EFFECT OF CULTIVATION SYSTEM ON QUALITY CHANGES IN DURUM WHEAT GRAIN AND FLOUR PRODUCED IN NORTH-EASTERN EUROPE

Joanna K. **Banach**^{1*}, Katarzyna **Majewska**², Krystyna **Żuk-Golaszewska**³

¹Institute of Management and Quality, Faculty of Economics, University of Warmia and Mazury
in Olsztyn, Poland

²Department of Food Plant Chemistry and Processing, Faculty of Food Science,
University of Warmia and Mazury in Olsztyn, Poland

³Department of Agrotechnology, Agricultural Production Management and Agribusiness,
Faculty of Environmental Management and Agriculture, University of Warmia and Mazury
in Olsztyn, Poland

***Corresponding author:**

E-mail: katarzyna.banach@uwm.edu.pl

17 Abstract

18 Grain of the highest hardness was produced from durum wheat grown without the growth
19 regulator, at the lowest sowing density (350 seeds m⁻²) and nitrogen fertilization dose of 80 kg ha⁻¹.
20 The highest values L* and b* were determined in the grain of wheat cultivated without additional
21 agrotechnical measures (growth regulator and nitrogen fertilization). Study results, supported by
22 correlation analysis, indicated that high-quality grain with desired flour quality parameters
23 (extraction rate, granulation and lightness) can be produced from spring durum wheat grown
24 without the growth regulator and at medium doses of nitrogen fertilization. Additionally, this variant
25 of applied cultivation system can reduce costs of durum wheat production and contamination of the
26 natural environment.

27

28 **Keywords:** durum wheat; integrated system; grain; flour; technological quality; relationships

29

30 1. Introduction

31 Next to maize and rice, wheat is one of the key cereals grown for consumption purposes
32 (Zarroug et al. 2015). Among its multiple species and subspecies, the most economically significant
33 ones include: common wheat (*Triticum aestivum*) representing soft wheats, and durum wheat
34 (*Triticum durum*) (De Santis et al. 2017; 2018). Considering its hardness and vitreousness as well
35 as a high content of carotenoid pigments, the grain of *Triticum durum* is mainly used to produce
36 special coarse flour (semolina), which in turn is used for making high-quality pasta, like e.g.
37 spaghetti and penne (Su, He and Sun 2015; Miskelly 2017; Hare 2017). In addition, due to high
38 contents of protein (14 – 15.5%) and gluten (42 – 46%), as well as a low activity of amylolytic
39 enzymes (falling number: 259 – 358 s), and relatively high contents of vitamins and minerals, it can
40 serve as a raw material to produce functional foods. Flour made of durum wheat grain is used to
41 produce bread loaves or as an additive improving its properties, as well as to produce cake dough,
42 pizza, cookies, couscous, and extruded products (extruded grain) (De Santis et al. 2017).

43 The technological value of durum wheat grain is principally indicated by its usability to
 44 manufacture the final product of a sufficient quality. The main ingredient of premium quality pasta
 45 is 100 percent durum wheat semolina. Semolina, which originates from the endosperm of durum
 46 wheat grain is essentially coarse flour. Good quality pasta can also be made of durum wheat flour
 47 or a blend of semolina and durum wheat flour (granular). Pasta can be produced using common
 48 wheat flour, but it is generally inferior in appearance (color). Semolina particle size distribution
 49 should be as narrow as possible to minimize uneven hydration during mixing in the pasta making
 50 process (Owens 2001). Apart from the pursuit of the best possible financial results by every link of
 51 the grain supply chain (farms) and grain processing into the flour (mills) grain hardness and color
 52 as well as the quantity and quality of flour made of it are becoming increasingly important (Delcour
 53 and Hoskeny 2010; Pauly et al. 2013).

54 Hrušková and Švec (2009) showed that wheat grain hardness results from adhesion between
 55 starch granules and storage proteins. Low molecular proteins of starch granules are present in a
 56 larger amount in soft wheat compared to hard cultivars. Moreover, non-uniform particle size
 57 distribution of semolina results in the uneven hydration and pasta defects (Morris and Fuerst 2015).
 58 Grain hardness is also affected by puroindolines, which act to soften the endosperm, but are lacking
 59 in durum wheat (Pasha, Anjum and Morris 2010; Boehm et al. 2018). Nagamine et al. (2003)
 60 demonstrated a significant correlation between flour color and hardness. In turn, Hrušková and
 61 Švec (2009) who analyzed correlations between grain hardness of wheat and its relation to other
 62 quality features, showed that the strongest relation was obtained for the grain ash content, semolina
 63 yield, and flour protein content.

64 The yellow-amber color of durum wheat grain, usually associated by consumers with its high
 65 quality, is mainly due to the accumulation of two groups of natural pigments: carotenoids and
 66 anthocyanins. Carotenoids contribute to the yellow color of the endosperm of durum wheat grain
 67 and semolina, whereas anthocyanins accumulate in the pericarp of durum wheat and contribute to
 68 the blue, violet, and red color of its grain. Apart from ensuring esthetic values, the pigments

contained in the grain play an important nutritional and health role, therefore their modification in the grain by means of agrotechnical factors is still valid and justified in research (Abdel-Aal et al. 2007, Nishino et al. 2009, Beleggia et al. 2010).

Changes in the quality parameters of wheat grain are affected, most of all, by varietal traits, habitat conditions, cultivation system, and agrotechnical measures, including nitrogen fertilization (Makowska et al. 2008; Giuliani et al. 2011; Ficco et al. 2014; Semenov et al. 2014; De Santis et al. 2017; Żuk-Golaszewska et al. 2018). Nitrogen is the major component of fertilizers which significantly influences crop yield and protein content (Giuliani et al. 2011).

Due to the above, the basic task of the modern plant production is to strive for high, stable and good-quality crops, with the lowest possible inputs and respect for the natural environment (Diacono et al. 2013, Ropelewska et al. 2019). Durum wheat is an agronomically competitive crop to common wheat, which exhibits tolerance to biotic and abiotic stress and is widely cultivated in regions with low rainfall (Marti and Slafer 2014; Kaur et al. 2015; Campiglia et al. 2015). Generally, nitrogen fertilizer management may influence wheat grain hardness (Giuliani et al. 2011). Makowska et al. (2008) showed that nitrogen fertilization had a distinct effect on grain hardness and vitreousness, but no significant effect on carotenoids content and color of pasta dough.

Investigations addressing the coupled use of a few treatments in crop cultivation systems, especially in an integrated farming system (Diacono et al. 2013; Walia et al. 2019), differing in nitrogen fertilization level and sowing density are sparse. The growing scale of production and the increasing diversity of wheat applications urge the need for assessing the quality of grain batches received by warehouses. In turn, the production of high-quality flour (semolina) requires sufficient raw material and continuous control of the production process (Mefleh et al. 2018).

Considering the above, a study was undertaken with the aim to determine the effect of applied cultivation system of spring durum wheat: differing in sowing density, retardant administration, and nitrogen fertilization dose, on the selected quality parameters of grain and flour made of it.

Moreover, an analysis of correlations between agrotechnical factors and technological parameters was performed to determine which factors significantly shape the technological quality of studied material.

2. Material and methods

2.1. Cultivation of durum wheat

Study material included grain of spring durum wheat cv. SMH 87 (Polish National List of the Research Center for Cultivar Testing, 2011) originating from the field experiment at the Production and Experimental Station in Bałcyny (53°40' N, 19°50'E) - harvest 2016, under integrated farming management. This is the first cultivar of durum wheat grown in Poland that is utterly adjusted to its climatic conditions. The experimental variables included:

- nitrogen fertilization: control, without nitrogen fertilization; 80 kg·ha⁻¹- 50 kg·ha⁻¹ before sowing and 30 kg·ha⁻¹ at the shooting stage (Z33); 120 kg·ha⁻¹- 50 kg ha⁻¹ before sowing, 30 kg·ha⁻¹ at the shooting stage (Z33), and 40 kg·ha⁻¹ at the early earing stage (Z51) (Zadoks, Chang, Konzak 1974),
- sowing density: 350; 450, and 550 seeds·m⁻²,
- application of growth regulator: without of application (WGR) or with the application (GR) Medax 350 S.C. as aprophylactic measure that may prevent crop lodging.

After the harvest, the grain was cleansed from physical impurities and residues of the seed coat. It had a standardized moisture content of 14±0.5%, that was assayed acc. to the Polish Standard (2012). The grain (ca. 500 g from each cultivation variant) was poured into glass bottles with a ground-glass stopper and stored in the climatic chamber (ICP 500, Memmert, USA) at air temperature of 20±0.1°C until analyzed.

2.1. Measurements grain hardness

Grain hardness was measured with a Universal Testing Device (Instron 5942; Instron Corp., USA). A uniaxial compression test (flat shank: Ø=12.6 mm; speed of the working head in the test: 10 mm/min) was carried out on individual wheat kernels placed on a measuring table crease down, in 20 replications for each sample. Grain hardness was determined based on the measured values of the maximal compression force ($F_{\max}$) needed to induce 50% deformation; values were expressed in N. The results of the tests were analyzed using the computer software Bluehill II.

2.2. Measurements of grain and flour color

Color measurements were made using a Hunter Miniscan XE Plus colorimeter (HunterLab, USA), which was set to collect spectral data with illuminant A/observer D65/10°. Prior to the measurements, the colorimeter was calibrated using a white and black ceramic plate. Grain and flour color was established based on measurements in the CIELab scale (L^* - lightness, a^* - redness, b^* - yellowness). Color measurements of both grain and flour were conducted in a black container (ca. 50 cm³) in 12 replications.

2.3. Determination of flour extraction rate

The flour extraction rate (FER) was determined by milling the grain in a laboratory Quadrumat Junior roller mill (Brabender®). Before milling, the grain was conditioned to achieve 14.5% moisture content. FER determination was conducted in 6 replications.

2.4. Determination of flour particle size (granulation < 400 µm)

Particle size of flour (FPS) obtained from the studied grain was determined according to the method of Haber and Horubałowa (1992). The flour (100 g) was sifted through a sieve with mesh size of 400 µm, using a laboratory sifter (type LPzE-2e, Multiserw Morek, Poland). Percentage contents of flour particle fractions less than 400 µm were determined based on 6 replications.

146 **2.5. Statistical analysis**

147 Calculations were carried out in Statistica 13.1 software (StatSoft Inc., Tulsa, OK, USA). The
148 results of analyses were presented as means $\pm$ standard deviations. One-way analysis of variance
149 was conducted to determine the influence of agrotechnical factors on the quality parameters of
150 durum wheat grain and flour; its results were reported at the following levels of significance $p < 0.01$
151 and $p < 0.05$. The relationships between agrotechnical factors and selected quality parameters of
152 grain and flour obtained from it were determined by correlation analysis by calculating the Pearson
153 coefficient at the significance level of $p < 0.01$ and $p < 0.05$ (SPSS ver. 25). However, in order to
154 show statistically significant differences between groups in terms of the use of GR or WGR, the
155 Mann-Whitney U test (nonparametric equivalents of analysis of variance) was conducted. This test
156 allowed verification of the null hypothesis, which assumes that the means of compared groups
157 (seeding density, nitrogen fertilization) show equality and are characterized by a similar
158 distribution.

160 **3. Results and discussion**

161 **3.1. Grain hardness**

162 Increasing the fertilization dose (0, 80, 120 kg·ha⁻¹) in the cropping system without the
163 growth regulator (WGR) and at sowing density of 350 and 450 seeds·m⁻² caused a significant
164 ($p < 0.01$, $p < 0.05$) decrease in the value of the maximal compression force ($F_{\max}$) from approx. 145
165 to 115N and from approx. 135 to 108N, respectively. An opposite observation was made at the
166 higher sowing density (550 seeds·m⁻²), i.e. $F_{\max}$ values increased from approx. 116 to approx. 148
167 N along with an increasing fertilization dose. The statistical analysis of results demonstrated also
168 that the increased nitrogen doses and sowing densities caused significant ($p < 0.01$; $p < 0.05$)
169 differences in $F_{\max}$ value determined for the grain from wheat grown in the WGR variant (table 1).

170 Table 1. Changes in the maximum compression force (mean values $\pm$ standard deviation) of the durum wheat grain depending on sowing density, growth
171 regulator application and nitrogen fertilization.

Sowing density (seeds·m ⁻²)		Maximum compression force - F _{max} (N)					
		Nitrogen fertilization (kg·ha ⁻¹)			Significant differences – 350/450/550		
		0	80	120	0	80	120
Without the application growth regulator - WGR							
350		144.82±35.91 ^{aC}	139.80±6.76 ^a	114.42±11.51 ^{bB}	*	**	**
450		135.11±8.90 ^{Ab}	119.44±17.64 ^{Ba}	108.11±15.33 ^a			
550		115.73±9.31 ^a	117.24±10.42 ^a	147.92±23.86 ^b			
With the application growth regulator - GR							
350		116.17±16.28 ^a	114.52±15.32 ^{aA}	137.20±25.13 ^{Ba}	NS	NS	NS
450		118.17±10.55 ^{Ac}	108.73±6.27 ^{Bb}	127.70±10.66 ^c			
550		128.80±15.12 ^a	134.57±20.62 ^a	136.12±17.45 ^a			
Significant differences – GR/WGR	350	NS	**	*	-	-	-
	450	**	NS	**			
	550	NS	NS	NS			

172 * – significant differences, p<0.05; ** – significant differences, p<0.01; NS – no significant differences

a-d – mean values in columns indicated with various small letters are statistically significantly different at p<0.01;

A-B – mean values in columns indicated with various capital letter are statistically significantly different at p<0.05

173 a-a – mean values in columns indicated with the same small letters non differ statistically

174 A strong impact of fertilization with nitrogen on the increased hardness of the grain was also
175 reported by other authors (Ciolek and Makarska 2004; Makowska et al. 2008; Szumilo and Rachoń
176 2010; Rachoń et al. 2015). So explicit tendencies were not observed in the cropping system with
177 the growth regulator (GR). Durum wheat cultivation at seeding rates of 350 and 450 seeds·m⁻²
178 contributed to the achievement of the lowest $F_{\max}$ value (approx. 115 and approx. 109 N) at nitrogen
179 fertilization dose of 80 kg·ha⁻¹ and the highest $F_{\max}$ value (approx. 137 and approx. 128N) at
180 nitrogen fertilization dose of 120 kg·ha⁻¹. Durum wheat cultivation with the application of GR, at
181 sowing density of 550 seeds·m⁻², and nitrogen doses of 0, 80, and 120 kg·ha⁻¹ allowed producing
182 grain which did not differ significantly in its $F_{\max}$ values (approx. 129-136N). Considering the
183 above, it was concluded that the highest maximal compression force ($F_{\max}$ of approx. 145 N) was
184 obtained for the grain from WGR system, with sowing density of 350 seeds·m⁻² and no fertilization
185 with nitrogen (0 kg·ha⁻¹) as well as for the grain from the variant with sowing density of 550
186 seeds·m⁻² and nitrogen dose of 120 kg·ha⁻¹ (approx. 148N) - table 1.

187 The statistical analysis of the effect of sowing density on durum wheat cultivation in the
188 WGR system demonstrated that this experimental factor caused significant ($p<0.01$; $p<0.05$)
189 differences in $F_{\max}$ value of the grain at each dose of fertilization, i.e. 0, 80, and 120 kg·ha⁻¹. In
190 contrast, in the GR cropping system, this experimental factor had no effect on values of this
191 parameter. The analysis of the GR/WGR effect showed significant ($p<0.01$; $p<0.05$) differences in
192 $F_{\max}$ of the grain, especially in the variants with lower seeding rates (350 and 450 seeds·m⁻²) and
193 higher fertilization doses (80 and 120 kg·ha⁻¹). Therefore, when growing crops in the WGR system
194 more consideration should be given to the sowing density and nitrogen dose, whereas effects of
195 these factors can be neglected in the GR system (tab. 1). According to Szychaj et al. (2011), grain
196 hardness is affected to a greater extent by weather conditions than by chemical plant protection
197 agents used during cultivation. In contrast, Rachoń et al. (2015) demonstrated that the
198 administration of plant protection agents had a positive effect on grain vitreousness, whereas
199 according to Fana et al. (2012) no interaction was observed between fertilization and grain

hardness, however this quality parameter positively correlated with flour yield. In turn, Nagamine et al. (2003) showed a significant relationship between flour color and hardness.

3.2. Grain color

Results of measurements of durum wheat grain lightness (tab. 2) confirmed results of measurements of the $F_{\max}$ value. The highest and similar L^* values were determined for the grain from durum wheat grown in the WGR system, at sowing density of 350 seeds·m⁻² and without nitrogen fertilization ($L^*=54.35$) as well as for the grain of durum wheat fertilized with a nitrogen dose of 80 kg·ha⁻¹ ($L^*=54.16$). The lowest L^* value (51.36) was demonstrated for the grain from wheat cultivated without the growth regulator, at sowing density of 450 seeds·m⁻² and nitrogen dose of 120 kg·ha⁻¹. As in the case of grain hardness, upon GR use, the L^* value of the grain was the highest (53.64) in the cropping with the sowing density of 350 seeds·m⁻² and nitrogen dose of 120 kg·ha⁻¹, whereas the lowest one at sowing density of 350 seeds·m⁻² and nitrogen application of 0 kg·ha⁻¹ (51.41). The hardness and lightness of the grain from durum wheat grown in the WGR system were significantly influenced by sowing density, especially at nitrogen fertilization doses of 80 and 120 kg·ha⁻¹ ($p<0.01$; $p<0.05$) – table 2. The higher L^* values of the grain testifies of its lighter color and better usability for semolina and pasta production (Ciolek and Makarska 2004). Results of an experiment conducted by Woźniak (2006) demonstrated intensive fertilization with nitrogen (120 kg·ha⁻¹) to significantly increase total ash content in durum wheat grain compared to the minimized fertilization (90 kg·ha⁻¹). In turn, according to Sulewska, Koziara and Bojarczuk (2007), nitrogen fertilization decreased ash content and, by this means, increased the lightness of kernels.

The statistical analysis of the effect of nitrogen fertilization dose showed that L^* values differed significantly ($p<0.01$) between the grain from durum wheat grown in the WGR system without fertilization (0N) and that from wheat grown with nitrogen fertilization at doses of 80 and 120 kg·ha⁻¹. It was also demonstrated that the sowing density had a significant ($p<0.01$ and $p<0.05$)

effect on L^* values of the grain produced from wheat grown in the GR system in each variant of nitrogen fertilization (0, 80, 120 kg·ha⁻¹) as well as on L^* values of the grain from durum wheat cultivated in the WGR system with nitrogen fertilization doses of 80 and 120 kg·ha⁻¹ ($p < 0.05$). The analysis of GR/WGR effect showed that this factor caused the greatest differences in L^* values of the grain from wheat grown at 0 kg·ha⁻¹ and sowing density of 450 and 550 seeds·m⁻², at 80 kg·ha⁻¹ /550 seeds·m⁻², and at 120 kg·ha⁻¹ /350 seeds·m⁻² (tab. 2).

Results of measurements of grain redness (a^*) demonstrated that its values were similar (8.17 – 9.13) and were not significantly affected by any of the factors tested (WGR/GR, 350/450/550; 0/80/120 kg·ha⁻¹) – table 2.

Results of measurements of grain yellowness (b^*), being indicative of the content of carotenoid pigments (Hentschel et al. 2002; Ciołek, and Makarska 2004; Colasuonno et al. 2019), demonstrated its values to range from 26.72 to 28.84 regardless of the analyzed variant and experimental factor. The highest saturation with yellow color ($b^* \approx 29$) was determined in the grain from durum wheat grown at GR/0N/450 seeds·m⁻². The b^* values obtained in the study (approx. 27.3 or higher) point to the good quality of the grain (Colasuonno et al. 2019; Zhang and Dubcovsky 2008). Durum grain with a higher content of yellow pigments is characterized by superior qualitative composition of gluten proteins and it has lighter and thinner hulls. In turn, the achieved lowest b^* values (GR/450: 27.48; WGR/550: 26.72) and the observed significant ($p < 0.01$) effect of WGR/GR and seeding rate (350/450/550) on b^* values of the grain from durum wheat fertilized with a nitrogen dose of 120 kg·ha⁻¹ (tab. 2) are indicative of the negative effect of fertilization with nitrogen on the content of carotenoid pigments (Sulewska, Koziara and Bojarczuk 2007). The levels of lightness (L^*) and redness (a^*) values of analyzed durum grain were relatively similar to these obtained for common wheat and spelt grain, whereas values of durum grain yellowness (b^*) were 1.5x higher than in the case of mentioned two wheat species (Żuk-Gólaszewska et al. 2018).

252 Table 2. Changes in the values (mean values $\pm$ standard deviation) of the color parameters L*, a*, b* durum wheat grain cultivated with the application
253 (GR) and without application (WGR) of the growth regulator with different sowing density and nitrogen fertilization.

Sowing density (seeds·m ⁻²)	Fertilization with nitrogen (kg·ha ⁻¹) and growth regulator - GR			Fertilization with nitrogen (kg·ha ⁻¹) and without growth regulator - WGR			Significant differences – 350/450/550						Significant differences – GR/WGR		
	0	80	120	0	80	120	GR			WGR					
							0	80	120	0	80	120	0	80	120
Parameter L*															
350	51.41±0.54 ^{aA}	53.33±0.40 ^b	53.64±0.44 ^{bB}	54.35±0.61 ^a	54.16±0.23 ^a	52.38±0.79 ^b	**	*	**	NS	**	*	NS	NS	**
450	53.51±1.04 ^a	52.95±0.36 ^a	52.94±0.49 ^a	53.59±0.57 ^a	53.30±0.67 ^a	51.36±0.64 ^b							**	NS	NS
550	52.45±0.59 ^a	52.46±0.71 ^a	51.99±0.80 ^a	53.83±0.64 ^a	52.32±0.25 ^b	52.45±0.61 ^{bc}							**	**	NS
Parameter a*															
350	8.17±1.25 ^a	8.42±0.97 ^a	8.45±0.91 ^a	8.67±1.14 ^a	9.14±0.27 ^a	8.94±0.34 ^a	NS	NS	NS	NS	NS	NS	NS	NS	NS
450	8.52±1.05 ^a	8.84±0.96 ^a	8.38±0.92 ^a	8.71±0.97 ^a	8.39±1.27 ^a	9.13±0.22 ^a							NS	NS	NS
550	8.55±1.14 ^a	8.63±0.96 ^a	8.44±1.31	8.08±1.29 ^a	8.72±0.92 ^a	8.79±0.40 ^a							NS	NS	NS
Parameter b*															
350	28.36±0.52 ^A	27.73±0.20 ^{Bb}	27.66±0.47 ^{bC}	28.70±0.86 ^{Ac}	27.66±0.22 ^{Bb}	27.35±0.53 ^b	NS	NS	*	NS	NS	*	NS	NS	NS
450	28.84±0.70 ^a	28.33±0.78 ^a	27.48±0.72 ^{ab}	28.19±0.54 ^a	27.99±1.14 ^a	28.02±0.44 ^a							NS	NS	NS
550	28.30±1.00 ^a	28.35±0.90 ^a	28.49±0.64 ^a	27.66±0.50 ^a	28.11±0.53 ^{aA}	26.72±1.17 ^{Bb}							NS	NS	**

a-d – mean values in columns indicated with various small letters are statistically significantly different at $p \leq 0.01$;

A-B – mean values in columns indicated with various capital letter are statistically significantly different at $p \leq 0.05$

a-a – mean values in columns indicated with the same small letters non differ statistically

* – significant differences, $p < 0.05$; ** – significant differences, $p < 0.01$; NS – non significant differences

3.3. *Flour extraction rate (FER)*

Being the basic tool used to monitor and control the milling process as well as its technological and economic outcomes in the milling industry, the flour extraction rate (FER) was described as a quality indicator which allows establishing the optimal conditions of crop cultivation (Żuk-Golaszewska et al. 2018). The yield of semolina declines as kernels become thinner because the proportion of endosperm concomitantly decreases. This is largely influenced by environmental conditions during the growing season and during harvest (Owens 2001).

Results of determination of the amount of flour produced from grain unit demonstrated a higher extraction rate of the flour made of the grain from durum wheat grown in the WGR system (68.69-59.38%), compared to the GR system (64.00 – 58.58%), however the highest FER value was obtained in the variant with 0N and 350 seeds m⁻² (68.96%) which allowed producing the hardest grain (tab.1). In addition, the sowing density factor (350/450/550) in the WGR system, caused significant ($p<0.01$, $p<0.05$) differences in FER, regardless of nitrogen fertilization dose. The lower FER value of flour from the grain of wheat cultivated in the GR system was also significantly ($p<0.01$) affected by sowing density at 80N fertilization dose. The highest FER values, being significantly different from these obtained at WGR/80N, were achieved during wheat cultivation at 80N fertilization and sowing densities of 350 seeds·m⁻² (64.00%) and 450 seeds m⁻² (63.92%) – table 3. Obtained FER values were comparable or even higher than domestic standards for this parameter, which were: 66.1% – spring common wheat cv. Tybalt; 61,7% – spring durum wheat cv. SMH87 (Polish National List of the Research Center for Cultivar Testing. 2011).

3.4. *Flour particle size (FPS)*

The particle size distribution of flour (FPS) is another quality indicator which affects its storage stability and technological usability (e.g. water absorption rate or dough formation time). Pasta producers are fully aware of the impact the particle size of durum wheat semolina or flour has on the pasts quality. However, detailed requirements regarding this quality indicator differ

282 significantly among countries. Due to the great advance in novel techniques and technologies
 283 employed in the pasta making process, the requirements set for pasta raw materials regarding
 284 particle size distribution have changed remarkably in recent years. The demand for coarse pasta
 285 flours has decreased, while that for semolina and durum flours with finer but uniform granulation
 286 has increased (Jurga 2007). For years, pasta has been produced with semolina having particle sizes
 287 of 125 to 630 μm , whereas today the most common and suitable raw material is that with finer
 288 particles being smaller than 400 μm (Polish National List of the Research Center for Cultivar
 289 Testing 2011). This allows shortening kneading time and achieving pasta dough with a more
 290 homogenous structure.

291 Results of FPS measurements demonstrate that flour from durum wheat grown in the WGR
 292 system was characterized by a wider range of values of this parameter (67.6 – 99.57%) and, that the
 293 lowest value was determined in the flour made of the grain from wheat grown without nitrogen
 294 fertilization at sowing density of 350 seeds m^{-2} . In turn, in the GR system, the range of FPS values
 295 was narrower, but the values achieved were higher, i.e. 91.03 – 99.77% (table 3).

296 The analysis of the effect of WGR/GR factor showed significant ($p < 0.01$, $p < 0.05$) differences
 297 in the FPS distribution of flour. In the cropping variants: 0/120 $\text{kg} \cdot \text{ha}^{-1}$ – 350 and 550 seeds m^{-2} , the
 298 FPS value of flour from WGR grain was lower compared to that of flour from GR grain. In
 299 contrast, the FPS values were significantly ($p < 0.05$) higher in the case of flours from WGR grain
 300 and 80 $\text{kg} \cdot \text{ha}^{-1}$ variant (at all sowing densities) – table 3. Obtained FPS values were also
 301 comparable or higher than domestic standards for this parameter, which were: 91.6% – spring
 302 common wheat cv. Tybalt; 82.2% – spring durum wheat cv. SMH87 (Polish National List of the
 303 Research Center for Cultivar Testing 2011).

304 Table 3. Changes in the extraction rate and particle size (mean values $\pm$ standard deviation) of flour from durum wheat grain depending on sowing
305 density, growth regulator application and nitrogen fertilization.

Sowing density (seeds·m ⁻²)		FER (%)						FPS (%)					
		Nitrogen fertilization (kg·ha ⁻¹)			Sig. diff. – 350/450/550			Nitrogen fertilization (kg·ha ⁻¹)			Sig. diff. – 350/450/550		
		0	80	120	0	80	120	0	80	120	0	80	120
Without the application growth regulator (WGR)													
350		68.96±1.10 ^a	59.91±2.18 ^a	60.15±0.89 ^a	**	**	*	67.60±0.75 ^a	97.11±0.07 ^a	95.94±0.76 ^a	**	**	**
450		67.52±1.09 ^a	60.45±0.44 ^a	62.02±0.92 ^{aA}				92.83±1.44 ^b	98.36±0.41 ^{bB}	99.57±0.15 ^b			
550		59.38±1.07 ^b	64.31±1.11 ^b	59.67±0.98 ^{Ba}				95.00±0.20 ^b	97.64±0.12 ^{Cc}	97.09±0.16 ^{ca}			
With the application growth regulator (GR)													
350		62.05±1.65 ^a	64.00±0.40 ^a	60.94±0.23 ^a	NS	**	NS	96.31±0.66 ^a	94.25±0.93 ^a	99.77±0.07 ^a	**	**	NS
450		62.99±0.71 ^a	63.92±0.89 ^a	58.58±1.70 ^a				91.03±0.84 ^b	93.62±0.11 ^a	99.37±0.06 ^{aB}			
550		61.28±1.51 ^a	61.22±0.63 ^b	59.82±1.40 ^a				97.11±0.57 ^{ca}	97.97±0.09 ^b	99.40±0.38 ^{Ca}			
Significant differences – GR/WGR	350	**	**	NS	-	-	-	**	**	**	-	-	-
	450	**	**	*				NS	**	NS			
	550	NS	*	NS				**	*	**			

306 FER - flour extraction rate; FPS – flour particle size.

a-d – mean values in columns indicated with various small letters are statistically significantly different at p<0.01;

A-B – mean values in columns indicated with various capital letter are statistically significantly different at p<0.05

307 a-a – mean values in columns indicated with the same small letters non differ statistically

308 * – significant differences, p<0.05; ** – significant differences, p<0.01; NS – no significant differences

309 **3.5. Flour color**

310 The highest values of L* color parameter of flour (91.93-91.81) of durum grain produced in
 311 WGR system were obtained for the variants WGR/80 kg·ha⁻¹ /350-450 seeds·m⁻² and WGR/0N/550
 312 seeds·m⁻². In case of GR system, a highest range of L* values (92.43-91.74) was reported for the
 313 flours made of the grain from the variants GR/0 kg·ha⁻¹/350-550 seeds·m⁻². In flours from the other
 314 variants, L* values ranged from 90.48 to 91.12. The analysis of the impact of agrotechnical factors
 315 demonstrated a significant (p<0.01; p<0.05) effect of GR/WGR on the lightness of flours from all
 316 cropping variants, except for the variant 120 kg·ha⁻¹/450 seeds·m⁻². The sowing density factor
 317 caused significant differences in L* values of flours made of the grain from the variant GR/0; 120
 318 kg·ha⁻¹ (p<0.01; p<0.05) and from the variant WGR/0; 80; 120 kg·ha⁻¹ (p<0.01) – table 4.

319 Results of redness measurements demonstrated that a* values of the flour made of the grain
 320 from the WGR system were higher (0.68-0.43) compared to a* values of flour from wheat grain
 321 from the GR system (0.62-0.40). The statistical analysis of the impact of agrotechnical factors
 322 demonstrated a significant (p<0.01; p<0.05) effect of the GR/WGR factor on a* value of the flours
 323 made of the grain produced from variants: 0 kg·ha⁻¹/350; 450 seeds·m⁻²; 80 kg·ha⁻¹/550 seeds·m⁻²,
 324 and 120 kg·ha⁻¹/450 and 550 seeds·m⁻². Sowing density caused significant (p<0.01) differences in
 325 a* values of flours produced from the grain from variants: WGR/0; 120 kg·ha⁻¹ and GR/80 kg·ha⁻¹
 326 (table 4).

327 The statistical analysis of the impact of agrotechnical factors demonstrated that only sowing
 328 density caused significant differences the yellowness (b*) of flour made of the grain produced from
 329 variants: GR/120 kg·ha⁻¹ (p<0.05) and WGR/0; 80 kg·ha⁻¹ (p<0.01) – table 4. The lack of an
 330 explicit effect of the agrotechnical factors on the yellowness of flour, like in the case of analyzed
 331 parameter b* of grain color, may be due to the complex nature of the yellow pigment in
 332 semolina/ flour from durum wheat grain, whose carotenoid fraction accounted for only 30-50%
 333 of the yellow pigment quantities. There are still compounds in durum wheat not yet identified that
 334 contribute considerably to the yellow color of the flour (Hentschel et al. 2002; Colasuonno et al.

335 Table 4. Changes in the values (mean values $\pm$ standard deviation) of the color parameters L*, a*, b* of flour from grain of durum wheat cultivated with
336 the application (GR) and without application (WGR) of the growth regulator with different sowing density and nitrogen fertilization.

Sowing density [seeds·m ⁻²]	Fertilization with nitrogen [kg·ha ⁻¹] and growth regulator - GR			Fertilization with nitrogen [kg·ha ⁻¹] and without growth regulator - WGR			Significant differences – 350/450/550						Significant differences – GR/WGR		
	0	80	120	0	80	120	GR			WGR			0	80	120
							0	80	120	0	80	120			
Parameter L*															
350	91.74±0.20 ^a	90.90±0.16 ^{aB}	90.60±0.25 ^{aC}	90.85±0.29 ^a	91.80±0.16 ^a	91.05±0.30 ^a	**	NS	*	**	**	**	**	**	*
450	91.78±0.23 ^a	91.12±0.30 ^{aA}	90.50±0.32 ^{aA}	90.96±0.67 ^{aA}	91.93±0.30 ^a	90.48±0.20 ^b							*	**	NS
550	92.43±0.43 ^b	90.77±0.23 ^B	90.90±0.16 ^B	91.81±0.34 ^{Bb}	91.07±0.24 ^b	90.50±0.17 ^b							*	*	**
Parameter a*															
350	0.41±0.08 ^{aB}	0.62±0.13 ^a	0.45±0.09 ^a	0.66±0.09 ^a	0.58±0.03 ^a	0.51±0.06 ^a	NS	**	NS	**	NS	**	**	NS	NS
450	0.50±0.10 ^{aA}	0.56±0.05 ^a	0.42±0.07 ^a	0.63±0.03 ^a	0.59±0.07 ^a	0.55±0.06 ^a							*	NS	**
550	0.40±0.05 ^B	0.45±0.02 ^b	0.42±0.04 ^a	0.43±0.08 ^b	0.68±0.12 ^b	0.65±0.04 ^b							NS	**	**
Parameter b*															
350	18.22±0.52 ^{aB}	19.30±0.89 ^a	19.14±0.31 ^a	17.82±0.24 ^a	19.22±0.29 ^{aC}	19.43±0.13 ^a	NS	NS	*	**	**	NS	NS	NS	NS
450	18.55±0.18 ^{aA}	19.54±0.21 ^a	19.52±0.35 ^a	18.60±0.40 ^b	19.69±0.10 ^{bA}	19.41±0.19 ^a							NS	NS	NS
550	18.12±0.30 ^B	19.51±0.41 ^a	19.73±0.40 ^a	18.21±0.33 ^b	19.52±0.09 ^B	19.66±0.51 ^b							NS	NS	NS

a-d – mean values in columns indicated with various small letters are statistically significantly different at p<0.01;

A-B – mean values in columns indicated with various capital letter are statistically significantly different at p<0.05

a-a – mean values in columns indicated with the same small letters non differ statistically

* – significant differences, p<0.05; ** – significant differences, p<0.01; NS – non significant difference

2019). The level of lightness L^* values of analyzed durum wheat flour was relatively similar to this obtained for flours of common wheat and spelt grain, whereas values of durum flour redness a^* and yellowness b^* were twice higher than in the case of mentioned two wheat species (Żuk-Gólaszewska et al. 2018).

3.6. Correlations

To determine the effect of agrotechnical factors (seeding density, nitrogen fertilization, retardant application) on the analyzed parameters of grain quality and flour obtained from it, an analysis of correlations between these variables was performed.

Analysis of the influence of sowing density and nitrogen fertilization grain cultivated without the application of growth regulator (WGR) showed that nitrogen fertilization had a significant ($p < 0.01$) and a strong effect on the color parameters L^* ($r = -0.665$) and b^* ($r = -0.488$) of the grain, and these correlations were negative (with increasing nitrogen dose, parameter values decreased). The sowing density was characterized by a smaller effect on the lightness of the grain ($r = -0.286$). The opposite relationship was observed for grain cultivated with the application of growth regulator (GR). Greater and negative correlation ($r = -0.676$, $p < 0.01$) was obtained between sowing density of grain and its lightness (L^*), while the effect of nitrogen fertilization on the hardness and its color parameters (L^* , b^*) was characterized by a significant, but of a smaller strength, correlation ($p < 0.05$) - table 5.

In the case of flour obtained from grain cultivated without the application of growth regulator (WGR), similar relationships were observed as for the grain itself. The most significant ($p < 0.01$) and strong effect of nitrogen fertilization was obtained for FPS ($r = -0.592$) and yellowness b^* ($r = 0.824$), and a slightly lower strength - for its FER ($r = -0.384$). However, the grain sowing density also significantly affected ($p < 0.05$) on the FPS. In the case of flour obtained from grain cultivated with the application of growth regulator (GR), significant effect ($p < 0.01$) and high

364 strength ($r = (-0.856) - (0.740)$) on the all tested technological parameters had nitrogen fertilization
365 - table 5.

366

367 Table 5. Correlation coefficients between agrotechnical factors (sowing density, fertilization with nitrogen,
368 WGR / GR) and selected qualitative parameters durum wheat grain and flour made of it.

Cultivation system	Wheat grain				Flour			
	Without the application growth regulator - WGR							
	F _{max} [N]	L*	a*	b*	FER [%]	FPS [%]	L*	b*
Sowing density	-0.117	-0.286*	-0.188	-0.080	-0.327	0.424*	-0.072	0.180
Fertilization with nitrogen	-0.163	-0.665**	0.222	-0.488**	-0.384*	-0.592**	-0.254	0.824**
	With the application growth regulator - GR							
Sowing density	0.238*	-0.676**	0.077	0.247	-0.212	0.196	0.177	0.136
Fertilization with nitrogen	0.240*	-0.290*	0.022	-0.334*	-0.567**	-0.594**	-0.856**	0.740**

369 F_{max} - maximum compression force of the durum wheat grain; FER - flour extraction rate; FPS – flour
370 particle size, L*- lightness, a*- redness, b*- yellowness
371 * – significant differences, $p < 0.05$; ** – significant differences, $p < 0.01$.

372

373 To determine the effect of application of GR during cultivation, the Mann-Witney's test was
374 carried out for 2 independent groups. The obtained results did not allow the rejection of the null
375 hypothesis (the means of the compared groups are equal), which means that the impact of sowing
376 density and nitrogen fertilization on both groups is similar - statistically insignificant.

377

378 4. Conclusions

- 379 1. Grain of the highest hardness was produced from durum wheat grown without the growth
380 regulator (WGR), at the lowest sowing density (350 seeds·m⁻²) and nitrogen fertilization dose of
381 80 kg·ha⁻¹.
- 382 2. The highest values of lightness (L*) and yellowness (b*) were determined in the grain of wheat
383 cultivated without additional agrotechnical measures (growth regulator and nitrogen
384 fertilization). The lightness (L*) of the grain produced from wheat cultivated with the support of

the growth regulator was negatively affected by increasing the sowing density to 550 seeds·m⁻² and nitrogen fertilization dose to 120 kg·ha⁻¹.

3. Study results, supported by correlation analysis, indicated that high-quality grain with desired flour quality parameters (FER, FPS, L*) can be produced from spring durum wheat grown without the growth regulator and at medium doses of nitrogen fertilization.

4. Obtaining good quality technological parameters of durum grain and flour in case of application medium doses nitrogen and without the growth regulator can reduce costs of durum wheat production and contamination of the natural environment.

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