Grain quality and yield of spring barley in field trials under variable growing conditions

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ABSTRACT

Effects of the year, previous crop and control of leaf diseases on grain yield, test weight, protein and starch content, Fusarium head blight (FHB) and deoxynivalenol (DON) content in grain were investigated in four spring barley varieties. The trials were set up in 2001–2004 at Kroměříž (235 m above sea level, average annual temperature 8.7°C, annual precipitation sum 599 mm) in a five-course crop rotation, where spring barley followed the previous crops sugar beet, winter wheat, maize, and oilseed rape. The experimental years differed a lot in temperature and precipitation. The years 2001 and 2002 were dry and warm and grain yield was much lower as compared to that in the following years even though the other growing conditions were identical. The most stable quality parameters were obtained after the previous crop sugar beet. The average value of test weight was 661 g/l (ranging from 629 to 685 g/l), protein content 11.2% (10.3–11.7%) and starch content 61.5% (58.9–64.9%). Grain yield averaged 6.67 t/ha. Test weight after maize was on average 658 g/l (619–692 g/l), protein content 11.5% (10.1–12.4%), starch content 60.7% (59.2–63.8%), and grain yield 6.24 t/ha. Test weight and starch content were lower and protein content higher after oilseed rape and winter wheat. A higher FHB incidence and DON content were found after the previous crop maize. In 2001 and 2002 with strong water deficit during the growing seasons, more grains infected by *Fusarium* spp. were detected and DON content was higher too. The increase was due to a short rainy period at heading of spring barley. Problems of variable conditions for growing malting varieties of spring barley and current possibilities of producing both good grain yields and quality are discussed.

Keywords: malting spring barley; yield; quality parameters; *Fusarium* spp.; deoxynivalenol

Successful growing of spring barley for malting purposes depends on many factors. The yield and its stability as well as grain quality are of great importance to growers. A critical role is ascribed to the previous crop and besides, time and method of its harvest, soil tillage and the method used to manage organic matter from the preceding harvest. These factors affect nutrient content in the soil environment, availability to the root system of spring barley, physical properties of the soil and health status of the crop stand. Here, an important role is played by the variety and its genetically determined resistance to diseases, a course of weather conditions during the year and relevant occurrence of diseases.

There are very good conditions for growing spring barley for malting in several regions in the Czech Republic. In the past, cultivation of barley in these regions was based on good crop rotations, where high quality of malting varieties was given by quality of the previous crop. The previous crops, which are mostly used now, were considered less favourable (oilseed rape) and barley was not grown after them at all. Farmers, being under economical pressure, grow barley even after summer intercrops. Furthermore, the barley management practice using the traditional previous crop sugar beet is not the same either, since beet tops are not harvested and producers have reduced a tillage system. Such a tillage system is very often used in the case of other commodities in rotation with barley including wheat, poppy, maize, and oilseed rape.

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Average grain yields of spring barley were low in the Czech Republic during the last years (2000 – 3.03 t/ha, 2001 – 3.75 t/ha, 2002 – 3.72 t/ha, 2003 – 3.92 t/ha, and 2004 – 5.00 t/ha). The low yields and their great variability are caused by not only changed growing conditions, but as well as by several years with less favourable weather effects.

A great number of authors solve the problems of yield stability in spring barley and usually conduct and evaluate the trials regardless of the current possibilities of farmers. This work evaluates results of trials that were carried out according to recommended crop management practices in the region which is favourable for growing spring barley.

The work presents results of four-year trials aimed at observing the effects of several factors (year, previous crop, variety, and control of leaf diseases) on grain yield and selected quality parameters (test weight, protein and starch content) under a uniform crop management practice and balanced soil nutrients (N, P, K), and soil pH in short crop rotations.

The objective was to determine what effects are induced by factors that can hardly be managed (seasonal weather conditions, current possibilities of crop rotations, option of the variety that is limited by users, and control of diseases that is limited by economic possibilities). Besides grain yield, a set of basic quality parameters was evaluated.

Considering grain quality of spring barley, the most important factors are nitrogen, saccharides, polyphenols, and enzymes. The protein content may vary from 8 to 16%. This parameter is strongly influenced by the year and crop management practice up to 80% (Prokeš 2005). Protein largely affects beer quality and therefore it is required to be between 10.5 to 11.7%. If the protein percentage is higher or lower, the malting process has to be adjusted. Higher protein content causes insufficient water absorption during malting. The whole malting process takes longer time and there is a danger of mould development. Moreover, the costs for malting increases. In contrast, there are problems with low enzyme activity in barleys with a lower protein content, which results in reduced quality of malt and beer.

In addition, *Fusarium* spp. incidences on spring barley grain and DON content were examined. The two parameters were assessed in the grain fraction above the 2.5-mm sieve (used for malting). The major pathogenic organisms producing mycotoxins, mainly DON, are *F. graminearum* and *F. culmorum* (Perkowski et al. 2003). Contamination of commodities by *Fusarium* spp. affects the competitiveness of barley production on both domestic and export markets (Váňová et al. 2004).

Table 1. Agrochemical soil analyses, content of available nutrients (mg/kg) in 0–30 cm layer and pH

Year	Previous crop	N mineral	P	K	pH
2001	sugar beet	14.3	107	234	6.2
	maize	14.7	101	245	6.0
	winter wheat	13.6	87	211	6.1
2002	sugar beet	14.1	122	250	6.1
	maize	11.8	96	232	6.1
	winter wheat	14.0	101	205	6.3
2003	sugar beet	12.5	115	247	6.4
	maize	14.3	117	250	6.2
	winter wheat	13.8	94	197	6.4
	oilseed rape	12.2	98	199	5.9
2004	sugar beet	13.7	110	216	6.5
	maize	14.5	89	224	6.4
	winter wheat	15.8	117	235	5.7
	oilseed rape	17.4	122	235	5.8

The soil samples taken from the topsoil horizon (0–30 cm) were analysed for P and K content using the method Mehlich III, N by analyser FP-528 (LECO), pH/KCl by electrometric method

Table 2. Sums of precipitation and average temperatures in each month

	Precipitation (mm)					Temperatures (°C)				
	2001	2002	2003	2004	N	2001	2002	2003	2004	N
January	44.6	7.1	18.9	19.4	27	–0.6	–0.7	–1.9	–3.2	–2.2
February	7.5	27.8	0.5	33.3	25	1.8	4.4	–2.8	1.0	–0.7
March	58.0	15.6	6.9	76.0	31	4.8	6.0	4.4	3.7	3.7
April	60.8	22.5	36.0	43.3	42	8.5	9.4	8.9	10.6	8.7
May	46.0	30.8	44.4	26.4	65	15.8	17.5	16.9	13.0	14.2
June	34.4	49.1	33.6	115.7	74	15.9	19.1	20.9	16.4	16.9
July	143.0	95.9	107.6	31.4	78	19.7	20.9	19.8	18.6	18.8
Sum	394.3	248.8	247.9	345.5	342					
Average	56.3	35.5	35.4	49.4	48.8	9.4	10.95	9.5	8.6	8.5

MATERIAL AND METHODS

Field trials were conducted at the Agricultural Research Institute Kroměříž, Ltd. (235 m above sea level, average annual temperature 8.7°C, annual precipitation sum 599 mm) in 2001–2004. The varieties Akcent, Jersey, Kompakt and Tolar were used in all the trials.

Sugar beet, maize, winter wheat and oilseed rape were the previous crops. The trials were arranged as a complete randomised block design with four replications for each treatment (variant). The harvesting area was 10 m^2. The plots were not artificially inoculated with spores of *Fusarium* spp.

Table 1 shows the results of agrochemical soil analyses before sowing, including the content of available nutrients in the depth of 0–30 cm. Table 2 gives data on precipitation and temperature from January to July in 2001–2004. Fungicides, active ingredients and their contents in particular products are in Table 3. Based on good supplies of phosphorus, nitrogen and calcium in the soil, mineral fertilisers were used at low levels.

In autumn, the fertiliser NPK (15:15:15) was applied at the rate of 100 kg/ha to soil after each previous crop. The seed rate was 4 million viable seeds per hectare. According to Kopecký (1985), it gives optimum assumption for good yield under Czech conditions. At the stage of three leaves (in spring), nitrogen at the rate of 30 kg/ha was applied. The level of nutrition was the same for all varieties and previous crops. Weeds and leaf diseases were controlled according to the methods valid for plant protection and depending on their presence in plots each year. No treatment was done against FHB.

The varieties of malting barley (Kompakt, Jersey, Tolar, and Akcent) with very good yield and quality parameters were selected for the trials. The yield and contents of protein and starch, test weight, number of grain infected by *Fusarium* spp. and content of DON mycotoxin in grain were tested by analysis of variance and successive Tukey's test using the software Statgraphics, version 4.

The method for assessment of *Fusarium* spp. and DON mycotoxin in grain. The grain samples were taken from four replications, screened on 2.5-mm sieve and ground. 200 g of samples were used to determine the presence of *Fusarium* spp. and to measure mycotoxin content.

The analytical method for determination of eight trichothecene mycotoxins. The multiresidual analytical method based on gas chromatography with electron catching detector (GC/ECD) was used for simultaneous determi-

Table 3. Fungicides, active ingredients and contents (g/l)

Fungicide	Active ingredients (g/l)
Amistar	azoxystrobin (250)
Atlas	quinoxyfen (500)
Archer Top	fenpropidin (275) + propiconazole (125)
Caramba	metconazole (60)
Cerelux	flusilazole (160) + fenpropimorph (375)
Charisma	famoxadone (100) + flusilazole (106.7)
Orius	tebuconazole (250)

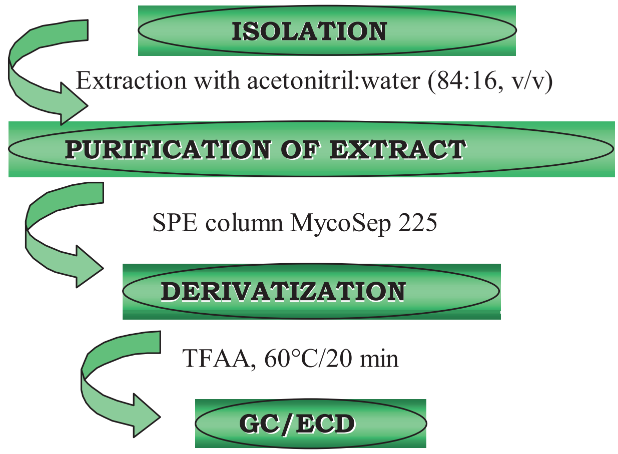

Figure 1. Scheme of analytical method

nation of 8 trichothecenes – nivalenol (NIV), T-2 tetraol, 4-deoxynivalenol (DON), fusarenon-X (FUS-X), 15-acetyldeoxynivalenol (15-ADON), 3-acetyldeoxynivalenol (3-ADON), HT-2 toxin, and T-2 toxin. The method consists (Figure 1) of the extraction with a mixture of acetonitril – water (84:16, v:v), shaking in a shaker for an hour, filtration through a folder paper, purification of the extract by SPE column MycoSep 225 and derivatization by trifluoroaceticanhydride (100 μl TFAA/20 min/60°C). The identification and quantification were provided by GC/ECD. The laboratory assay described by Tvarůžek et al. (2003) was used. The method for determination of test weight complied with ISO 7971-2. The method for determination of protein content in dry matter complied with ICC standard No. 167. The method for determination of starch content in dry matter complied with EN ISO 10520.

RESULTS AND DISCUSSION

Grain yield

Grain yield (Table 4) was significantly affected particularly by the year (seasonal weather conditions). Considerably lower yields were obtained in dry and warmer years 2001 and 2002 than in the years 2003 and 2004 with more favourable precipitation and temperature. Despite that the location where the trials were conducted belongs to the production regions with favourable conditions for growing spring barley, a strong relationship between grain yield and precipitation and temperatures is apparent in each year. It is due to a finer and shallower root system and a need for intensive uptake of nutrients from the soil during a short growing season (Conry 1998). Heat and drought stress of the two years (2001 and 2002) affected barley performance and grain yields were lower. Under hot temperatures and dry conditions, barley crops at other locations (not only in plots) did not perform well. Barley is very sensitive to heat and water deficit, especially during tillering (Svobodová and Míša 2004). There was a greater reduction in the number of tillers and ears per m^2.

Since nothing can be done to change the current weather patterns, producers must think about changing their cropping systems to adjust to the weather. We know it gets hotter earlier in the year now therefore we have to sow very early (as soon as possible). Early sowing is very important, but on the other hand the advisability of sowing early is less than ideal for seedbed conditions (Conry 1998). According to Bleasdale (1984), it is difficult to give an accurate description of the soil characters which constitute good sowing conditions.

The large variations in yields and quality parameters of malting barley have interactions to phenological and meteorological data. The analyses were focused mainly on the grain filling period (Schelling et al. 2003). Duration and occurrence of this development stage showed remarkable differences from year to year. Yields above 6 t/ha on average were achieved in our trials in 2003 and 2004 only, when the grain filling period was longer. The strongest influence on the duration of grain filling was found for temperature, which was too high in 2001 and 2002 (Table 2). According to Schelling et al. (2003), relative air humidity during grain filling

Table 4. Analysis of variance for yield (t/ha) and test weight (g/l); there is no significant difference between the variants marked with the same letter (Tukey $P_{0.05}$)

	Yield (t/ha)				Test weight (g/l)				
Year									
2002	5.48	A			649.0		B		
2001	5.74	A			617.0	A			
2004	7.03		B		660.3			C	
2003	8.05			C	677.2				D
Previous crop									
Maize	6.24	A			658.6		B		
Oilseed rape	6.50	A	B		642.8	A			
Sugar beet	6.67		B	C	660.8		B		
Cereal crop	6.88			C	641.2	A			
Cultivar									
Akcent	6.22	A			656.1		B		
Jersey	6.63		B		650.7		B		
Kompakt	6.64		B		641.2	A			
Tolar	6.80		B		654.5		B		
Treatment									
Archer Top 1.0 + Amistar 0.8	4.97	A			655.9		B	C	
Atlas 0.2 + Orius 1.0	5.81	A	B		624.4	A			
Amistar 1.0	5.97	A	B		615.1	A			
Control	6.47		B		651.0		B		
Archer Top 1.0	7.00			C	662.6			C	
Cerelux+ 0.6 + Amistar 0.6	7.12			C	670.5			C	
Cerelux+ 0.6 + Charisma 1.0	7.16			C	669.0			C	
Caramba 0.6 + Charisma 1.0	7.21			C	662.2		B	C	
Caramba 0.6 + Amistar 0.6	7.35			C	664.0		B	C	

can be a good parameter to describe drought stress effects rather than precipitation amounts.

Previous crop

Growers use several different rotation patterns depending on their individual situation. The effect of the rotation depends on the number of the following years in rotation and how the fallow is utilised. Rotation can have a beneficial effect on controlling weeds, diseases, and pests. The number of following years in rotation is very important. The effect of the previous crop is diminished in a short crop rotation.

In our trials with short crop rotations (four courses), the differences among previous crops were lower (6.24–6.88 t/ha), however statistically significant differences were found among all of them. The lowest grain yield was obtained after maize and the highest one after winter wheat. The difference in grain yield after sugar beet and winter wheat was not significant.

Variety

Great importance is generally attached to the variety considering both grain yield and quality (Ehrenbergerová et al. 1999). Conry (1998) states that the year and soil type exhibit twice to three times higher influence. In our trials with four varieties, significantly lower yield was assessed in Akcent only. It demonstrates high and balanced yield potential of currently grown malting varieties. However, the variety is not chosen with regard to its maximum suitability (adaptation) for a certain region, but according to requirements of the local processing industry.

Fungicide application increased grain yield in five variants examined. In three variants, the yield was lower than in the control. The significantly lower yield than in the control was in one variant only. The increase in yields due to fungicide application is reported by many authors (Yang et al. 2000). On the contrary, there are also results when fungicide application did not influence grain yield (McAndrew et al. 1994) and in some cases the grain yield was reduced.

The effect of only one fungicide application against leaf diseases on spring barley need not be necessarily positive even though spring barley has a short growing season. Among the examined varieties, only the variety Jersey has genetically based resistance to powdery mildew (*Blumeria graminis*). The other varieties are susceptible to this disease. Another important disease that occurred in the trials is net blotch (*Pyrenophora teres*). All of the presented varieties are susceptible to this disease. A final effect of treatments against leaf diseases depends on efficacy on a prevailing disease spectrum and the time

Table 5. Analysis of variance for protein and starch content in %; there is no significant difference between the variants marked with the same letter (Tukey $P_{0.05}$)

	Protein (%)						Starch (%)				
Year											
2003	11.56	A					63.65				D
2002	11.68	A					58.33	A			
2001	12.47		B				59.33		B		
2004	12.71		B				59.88			C	
Previous crop											
Sugar beet	11.17	A					61.44			C	
Maize	11.44	A					60.69		B		
Cereal crop	12.76		B				59.55	A			
Oilseed rape	13.05		B				59.51	A			
Cultivar											
Jersey	11.79	A					60.37		B		
Kompakt	11.93	A					61.06			C	
Tolar	12.29		B				59.77	A			
Akcent	12.41		B				59.99	A			
Treatment											
Archer Top 1.0 + Amistar 0.8	10.23	A					59.20	A	B	C	
Cerelux+ 0.6 + Amistar 0.6	11.31	A	B				61.68			C	
Cerelux+ 0.6 + Charisma 1.0	11.55		B	C			61.35		B	C	
Control	11.96			C	D		60.60	A	B	C	
Atlas 0.2 + Orius 1.0	12.08		B	C	D	E	59.63	A			
Amistar 1.0	12.47				D	E	59.58	A			
Archer Top 1.0	12.47				D	E	60.89	A	B	C	
Caramba 0.6 + Amistar 0.6	12.53				D	E	60.14	A	B		
Caramba 0.6 + Charisma 1.0	12.76					E	60.00	A	B		

for which chemical products are able to keep a good health status.

Examination of the data revealed that the yield of spring barley is given by a region in a certain country and can be very different by different weather conditions within the growing season. Advances in crop management practices, in breeding and disease control tend to reduce yield variability. On the other hand, their possibility to reduce larger varying of weather conditions in the case of spring barley is more limited.

Quality parameters (test weight, protein and starch content)

Test weight ranged from 611 to 692 g/l at the average of 650 g/l during the period 2001–2004. The significantly lowest test weight was assessed in the variety Kompakt. There were no significant differences among the other varieties (Table 5). The test weight after sugar beet and maize was significantly higher than that after oilseed rape and winter wheat. The year considerably affected this parameter and there were significant differences among all years under the study. The highest values were obtained in 2003 and 2004, when the superior yields were also recorded. The lowest test weight was in 2001. If fungicides were applied, test weight increased in six of eight variants.

Protein content ranged from 10.1 to 14.5% at the average of 12.1% during the period 2001–2004. The protein content after sugar beet and maize was lower than that after winter wheat and oilseed rape. This parameter was higher after winter wheat and oilseed rape above all in 2004, which was caused by their very low yields in 2003, when they were damaged by frost, were thin and higher reserves of mineral N remained in the soil. Such an event can be considered extreme. However, with regard to the fact that grain yield has been either positively or negatively influenced by various extreme weather conditions during recent years, it is also necessary to quantify a level of the effect for individual types of previous crops. In our trials, spring previous crops manifested more stable effects than winter ones. These variable effects have to be taken into account above all in oilseed rape, whose yields markedly varied in individual years. Similar cases can be expected in other previous crops, such as poppy, caraway or summer intercrops. The effect of the variety in this type of trials was evaluated with regard to stability of quality parameters. The varieties Jersey and Kompakt produced significantly lower protein content as compared to Tolar and Akcent over the whole period under study.

Starch content ranged from 57.6 to 64.9% at the average value of 60.3% in the examined period (2001–2004). The varieties Jersey and Kompakt had significantly higher starch content (in %) than Tolar and Akcent. The highest starch content was assessed after the previous crops sugar beet and maize. In comparison with these previous crops, the significantly lower starch content was obtained after oilseed rape and winter wheat.

The most stable quality parameters were obtained after the previous crop sugar beet. The average value of test weight was 661 g/l (ranging from 629 to 685 g/l), protein content 11.2% (10.3–11.7%) and starch content 61.5% (58.9–64.9%). Test weight after maize was on average 658 g/l (619–692 g/l), protein content 11.5% (10.1–12.4%), and starch content 60.7% (59.2–63.8%).

Occurrence of *Fusarium* spp. and DON content

At many laboratories throughout the world, it has been found that global significance of *Fusarium* spp. attests to not only winter wheat. Spring barley can be naturally infected too. Minimising the damage by FHB in spring barley is desirable mainly to export of barley and malt.

FHB has been found in many barley fields in the Czech Republic. Hýsek et al. (2003) defined as causal organisms *F. graminearum*, *F. culmorum*, *F. avenaceum*, and *F. poae*. *F. graminearum* and *F. culmorum* are the major pathogenic organisms producing mycotoxins mainly DON and its acetylated derivatives (Petrowski et al. 2003).

Along with food safety issues due to mycotoxins, the effect of *Fusarium* infections on malt and beer quality can be disastrous (Wolf-Hall and Schwarz 2002). *Fusarium* spp. produce components, which can cause gushing in beer. It can decrease profitability and viability of beer industries and integrity of exports.

The occurrence of *Fusarium* spp. in our trials in 2001–2004 is given in Table 6. The highest occurrence was in 2001, however the values of DON mycotoxin in this year did not statistically differ from the values found in 2002, when the amount of infected grains was lower. It confirms numerous findings that even grains without visible symptoms of infection may contain detectable levels of mycotoxins.

Table 6. Analysis of variance for mycotoxin DON v μg/kg and *Fusarium* spp. on the grain in %; there is no significant difference between the variants marked with the same letter (Tukey $P_{0.05}$)

	DON (μg/kg)				Fusaria (%)			
Year								
2004	85.98	A			8.55	A		
2003	311.37		B		9.73	A		
2002	411.75		B	C	40.87		B	
2001	451.65			C	10.51	A		
Previous crop								
Sugar beet	80.40	A			14.94	A	B	
Cereal crop	136.45	A			13.26	A		
Oilseed rape	292.76		B		16.94		B	
Maize	751.142			C	24.53			C
Cultivar								
Jersey	177.33	A			13.44	A		
Tolar	252.42	A	B		16.50		B	
Akcent	314.94		B		17.58		B	
Kompakt	516.06				22.14			C

In these two years, conditions for growth and development of the pathogen were unfavourable due to drought, therefore lower occurrence of *Fusarium* spp. could be assumed. However, the comparison of precipitation in July and subsequent incidence of the pathogen and DON content reveal that the precipitation at heading of spring barley in 2001, 2002 and 2003 increased infection and induced higher production of the mycotoxin as compared to the year 2004, when the weather was dry during anthesis.

The effect of previous crops on the occurrence of both *Fusarium* spp. and DON mycotoxin content was more pronounced than that of the year. The highest occurrence on grain and the highest DON content were found after the previous crop maize and on the contrary, the lowest DON values and the lowest *Fusarium* spp. occurrence on grains were detected after sugar beet. Obst et al. (1997) and Krauthausen et al. (2003) reported high content of DON and incidence on grains when the previous crop was maize (mainly for grain).

Reaction of barley varieties to FHB varies. In our trials, the most susceptible variety was Kompakt. This variety exhibited the most apparent symptoms of grain infection and the highest DON content. The wide, but stepwise range in visual reactions and other measured parameters suggests that genes acting additively confer resistance to *Fusarium* (Tekauz et al. 2000). Knowing the level of resistance or tolerance present in varieties helps when attempting to manage FHB in an integrated manner. The effect of fungicides on the occurrence of *Fusarium* spp. was not assessed since the fungicides were applied at GS 37 against leaf diseases.

In short crop rotations, when shallow incorporation of organic matter into soil was applied, the relationship between previous crops and the grain yield was significant, however the differences among them were low. Similarly, the differences among varieties were smaller and only one variety from the set had significantly lower yield. The year and control of leaf diseases exhibited very strong effects. Quality parameters, above all protein content, were considerably influenced by the previous crop, year, variety, and fungicide application. Higher DON content was found in rainy years in the variety Kompakt at GS 51-59 after maize.

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