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Evaluation of photosynthetic pigments content and agronomically valuable traits in Lithuanian spring barley varieties

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Plant yield and its quality depend on many processes occurring during the growing season and on growing conditions. Spike productivity is determined by many parameters, such as chlorophyll content in leaves, carotenoid content, etc., as they are indicators of physiological activity in leaves. During 1999–2002, the content of photosynthetic pigments at two plant growth stages and agronomically valuable characters were evaluated in 13 Lithuanian spring barley varieties in LIA. In the examined varieties, larger amounts of pigments were accumulated in 'Dotnuvos ketureiliai' and the new variety 'Aura' at both growth stages. The variability of chlorophyll *a* and chlorophyll *b* content and carotenoid content was low and medium. The strongest correlation between pigment content and grain per spike and grain weight per spike was established at tillering stage. The coefficients of correlation were respectively 0.485–0.775 and 0.463–0.746.

Key words: spring barley, varieties, chlorophyll, agronomic performance, main yield components

INTRODUCTION

Barley (*Hordeum vulgare* L.) is superior to other cereals by the diversity of biological types, capability to grow in different conditions, duration of growing season [12]. Spring barley is one of the most common crops in Lithuania, covering 66.3% of the total spring cereal sowing area. The cultivation of spring barley has long-standing traditions in Lithuania. Barley breeding was started at the Dotnuva Plant Breeding station in 1924 [4]. Altogether fifteen spring barley varieties have been bred since the start of barley breeding at the Dotnuva Plant Breeding Station and later at the Lithuanian Institute of Agriculture. Plant yield and its quality depend on many processes occurring during the growing season and on growing conditions [8]. The productivity of cereals is often associated with the parameters of plant assimilation apparatus [10]. The content of pigments is an important factor, which determines the intensity of photosynthesis. The amount of pigments varies in relation to plant development stage and growing conditions [2, 8, 11]. Biosynthesis of pigments in spring barley leaves is most intensive at plant heading stage [17]. The assimilates, which are accumulated in two upper leaves, are most important for the formation of structural elements of cereal spikes [9]. Analysis of assimilates transport in the spike structural elements suggests that at spring barley heading, part of leaf assimilates are used for stem building. The leaf assimilates at the stem elongation phase are used only for the building of spike structural elements [14]. Other yield components have an effect on barley spike productivity too [15]. There is a certain relationship between barley yield and main yield components [9]. Spike productivity is associated with many parameters such us leaf mass and to some extent chlorophyll content in leaves, as they are indicators of physiological leaf activity [9]. A direct relationship between photosynthetic pigments and yield is not always observed, but often a close correlation between individual yield components and photosynthetic pigments is determined [5, 17]. Some authors have reported that weather conditions, pesticides and varietial peculiarities affect chlorophyll content [1].

The objective of this study was to evaluate the main agronomically valuable traits and photosynthetic pigments content in the leaves of Lithuanian spring barley varieties in field trials and to identify the relationships between them.

MATERIALS AND METHODS

Thirteen Lithuanian spring barley varieties were evaluated agronomically and biochemically in 1999–2002 (Table 1). The Lithuanian spring barley variety 'Ûla' was used as a control variety. Spring barley varieties were planted in 2 m^2 plots without replications in the collection nursery. The soil of the experimental site was Endocalcari-Epihypogleyic Cambisoil (CMg-p-w-can) (soddy- gleyic) light loam. The preceding crop was seed clover of the 1st year. $N_{60}P_{60}K_{60}$ fertilization was applied. The period 1999–2002 was rather good for the assessment of spring barley varieties due to diverse weather conditions (1999 – dry, 2000 – wet, 2001 – normal, 2002 – dry). It helped to achieve a versatile evaluation of the varieties. In the trails we evaluated the period of maturity (days), plant height (cm), lodging resistance (1–9, 9 all plants stand), grain yield (t ha^{-1}), main yield components (spike length, grain per spike, grain weight per spike), 1000 kernel weight (g), hectoliter weight (g l^{-1}).

The measurements of chlorophyll were performed on 30 randomly selected plants from each spring barley variety twice during the growing season at GS 29–30 (tillering) and GS 40–49 (booting). The growth stages of spring barley were defined by a decimal code developed by Zadoks et al. [7]. The next to last fully developed leaf was taken for chlorophyll extraction in acetone (strength of acetone 100%) and evaluation by the spectrophotometric method. Chlorophyll *a* (663 nm), chlorophyll *b* (645 nm), chlorophyll *a* + *b* and content of carotenoids (440.5 nm) were determined [13].

The level of statistical significance of data was calculated by the method of dispersion analysis using the ANOVA software, the correlation of traits was calculated using the GENKOR software, and the variability of traits was characterized by the coefficient of variation (<10% – low, 10.1–20.0% – medium, >20% – high) using the STATENG software [6].

RESULTS AND DISCUSSION

Table 2 shows the yield data of spring barley varieties and the main yield components, which are related with photosynthetic pigment contents. Plant height is very closely related with lodging resistance, which affects plant yield and grain quality [16]. Plant height ranged from 47 to 110 cm in different years. The variety 'Aidas' was characterised by the shortest straw throughout the years of evaluation. Lodging resistance ranged from 2 to 9 points depending on years. In the dry year of 1999 no lodging was observed. The best lodging resistance was shown by the varieties 'Aidas', 'Alsa', 'Aura' and 'Ûla'. The maturity time ranged between 71 and

Table 1. **Lithuanian spring barley varieties used in the trials**

Variety	Pedigree	Released	Registered
'Auksiniai'	Individual selection from Gull	1927	
'Dotnuvos ketureiliai'	Individual selection from landrace	1930	
'Džiugiai'	Individual selection from landrace	1947	1950–1975
'Auksiniai II'	Abed Kenia × Ackerman Isaria	1947	1950–1990
'Gausiai'	Auksiniai II × (Viner + Abed Archer + Bigo)	1961	
'Gintariniai'	KM 1081252 × Pallas	1973	1979–1986
'Dainiai'	(Gausiai x Gaaselle) × Abed 3371	1981	
'Auksiniai 3'	Carina × Tarra 26	1983	1987
'Vilnieèiai'	Mutant from Pallas	1986	
'Aidas'	(KM 1192 × Ofir) × Effendi	1990	1994
'Ûla-st.'	Roland × Ca 33787	1992	1995
'Alsa'	(Mirena × mutant from Gintariniai) × (Abava × Emir)	1993	1996
'Aura'	(Mirena × mutant from Gintariniai) × Lina	1997	1999

Table 2. **Yield and its main components of Lithuanian spring barley varieties, 1999–2002**

Variety	Yield		Plant height cm	Lodging resistance (1–9)	Maturity (days)	Spike length cm	Grain per spike	Grain weight per spike	TKW g	HLW g l^{-1}
	t ha^{-1}	%								
'Ûla-st'	4.11	100	70.0	7.8	83	7.4	20.9	1.05	51.0	678
'Auksiniai'	4.04	98.5	77.2	5.2	82	7.2	20.6	0.85	42.1	673
'Dotnuvos ketureiliai'	3.08	74.9	85.0	4.8	81	6.9	42.8	1.76	41.8	641
'Dþiugiai'	3.46	84.2	87.8	4.8	83	8.9	22.3	0.96	43.7	678
'Auksiniai II'	4.17	101.5	77.2	5.0	84	7.9	21.7	0.91	43.4	671
'Gausiai'	3.59	87.4	73.8	5.5	81	7.7	19.7	0.83	42.9	657
'Gintariniai'	4.38	106.6	68.5	7.2	82	7.4	20.7	0.85	42.6	656
'Dainiai'	4.56	110.9	76.8	7.2	83	8.1	22.6	1.01	45.8	673
'Auksiniai 3'	3.82	93.0	74.8	7.5	83	7.7	21.2	0.90	44.0	701
'Vilnieèiai'	4.18	101.7	74.8	7.5	83	7.6	22.1	1.00	46.4	685
'Aidas'	4.20	102.2	66.8	8.2	84	8.2	20.9	0.98	48.2	680
'Alsa'	4.23	103.0	70.0	8.0	84	6.9	23.8	1.05	45.8	654
'Aura'	4.58	111.5	69.2	7.8	84	6.4	21.3	1.00	47.7	665
LSD_{05}	0.707	17.56	7.46	1.56	1.8	0.72	4.75	0.232	2.19	22.4

100 days depending on years. The longest maturity time was in the wet year of 2000 (94–100 days); the shortest maturity time was in the dry year of 1999 (71–76 days).

The grain yield of the spring barley varieties varied between years. The year 1999 was dry and extremely unfavourable for spring barley. The tested spring barley varieties produced a rather poor yield (1.39–2.65 t ha^{-1}). The year 2000 was better for the spring barley varieties. They produced yields of 2.32–5.50 t ha^{-1}. In the year 2001 the grain yield of spring barley varieties was 4.05–5.61 t ha^{-1}. 2002 was dry and unfavourable for spring crops, but spring barley varieties produced yields of 4.01–5.16 t ha^{-1}. The grain yield of Lithuanian spring barley varieties 'Gintariniai', 'Dainiai', 'Aidas', 'Alsa' and 'Aura', was higher than that of the control variety. These varieties distinguished themselves by spike length and grain number per spike or 1000 kernel weight. Evaluation of individual yield components showed that yield differences were caused by the variation of spike productivity (spike length, grain per spike, grain weight per spike), 1000 kernel weight and plant number per plot [3]. Weather conditions of the experimental years influenced plant growth and development and were associated with the processes of the formation and reduction of yield components. Spike length ranged between 5.4 and 9.2 cm in different years. The variety 'Dþiugiai' significantly surpassed the control variety. Grain per spike is very important for the creation of varieties with a high productivity. It ranged between 16.2 and 26.7 (28.5–52.4 in the six row variety 'Dotnuvos ketureiliai'). The highest grain number was identified in the variety 'Alsa'. Grain weight per spike ranged between 0.69 and 1.31 g and 1000 kernel weight varied from 35.5 to 55.2 g depending on years. Analyses of 1000 kernel weight showed that all the spring barley varieties had smaller grains than the control variety 'Ûla'. Hectolitre weight ranged from 584 to 728 g l^{-1} in different years, however, only the variety 'Auksiniai 3' surpassed the control variety 'Ûla'. The key grain yield components of the spring barley varieties were the number of grains per spike and 1000 kernel weight.

Photosynthetic pigments content in the barley varieties were lower at GS 29–30 (tillering) than at GS 40–49 (booting) (Table 3). Larger amounts of pigments were accumulated in 'Dotnuvos ketureiliai' and the new variety 'Aura' at both growth stages. The varieties 'Auksiniai II' accumulated large amounts of chlorophyll *b* at tillering, 'Vilnieèiai' – chlorophyll *a* and $a + b$ amount at booting stage, and 'Gausiai' – high photosynthetic pigment amounts at tillering stage. Some varieties showed a stability of particular indicators: 'Dainiai' of chlorophyll *b* content at tillering and 'Gausiai' of chlorophyll $a+b$ content at booting stage.

At GS 40–49 (booting), compared with tillering, the content of photosynthetic pigments on average increased: chlorophyll *a* by 29.4, chlorophyll *b* 22.0, chlorophyll $a + b$ 41.3, and carotenoids 35.4 mg/100 g crude matter (Table 4). Chlorophyll *a*, *b*, $a+b$ contents, especially at tillering stage, were close to the average value of individual years. However, there was a variation of these indices among varieties. The variability of chlorophyll *a* content was low: the coefficient of variation at tillering stage (GS 29–30) was 7.5–10.0% and at booting stage (GS 40–49) 4.6–5.6%.

Table 3. **Content of photosynthetic pigments (mg/100 g) of spring barley varieties at different growth stages, 1999–2002**

Variety	I*				II*			
	*a***	*b*	*a+b*	carotenoids	*a*	*b*	*a+b*	carotenoids
'Ûla-st'	80.7	24.6	105.3	78.7	112.8	49.2	162.0	105.9
'Auksiniai'	78.8	26.9	105.7	72.3	112.3	45.9	158.2	110.9
'Dotnuvos ketureiliai'	99.1	32.6	131.7	103.3	120.0	49.9	169.9	120.5
'Dþiugiai'	84.1	23.3	107.4	83.7	108.8	41.6	150.4	99.0
'Auksiniai II'	83.3	29.6	112.9	85.2	109.2	43.4	152.8	102.3
'Gausiai'	87.8	27.8	115.6	94.1	115.0	43.7	155.2	116.1
'Gintariniai'	83.1	22.6	106.7	87.9	115.2	47.5	162.7	118.1
'Dainiai'	80.7	24.3	105.0	85.0	109.0	42.7	151.7	111.9
'Auksiniai 3'	83.8	24.2	108.0	88.5	115.3	46.8	162.1	114.0
'Vilnieèiai'	85.1	24.9	110.0	88.3	119.6	47.7	167.3	117.0
'Aidas'	79.3	21.0	100.3	81.8	114.6	47.4	162.0	112.9
'Alsa'	84.3	22.4	106.7	89.6	113.9	48.2	162.1	116.4
'Aura'	89.8	27.1	116.9	92.9	120.8	50.2	171.0	120.2
LSD_{05}	7.35	5.26	10.39	8.11	7.05	5.89	10.43	10.74

* I – GS 29–30, II – GS 40–49.
** – Chlorophyll.

Table 4. **Content variation of photosynthetic pigments (mg/100 g) of spring barley varieties at different growth stages, 1999–2002**

Year	Mean result, ×		Standard error of the mean, *Sx*		Means of data				Coefficient of , variation V %	
					min		max			
	I*	II*	I	II	I	II	I	II	I	II
					Chlorophyll *a*					
1999	80.9	133.5	1.68	1.99	72.3	124.7	94.6	144.2	7.5	5.4
2000	89.7	111.4	1.88	1.41	78.5	104.6	102.4	120.2	7.6	4.6
2001	80.9	101.3	2.24	1.58	72.5	92.8	102.1	109.2	10.0	5.6
2002	87.1	110.0	1.82	1.52	79.8	99.2	103.6	122.1	7.5	5.0
X	84.6	114.0			75.8	105.4	100.7	123.9		
					Chlorophyll *b*					
1999	25.8	42.1	1.16	1.63	20.5	31.2	32.7	49.4	16.2	14.0
2000	27.2	39.6	1.07	1.00	20.2	34.0	33.7	46.7	14.3	9.1
2001	27.6	60.4	1.56	1.29	20.9	54.0	41.4	70.1	20.4	7.7
2002	21.2	43.9	1.15	1.05	14.8	37.3	27.6	50.3	19.6	8.6
X	25.4	47.4			19.12	39.1	33.9	54.1		
					Chlorophyll *a* + *b*					
1999	106.7	175.6	2.42	3.36	97.2	158.0	127.0	191.8	8.2	6.9
2000	116.9	151.0	2.47	2.19	103.4	142.0	136.2	166.9	7.6	5.2
2001	108.4	161.7	3.60	2.45	97.2	144.1	143.4	175.5	12.0	5.5
2002	97.7	106.7	2.48	1.92	84.6	95.7	114.8	119.1	9.2	6.5
X	107.4	148.7			95.6	134.9	130.3	163.3		
					Carotenoids					
1999	86.5	157.4	2.82	4.14	77.7	125.7	104.5	176.5	11.8	9.5
2000	94.0	113.5	2.30	1.86	82.2	105.4	107.3	127.7	8.8	5.9
2001	69.1	72.4	2.48	1.67	55.0	62.5	91.0	84.3	13.0	8.4
2002	108.3	155.5	2.56	2.00	96.4	136.5	126.4	163.6	8.5	4.7
X	89.3	124.7			77.8	107.5	107.3	138.0		

* I – GS 29–30, II – GS 40–49.

Table 5. **Correlation coefficients between photosynthetic pigments content (mg/100 g) and some spike yield components, 1999–2002**

Photosynthetic pigments	GS[1)]	Grain number per spike				Grain weight per spike			
		1999	2000	2001	2002	1999	2000	2001	2002
Chlorophyll *a*	I	0.436	0.485	0.646*	0.805*	0.459	0.408	0.670**	0.811**
	II	0.229	0.138	0.192	0.163	0.128	0.163	0.271	0.116
Chlorophyll *b*	I	0.385	0.467	0.683**	0.177	0.333	0.482	0.630*	0.203
	II	0.067	0.462	0.570*	–0.206	0.005	0.395	0.688**	0.185
Chlorophyll *a* + *b*	I	0.485	0.594*	0.775**	0.599*	0.463	0.547*	0.746**	0.531*
	II	0.103	0.513	0.424	0.458	0.178	0.534*	0.538*	0.443
Carotenoids	I	0.604*	0.240	0.752**	0.653*	0.560*	0.153	0.731**	0.670**
	II	0.174	0.154	0.132	0.036	0.126	0.122	–0.129	0.024

[1)] I – GS 29–30, II – GS 40–49;
* Coefficients of correlation significant at 95% probability;
** Coefficients of correlation significant at 99% probability.

The variability of chlorophyll *b* content was medium (14.3–20.4%) at tillering stage (GS 29–30) and declined (7.7–14.0%) at booting stage (GS 37–49). The variability of carotenoid content was low: the coefficient of variation at tillering stage (GS 29–30) was 8.5–13.0% and at booting stage (GS 40–49) 4.7–9.5%. Like chlorophyll content, this index had a higher variability at tillering stage. Small amounts of carotenoids were observed in 2001, when June was cool and rainy. Carotenoid content slightly increased at booting. The correlation coefficients between some yield components and chlorophyll content were calculated. The strongest correlation among pigment content and grain number and weight per spike was established at tillering stage (Table 5). The coefficients of correlation were respectively 0.485–0.775 and 0.463–0.746. The relationship between these indices is poorer at booting stage, except for the correlation coefficient between chlorophyll *b* content and grain weight per spike in 2001. The findings of our evaluation corroborate the data of other authors maintaining that not all leaf assimilates are used for the building of spike structural elements at heading stage [14]. In the dry year of 1999 the correlation was poorer than in 2000–2002. In 1999 the grain yield of spring barley varieties was lower too. The strongest correlation was determined between chlorophyll *a* + *b* and spike productivity elements. The relationship between chlorophyll content and other components of productivity such as 1000 kernel weight and hectolitre weight is inconsistent and irregular irrespective of plant growth stage.

CONCLUSIONS

1. Among the examined varieties, larger amounts of photosynthetic pigments were accumulated in 'Dotnuvos ketureiliai' and the new variety 'Aura' at both growth stages.

2. The variability of chlorophyll *a* content and carotenoid content was low and variability of chlorophyll *b* content was medium. The other indexes had a higher variability at the tillering stage.

3. The strongest correlation was established between photosynthetic pigment content and grain per spike, as well as between the former and grain weight per spike at the tillering stage. The coefficients of correlation were respectively 0.485–0.775 and 0.463–0.746.

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LIETUVIÐKØ VASARINIØ MIEÞIØ VEISLIØ ÛKIÐKAI VERTINGØ SAVYBIØ IR FOTOSINTETINIØ PIGMENTØ KIEKIO TYRIMAS

S a n t r a u k a

Augalo derliaus dydis ir kokybë priklauso nuo daugelio procesø, vykstanèiø augalø vegetacijos metu, ir augimo sàlygø. Didelis varpos produktyvumas asocijuojasi su chlorofilø kiekiu lapuose, nes jie yra lapø fiziologinio aktyvumo rodikliai. 1999–2002 m. Lietuvos þemdirbystës institute tirta 13 lietuviðkø vasariniø mieþiø veisliø ir ávertintos jose pagrindinës ûkiðkai vertingos savybës bei fotosintetiniø pigmentø kiekis krûmijimosi ir vamzdelëjimo tarpsniuose. Tarp tirtø veisliø abiejuose iðsivystymo tarpsniuose daugiau pigmentø sukaupë veislës ‘Dotnuvos ketureiliai’ ir ‘Aura’. Tirtose vasariniø mieþiø veislëse didesni pigmentø kiekiai nustatyti augalø vamzdelëjimo metu, nors ðiø rodikliø kiekio variacija tarp veisliø didesnë krûmijimosi tarpsniu. Glaudþiausia ir pastoviausia koreliacija nustatyta augalø krûmijimosi metu tarp chlorofilø *a* + *b* kiekio ir grûdø skaièiaus varpoje bei vienos varpos grûdø masës. Koreliacijos koeficientas buvo atitinkamai 0,485–0,775 ir 0,463–0,746.

Raktaþodþiai: vasariniai mieþiai, veislës, chlorofilas, pagrindiniai derliaus komponentai

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ИЗУЧЕНИЕ ХОЗЯЙСТВЕННО ЦЕННЫХ СВОЙСТВ И КОЛИЧЕСТВА ФОТОСИНТЕТИЧЕСКИХ ПИГМЕНТОВ В ЛИТОВСКИХ СОРТАХ ЯРОВОГО ЯЧМЕНЯ

Р е з ю м е

Величина и качество урожая растения зависят от множества процессов, происходящих во время роста и развития растений, а также от условий роста. Высокая продуктивность колоса ассоциируется с количеством хлорофилла в листьях, так как последний тесно связан с физиологической активностью листа. В 1999–2002 гг. в Литовском институте земледелия изучалось 13 литовских сортов ярового ячменя, также дана оценка главных хозяйственно ценных свойств и количества фотосинтетических пигментов в фазах кущения и выхода в трубку. Наибольшее количество пигментов в обеих фазах развития растений накопили сорта ‘Dotnuvos ketureiliai’ и ‘Aura’. В изучаемых сортах больше пигментов было накоплено в фазе выхода в трубку, хотя вариация этих показателей между сортами выше в фазе кущения. Тесная корреляционная связь установлена между хлорофиллом *a* + *b* в фазе кущения растений и количеством зерна в колосе, а также массой зерна в колосе. Коэффициент корреляции составил соответственно 0,485–0,775 и 0,463–0,746.

Ключевые слова: летний ячмень, сорта, хлорофилл, основные компоненты урожая