QUALITY AND YIELD OF TRITICUM DURUM UNDER TEMPERATE CONTINENTAL CLIMATE OF THE CZECH REPUBLIC

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Abstract


In Europe, durum wheat is traditionally grown primarily in the Mediterranean region. A question arises as to whether now, in a situation of global climate change, the conditions for durum wheat might be more favourable also in countries with temperate continental climate. Field trials at a location in the south-eastern part of the Czech Republic with a typical European continental climate were established in four harvest years (2011 – 2014). Yield, quality and deoxynivalenol content were evaluated and the impact of year and variety was studied. The best quality was achieved in 2013, when 4 of 5 varieties met all the quality requirements for durum wheat according to Commission Regulation (EU) No. 1272 / 2009. The most frequent reason for unsatisfactory quality was loss of vitreousness and low falling number. In 2012, three varieties froze, and this year was therefore excluded from evaluation. Yield varied between 7.6 t ha⁻¹ in 2013 to 10.9 t ha⁻¹ in 2014 and it was in a negative, statistically significant relationship with most of qualitative traits, particularly with vitreousness (r = −0.72). The strongest correlation between qualitative traits was found between vitreousness and thousand kernel weight (r = −0.73) and vitreousness and test weight (r = 0.70).

Keywords: durum wheat, weather, technological quality, vitreousness, falling number, protein content, test weight, deoxynivalenol, yield

INTRODUCTION

Quality requirements for durum wheat for the purposes of intervention buying-in are defined in the EU by Commission Regulation (EU) No. 1272/2009 (European Union, 2009). Vitreousness (endosperm translucency) is an essential quality factor for durum wheat and it is related to the firmness of the starch-protein matrix. The proportion of vitreous grains should be at minimum 83%. Bulk density, as measured by test weight (TW), should be at least 78 kg hl⁻¹. TW is known to be positively correlated with semolina yield within a wide TW range (Fabriani and Lintas, 1988). Other evaluated parameters include crude protein content in dry matter (CPC, min. 11.5%); falling number (FN, min. 220 s); and ratio of admixtures and impurities (max. 12.0%). It is necessary to take into consideration also contamination by Fusarium mycotoxins. Two of those, deoxynivalenol (DON) and zearalenone, are limited by Commission Regulation (EU) No. 1881/2006 (European Union, 2006). There is a higher limit for maximum DON content in T. durum grain (1,750 μg kg⁻¹) as compared to that in T. aestivum (1,250 μg kg⁻¹). Durum wheat is usually more susceptible to infection by Fusarium head blight and contamination with Fusarium mycotoxins than is T. aestivum if both are grown in similar conditions (Clear et al., 2005).

Environment and potential interaction between environment and genotype are important factors influencing the quality parameters of durum wheat grain (Lerner et al., 2004). Weather conditions have strong influence on the majority of quality traits in durum wheat. Moisture stress during grain filling can negatively affect grain quality by reducing TW, and grain vitreousness (Rharrabti et al., 2003a).
Abad et al. (2004) reported variability in grain protein content according to growing season and location, and they also observed variability for other quality parameters such as gluten strength, vitreousness, and carotenoid content. Preharvest sprouting, connected with increased amylolytic activity, adversely affects FN, vitreous kernel content, and number of damaged kernels (Dick et al., 1974). A general conclusion can be drawn that rainfall and temperatures during grain formation and ripening are critical for durum wheat quality (Garrido-Lestache et al., 2005). The aim of the present study was 1) to evaluate yield, quality and DON contamination of 5 durum wheat varieties grown in the climatic conditions of the south-eastern part of the Czech Republic, 2) to study impact of year and variety on the individual qualitative properties, and 3) to analyse relationships between quality traits and yield.

**MATERIALS AND METHODS**

**Samples and agronomic conditions**

Field experiments were carried out at a location Kroměříž (Czech Republic) during the four growing seasons 2010/2011 to 2013/2014. Kroměříž (49°16′–17°N/17°21′–22°E) is located within a sugar beet agricultural production area at an altitude of 235 m. Average annual temperature during the period 1971–2010 was 9.2 °C, and the average total annual precipitation is 576 mm. The soil is classified as silt loam Luvic Chernozem. Five winter type varieties of *T. durum* were included: four Austrian varieties (Saatzucht Donau GesmbH. and CoKG) – Auradur (year of registration – 2004), Logidur (2006), Lunadur (2006), and one Slovak variety (ISTROPOL Solary a.s.) – IS Pentadur (2007).

The field trials were established as orthogonal randomized blocks with 6 replications. Varieties in individual blocks were arranged in rows, identically across years. The size of individual plots was 10 m². The experimental blocks were situated on the same field (large long-term crop rotation trial) in all years, but shifted to its different parts, and the crop succession was as follows: 1. spring barley, 2. lucerne (alfalfa), 3. lucerne (alfalfa), 4. durum wheat. The blocks were isolated from external environment by the bands (3 m) of soil sown by *T. durum*. Sowing dates are together with other important agronomical dates and crop protection measures (fungal disease) summarised in Table 1. Sowing rate was 4 million of germinating seeds per ha. Sowing rate and crop management practices were appropriate to the soil and climatic conditions in order to achieve good crop health and yield. Before sowing, 45 kg ha⁻¹ of P₂O₅ (superphosphate 43%) and 125 kg ha⁻¹ of K₂O (potassium salt 60%) were applied. Nitrogen was added in the form of potassium nitrate (27%) and so-called DAM (42.2% ammonium nitrate and 32.7% urea) to apply a total dose equal to 160 kg N ha⁻¹, split into regenerative, production, and qualitative applications. The trial plots were treated with growth regulators Retacel extra R 68 (chloromequat – chloride 720 g L⁻¹) at dose 1.5 L ha⁻¹ (BBCH 30) and Moddus (250 g L⁻¹ trinexapac-ethyl) at dose 0.3 L ha⁻¹ (BBCH 31–32). Individual plots were harvested by small plot combine (Sampo SR 2010, SAMPO ROSENLEW, Ltd., Pori, Finland).

Meteorological data (daily and monthly sum of rainfall, daily and monthly average temperatures, sunshine hours) were taken from an automated climate station of the Czech Hydrometeorological Institute located in the close vicinity (approx. 500 m) of the trial field (Fig. 1a,b). A more detailed course of weather for the period from the day of heading to harvest is documented in Table II.

**Analytical methods**

FN was determined according to EN ISO 3093:2009 (CEN, 2009a) using a LM 3120 mill (Perten Instruments, Stockholm, Sweden). CPC in dry matter was assessed by the Dumas combustion method according to ICC Standard No. 167 (ICC, 2009) using a FP-528 analyser (LECO Corporation, St. Joseph, MI, U.S.). Vitreousness was determined according to EN 15585:2008 (CEN, 2008) and is expressed as percentage of vitreous grains. TW was determined according to EN ISO 7971–3:2009 (CEN, 2009b). Concentration of the mycotoxin DON in grain was determined using an ELISA method (kit: Ridascreen, R-Biopharm AG, Darmstadt, Germany) with limit of quantification equal to 20 μg kg⁻¹.

**Statistical analysis**

The analytical data were reported as mean ± standard deviation of six replications. Because of compositional character of some data (Pawlowsky and Buccianti, 2011), protein, vitreousness, and DON were evaluated using the additive log-ratio transformation (alr). Normality of data was assessed using Shapiro-Wilk test. The data from each year and genotype were tested by a one-way ANOVA and those from the three years combined were analysed using the mixed-effect model, with a year included as a random effect. Statistical comparison of the means was made by post-ANOVA Tukey (HSD) test when significant main effects were detected. Correlations between the parameters were determined using the Pearson's correlation test. All calculations were performed using the STATISTICA Cz 12 software package (StatSoft, CR s.r.o). p < 0.05 was considered significant.

**RESULTS**

**Quality, yield, and influence of year and variety**

In 2011/2012, varieties IS Pentadur, Auradur and Lupidur did not regenerate in the spring. This year, the winter was exceptionally cold, with
Quality and Yield of Triticum Durum Under Temperate Continental Climate of the Czech Republic

I: Important agronomical dates of field experiments

<table>
<thead>
<tr>
<th>Vegetation season</th>
<th>sowing</th>
<th>Date of heading</th>
<th>Date of maturity</th>
<th>Date of harvest</th>
<th>Fungicide treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010/11</td>
<td>7 Oct</td>
<td>25 May</td>
<td>2 Aug</td>
<td>4 Aug</td>
<td>14 Mar(^1), 9 May(^2), 3 Jun(^3)</td>
</tr>
<tr>
<td>2012/13</td>
<td>11 Oct</td>
<td>30 May</td>
<td>28 Jul (4 Aug(^4))</td>
<td>1 Aug (8 Aug(^5))</td>
<td>16 May(^6), 7 Jun(^6)</td>
</tr>
<tr>
<td>2013/14</td>
<td>2 Oct</td>
<td>20 May</td>
<td>14 Jul (17 Jul(^7))</td>
<td>3 Aug</td>
<td>25 Apr(^8), 20 May(^8)</td>
</tr>
</tbody>
</table>

1) Lupidur \(^1\) Prosaro 250 EC 0.3 L ha\(^{-1}\) (prothioconazole 125 g L\(^{-1}\), tebuconazole 125 g L\(^{-1}\)) + Fandango 200 EC 0.5 L ha\(^{-1}\) (100 g L\(^{-1}\) prothioconazole, 100 g L\(^{-1}\) fluoxastrobin)

2) Hutton 0.8 L ha\(^{-1}\) (spiroxamine 250 g L\(^{-1}\), prothioconazole 100 g L\(^{-1}\), tebuconazole 100 g L\(^{-1}\)) \(^8\) Prosaro 250 EC 0.75 L ha\(^{-1}\)

II: Weather conditions in given periods (10, 15, 20, 25, 30 days before harvest and in the period from heading to harvest) in harvest years 2011, 2013 and 2014, Kroměříž, Czech Republic.

<table>
<thead>
<tr>
<th>Days before harvest</th>
<th>(R) (mm)</th>
<th>(R.d.)</th>
<th>(S) (h)</th>
<th>(\Sigma T) (mm)</th>
<th>R (mm)</th>
<th>R.d.</th>
<th>(S) (h)</th>
<th>(\Sigma T) (mm)</th>
<th>R (mm)</th>
<th>R.d.</th>
<th>(S) (h)</th>
<th>(\Sigma T) (mm)</th>
<th>R (mm)</th>
<th>R.d.</th>
<th>(S) (h)</th>
<th>(\Sigma T) (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2011</td>
<td>226</td>
<td>37</td>
<td>490</td>
<td>4931</td>
<td>142</td>
<td>20</td>
<td>544</td>
<td>4504</td>
<td>170</td>
<td>21</td>
<td>633</td>
<td>5156</td>
<td>160</td>
<td>32</td>
<td>612</td>
<td>5229</td>
</tr>
<tr>
<td>2012</td>
<td>107</td>
<td>18</td>
<td>190</td>
<td>563</td>
<td>3</td>
<td>6</td>
<td>323</td>
<td>641</td>
<td>30</td>
<td>4</td>
<td>332</td>
<td>673</td>
<td>76</td>
<td>17</td>
<td>237</td>
<td>645</td>
</tr>
<tr>
<td>2013(^\ast)</td>
<td>107</td>
<td>17</td>
<td>137</td>
<td>459</td>
<td>2</td>
<td>5</td>
<td>269</td>
<td>538</td>
<td>30</td>
<td>3</td>
<td>285</td>
<td>576</td>
<td>74</td>
<td>15</td>
<td>191</td>
<td>533</td>
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<tr>
<td>2014</td>
<td>96</td>
<td>15</td>
<td>89</td>
<td>349</td>
<td>2</td>
<td>4</td>
<td>210</td>
<td>438</td>
<td>30</td>
<td>3</td>
<td>233</td>
<td>475</td>
<td>67</td>
<td>11</td>
<td>164</td>
<td>443</td>
</tr>
<tr>
<td>2015</td>
<td>93</td>
<td>12</td>
<td>48</td>
<td>254</td>
<td>2</td>
<td>3</td>
<td>166</td>
<td>344</td>
<td>30</td>
<td>3</td>
<td>170</td>
<td>367</td>
<td>65</td>
<td>9</td>
<td>105</td>
<td>327</td>
</tr>
<tr>
<td>2016</td>
<td>32</td>
<td>9</td>
<td>31</td>
<td>173</td>
<td>2</td>
<td>3</td>
<td>110</td>
<td>236</td>
<td>29</td>
<td>2</td>
<td>113</td>
<td>247</td>
<td>19</td>
<td>6</td>
<td>63</td>
<td>214</td>
</tr>
</tbody>
</table>

L for variety Lupidur harvested 7 days later
R – sum of rainfall, R.d. – number of rainfall days, S – number of hours of sunshine, \(\Sigma T\) – sum of temperatures.

\(^1\) Monthly sum of rainfall (a) and average temperatures (b) during vegetation periods in experimental years and comparison with long-term average (1971-2010), meteorological station Kroměříž, Czech Republic.
the average temperature for the month February
−4.3 °C (long-term average: +0.4 °C). February daily
temperatures in the first decade around −10 °C and
minimum temperature reached −18.6 °C. There was
no snow cover. Only varieties Logidur and Lunadur
survived and were left for harvest, but their yield
was significantly reduced (Logidur 2.7 t ha−1 and
Lunadur 3.9 t ha−1) in comparison with other years
(Tab. VII). Therefore, results of the 2012 harvest
were not included in the statistical processing and
the trial was evaluated as the three-year.
The individual years differed significantly in all
qualitative traits and also in DON content (Tab. III).
For FN, no variety conformed to the demand at least
220 s in 2011 (the average 80 s), 4 varieties conformed
in 2013 (247 s), and 1 variety in 2014 (154 s). For
vitreousness, no variety was in conformance to
demand at least 83 % vitreous kernels in both 2011
(the average proportion of vitreous kernels 50.4%),
and 2014 (2.6%). In 2013, the average of vitreous
kernels was 76.1% (Tab. III), and four out of five
varieties complied. The only variety with lower
vitreousness was Lupidur, which was harvested
seven days later than the other varieties due to its
delay mature. Moreover, the prolonged period of
Lupilur maturation met with strong precipitation
(28 mm) occurred 4 days before harvest. Thus,
the proportion of vitreous kernels was only 23.8%.
Regarding TW, no variety conformed to
the demand at the level of 78 kg hl−1 in 2014 (the
average 75.4 kg hl−1), three of five conformed in
2011 (the average 77.9 kg hl−1), and in 2013, all
varieties conformed (the average 81.3 kg hl−1).
The requirement to have CPC at least 11.5% was
fulfilled for all years and varieties. The lowest
CPC was achieved in 2011 (the average 12.6%),
the highest in 2013 (14.2%). The effect of the year on
all qualitative traits was the most important, but also
the influence of variety and interaction between
 them were significant (Tab. IV).

The highest content of DON was performed in
2011 with mean amount 1,312 μg kg−1 that exceeded
the maximum limit for DON content in case of
Lupilur (2,095 μg kg−1). In other years, the average
DON content ranged from 222 μg kg−1 (2014) to
568 μg kg−1 (2013). The variation of DON content
was significant in years and varieties, without
significant interaction between these effects.
Grain yield reached in 2013 (7.6 t ha−1) was
significantly lower than both in 2014 (10.9 t ha−1)
and 2011 (10.7 t ha−1). The variation of grain yield
was significant in years, varieties and also significant
interaction between these effects were proved.

Relationships between qualitative traits and
yield
The strongest correlation between individual
qualitative traits was found between vitreousness
and TKW (r = −0.73) and vitreousness and TW
(r = 0.70) (Tab. V). Other statistically highly significant
(p < 0.001) correlations were found between FN and
TW (r = 0.62), TW and TKW (r = −0.62), and TKW and
FN (r = −0.39). DON had highly significant negative
correlation with FN (r = −0.42) and TKW (r = −0.34).
Yield was strongly correlated with all of analysed
qualitative traits. Negatively with CPC (r = −0.72),
FN (r = −0.56), vitreousness (r = −0.50), and TW
(r = −0.48), positive correlation was found with TKW
(r = 0.64).

Variety performance
For all varieties, the three-year average values of
FN were lower than the required value (220 s),
but there were significant differences between
varieties. Lunadur and Lupidur had significantly
lower three-year averages for FN than did the other
3 varieties (Tab. VI).

According to vitreousness, varieties split into
three groups. The highest average vitreousness
was found for Auradur, the lowest for IS Pentadur
and Lupidur. The results of variety Lupidur are
influenced by the fact, that in the year 2013 its
harvest was postponed because it was not fully
matured and it was harvested 7 days later than other
varieties. In the interim, 4 days before harvest,
precipitation of 28 mm fell during an afternon
storm and in addition to moistening spikes
caused severe lodging of Lupidur trial plots. As
a consequence, the vitreousness of variety Lupidur
was reduced by 65.4% compared to the collective
average of the other, earlier harvested varieties.
A decrease neither in FN nor in CPC was observed, but
there was substantial reduction in yield (Tab. VII).

Based on the CPC values, 4 statistically distinct
groups were formed. The highest three-year average
was found for variety Lunadur, on the subsequently
lower level were varieties Lupidur and Auradur,
followed by variety Logidur and the lowest CPC
was found for IS Pentadur. Logidur had the highest
average TW value, on the contrary the lowest TW was
found for Lupidur and Auradur. On the basis of TKW,
varieties were divided into 4 groups. The highest
three-year average was found for Lunadur, on
the subsequently lower level was IS Pentadur and
the lowest value was found for Auradur.

Contamination by DON was higher for Lupidur
(mean value 1,106 μg kg−1) and Auradur (832 μg kg−1)
than for IS Pentadur (381 μg kg−1), Lunadur (560 μg kg−1)
and Logidur (624 μg kg−1). Lupidur was
the only variety exceeding the maximum limit
for DON content, this was the case in 2011.
Concerning yield, IS Pentadur had the highest
yield together with Logidur and Lunadur and they
differed in a statistically significant manner from
Lupidur. Yield of variety Lupidur was influenced
by severe lodging due to its postponed harvest in 2013,
when the yield of Lupidur was at the level of 72% of
the average of other, earlier harvested varieties.
In 2011 and 2014, the yield of Lupidur was at the level
of 100% and 99.5% of the average of other varieties
respectively.
DISCUSSION

Vitreousness is an essential quality factor of durum wheat. Kernels with non-vitreous regions tend to reduce semolina yield (Wrigley and Batey, 2010) as more flour instead of semolina is produced during milling (Sissons, 2004). In our field trial, considerable variability in vitreousness between individual years was observed (2.6–76.1%) and although the harvest year had dominant influence on all of the analysed qualitative traits, the most affected among them was just vitreousness. A similarly substantial year dependence for durum
### VII: Qualitative parameters and yield as mean values and standard deviations for five varieties of T. durum grown in harvest years 2011, 2013 and 2014.

<table>
<thead>
<tr>
<th>Year</th>
<th>Variety</th>
<th>FN</th>
<th>Vitreousness (%)</th>
<th>Protein (%)</th>
<th>Test weight (kg hl⁻¹)</th>
<th>TKW (g)</th>
<th>DON (μg kg⁻¹)</th>
<th>Yield (t ha⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2011</td>
<td>IS Pentadur</td>
<td>116</td>
<td>a</td>
<td>21.4</td>
<td>0.4</td>
<td>78.4</td>
<td>ab</td>
<td>0.7</td>
</tr>
<tr>
<td></td>
<td>Logidur</td>
<td>97</td>
<td>a</td>
<td>27</td>
<td>0.4</td>
<td>79.3</td>
<td>a</td>
<td>1.3</td>
</tr>
<tr>
<td></td>
<td>Auradur</td>
<td>62</td>
<td>b</td>
<td>1</td>
<td>9.2</td>
<td>0.4</td>
<td>76.6</td>
<td>b</td>
</tr>
<tr>
<td></td>
<td>Lunadur</td>
<td>62</td>
<td>b</td>
<td>0</td>
<td>8.0</td>
<td>0.2</td>
<td>78.1</td>
<td>ab</td>
</tr>
<tr>
<td></td>
<td>Lupidur</td>
<td>62</td>
<td>b</td>
<td>0</td>
<td>11.1</td>
<td>0.4</td>
<td>77.4</td>
<td>ab</td>
</tr>
<tr>
<td>2013</td>
<td>IS Pentadur</td>
<td>238</td>
<td>b</td>
<td>19</td>
<td>2.0</td>
<td>0.2</td>
<td>82.0</td>
<td>b</td>
</tr>
<tr>
<td></td>
<td>Logidur</td>
<td>308</td>
<td>a</td>
<td>22</td>
<td>1.1</td>
<td>0.4</td>
<td>83.7</td>
<td>a</td>
</tr>
<tr>
<td></td>
<td>Auradur</td>
<td>188</td>
<td>c</td>
<td>26</td>
<td>0.3</td>
<td>78.8</td>
<td>e</td>
<td>0.9</td>
</tr>
<tr>
<td></td>
<td>Lunadur</td>
<td>258</td>
<td>b</td>
<td>19</td>
<td>3.7</td>
<td>0.2</td>
<td>82.8</td>
<td>ab</td>
</tr>
<tr>
<td></td>
<td>Lupidur</td>
<td>240</td>
<td>b</td>
<td>16</td>
<td>2.8</td>
<td>0.3</td>
<td>79.1</td>
<td>c</td>
</tr>
<tr>
<td>2014</td>
<td>IS Pentadur</td>
<td>170</td>
<td>b</td>
<td>14</td>
<td>0.7</td>
<td>0.3</td>
<td>75.5</td>
<td>b</td>
</tr>
<tr>
<td></td>
<td>Logidur</td>
<td>114</td>
<td>d</td>
<td>9</td>
<td>1.5</td>
<td>0.3</td>
<td>77.1</td>
<td>a</td>
</tr>
<tr>
<td></td>
<td>Auradur</td>
<td>252</td>
<td>a</td>
<td>9</td>
<td>1.3</td>
<td>0.3</td>
<td>77.4</td>
<td>a</td>
</tr>
<tr>
<td></td>
<td>Lunadur</td>
<td>94</td>
<td>d</td>
<td>13</td>
<td>0.6</td>
<td>0.3</td>
<td>72.3</td>
<td>c</td>
</tr>
<tr>
<td></td>
<td>Lupidur</td>
<td>142</td>
<td>c</td>
<td>18</td>
<td>1.5</td>
<td>0.3</td>
<td>74.7</td>
<td>b</td>
</tr>
</tbody>
</table>

FN – falling number, TKW – thousand-kernel weight, x – mean, std – standard deviation, * ln transformed values, ‡ minimum value possible by the method. Means with same letters are not significantly different (Tukey HSD, \( p \geq 0.05 \)).
wheat vitreousness in conditions of Central Europe was observed also by Vida et al. (2002), who analysed a large set of genotypes and reported comparably wide deviation in the vitreousness values (3–100%). Durum wheat crop at the end of the grain filling period can lose its vitreousness if exposed to damp conditions. This is a severe problem for durum production in regions, where rain regularly occurs around harvest. This damage, however, seems to vary across varieties, regions and years (Dexter et al., 1989; Sieber et al., 2015) and further research is necessary, particularly with regard to stability of vitreousness under the influence of humidity. Among our experimental years, the best vitreousness was achieved in 2013, when in the heading-to-harvest period the precipitation sum and number of rainy days were the lowest and the sunshine duration the highest. The total precipitation sum in 30 days before harvest was 3 mm only. In other two harvest years, the vitreousness was much lower, particularly in 2014, varying only from 0.7% to 4.2% for individual varieties. Surprisingly, in 2011, when the sum of precipitation was higher and there were more precipitation days both in the whole period from heading to harvest and in all sub-periods of 30, 25, 20, 15, 10 days before harvest than in 2014, the vitreousness was better (from 21.4% to 67.3% for individual varieties). The cause of this discrepancy might be, that in 2014 the crop was exposed to repeated precipitation during the full maturity stage as there was a long gap between reaching full maturity and harvest. As was reported by Sandhu et al. (2009), even a short exposure (1–3 days) to high humidity when the grain is ready for harvest can cause a reduction in vitreousness. In our trial in 2014, fully matured grain was left in the field for 20 days and among them, 11 rainy days with total precipitation of 67 mm occurred. In 2011, full maturity was reached on 2 August and the crop was harvested on 4 August, so most of the precipitation fell on the crop before reaching full maturity.

Vitreousness of a durum wheat variety depends on the potential to form vitreous kernels and also to maintain this vitreousness under the influence of environment humidity (Sieber et al., 2015). In our experiment, there were observed significant differences in vitreousness between varieties. Three statistically distinct groups were formed among 5 varieties included in our study, but the weather conditions in two of three harvest years were to such an extent adverse, that in individual harvest years either no variety was in conformance for vitreousness (2011 and 2014) or all complied (2013, with exception of later harvested Lupidor). Associations between quality parameters are of great interest in defining optimal values of grain quality for a particular region and to help breeders to produce varieties with a good quality. In our study, vitreousness was negatively related to TKW (r = −0.73) and such association were also reported by Rharrabti et al. (2003b) and Bilgin et al. (2010). Higher temperatures and lower water availability during the grain filling season can be beneficial for vitreousness of the grain, but could lead to lower TKW. Between vitreousness and TW we found strong positive relationship (r = 0.70), the same as Debboz et al. (1995) and Novaro et al. (1997). TW, similarly as vitreousness, is positively correlated with semolina yield (Fabiani and Lintas, 1988). Relationship between TW and TKW is controversially reported in the literature. While some authors stated that durum wheat samples with low TKW tend to have low TW (Dexter et al., 1987; Dick and Matsuo 1988); Rharrabti et al. (2003b) and El-Khayat et al. (2006) reported a strong negative correlation, which is in agreement with our findings (r = −0.62). The reason for this ambiguity could be, that relationships between quality traits might be influenced by climatic conditions during grain filling and could depend on temperatures and water input during this phase (Rharrabti et al., 2003). Both kernel vitreousness and protein content can significantly affect durum milling quality (Fu et al., 2018). Vitreous kernels are high in protein content (Dexter et al., 1989) and positive associations between protein content and vitreousness have been often reported (Rharrabti et al., 2003a; Sissons, 2004; Bilgin et al., 2010, Sieber et al., 2015; Fu et al., 2018). In agreement with previous studies, significant (p < 0.01) positive correlation was found also in our trial. According to Fu et al. (2018), vitreousness increases with higher protein content in the range of 9.5–12.5%, but this relationship is less evident in durum samples with high protein content (12.5–14.5%). This could explain our results, when correlation between vitreousness and CPC was weaker than e.g. between vitreousness and TW, as most of CPC values were higher than 12.5%.

Yield was in a negative, statistically significant relationship with most of the qualitative traits, mainly vitreousness (r = −0.72), FN (r = −0.56), CPC (r = −0.50), and TW (r = −0.48), while positive correlation was found between yield and TKW (r = 0.64). As reported by Borghi et al. (1997), vegetation seasons with weather conditions providing the opportunity for a good expression of quality parameters of durum wheat can cause a large fluctuation in yield.

The negative relationship between yield and CPC content is well known and for durum wheat was described in detail by Blanco et al. (2012). CPC was from the point of view of demand of Commission Regulation (EU) No. 1272/2009 (at least 11.5%) a non-problematic parameter and satisfactory CPC was achieved across all years and varieties. Although we found a negative relationship between yield and CPC, requirement on CPC content was fulfilled even in the high-yield year 2014 (in average 10.94 t ha⁻¹) with the mean CPC content at the level of 13.1% and also in 2011, when the yield reached 10.71 t ha⁻¹ and the mean CPC content was 12.6 %. The negative relationship between yield and vitreousness was for durum wheat reported also e.g. by Korkut et al. (2007) and Bilgin et al. (2010) and it is a consequence
of negative association between yield and CPC and positive association between CPC and vitreousness.

In the frame of all years, correlation between DON and FN proved to be negative and highly significant ($r = -0.42$). Precipitation during wheat flowering and onwards till the harvest can support head infection by Fusarium spp. and contamination of grain by mycotoxins (De Wolf et al., 2003; Wegulo, 2012). Wet kind of weather near the harvest could lead also to increased amylolytical activity and lower FN (Wrigley and Batey, 2010). In our study, DON content was the highest in harvest year 2011, when limit for maximum DON content in $T. \text{durum}$ grain at the level of $1,750 \mu g \text{kg}^{-1}$ was exceeded by variety Lupidur, having $2,095 \mu g \text{kg}^{-1}$. It was the only case across all varieties and experimental years not falling below the limit given by Commission Regulation (EU) No. 1881/2006 at the level of $1,750 \mu g \text{kg}^{-1}$. In 2011, the highest sum of precipitation was recorded in the period between heading to harvest and in addition to the highest DON contamination, the lowest FN was observed.

**CONCLUSIONS**

The most vulnerable quality trait in given environment seem to be vitreousness as rainfalls around harvest can cause its substantial irreversible loss. The risk, that satisfactory quality will not be achieved, could be reduced by carefully timed harvest, because the deteriorating effect of weather on quality was the worst in the stage of full grain maturity. Our results shown, that the conditions for durum wheat might be acceptable favourable also in countries not yet traditionally associated with growing this crop. It could be a new profitable opportunity for local farmers and not negligible would be contribution for increasing regional self-sufficiency.

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