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Combined effect of high temperature and drought on yield and malting quality of barley

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Abstract: Spring barley varieties Tolar and Marthe were grown under the standard conditions and stress conditions with a combined effect of high temperature and drought in three experiments conducted in the greenhouse of phytotron type. The results showed that growing under the stress conditions led to reduced yield, grain quality and malt quality. This effect was observed both in the individual years and on average for the entire study period. Average yield of grain declined by ca 53% and retention above 2.5 mm screen decreased by ca 28% (P = 0.001). Further, average content of proteins rose by 3.7% while starch content decreased by 5.1% (P = 0.01). In malt samples, average extract and friability were reduced by 5.8% and 15%, respectively, and average protein content increased by 3.8% (P = 0.01). The growing conditions were a dominant factor in the conducted experiments.

Keywords: grain quality; abiotic stress; malt quality

High temperature and drought are climatic factors (abiotic stresses) which adversely affect cereal yield and quality (Högy et al. 2013). They are main causes of losses of the world production of these crops. Similarly, in barley, the weather conditions are considered to be the main cause of reduced yield and malting quality. This fact is further enhanced by a prognosis of climate change, supposing an increasing frequency of periods with high temperature and drought. Drought or water deficits are considered main abiotic stresses limiting namely the yield and quality of malting barley. The negative effect of drought depends on its length and intensity (Paynter and Young 2004; Samarah et al. 2009). The phenological stages of barley development in which drought occurs play a role in the malting quality deterioration (Savin and Nicolas 1999; Qureshi and Neibling 2009).

The effect of a high temperature on barley yield and quality is classified to two thermal ranges: (i) moderately high temperature with a daily average of 25–30 °C and maximum to 35 °C occurring during several weeks and (ii) very high temperature (called also heat stress) with a daily maximum of 35–40 °C that occurs only for a few days. It has been proved that heat stress significantly reduces grain weight and starch content and increases the content of crude protein (Savin et al. 1997).

The phenological stage of barley growth during which the high temperature occurs also plays an important role. In the stage before flowering, a number of grains and their weight decrease, which leads to reduced yield (Ugarte et al. 2007). In the flowering stage, yield is reduced, starch content declines and protein content increases (Reinhardt et al. 2013). Grain filling is the most

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important phase in terms of malt quality (Wallwork et al. 1998; Passarella et al. 2005) when the high temperature markedly decreases grain weight and yield while crude protein is increasing. Further, a decrease in malt extract was recorded (Passarella et al. 2002).

The combined effect of several abiotic stresses, namely high temperatures and drought, is more harmful to plants than their separate effects (Mittler 2006). This has been proved, for example, in a combined effect of high temperature and drought on the yield of wheat (Prasad et al. 2011) or barley (Savin and Nicolas 1996). In barley grain, starch content was significantly reduced, and the percentage of nitrogen increased.

Studies conducted so far, however, have mostly aimed at monitoring of the individual impact of drought and high temperature on barley yield and quality. Only a few studies have investigated a combined effect of these stresses. For this reason, Jagadish et al. (2014) emphasized the importance of research into the combined influence of multiple abiotic stresses.

The aim of the present study was to monitor the combined effect of high temperature and drought on the yield and quality of barley grain and quality of produced malt.

MATERIAL AND METHODS

In 2009–2011, contrasting varieties Marthe and Tolar were chosen for the experiments. In the given period, both the varieties were undergoing the tests to be included in the List of Recommended Varieties (Horáková et al. 2010). The retention above 2.5 mm screen in Marthe in the maize testing area was very high, while the retention of Tolar was only low. In the Czech Republic, the maize testing area is an area with higher average annual temperature (around 9 °C) and lower annual precipitation (to 500 mm).

The retention above 2.5 mm screen reflects the ability of a variety to cope with these conditions. Varieties were grown in the greenhouse of phytotron type where the temperature was regulated and automatically recorded. The intensity of light was supplemented with sodium lamps. Soil moisture was maintained at the desired level by manual watering with deionized water and checked using the HH2 Moisture Meter (Mettler-Toledo GmbH, Germany). Cultivation was carried out in plastic pots with the capacity of 12 dm^3 filled with 11 dm^3 of homogenized soil (loamy brown soil on loess) and with a supply of nutrients.

The Tolar variety was grown in thirty containers and Marthe was also grown in 30 containers. Seventy grains were planted per pot. No seed dressing was applied. Plants were cultivated in two variants of growing conditions:

Variant A – standard (stress-free) conditions. Temperature regime: day 20 °C to 23 °C; night 10 °C to 15 °C. Soil moisture was ca 20%, which is the optimum humidity for the soil used. The temperature and soil moisture were maintained throughout the whole growing period.

Variant B – stress conditions with high temperature and drought in the stage of grain filling. From sowing to the heading phase, the growing conditions were the same as in the standard variant. From heading to harvest, the following temperature regime was maintained: day 27 °C to 32 °C; night 20 °C to 25 °C; the soil moisture content ca 10–15% (i.e. around 50% of the optimum moisture content).

All containers were first placed in a box with standard environmental conditions (Variant A). After the emergence and at the beginning of leaf sheath elongation, plants were watered with 50% Knop's solution.

At the beginning of heading, 20 containers of each variety were placed to a box with stress environmental conditions (Variant B) where they were kept till harvest. The ten remaining containers from each variety were kept till harvest in the box under the standard conditions. Harvest was performed by manual separation of mature grains from the ears, which were subsequently weighed.

Malting was conducted in a micro-malting plant (KVM Company, Czech Republic). Samples (200 g) of grains were not graded. The MEBAK method was used for malting (MEBAK 2011).

Analytical methods. Yield was determined by weighing the harvested barley grains and recalculated per 100 g of sown grain. Starch content (ČSN EN ISO 10520, 1999), bulk density (MEBAK 2011), crude protein content and the retention of grains above 2.5 mm screen (EBC Analysis Committee 2010) were assessed in grains.

In the malt sample extract, crude protein content, soluble nitrogen and friability were determined (EBC Analysis Committee 2010).

Statistical evaluation of results was performed by the analysis of variance (two-way ANOVA), models with fixed and random effects were assessed using the statistical programs Statgraphics 7 and Statistica 8.

RESULTS AND DISCUSSION

Moderately high temperature and drought in the period of grain filling, which suitably simulate the extremes at barley growing in the Czech Republic, were selected as stress conditions of barley growing.

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Table 1. Selected characters of barley grown under standard and stress conditions

Year	*n*	Variety	Yield ($g\ g^{-1}$ sown grain)		Protein content (%)		Starch content (%)		Bulk density ($g\ dm^{-3}$)		Grading > 2.5 mm (%)	
			A	B	A	B	A	B	A	B	A	B
2009	1	Marthe	860	445	12.1	14.3	64.9	59.5	66.1	61.5	88.9	69.4
	1	Tolar	580	252	12.1	14.5	64.9	59.6	68.5	52.5	87.9	58.3
2010	1	Marthe	681	346	15.2	19.7	59.5	52.5	66.8	60.1	68.6	36.5
	1	Tolar	567	211	15.4	23.5	59.2	50.4	68.4	52.5	71.7	38.4
2011	1	Marthe	950	481	15.9	19.1	58.7	57.1	64.5	58.4	64.8	39.4
	1	Tolar	565	255	13.6	16.1	62.2	59.3	65.5	57.8	83.0	47.0
Mean	3	Marthe	830	424	14.4	17.7	61.0	56.4	65.8	60.0	71.1	48.4
2009–2011	3	Tolar	571	239	13.7	18.0	62.1	56.5	67.5	54.3	80.9	47.9

A – standards conditions; B – high temperature and drought during grain filling

The tolerance of barley varieties to theses stresses, either natural or acquired by breeding, plays a positive role in drought and high temperature defence (Vaezi et al. 2010; Cattivelli et al. 2011). Therefore, the contrasting varieties Tolar and Marthe were included in the experiments. In the experimental localities of the driest area in the Czech Republic, the Marthe variety achieved 20–25% higher retention above 2.5 mm screen than Tolar (Psota et al. 2008).

The grain yield and quality and the quality of produced malt obtained in 2009–2011 are given in Tables 1 and 2. This data set indicates that growing under the stress conditions, compared to the standard conditions, affected negatively all studied characters of barley grain quality and produced malt both in the individual years and on average for the studied period.

First of all, the yield of barley (on average, in the Tolar variety by 58.1% and in Marthe by 48.9%) and retention above 2.5 mm screen (on average, in the varieties Tolar and Marthe by 33% and 22.7%, respectively) were reduced significantly in the stress-treated variants with respect to the standard ones. Crude protein content in barley grain increased on average by 4.3% and 3.3% in the varieties Tolar and Marthe, respectively. This was also connected with the reduced content of starch on average by 5.6% and 4.6% in Tolar and Marthe, respectively, compared to the standard variants.

The experimental data were statistically evaluated (Table 3). In case of yield and retention above 2.5 mm screen, compared to the standard growing conditions, the difference at the significance level of $P = 0.001$ was detected. The value of this difference in crude protein

Table 2. Selected characters of malt made from barley grown under standard and stress conditions

Year	*n*	Variety	Protein content (%)		Extract (%)		Friability (%)		Soluble nitrogen ($mg\ dm^{-3}$)	
			A	B	A	B	A	B	A	B
2009	1	Marthe	11.6	13.7	82.9	79.7	92	80	0.689	0.733
	1	Tolar	11.4	13.9	81.0	77.4	76	66	0.733	0.876
2010	1	Marthe	14.7	19.0	77.4	71.3	68	52	0.931	1.186
	1	Tolar	14.6	22.7	77.9	68.0	75	53	0.948	1.367
2011	1	Marthe	15.7	18.6	77.3	74.2	59	44	0.922	1.136
	1	Tolar	12.6	15.8	79.6	76.9	73	58	0.858	1.091
Mean	3	Marthe	14.0	17.1	79.2	75.1	73	59	0.847	1.018
2009–2011	3	Tolar	12.9	17.5	79.5	74.1	75	59	0.846	1.111

A – standards conditions; B – high temperature and drought during grain filling

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Table 3. Analysis of variance and estimated components of variance for grain-related characters

Source of variation	d.f.	Significance level	Estimated components of variance relative value (%)
Yield (g)			
Year	2	NS	2.49
Growing conditions (A, B)	1	***	69.06
Variety	1	***	24.65
Residual	7		3.80
Protein content (%)			
Year	2	*	37.05
Growing conditions (A, B)	1	**	41.85
Variety	1	NS	0.00
Residual	7		21.09
Starch content (%)			
Year	2	**	39.69
Growing conditions (A, B)	1	**	46.75
Variety	1	NS	0.00
Residual	7		13.56
Bulk density (g dm^{-3})			
Year	2	NS	0.00
Growing conditions (A, B)	1	**	80.23
Variety	1	NS	0.63
Residual	7		19.14
Grading > 2.5 mm (%)			
Year	2	**	21.79
Growing conditions (A, B)	1	***	71.68
Variety	1	NS	0.00
Residual	7		6.54

d.f. – degrees of freedom; *P = 0.05; **P = 0.01; ***P = 0.001; NS – not significant

content, starch content and bulk density was detected at the level of P = 0.01.

The Marthe variety exhibited better absolute values of the studied characters than the Tolar variety. Nevertheless, with the exception of the yield (P = 0.001), the differences between other characters were not confirmed statistically.

Further, it is apparent from Table 3 that the growing conditions played a key role in all changes in the studied characters. They affected significantly negatively grain yield (from 69%), bulk density (80%), retention above 2.5 mm screen (72%) and contents of crude protein and starch from 42 and 47%, respectively. The effect of varieties on yield was 25%.

The effect of the year was not statistically significant either in yield or in bulk density. Contents of crude protein and starch and retention above 2.5 mm screen were affected by the year from 37%, 40% and 22%, respectively.

Reduced grain quality of barley grown under the stress conditions was also reflected in the deteriorated quality of produced malts (Table 2). Crude protein content in malt samples prepared from the Tolar variety increased by 4.6% in the stressed variant, by 3.1% in Marthe. The increase in the crude protein content subsequently resulted in a lower extract content in the dry matter of malt: on average by 5.4% in the Tolar variety and by 4.1% in Marthe.

Content of soluble nitrogen in wort also increased: on average by 0.265 mg dm^{-3} in the Tolar variety and by 0.171 mg dm^{-3} in Marthe. The stress conditions also worsened friability in the Tolar variety on average by 16.0% and in the Marthe variety by 14.0%.

Deterioration in the quality of malt samples produced from barley grain grown under the stress conditions was also confirmed statistically (Table 4). Compared to the malts from the samples of barley grown under the standard conditions, a difference in extract, total nitrogen and soluble nitrogen was found at the significance level of P = 0.01. In friability, the difference at the significance level of P = 0.05 was found. The effect of varieties on the studied malt characters was not statistically significant.

It is known that smaller grain contains more nitrogen compounds and less starch. In the present study, the portion of grain above 2.5 mm differed each year. Increased or decreased contents of nitrogen compounds and starch were reflected in the resulting values of the studied malting characters. In most cases, a higher effect of growing conditions on the characters of unmalted grain was found (Tables 1 and 3) compared to the effect of growing conditions on malting characters (Tables 2 and 4). Very probably, this was due to the unequal portion of grain above 2.5 mm in the individual years, which is confirmed by soluble nitrogen of malt. Soluble nitrogen of malt was affected more by the year than by the growing conditions.

Content of nitrogen compounds was affected by the year from 36% and growing conditions from 43%. Extract content in malt was affected by the year from 39% and growing conditions from 43%. Content of soluble nitrogen was affected by the year more markedly (50%) than by the growing conditions (37%). The effect of the year and growing conditions on the level of friability was nearly identical (37% and 38%) (Table 4).

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Table 4. Analysis of variance and estimated components of variance for malt-related characters

Source of variation	d.f.	Significance level	Estimated components of variance relative value (%)
Total nitrogen of malt (%)			
Year	2	*	35.88
Growing conditions (A, B)	1	**	42.87
Variety	1	NS	0.00
Residual	7		21.24
Extract of malt (%)			
Year	2	**	39.18
Growing conditions (A, B)	1	**	42.58
Variety	1	NS	0.00
Residual	7		18.23
Friability (%)			
Year	2	**	36.46
Growing conditions (A, B)	1	**	38.00
Variety	1	NS	0.00
Residual	7		25.54
Soluble nitrogen of malt (mg dm^{-3})			
Year	2	*	50.08
Growing conditions (A, B)	1	*	37.19
Variety	1	NS	0.00
Residual	7		12.73

d.f. – degrees of freedom; $^{*}P = 0.05$; $^{**}P = 0.01$; $^{***}P = 0.001$; NS – not significant

The growing conditions were a dominant intervention in the experiment. Stress conditions largely eliminated the differences in malt quality between the varieties. Given the small scope of the experiment, the difference between the selected varieties was not statistically significant.

Recent studies have revealed that the response of plants to a combination of different abiotic stresses is unique and cannot be directly extrapolated from the response of plants to each of the different stresses applied individually (Ahmed et al. 2013; Rollins et al. 2013).

For this reason, it is difficult to compare our data with the data of studies describing the individual effect of high temperature or drought on the yield and quality of barley. In compliance with our findings, significant reductions in barley yield and quality as a result of the combined effect of high temperature (repeated heat stress) and drought were reported by Savin and Nicolas (1996). To our knowledge, no other studies on the combined effect of drought and high temperature under similar experimental conditions have been found.

However, the results of our experiments are indirectly confirmed by statistical studies of long-term monitoring of the effect of climatic conditions on the yield of spring barley performed in the northern and southern Moravian regions (Kolar et al. 2014; Brázdil et al. 2015). These studies reported the lowest yields in years with the highest average temperature and the lowest total precipitation.

CONCLUSION

Based on the acquired experimental data, it is possible to state that growing under the stressed conditions, compared to the standard conditions, affected negatively all the studied quality characters of barley grain and malt produced both in the individual years and on average for the studied period. It was demonstrated statistically that the growing conditions were a dominant factor in the experiment. The stress conditions, however, greatly eliminated the differences in grain and malt quality between the varieties, which due to a small scope of the experiments could not be statistically demonstrated.

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