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Genetic resources of spring barley: screening for yield stability and grain malt quality traits

A. Leistrumaitë,

V. Paplauskienë

Lithuanian Institute of Agriculture, LT-58344 Akademija, Këdainiai distr., Lithuania
E-mail: alge@lzi.lt

The development of malting and brewing industry increased interest in selection of high quality malting barley initial material for breeding programmes. During 2002–2004, grain stability and malt quality characteristics of accessions from a spring barley genetic resources collection were investigated at the Lithuanian Institute of Agriculture. The effects of the experimental year, genotype of variety or breeding line, and variety and year interactions on spring barley grain yield, grain >2.5 mm yield and extract yield were measured. Using the STABLE computer programme, selection of lines promising in terms of grain yield, grain >2.5 mm yield and extract yield, able to realize their genetic potential in various growing conditions was made. The highest sum of integral assessment of grain yield, grain >2.5 mm yield and extract yield was identified for the breeding lines 7955-5 (49+); 7939-1(46+); 7661-1; 7422-3 (36+); 7101-1 (34+); 7967-2 (20+). These breeding lines are characterized by a high grain yield, extract content, starch content, grain grading and low protein content. All these lines have been transferred to the Lithuanian Gene Bank for a long-term conservation. Part of them have been involved in the malting barley breeding programme. The breeding lines 7101-1 and 7967-2, which showed a high grain stability and were distinguished by grain quality and other agronomic traits were transferred to the Lithuanian Official Trials for testing.

Key words: spring barley, genetic resources, yield stability, malting quality traits

INTRODUCTION

Barley is a major crop in the world, used for food, feed and malt. About 10% of worldwide obtainable barley harvest is used for malt production in brewing industry [1]. However, only 10–12 million ha are suitable for malting barley growing. In Lithuania, barley has been cultivated since olden times. The country's climate is sufficiently humid (annual precipitation rate 450–650 mm) with warm summers, which enable barley to perform well. The development of malting and brewing industry increased interest in high quality malting barley. However, spring barley grain yield and quality are subject to various factors varying on a large scale. The genotypic peculiarities of a variety and growing climatic conditions are the key factors influencing grain yield and its quality [2–4]. The first step to success in the growing systems of malting barley is the choice of appropriate variety. The varietal effect accounts for 25–40% of malting performance compared with growing conditions [5].

Quality requirements to malting barley are far more complex than those to feed barley. More than 30 parameters are applied for characterization of the malting quality of barley grain [6]. Grain grading is a very important quality characteristic. This index is strongly related with grain plumpness. The percentage of plump grain on a 2.5 × 20 mm sieve for malt barley must be no less than 90%. Grain grading is a varietal feature, but it depends on environmental conditions too [7]. This trait is markedly affected by varying moisture supply during grain filling stage [4]. Plump grains accumulate more starch than protein [6]. In order to secure a good and uniform malting process, a big and uniform kernel size is required [8].

Another important trait of malting barley is grain protein content, which is relevant in the brewing process and affects beer quality [9]. Trials of spring barley grain yielding and quality traits conducted at LIA during 1994–1998 showed that the highest protein content was accumulated when the weather in July was warm and dry (10.6–16.9%) and lower when July was cool and rainy (9.6–13.6%) [10]. A strong correlation was found between grain protein content and extract content, according to which regression equations were made, allowing a tentative evaluation of malt extractivity [11, 12]. Plant breeders have selected barley for large kernels, thin husk and low protein content in order to improve extract yield [13]. Grain yield and quality traits of spring barley varieties and breeding lines varied greatly due to growing conditions. Stability of grain yield performance is an important characteristic in the selection of new crop varieties [10, 14]. Different mathematical models were developed for analysis of varietal grain yield stability. They enable us to estimate the genotype–environment interactions and to select the most valuable varieties or breeding lines [15].

The objectives of the present study were to identify grain yield, grain >2.5 mm yield and extract yield stability parameters of spring barley accessions from a genetic resources collection, to select the most promising lines to malting barley breeding programmes and to assess their grain quality traits.

MATERIALS AND METHODS

The agronomic assessment of yield and quality stability was conducted during 2002–2004. The varieties 'Ûla', 'Luokë', 'Auksiniai 3' and 12 promising breeding lines from the spring barley genetic resources collection recently developed at the Lithuanian Institute of Agriculture were selected for the present study. The spring barley varieties and breeding lines were grown on 20 m^2 plots with a standard level of fertilization by 60 kg ha^{-1} of N, P, K, respectively. The experiments were carried out in a randomized block design with four replications. The soil of the experimental site was Endocalcari-Epihypogleyic Cambisoil (CMg-p-w-can) light loam. The preceding crop was seed clover of the 1st year.

The period 2002–2004 was rather favourable for spring barley versatile evaluation because of the variable weather conditions (2002 – dry, 2003 – cool and dry, 2004 – wet). In the trials we evaluated grain yield (t ha^{-1}), 1000 kernel weight (TKW) (g), hectolitre weight (HLW) (g l^{-1}). In grains we determined malt extract content (%), protein content (%), starch content (%), and grain grading (%). Protein content was measured by the Kjeldahl method, starch content by hydrochloric acid dissolution. Malt extract content was determined on the basis on EBC (Analytica-EBC, 1987).

The level of statistical significance of data was calculated by the method of analysis of variance using the ANOVA software [16], and for assessing the stability of traits the STABLE computer programme [17] adapted by Dr. P. Tarakanovas at the LIA was used.

RESULTS AND DISCUSSION

The analysis of variance showed that for spring barley, grain yield, grain >2.5 mm yield and extract yield were most significantly affected by the year of experiment, the genotype of variety or breeding line and variety–year interactions (Table 1). Particularly important was variety–year interaction. The significant differences obtained ($P < 0.01$) provide a solid basis for continuing the analysis. The climatic conditions in each of the three seasons had significant effects on barley productivity and quality. The impact of drought was relevant during the years 2002–2003, as it was manifested in the reduction of grain yield by about 9–15%. Analysis of weather impact showed that the dry weather of the year 2002 had the most negative impact on spring barley grain yield and malting grain quality, while the cool and wet year 2004 was optimum for those traits. The highest spring barley grain yield was accumulated that year. Almost all studies indicate that the trait most strongly correlated with grain yield is the number of fertile culms per unit of area, followed by average kernel weight and seed number per spike [18]. In 2004, there was enough moisture after sowing, and spring barley produced many productive tillers, in contrast to 2002–2003 when after sowing the weather was dry and warm. In 2002 and 2003, the interval from heading to yellow ripeness stage was short, contrary to 2004. In many studies of barley, low grain yields have been related to the short duration of this period [19].

Compatibility of high yield and stability of grain yield performance is an important characteristic for the selection of the best crop varieties and breeding lines. The STABLE programme was used for this purpose [20]. An integral evaluation of varieties and breeding lines based on rank evaluation sum by grain yield and stability is adapted in this programme. This

Table 1. **Mean-square of the analysis of variance of spring barley grain, grain >2.5 mm and extract yields. Dotnuva, 2002–2004**

Dispersion	DF	Mean square of the yield (MS)		
		grain t ha^{-1}	grain >2.5 mm t ha^{-1}	extract t ha^{-1}
Varieties (V)	14	6.081**	6.338**	7.213**
Year (Y)	2	46.179**	4.656*	51.202**
Interaction (V x Y)	42	1.942**	1.573*	1.965**
Heterogeneity	14	0.199	0.210	0.130
Standard error	126	0.128	0.157	0.076

*P < 0.05; **P < 0.01.

Table 2. **Assessment of spring barley varieties and breeding lines according to grain yield and stability. Dotnuva, 2002–2004**

Variety, breeding line	Grain yield				Stability		Integral
	$t\ ha^{-1}$	ranks	revised rank evaluation	sum of ranks	σ^2	assessment (ranks)	assessment (ranks)
Ûla	4.37	2	–2	0	0.569*	–4	–4
Auksiniai 3	3.78	1	–3	–2	0.268	0	–2
Luokë	4.52	3	–1	2	0.468*	–4	–2
7222-3	4.74	4	1	3	0.002	0	3
7322-6	4.81	5	1	6	0.109	0	6
7101-1	4.93	11	1	12	0.029	0	12+
7422-3	4.94	13	1	14	0.047	0	14+
7661-1	4.90	9	1	10	0.004	0	10+
7695-4	4.84	7	1	8	0.052	0	8+
7773-2	4.92	10	6	11	0.490*	–4	7+
7904-2	4.86	8	1	9	0.759**	–8	1
7939-1	5.26	15	2	17	0.113	0	17+
7955-5	5.21	14	2	16	0.074	0	16+
7963-7	4.82	6	1	7	0.161	0	7+
7967-2	4.94	12	1	11	0.591*	-4	9+

X = 4.788 YS = 6.8

LSD_{05} = 0.289; *$P < 0.05$; **$P < 0.01$.

Table 3. **Grain quality traits of spring barley varieties and breeding lines. Dotnuva, 2002–2004**

Variety, breeding line	TKW g	HLW $g\ l^{-1}$	Protein content %	Starch content %	Extract content %	Grading >2.5 mm %
Ûla	55.7	702	13.2	57.1	76.1	92.4
Auksiniai 3	47.5	717	13.5	57.9	78.4	91.7
Luokë	52.1	689	13.1	55.8	75.6	90.7
7101-1	53.7	701	13.0	56.6	77.1	89.7
7222-3	57.1	696	13.0	56.7	77.3	92.6
7322-6	52.3	688	13.7	57.1	77.5	91.5
7422-3	50.0	702	13.1	58.5	79.5	86.3
7661-1	51.6	697	13.0	57.3	78.9	91.4
7695-4	50.4	693	12.5	55.8	76.4	83.8
7773-2	52.5	709	13.0	56.6	78.3	92.3
7939-1	46.8	693	12.7	56.8	78.1	85.5
7955-5	48.6	703	12.6	57.7	78.8	90.8
7963-7	48.8	705	13.2	56.4	78.1	81.9
7967-2	47.0	698	12.1	58.9	80.3	73.8
LSD_{05}	2.610	15.379	0.832	1.726	1.071	6.697

or analogous programmes are successfully used for the selection of promising breeding material of cereals and grasses [15]. Table 2 shows assessment of spring barley varieties and breeding lines according to grain yield and stability using this programme. The varieties that surpassed the average integral evaluation of the trial are indicated by (+). Among the breeding lines evaluated in 2002–2004, an especially high integral assessment was given the lines 7939-1 (17+); 7955-5 (16+); 7422-3 (14+); 7101-1 (12+); 7661-1 (10+). These lines combined high yield (5.26–4.90 $t\ ha^{-1}$) with low variance of stability (s^2) (0.004–0.113). Slightly lower were assessed the lines 7967-2 (9+); 7695-4 (8+); 7963-7 (7+); 7773-2 (7+). The lowest assessment was given to the control variety 'Ûla'.

Grain grading is an important parameter both for food and malt barley. Grain grading percentage over 90% required a longer grain filling period [19]. Weather conditions had the strongest influence on the length of the grain filling period. The lack of moisture does not allow for the genetic peculiarities of a variety to reveal and equalises the grain grading percentage. After mathematical assessment of grain >2.5 mm yield of spring barley varieties and breeding lines, the most highly assessed were the lines

7955-5 (16+); 7661-1 (14+); 7939-1 and 7101-1 (13+); 7322-6 (12+); 7222-3 (11+). Positive assessment was given to the varieties ‘Ûla’ and ‘Luokë’. The variety ‘Ûla’ and the lines 7222-3, 7773-2 met the requirements for malting barley grain grading throughout all experimental years.

Integral assessment of extract yield of breeding lines confirms that some lines are distinguished according to this parameter. High integral assessment was given to the lines 7955-5 (17+); 7939-1 (16+); 7422-3 (13+), 7661-1 (12+) and 7967-2 (11+). These lines combined a high extract yield with a low variance of stability (σ^2) (0.004–0.031) and showed a high extract content (Table 3).

The value of the breeding lines tested was determined on the basis of the sum of integral assessments. The highest sum of grain yield, grain grading and extract yield was found in the breeding lines 7955-5 (49+); 7939-1 (46+); 7661-1; 7422-3 (36+); 7101-1 (34+); 7967-2 (20+). These breeding lines were characterized by a high grain yield (4.90–5.26 t ha^{-1}). They significantly outyielded the standard variety ‘Ûla’ (Table 2). The breeding lines 7955-5, 7939-1 and 7967-2 showed a low protein content (12.1–12.7%). The breeding lines 7955-5, 7422-3 and 7967-2 were noted for a high extract content (78.8–80.3%), lines 7422-3 and 7967-2 for a high starch content (58.5–58.8%), and lines 7955-5 and 7661-1 for grain grading (90.8–91.4%).

The spring barley varieties ‘Auksiniai 3’, ‘Luokë’ and ‘Ûla’, received the lowest overall assessment though the latter variety showed a high TKW, because ‘Luokë’ and ‘Ûla’ are feeding varieties, whereas ‘Auksiniai 3’ is an old and not high yielding variety.

The breeding lines 7955-5, 7939-1, 7661-1, 7422-3, 7101-1 and 7967-2 have been transferred to the Lithuanian Gene Bank for long-term conservation. The breeding lines 7101-1 and 7967-2, which showed high grain stability, grain quality and other agronomic traits were passed on to the Lithuanian Official Trials for testing in 2004 and 2005, respectively.

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A. Leistrumaitë, V. Paplauskienë

VASARINIØ MIEÞIØ GENETINIAI IÐTEKLIAI: DERLIAUS IR PAGRINDINIØ SALYKLINIØ SAVYBIØ STABILUMO TYRIMAI

Santrauka

Iðaugæs salyklíniø mieþiø poreikis alaus pramonei skatina atlikti iðsamesnius genetiniø iðtekliø tyrimus, ávertinti turimos pradinës medþiagos genetinæ ávairovæ ir atrinkti tinkamà salyklíniø mieþiø kûrimo programai. 2002–2004 m. Lietuvos þemdirbystës institute tirtas vasariniø mieþiø genetiniø iðtekliø kolekcijos pavyzdþiø tinkamumas salyklíniø mieþiø programai. Nustatytas derliaus ir salyklíniø savybiø stabilumas. Ávertinta bandymø vykdymo metø, veislës ir jø tarpusavio sàveikos átaka grûdø derliui, stambiø grûdø ir ekstrakto iðeigos pakitimams. Naudojant pritaikytà kompiuterinæ programà STABLE atrinktos perspektyviausios pagal ðiuos rodiklius selekcinës linijos, galinèios realizuoti savo genetines galimybes ávairiomis augimo sàlygomis. Aukðèiausià integraliná vertinimà, pagrástà rangø vertinimø suma, gavo selekcinës linijos: 7955-5 (49+); 7939-1 (46+); 7661-1; 7422-3 (36+); 7101-1 (34+); 7967-2 (20+). Ðios linijos padëtos ilgalaikiam saugojimui á Augalø genø bankà, dalis átraukta á salyklíniø mieþiø kûrimo programà. Selekcinës linijos 7101-1 ir 7967-2, pasiþymëjusios stabiliu derliumi, geromis salyklinëmis ir kitomis agronominëmis savybëmis, perduotos tirti Lietuvos valstybiniam augalø veisliø tyrimo centrui.