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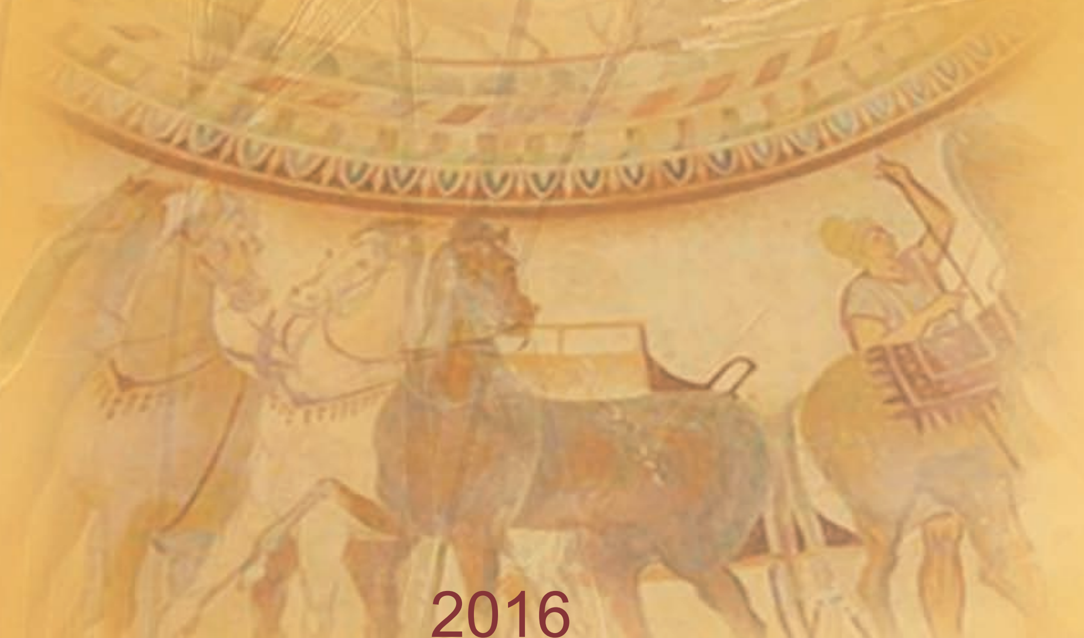

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Review

Strategies for durum wheat fertilization

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Abstract. *Durum wheat (Tr. durum Desf.) ranks second in the world cereal production after common wheat. It differs from the other species with its high grain protein content, especially with gluten quality, which makes it suitable for producing spaghetti, macaroni, semolina flour and other products for the food industry. The purpose of this review was to summarize the results obtained in Bulgaria and in the world on the impact of mineral fertilization on yield and quality of durum wheat. All authors confirm that a significant increase of the grain yield in the last decades was achieved by both using new varieties and through optimal fertilization. Nitrogen as a nutrient is of great importance for wheat productivity. Nitrogen fertilization leads to stronger increase of leaf area, dry matter accumulation, content of protein and gluten. Accumulated nitrogen and phosphorus depend mainly on the formed dry matter. At low nitrogen rates yield increased at higher phosphorus level. Suppressant effect of high nitrogen and phosphorus rates on growth and development is emphasized in richer soil. A number of authors have found genotypic specificity regarding grain yield in dependence on the level of fertilization. Problems of genetically determined and improved grain quality under different durum wheat varieties are the subject of extensive research. The opinions of all authors are one-way for the positive influence of fertilization and in particular nitrogen on the technological quality parameters – protein content, wet and dry gluten, vitreoussness, carotenoids pigment, although the values vary significantly. The influence of fertilization is insignificant on the test weight.*

Keywords: durum wheat, fertilization, yield, quality.

Introduction

Durum wheat (*Tr. durum* Desf.) ranks second in the world in terms of area and production of cereals after common wheat. The world trend shows increased demand for this crop. The importance of durum wheat also increases because its production is concentrated in limited areas – the Mediterranean and North Africa, North and South America, Australia and others. In the countries where durum wheat is part of the national cuisine and is used for local unleavened bread, bulgur, couscous (Morocco, Syria, Algeria, Tunisia, Ethiopia and others) its production takes 50 – 75% of the total wheat production. Over the last years, Italy, the USA and Brazil have been the largest producers of pasta products in the world (1.3 – 3.2 million tons annually), with strong increase in the consumption of products from durum wheat: from 4.7 million tons in 1991 to 13 million tons in 2010. In the countries of the European Union there is shortage of durum wheat and grain is mainly imported from Canada and the United States.

The attention paid to durum wheat (*Tr. Durum* Desf.) is caused by its grain quality: high vitreousness, less starch and high content of protein, high content and good quality of gluten proteins with great extensibility and small elasticity, high content of amino acids, vitamins, fatty acids, high digestability and energy value of pasta for the human body. The high content of carotenoids brings a nice amber color to the grain. The physical and chemical properties of durum wheat gluten ensure stability of dough and make it an excellent raw material for pasta with high nutritional value and specific taste. After processing, durum wheat grain has 15 – 20% more semolina compared to common wheat. Pasta flour as an enhancer increases protein content in bread (Amri et al., 2000).

In growing durum wheat, more attention is now being paid to nutrition as a factor to increase productivity and grain quality, to soil supply of main macroelements and soil fertility as a whole. Durum wheat also successfully develops in crop rotation couples with later harvested crops and after application of mineral fertilizers where the two crops actively participate in the re-distribution and absorption of nutrients. The Bulgarian varieties have very good properties and are not worse than the imported varieties, exceeding in protein and carotenoid grain content a number of foreign varieties (Dechev, 1995).

The purpose of this review is to summarize the results obtained in Bulgaria and in the world regarding the effect of fertilization on yield and quality of durum wheat.

Influence of fertilization on the development of plants and grain yield of durum wheat

The significant increase of wheat yield in the last decades was achieved by both using new varieties and through optimal application of fertilizers, pesticides and mechanization (Dechev and Dechev, 2009; Faidley, 1992). Major influence on the yield of durum wheat is observed by soil, weather factors and nutrients in the critical stages (Faidley, 1992). Nutrients at later stages are of greater importance for the productivity of durum wheat compared to common wheat. The successful application of technology for the cultivation of durum wheat depends on the specific economic and environmental conditions, predecessor, the genetic potential of varieties, fertilization and other agronomic factors, as a result of which there are differences in the final results (Delchev, 2009;

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Delchev et al., 2006; Ivanova and Tsenov, 2010; Lalev et al., 2000; Mohammadi and Amri, 2009; Panayotova, 2004; Saldzhiev, 2008; Yanev et al., 2006).

Drought, variable temperatures particularly terminal heat, and low soil fertility are considered the most limiting factors that affect grain yield and grain quality (Lòpez-Bellido et al., 2001; Nachit, 1998; Verma et al., 1998). However, genotype x environment interaction effects and common cultural practices would affect both water and nitrogen use efficiencies (Chandrasekaran et al., 2010; Gate, 1995). The total uptake of nitrogen and phosphorus depends mainly on formed dry matter (Arduini et al., 2006; Panayotova, 2004; Panayotova and Dechev, 2004). The nitrogen content in grain is more closely connected to accumulation of dry matter after flowering, than phosphorus (Geleto et al., 1996). Therefore, the nitrogen content in grain is more closely connected to environmental conditions, whereas phosphorus content in the grain – to the genetic properties. With increasing the nitrogen rate and the soil fertility the nitrogen content in grain and straw also increases (Rharrabti et al., 2003). The fertilized plants move about 53 % more nitrogen to the grain compared to the unfertilized (Dhugga and Waines, 1989; Ricciardi, 2001).

It was established that the uptake of N, P and K for 100 kg grain after fertilization with 60 to 180 kg/ha is 3.05–4.37 кg N, 1.2–1.5 кg P_2O_5 and 1.7 – 2.4 кg K_2O, respectively (Panayotova, 2005). Nitrogen fertilization increased grain yield by 29.0 – 46.0%, nitrogen uptake by 60.8 – 108.9% compared to unfertilized (109.6 kg N/ha) and significantly improved the technological properties of grain – content of crude protein, wet and dry gluten, vitreousness. NHI was 0.760-0.776, and the effectiveness of N reutilization was 66.4 – 68.7% and it was better expressed with the increase of the fertilization rate. N fertilization was proven to affect the concentration, content and uptake of N. The effect of 1 kg N was high after fertilization with N_{60-120} (13.6 – 17.3 kg grain) and decreased with increasing the nitrogen rate.

The grain yield of durum wheat strongly varied depending on the area, weather conditions, genetic potential of the variety, soil fertility and applied fertilization. The main requirement for high yield combined with good grain quality was for the plants to receive an optimal amount of nitrogen during vegetation (Annicchiarico and Mariani, 1996; Delchev and Panayotova, 2010; Dechev and Panayotova, 2010; Ivanova and Tsenov, 2010; Kolev et al., 2010; Modhej et al., 2008; Pacucci et al., 2004; Panayotova, 1998; Semkova et al., 2007).

All authors are unanimous that nitrogen as a nutrient is of great importance for wheat productivity. According to Smil (2001), the increase of yields over the last 50 years was greatly due to nitrogen fertilization. Delchev (2009) found that soil nitrogen fertilization leads to stronger increase of leaf area and yield compared to foliar feeding. The dynamics of dry matter accumulation depends on variety and nitrogen fertilization (Almliev et al., 2012). Weisz et al. (2007), Hussain et al. (2006) and others specified that wheat growth and yield increased by increasing the content of nitrogen. According to Boukef et al. (2013) growth significantly increased after nitrogen fertilization at higher N rate - 93.8 kg N/ha. Bali (2011) indicated that increasing the nitrogen rate to 392 kg/ha did not contribute to yield increase but significantly increased the protein content, whereas after low nitrogen rates yield increased with the increase of the phosphorus fertilization rate. Some authors indicated that a higher N rate increased the plant growth, dry weight, number of grains per spike (Sobh et al., 2000; Sorour et al., 1998).

The main requirement for high yield combined with good grain quality is for the plants to receive the optimal amount of nitrogen during the growing season (Delchev and Panayotova, 2010; Schillingb, 2003). According to Giorgio and Fornaro (2004) grain yield was proven to increase at N_{60}, and was weaker at N_{120}. In southern Italy the applied nitrogen fertilizers at rate of 80 kg/ha most effectively influenced the yield in the lowlands, whereas in the hilly areas the effect of fertilization was weaker. After fertilization of varieties Modos and Leeds under irrigated conditions in California with nitrogen rates of 90, 180 and 270 kg/ha, it was established that the grain yield of durum wheat varied inversely, whereas the accumulation of protein was directly proportional to these nitrogen rates.

Belay (2014) reported that on Vertisol all agronomic traits of twelve durum wheat genotypes respond positively to applied nitrogen rates (69 and 115 kg N/ha). The studied traits, except days to heading, grain filling period and biomass production efficiency did not respond to the genotype by nitrogen interaction effect. Grain yield was positively correlated with plant height (r = 0.53), total plant biomass (r = 0.81). Geleto et al. (1996) also reported that nitrogen deficiency is a common problem in cool, wet areas, such as in highland Vertisols. Therefore, in addition to draining the soil, nitrogen fertilization of durum wheat is very important to mitigate the risk of N losses and to improve the grain quality. According to Panayotova and Dechev (2003) and Panayotova et al. (2006) the optimal yield is formed at fertilization rates of $N_{100-140}$, but with high breeding and agronomic value regarding the simultaneous evaluation of yield and stability for a set of genotypes over the different years in meteorological terms stood out the N rate of 90 kg/ha.

Nitrogen strongly affects growth, but its effect on yield, leaf area and accumulation of dry matter depends on the growing conditions for the crop. During the favorable years was markedly observed the effect of higher nitrogen rates (Giorgio et al., 1992; Kostadinova and Panayotova, 2003; Panayotova and Kostadinova, 2011; Panayotova et al., 2012, 2013), whereas over the years of drought during the spring and summer fertilization, nitrogen rates of over 10 kg/da were not effective and the high fertilization rates had a suppressive effect on growth and development (Panayotova and Dechev, 2003).

The difference in published opinions was mainly due to the different conditions of the experiments and to the biological characteristics of the test varieties. Ercoli et al. (2013) reported that fertiliser splitting affected durum wheat grain yield and N concentration, variations due to splitting reached 1 t in grain yield and 7 g/kg in N concentration of grain, corresponding to 4% increase in protein content. The highest grain yield, protein concentration, nitrogen use efficiency and nitrogen uptake efficiency were obtained with the application of 30 kg N/ha before seeding. The yield advantage was related to higher number of kernels per spike, resulting in higher number of fertile spikelets per spike. Grain yield was not affected by nitrogen source applied before seeding, but was modified by topdressing N fertiliser. Yield increased by 0.4 t/ha with urea, compared to ammonium sulphate, owing to a greater number of kernels per spike.

A number of authors (Gorbanov, 2010; Dechev et al., 2010; Delchev and Panayotova, 2010; Moral et al., 2003; Panayotova, 1998a, 2001; Saldzhiev, 2008) pointed that through optimum nitrogen nutrition – single or combined with phosphorus and potassium, high-quality grain yield is achieved. According to Abad et al. (2004) under the Mediterranean conditions, good yields of durum wheat were obtained after fertilization with 100 kg N/ha, but for maximum yield with good quality grain indexes was required a rate of 200 kg N/ha.

Kostadinova and Panayotova (2013) established that in testing various systems of nitrogen and phosphorus fertilization the independent phosphorous fertilization at rate P_{160} reduced the grain yield of durum wheat variety Progress under the unfertilized and recommended lower levels P_{80}. The combined NPK-fertilization affected to a greater extent the growth and productivity of durum wheat, where the yield exceeded the unfertilized control (298 kg/da) with 52.6 – 72.2% for various tested rates of nutrients (Dechev et al., 2010; Panayotova, 2007). The evaluation of grain yield of durum wheat cultivars, grown under different levels of fertilization by Dechev and Panayotova (2010) established that average for the 11-year period the grain yield was 4.27 t/ha and the same increased from 3.19 t/ha without fertilization to 4.93 t/ha at N_{160}.

Genotypic specificity as related to grain yield depending on the level of nutrition

A number of authors (Deshmukh et al., 1990; Dhugga and Waines, 1989; Kolev et al., 2011; Kolev et al., 2011a; Kolev et al., 2012; Panayotova, 2001; Panayotova and Dechev, 2002; Panayotova and Yanev, 2001; Saldzhiev, 2007; Sairam et al., 2001) established the effectiveness of fertilization on varieties of different genetic specifics in differentiated soil fertility. It is a common understanding that the varieties differ in their responsiveness to accummulation of nitrogen in the vegetative parts. The creation of varieties with high productivity and stability is the main task of breeding (Petrova, 2009**)**. A genotypic specificity was found regarding grain yield depending on the level of fertilization (Panayotova, 2001). The cultivar Zagorka, fertilized with $N_{120-180}$ and cultivar Vazhod x N_{120} was formed the maximum stable yield (Panayotova and Dechev, 2003).

As a result of testing specific biological and technological qualities of one French and three Bulgarian durum wheat cultivars in Plovdiv region with nitrogen rates from 60 to 180 kg/ha against a background of P_{48}, Kolev et al. (2010) recommended fertilization of durum wheat with N_{120}, and at this level the yield was proven to be the highest, and grain quality did not differ significantly from the one received at N_{180}. With these varieties the effect of fertilization was most markedly expressed for the indicators of vitreousness and protein in the grain. It is well-documented that wheat genotypes differ greatly in adaptive mechanisms to phosphorus deficiency stress, P utilization and P efficiency (Batten, 1986; Fageria and Baligar, 1999; Gahoonia et al., 1999; Horst et al., 1993; Marschner, 1995; Ozturk, 2005; Yao et al., 2001).

Effect of mineral fertilization on the quality of durum wheat grain

All authors agree on the positive influence of fertilization and particularly of nitrogen on the technological indicators of grain, even though the values vary significantly. Nitrogen fertilization and soil nitrogen have strong positive impact on the protein content of durum wheat grain (Grant et al., 2001; Kolev et al., 2011; Motzo et al., 2007; Ottman et al., 2000; Panayotova and Gorbanov, 1999; Saint Pierre at al., 2008), resulting in an increase of gliadins and glutenins (Dupont and Altenbach, 2003). Nitrogen nutrition is widely considered as the main factor that affects storage proteins as well as the technological quality of grain (Wieser and Seilmeier, 1998). Limited investigations indicated that positive correlation between nitrogen applications and the rate of grain filling were reported (Hussain et al., 2006; Warraich et al., 2002). Improving grain protein would imply the improvement of translocation and nitrogen transfer and nitrogen source-sink relationship. This is because nitrogen reprensents 7% of total dry matter in plants and it is one of the principal cell components of nucleic acids, aminoacids, enzymes, and photosynthetic pigments (Bungard et al., 1999; Brown, 2000; Clarke, 2001). Therefore, it is assumed that Ottman et al. (2000) pointed out that the application of 4.3 kg N/da increased the content of grain protein by about 1%.

Grain quality is the most important criterion in the breeding of durum wheat to produce high quality pasta. Experimental data indicate that the new genotypes combine high productivity with good quality. The problems for genetically determined and improved grain quality of different durum wheat varieties are the subject of extensive scientific work (Dechev, 1995, 2004, 2008; Kolev et al., 2000; Kolev et al., 2010; Mangova et al., 2013; Mariani, 1995; May et al., 2008; Mohammadi and Amri, 2009; Panayotova and Gorbanov, 1999; Panayotova and Valkova, 2010; Rharrabti et al., 2003; Yanev and Kolev, 2008). According to Panayotova and Valkova (2010) the reaction of durum wheat to direct nitrogen fertilization is more strongly expressed in comparison with the preceding nitrogen fertilization and they indicate that out of the physical properties of grain after nitrogen fertilization with 60 to 180 kg/ha, vitreousness increases by 28.2 – 78.8% compared to unfertilized plants, the 1000 grain weight average for the four varieties varies from 45.5 g for Beloslava to 56.8 g for Progress, whereas the effect of nitrogen on the tested weight is insignificant, regardless of variety and year conditions. Bauer et al. (1987) reported that higher nitrogen rates and rich nitrogen soil supply leads to significant enrichment with grain protein. Gerba et al. (2013) indicated that increase in the rate of applied nitrogen beyond 120 kgN/ha increased the vitreousness, wet gluten content, grain protein content, test weight and thousand-kernel weight of durum wheat. According to Motzo et al. (2004) and Brown et al. (2005) grain protein content is a function of total nitrogen uptake and the partitioning of nitrogen and dry matter to the grain

High protein content is a primary factor associated with good pasta cooking quality (Grzybowski and Donnelly, 1979). Low soil N results in low grain protein content in wheat (Terman et al., 1969). Application of N fertilizer usually results in increased wheat protein content and thereby improved end use quality (Ames et al., 2003; Dexter et al., 1982; Gashawbeza et al., 2003). However, Bole and Dubetz (1986) found that low rates of N fertilizer can decrease grain protein content when grain yield is increased more by fertilization than N uptake. They also observed that irrigation can decrease grain protein content due to dilution with carbohyrates if N availability is not increased proportionally. A deficit of water increases grain protein content (Terman et al., 1969; Entz and Fowler, 1989).

Yellow berry resulted from an endosperm dysfunction that gives kernels a yellowish color caused by low protein content (Sharma et al., 1983) affecting the quality of the flour and the end product such as pasta. The reduced yellow berry incidence under N fertilization was attributed to the endosperm and aleurone cells fractured around the starch granules and cytoplasm (Sharma et al., 1983).

The gluten proteins constitute about 80% of the proteins contained in mature wheat grains (Shewry et al., 1995) conferring properties of elasticity and extensibility of wheat flours (Kuktaitė, 2004). Grain protein is driven from the interaction of nitrogen, water availability and temperature (Zhao et al., 2009; Giambalvo et al., 2010; Moral, 2003).

According to Panayotova and Dechev (1997) and Semkova (2014) the increase of nitrogen rate affects the formation of 1000 grain weight in durum wheat, where the grain weight rose up to rate N_6, and then this index decreased. The application of high nitrogen rates positively influences the content of crude protein in the grain, regardless of the effect on grain yield. Dechev et al. (2010) and Panayotova (2007) reported that after NPK-fertilization the content of crude protein increases by 23.3 –39.8%, wet gluten by 20.1 – 49.5%, dry gluten – by 16.8 – 41.1%, and 1000 kernel weight is 52.8 – 54.6 g.

The interaction between the environmental conditions and nitrogen rates has a significant impact on grain quality (Filipov and Vasileva, 2005; Flagella et al., 2010; Mariani, 1995; Panayotova and Dechev, 2002, 2003). According to Filipov (2004), increasing the fertilization to 120 kg/ha for wheat also increases the stability of yields, and a further increase of the nitrogen levels increases grain quality, but productivity decreases. He recommends that fertilizer rates comply not only to the possible yield, but also to the necessary grain quality for its various further uses.

Schulthess et al. (1993) reported that nitrogen content in grain is proven to correlate with the year conditions. The yield is the highest and of best quality when at the end of grain filling drought occurs slowly and the temperature gradually increases. With water deficit and lower temperatures, the accumulation of starch is reduced, the grain remains insufficiently filled and relatively rich in protein, and for that reason the protein content of grain is higher in drier areas and years (Filipov, 1995). Carr et al. (2003) found that grain protein decreases with increasing the seeding rate due to increased competition for nitrogen.

Khila et al. (2013) established high 1000 grain weight in the years with good moisture supply during grain filling, and low 1000 grain weight under 50 and 75% moisture supply. Precipitation and low temperatures decrease vitreousness of grain during the period of grain filling and ripening (Panayotova and Kostadinova, 2011). The year conditions had greater effect on the nitrogen content in grain compared to genotype and grain yield is of decisive significance for the yield of crude protein per unit area (Panayotova and Kostadinova, 2011).

The opinions of researchers on the effects of fertilization on test weight and 1000 grain weight are not unanimous. According to some, after fertilization these indicators decrease, according to others, they vary in increase. The test weight and 1000 grain weight deteriorate with lodging of plants, especially at higher nitrogen rates. High levels of nitrogen nutrition do not stimulate obtaining higher test weight and 1000 grain weight. The influence of genotype and year conditions are decisive for the formation of grain mass. The influence of fertilization is insignificant for test weight, whereas the weather conditions stand as a strong impact factor (90.1%). According to Uppal et al. (2002), high fertilization rate of 240 kg/ha has an unfavourable impact on forming the typical yellow color of the durum wheat grain, as well as reducing the 1000 grain weight. A dominant factor for the quality indicators of vitreousness, protein and gluten is the level of nitrogen nutrition. Soomro (2009) established that the higher seed rates produced significantly lower thousand grain weight, and conditions of increased nitrogen fertilization and water deficit yield small and underfed grain. Fois et al. (2009) found that shortening the duration of grain fill leads to reduced kernel weight in the main spike.

Nitrogen fertilization has a positive effect on the content of wet and dry gluten. The physical and chemical properties of durum wheat gluten ensure stability of dough and make it an excellent raw material for the production of pasta of high nutrient value and specific taste. The quality and quantity of gluten are most influenced by the fertilization rates (Saldzhiev and Deneva, 2000), whereas grain yield is more strongly associated with productive tillering, with grain weight per spike and 1000 grain weight.

Fuertes-Mendizábal et al. (2010) and Blandino et al. (2015) reported that not only increasing the N fertilization rate, but also splitting the N fertilization into two or more soil amendments had a beneficial effect on protein content and on wheat rheological quality. Timing the N application to correspond to reproductive development leads to higher protein synthesis and storage of grain, but delaying fertilization too long may restricts the amount of N that can be converted into quality protein (Brown et al., 2005). Nitrogen applied between boot and anthesis could be effective in enhancing protein content, although they do not generally increase grain yield (Borghi et al., 1995). Taking into account different application timings, Brown et al. (2005) and Ayoub et al. (1994) reported that N soil fertilization at heading resulted in higher flour protein concentration; moreover, Ottman et al. (2000) and Jones and Olson-Rutz (2012) indicated that this late-season soil application should be in the 30 to 50 kg N/ha.

Conclusion

All authors confirm that a significant increase of grain yield in the last decades was achieved by both using new varieties and through optimal fertilization. Nitrogen as a nutrient is of great importance for wheat productivity, leads to stronger increase of leaf area and dry matter accumulation. The suppressant effect of high nitrogen and phosphorus rates is emphasized in richer soil on growth and development. A number of authors found a genotypic specificity regarding grain yield depending on the level of fertilization. Problems of genetically determined and improved grain quality under different durum wheat varieties are the subject of extensive research. The opinions of all authors are unanimous about the positive influence of fertilization and in particular about nitrogen on the technological quality parameters – protein content, wet and dry gluten, vitreoussness, carotenoids pigment, although the values vary significantly. The influence of fertilization on the test weight is insignificant. The results underline that the grain from Bulgarian cultivars of durum wheat is a high quality raw material for production of pasta and other products.

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