shades of yellow. Research by Sulewska et al. (2007) indicate that increasing nitrogen fertilization had an adverse effect on ß-carotene content. Abad et al. (2000) have shown that, under Spanish conditions, the content of yellow pigments in durum wheat grains has increased with the increase in nitrogen fertilisation. However, Obuchowski (2007) recorded no effect of increasing nitrogen fertilization (0–50–100–150 kg N ha^{-1}) on the content of carotenoid dyes. Nitrogen fertilization also increases the yield of wheat grain (Table 4). In a study Jarecki et al. (2013) on fertilization of two durum wheat cultivars (Duroflavus and Durobonus), an increase in nitrogen dose from 90 to 150 kg ha^{-1} significantly increased the number of ears per 1 m^2, number of grains per spike, and protein content in grains.

One of the basic elements of agrotechnology determining the growth and yields of plants is the sowing density. In the study by Panasiewicz et al. (2009) sowing density significantly modified the grain yield of durum wheat cultivar Komnata. The highest yield (4.67 t ha^{-1}) was recorded at the sowing density of 200 and 350 pcs m^{-2}. Further increase of sowing density to 500 pcs m^{-2} resulted in a significant decrease in yield. Moreover, the increase in plant density resulted in a decrease in the number of grains per ear and the 1000 grain weight (Table 5). In turn, Arduni et al. (2006) demonstrated that the highest grain yield of durum wheat was achieved at the sowing density of 400 grains m^{-2}. According to Ghaffari et al. (2001), the optimum density for this species in temperate climates is 300–600 grains m^{-2}. In the case of spring durum wheat, Sulewska et al. (2007) found that the yield of spring durum wheat grain was the highest for sowing density of 500–600 grains m^{-2}. Similar observations were made by Rachoń (2001), who found an increase in the yield of spring durum wheat forms together with an increase in sowing density to 600 grains m^{-2}.

An important criterion for the agricultural assessment of *T. durum* wheat cultivars is disease resistance. The use of fungicide treatments in wheat cultivation generates economic benefits due to the reduction in the occurrence of pathogens and the consequent increase in yields. Fungicides can contribute to changes in the quality of grain, flour and pasta (Bojarczuk, 2005; Jurga, 2007). Research of Spychaj et al. (2011) indicate that after the application of seed dressing with two fungicide treatments, grains with the highest vitreous aspect ratio (77%) and high bulk density (81.5 kg hl^{-1}) as well as 1000 grain weight (61.9 g), were obtained. The quality traits of durum wheat flour, except for total protein in grain and wet gluten solubility, were not modified by the plant protection method (Table 6). Rachoń et al. (2002) concluded that the application of intensive chemical plant protection product resulted in obtaining spring wheat grains with better physical traits than under minimum protection conditions.

Table 6. Quality traits of flour from durum wheat cultivar Komnata (Spychaj et al., 2010).

Way of chemical plant protection	Grain glassiness [%]	Bulk density [kg ha^{-1}]	1000 grain weight [g]	Grain uniformity [%]	Falling number [s]	Wet gluten [%]	Zeleny's sedimentation index [cm^3]
Control	74 a	80.8 b	57.2 c	95 a	395 a	25.6 a	19.5 a
Seed dressing	70 b	81.3 ab	59.2 b	94 a	397 a	25.0 a	19.2 a
Seed dressing + 1 x fungicide	71 b	81.2 ab	61.4 a	95 a	393 a	25.4 a	19.7 a
Seed dressing + 2 x fungicide	77 a	81.5 a	61.9 a	95 a	373 a	25.8 a	18.6 a

The values marked with the same letters in the columns do not differ significantly (p = 0.05)

Crop rotation has a significant effect on the yield of durum wheat. Cultivation of durum wheat after proper preceding crops and appropriate crop rotations guarantees high yields of grain of good quality. According to Woźniak et al. (2005), the cultivation of durum wheat in monoculture causes significant yield reduction. Reduced grain yield resulted from a reduction in the number of ears per unit area (m^2), lower weight of grains per ear, and lower number of grains per ear. Wheat cultivation in monoculture resulted in higher plant infestation by stem and root base diseases, increased weed infestation of the stand and accumulation of weed seeds in the soil.

CONCLUSIONS

The increased interest in the cultivation of durum wheat results from the unfeasibility of replacing this raw material with common wheat grain, but also from climate changes in the last few decades, which create opportunities for the cultivation of pasta wheat in Poland. Durum wheat is very sensitive to changing weather conditions. In dry and hot years, a good yield the crop of high technological value is obtained, and in the case of cold and wet summer, not only the yield but also the quality of this wheat significantly deteriorates. Durum wheat grain is of high quality and is in demand on the international market. The specific properties of the grain allow it to produce semolina, which is used for pasta production. The technological value of durum wheat grains, apart from the genetic factor, is greatly influenced by habitat conditions and crop management factors. The main factor that determines the technological value of grain is nitrogen fertilization.

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