Effect of weather conditions and genotype on the content of non-starch polysaccharides in spring barley breeding

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Introduction

Barley growing in the Czech Republic is historically connected with malt and beer production, it is also important feed. The ancient world used the barley grain as food and this tradition has still remained in some regions. Today we observe renaissance of barley in human nutrition; in advanced countries, barley is used for the production of so-called functional foodstuff for valuable components of the grain (so-called nutraceutics).

Non-starch polysaccharides - components of dietary fiber - ß-glucans (1-3)(1-4) and arabinoxylans belong to nutraceutics. Beta-glucans are cell wall constituents that are found especially in grains of oats and barleys. Beta-glucans from waxy hulless barley (*Hordeum vulgare* L.) are important sources of water soluble plant fiber needed in human diets to lower serum cholesterol (NEWMAN et al., 1989, POMEROY et al. 2001). Beta-glucans decrease and stabilize levels of serum glucose and insulin (JENKINS et. al., 2000). Positive effects of ß-glucans for curing diabetes and their anticarcinogenic effects are known (McINTOSH, 1998). Their content in barley grain is not desirable for brewing technology and quality of the final product - beer. The same holds true for feeding monogastric animals as they reduce conversion of feed or induce digestion maladies.

Non-starch polysaccharides of barley grain also account for problems in brewing industry - high wort viscosity, low filterability, haze formation, low extract content. Most problems are assigned mainly to water-soluble ß-glucans and also to arabinoxylans (DERVILLY et al., 2002).

For the above-mentioned reasons it is desirable to enhance by breeding content of the given phytonutrients in food and non-malting types of barley and on the contrary to reduce them in malting and feed types.

In our study we assessed malting and *waxy* (donors of ß-glucans) varieties and lines which we bred with the aim to achieve higher concentrations of ß-glucans and acceptable yield levels to food use.

Abstract

The aim of the study was to increase the content of ß-glucans in a grain of spring barley by breeding, to assess contents of ß-glucans, arabinoxylans and possible factors affecting their content.

Non-starch polysaccharides (ß-glucans and arabinoxylans) in a barley grain are a significant component of a dietary fiber affecting favorably human health. However, they are not desirable in brewing and feed industries.

Significantly higher ß-glucan content in a five-year period (2000-2004) was detected in the *waxy* varieties Washonubet, Wabet and Wanubet (6.77-7.57 %) and lines formed by crossing these varieties with the malting varieties (5.78 -7.03 %). Conversely, the hulled varieties of the malting type Kompakt (4.03 %) and Krona (4.30 %) had significantly lower content. The variety Krona also had significantly lower mean content of arabinoxylans (5.45 %) in 2002-2004 versus majority of varieties/lines but on the contrary, the variety Wabet had the highest content of arabinoxylans (7.78 %).

Results in the years 2000-2004 show that concentrations of ß-glucans and arabinoxylans in 2002-2004 were significantly affected by the varieties, course of the weather conditions in the growing periods and interactions of both these factors. Higher precipitation during the flowering time and grain filling period and lower temperatures during the flowering time in 2002 had negative effect on concentration of both substances. Conversely, drier and warmer weather in 2003 enhanced their content. Different influence of weather is documented by contrasting values of hydrothermic coefficients (it was 9.81 in 2003 and 19.00 in 2002). There was close, positive relationship between the content of ß-glucans and arabinoxylans (r = 0.99*).

The given results show that it is possible to increase by breeding the content of non-starch polysaccharides in a grain of spring barley for food use. Compared to the parental malting varieties, the mean content of ß-glucans in F4 - F7 generations were increased by 1.8 and 2.0 % by recombinations in lines (Ko x Wb and Wnb x Kr).

Key words: spring barley, hulled and hulles varieties, ß-glucan, arabinoxylan, weather conditions

Material and methods

In the experiments we used the varieties of the malting type Kompakt and Krona (at the time of establishment of experiments already registered in the CR), *waxy*: hulless varieties (Wanubet, Washonubet) and the hulled variety (Wabet), which we obtained from Prof. NEWMAN from University in Montana as donors of high ß-glucan content (*Table 1*). The third group was formed by the lines (F4 - F8) bred by crossing from both previous groups and by selection.

Table 1: **List of lines and their symbols**

Lines	Symbol
Kompakt x Krona	Ko x Kr
Krona x Kompakt	Kr x Ko
Kompakt x Wabet	Ko x Wb
Krona x Wanubet	Kr x Wnb
Wanubet x Krona	Wnb x Kr
Wabet x Washonubet	Wb x Wsnb

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Seed samples used for the analyses were supplied from hand sown and hand harvested plants grown in field trials in spacing 15 x 10 cm on the field of the experimental station of MUAF in Zabcice near Brno. This station lies in the maize production area, at the altitude of 184 m above the sea level. It is characterized as a warm, moderately dry locality with mild winter. The weather conditions in the years of experiments are included in *Figure 2* and further they were evaluated by the hydrothermic coefficient (BRÁZDIL and ROZNOVSKÝ, 1996). A soil type is classified as fluvi-eutric gleysol, this is a heavy to mid-heavy soil, soil type - clay-loam to clay. The previous crop was winter wheat. Classification of plants growth was taken Zadoks scale (DC 00 - 91).

Beta-glucans were assessed by the method FIA (HAVLOVÁ, 2001), in 2000 - 2004, arabinoxylans by Douglas's method (1981) in 2002-2004.

Data acquired from chemical analyses were evaluated by the analysis of variance and multiple testing of mean values (LSD-test, P = 0.05) in program Unistat for Excel.

Results and Discussion

Beta-glucan content in a grain of 11 varieties/lines of spring barley from field experiments in 2000-2004 was significantly affected by cultivars/lines, weather conditions in years and interactions of both factors (*Table 2*). DOEHLER et al. (2001) found significant effect of interactions of genotypes x environment on β-glucan content in oats grain. SAASTAMOINEN et al. (2004) also showed a significant effect of years, cultivars and their interactions on the ß-glucan content in oats in three types of experiments. Unlike these authors who found only small differences among the oats varieties (ca. 1 %) and presume extensive genetic regulations, we in our experiments found bigger, significant differences among the barley genotypes (by 3.5 %), which proved a strong genotype effect (*Figure 1*).

The *waxy* varieties Wanubet, Wabet and Washonubet (7.57, 6.90 and 6.77 % - *Figure 1*) - donors of β-glucan, lines Wabet x Washonubet (7.03 %), Wanubet x Krona (6.38 %) and Kompakt x Wabet

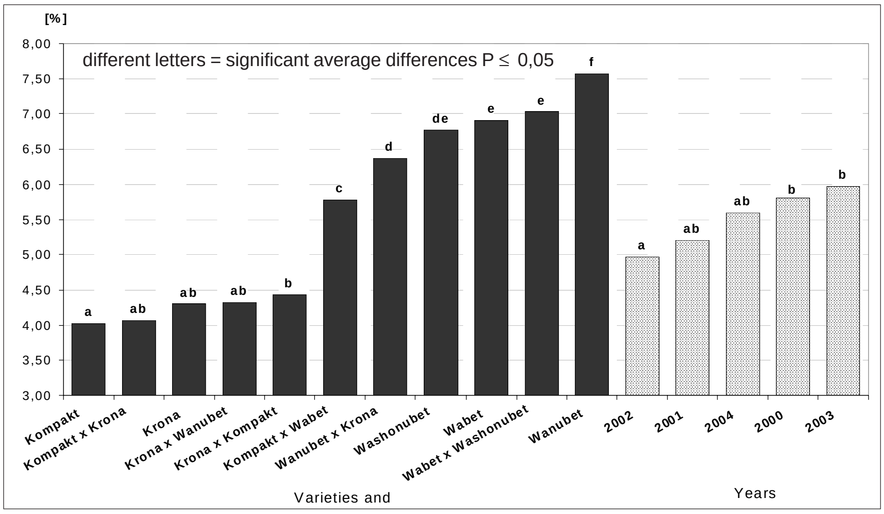

Figure 1: **Mean β-glucan content of varieties and lines in 2000 - 2004**

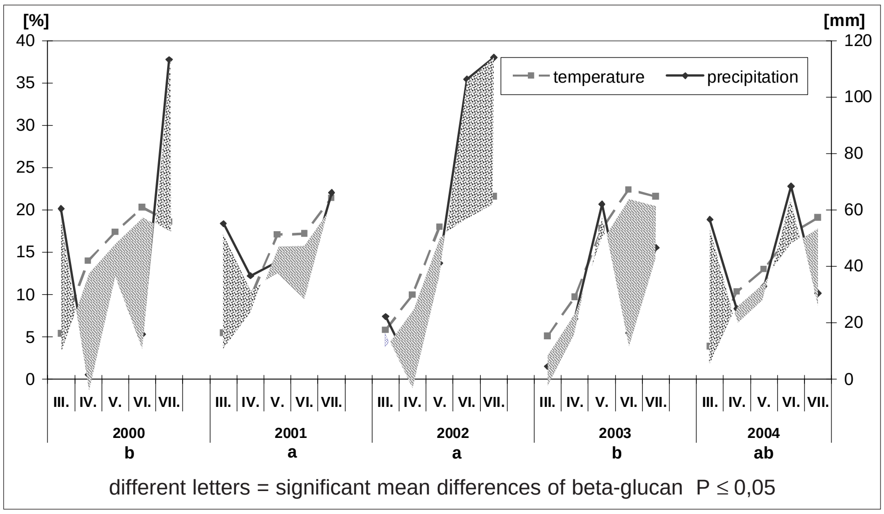

Figure 2: **The climate diagram according to Walter-Lieth**

Table 2: **Mean squares from analysis of variance for beta-glucans and arabinoxylans**

Source of variability	Beta-glucans d.f.	Beta-glucans MS	Arabinoxylans d.f.	Arabinoxylans MS
Varieties	10	43,426***	10	2,682***
Years	4	5,115***	2	7,459***
Interactions: Varieties x years	37	0,780***	17	3,064***
Error	193	0,294	54	0,179
Total	244	2,197	83	1,320

*** P ≤ 0,001

(5.78 %) had significantly higher ß-glucan content than the other varieties/lines, as previously also published by EHRENBERGEROVÁ et al. (1999).

The hulled varieties of the malting type Kompakt (4.03 %), Krona (4.30 %), lines from their reciprocal crossing and exceptionally also the lines Krona x Wanubet (4.32 %) with a paternal line - β-glucan donor exhibited a significantly lower β-glucan content. Thus we can assume that the parental cultivars used as donors of a high β-glucan content (NEWMAN, 1989) transferred this character to progenies formed by crossing with the malting type varieties.

The *waxy* hulless cultivar Wanubet (7.57 %) had statistically significantly higher β-glucan content than all genotypes. Strong interaction with years was not observed in Wanubet nor in the line Wnb x Kr (6.37 %), not even in 2002 when most varieties and lines exhibited a significant reduction. Significantly op-

Table 3: **Mean temperatures and sums of precipitation in the growth period (2000 - 2004)**

	Years									
	2000		2001		2002		2003		2004	
Month	t (°C)	p (mm)	t (°C)	p (mm)	t (°C)	p (mm)	t (°C)	p (mm)	t (°C)	p (mm)
III.	5,4	60,4	5,5	55,2	5,8	22,2	5,1	4,5	3,9	56,7
IV.	14,0	1,6	9,6	36,7	10,0	2,9	9,7	21,4	10,4	25,0
V.	17,4	39,7	17,1	41,6	18,0	41,2	17,8	62,0	13,0	33,0
VI.	20,3	16,0	17,2	33,1	20,0	106,3	22,4	16,5	17,2	68,4
VII.	18,6	113,3	21,4	66,1	21,6	114,0	21,6	46,7	19,1	30,5
III.-VII. Sums of p		231,0		232,7		286,6		151,1		213,6
III.-VII. Mean of t	15,1		14,2		15,1		15,3		12,7	
Hydrothermic coefficient	15,3		16,4		19,0		9,8		16,8	

t ….. temperature p…..precipitation

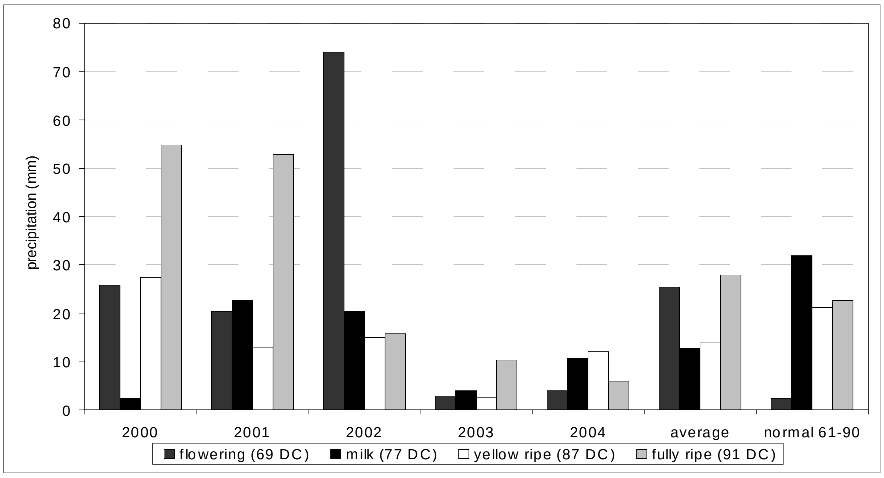

Figure 3: **Sums of precipitation for phenophases in 2000 - 2004**

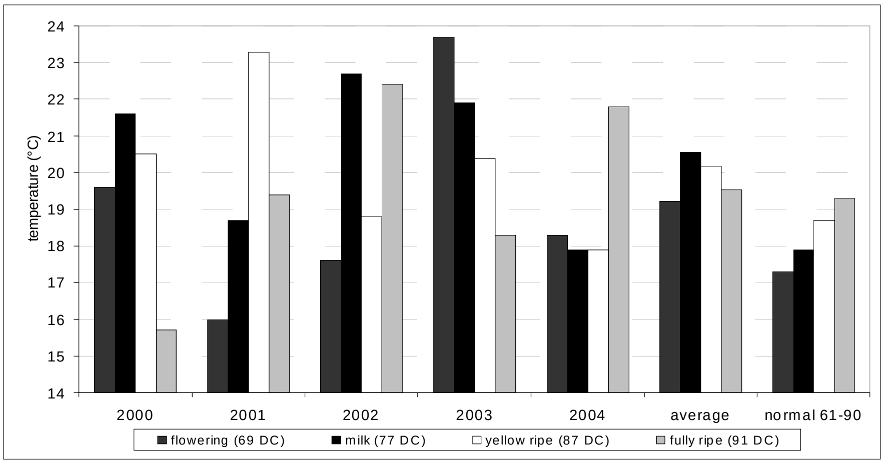

Figure 4: **Mean temperatures of phenophases in 2000 - 2004**

posite reaction was observed for example in the line Wabet x Washonubet with the second highest mean content (7.03 %).

Our *waxy* cultivars were earlier, which corresponds with the results of MOLINA-CANO et al. (1982), PELTONEN-SAINIO and PELTONEN (1993). It results from them that the early maturity reduces synthesis of proteins, lipids and ß-glucans less than that of starch. Our findings are in compliance with the results of DUBUC and COMEAU (1988) and HUMPHREYS et al. (1994), who found in the early oats variety Marion QC significantly higher ß-glucan content compared to the other three tested varieties even in a hotter year with late sowing than in a cold year with early sowing.

The highest mean β-glucan contents (5.97 and 5.80 % - *Figure 1*) were determined in 2003 and 2000 and they differed significantly from 2002 (4.90 %). The course of weather in 2003 resembled to 2000 and the highest ß-glucan contents corresponded to it. 2004 resembled most to 2000 and 2001 in terms of precipitation in spring (but 2001 was richer in this precipitation). The growing period of 2003 was the hottest and driest (*Figure 2*) of all the followed years (mean temperature was 15.3°C) and by DC 87 (yellow ripeness) the rainfall was only 103 mm (*Figure 3*). SAASTAMOINEN et al. (2004) in Finland also found, in organic trials with eight oats varieties, that the average β-glucan content in cold and rainy year 1998 was significantly lower in comparison with dry and hot year 1997. In the growing period of 2003 there was nearly half precipitation compared to 2002 (186 mm - *Figure 3*, *Table 3*). Of all five years, the year 2002 was the richest in the precipitation, the highest amount was in June and at the beginning of July (110 mm), i.e. in the period of grain filling and grain maturation. Conversely, in 2003 and 2000 there was dry and hot weather (*Figure 2* and *4*) in June with low precipitation (16 mm), mean temperatures were 22.4 and 20.3°C (*Figure 4, Table 3*). Rates of temperatures and precipitations in the evaluated phenophases of spring barley in 2000 - 2004 were much variable from the bio-climatological aspect. With respect to the fact that plant growth and development is affected by temperatures together with precipitations, we used the rate between totals of precipitations and mean temperatures of the air during the vegetation period for evaluation. This is an analogy of hydrothermic coefficient (BRÁZDIL and ROZNOVSKÝ, 1996).

The lowest value of a hydrothermic coefficient was in 2003 (9.81 - *Table 3*) and on the contrary the highest (double) value of all the studied years was determined in 2002 (19.00) documents the difference of the weather. JACKSON et al. (1994) also found that environmental factors influenced ß-glucan content in a grain of *waxy* hulless barley more than nitrogen fertilization and they assume that the ß-glucan yield in these varieties in the dry Montana region is higher than in oats varieties.

In 2001 and 2004 precipitation in June were lower (33 and 68 mm - *Figure 2* and *3*) than in 2002. High precipitation in June appeared to be in negative correlation with synthesis and following ß-glucan concentration in a barley grain (correlative coefficient for ß-glucan content and precipitation in June = -0.69). ZHANG et al. (2001) also confirmed, besides negative significant effect of precipitation during the grain development, significant effect of temperatures (25 - 30°C) on ß-glucan content in a grain of malting barley varieties. In our experiments higher precipitation (in year 2002) and lower temperatures mainly in the time of flowering and grain development also affected unfavourably the ß-glucan content. The highest temperatures in June 2002 did not compensate the negative effect of high precipitation on ß-glucan content either.

Years 2001 and 2004 did not differ in terms of mean ß-glucan content from 2002 with significantly the lowest mean value, nor from 2003 with the highest mean content (*Figure 1*). Their growing periods (to DC 87) had nearly the same precipitation (180 and 186 mm - *Table 4*), mean temperatures were 14.2 and 12.7°C. They also had cold June (17.2°C), precipitation (33 and 68 mm - *Table 3*) were higher than in 2000 and 2003 (16 mm). But the biggest amount of precipitation fell on June 3, 2004 (21 mm - *Figure 3*) and due to later beginning of the phase of grain filling, they probably did not negatively affect the ß-glucan content. This phase, however, was the longest of all five years and this may account for the third highest ß-glucan concentration in year order.

The relationships between grain yield per plant and yield and ß-glucan contents varied from 0 in the *waxy* variety Washonubet to r = 0.80 in the varieties Kompakt, Wanubet, and line Ko x Wb,

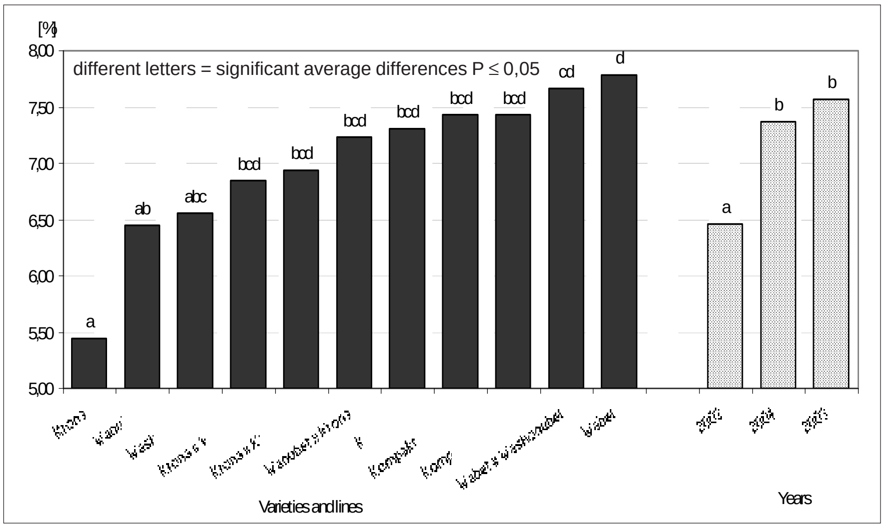

Figure 5: **Mean arabinoxylan content of varieties and lines in 2002 - 2004**

Table 4: **Sums of precipitation for phenophases**

Years	2000	2001	2002	2003	2004
Precipitation (mm) to DC 87 -yellow ripe	135,00	180,00	186,00	103,00	206,00
Precipitation (mm) do DC 91 -fully ripe	189,80	232,80	201,75	113,40	212,00

JACKSON et al. (1994) did not prove the relationship of ß-glucans to the protein content in a grain in the barley waxy types but to test weight.

The close positive relationship for three years 2002 - 2004 (when arabinoxylans were determined) was calculated between content of ß-glucans and arabinoxylans (r = 0.98*). Consistently with the ß-glucan content, the highest mean content of arabinoxylans was also assessed in the driest year 2003 (7.56 % - *Figure 5*) and it did not differ, unlike the glucans, from the content in 2004 (7.36 %). Statistically significantly lower content of arabinoxylans was determined in 2002 (6.46 %) versus both mentioned years. Only in comparison with the varieties Krona, Wanubet, and Washonubet, the waxy variety Wabet (7.78 % - *Figure 5*) had statistically significantly higher mean content of arabinoxylans. The malting variety Krona (5.45 %) had significantly lower content of arabinoxylans compared to all other varieties/lines except the above-mentioned varieties Wanubet and Washonubet. Besides the effects of genotypes and course of weather in individual years, interactions of the varieties with years also played a significant role in arabinoxylans content. Concentration range of arabinoxylans determined by us (5.45 - 7.78 %) was in compliance with the results of DERVILLY at al. (2002).

Conclusions

Results in the years 2000-2004 show that concentrations of ß-glucans and arabinoxylans in 2002-2004 were significantly affected by the varieties, the weather conditions in the growing periods and interactions of both these factors. Higher precipitation during the flowering time and grain filling period and lower temperatures during the flowering time in 2002 had negative effect on concentration of both substances. Conversely, drier and warmer weather in 2003 enhanced their content.

The given results show that it is possible to increase by breeding the content of non-starch polysaccharides in a grain of spring barley for food use. Compared to the parental malting varieties, the mean content of ß-glucans in F4 - F7 generations were increased by 1.8 and 2.0 % by recombinations in lines (Ko x Wb and Wnb x Kr).

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