

Original Research

Agronomic Performance of Spring Barley Cultivars under Different Eco-Environmental Conditions

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Abstract

In this study, five agronomic traits of 29 barley accessions were evaluated in different agro-environmental conditions. Accessions represented cultivars from Kyrgyzstan, Ukraine, and the Nordic and Baltic countries as well as landraces from northeastern and eastern Russia. The field experiments were carried out in two countries (Latvia and Kyrgyzstan) in order to select the suitable genotypes or cultivars as a source for Kyrgyz barley breeding programs. Among the accessions studied, we found material that can be used in Kyrgyz breeding as potential sources of earliness, spike length and TKW. Among the cultivars, 'Cecilia' from Sweden showed an attractive agronomic performance, and had constant behaviour under Kyrgyz climatic conditions during two years of trials. Other cultivars like 'Saana', 'Sencis' and 'Mette' can also be included in future breeding due to their earliness, plant height, spike length and number of kernels. There were cultivars that had the stable response of number of agronomic characters in these two locations over both years of trials. For example, the cultivars 'Cecilia', Mette, 'Saana' were stable in HD, SL, and NGS in different climatic conditions. Also, among the landraces there were candidates who showed stable behaviour for SL and TKW.

Keywords: breeding, germplasm, cultivar, variety

Introduction

Barley (*Hordeum vulgare L.*) is an important cereal crop around the world and is of major importance to many countries [1-2]. In terms of global acreage and

production, barley is the fourth major cereal crop after wheat, rice and corn globally [3], and is regarded as one of the most tolerant crops for drought and alkaline soils, and it has the highest water-use efficiency compared to other cereal crops, but it is less tolerant to acidic soils [4-7].

Cultivation conditions of barley genetic diversity are essential for adapting to future environmental changes,

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and are increasingly recognized as a crucial aspect of agricultural systems, especially considering the impacts of climate change [8-10].

The genetic variation between cultivars of barley and their related wild species easily gives way to use for the hybridization process in plant breeding. Barley has become a model plant experimental system for much scientific research around the world [11-18].

The cultivation conditions of barley are quite diverse, and the eco-geographic range from the highest arable mountain areas down to sea level and from high latitudes above the arctic circle to the tropics [19].

Knowledge about crop yield variability of crop cultivar is very useful regarding its selection and cultivation in a target region, as well as under specific cultivation regime [20]. Today, barley is grown on around 47.0 M/ha across the globe [21]. It has great stability against climate fluctuations during the growing season, which reduces the risk for low yield in unfavorable years [22-23]. Major cereal yields are expected to decline significantly in coming years due to the effects of climate change temperature rise [24]. One advantage with barley is its ability to grow in harsh environments where most other crops would have difficulty to survive, for example in high-altitude areas (2.700-3.500 m a.s.l.) with a very short vegetation period [25-26].

Barley has thus a number of advantages as a cereal crop in mountainous areas of Central Asia, where the Kyrgyz Republic is one of the most mountainous agrarian countries. Agriculture is a significant economic sector of the country, and animal husbandry is a priority area, which has led to increasing barley production for feed since livestock every year – especially in the high mountain provinces of the country. For example, from 2005 to 2016 the number of sheep increased from 2.5 million up to 5.16 million heads [27].

Globally, population size will increase by 2050 and incomes will combine with dietary shifts to raise meat human consumption for each person to around 49 kg for the world (91 kg in high-income countries), and demand for total meat in Europe and Central Asia is projected to be 71 million tons [28]. Barley is considered the largest component of coarse grains used as animal feed [28], and globally, produced barley grain used for animal feed is about 35% of total grain produced.

Since barley is one of the most reliable crops for the majority of farmers in Kyrgyzstan, it is grown in all regions of the country, but dominates in the mountain provinces 'Issik-Kul' and 'Naryn' with prevailing severe winters and short summers. Spring barley is not only a universal crop but is also a substitute for winter crops. In years with massive loss of winter crops, farmers can expand the spring barley sowing. In most agricultural zones in Kyrgyzstan, barley is the most productive crop among spring cereals. The versatile use of barley grain for animal feed and the production of national drinks for human consumption further reinforces the importance of barley in grain production. An average

of 238.5 metric tons was produced during the last five years. The area of barley cultivation during the last decade was around 243.000 hectares, but at present, due to unsuccessful agrarian reform, the total sown area of barley has been extremely reduced almost to half.

During the Soviet time there were altogether 574 major state farms, but after the independence of the country these larger kolkhozes and sovkhozes were split into many small private farms. Today, there are approximately 344,000 farms registered in Kyrgyzstan. The average yield of barley is very low and during the last five years (2012-2016) it was only about 1.9 t/ha [29]. The area of barley cultivation during the last decade was around 243,000 hectares, but at present, due to unsuccessful agrarian reform, the sown area of barley has been reduced by half [30].

The highly diverse climatic zones of Kyrgyzstan make it desirable to produce a variety of new cultivars of spring barley adapted to each zone with different growth conditions and duration of the growing season. For high mountain zones it is necessary to have early maturing cultivars, which can guarantee grain maturation during the short growth season. However, also for the central and south part of the country with longer growth seasons, early maturity cultivars are required. Here the cultivars must set grains before the start of the drought period. Another advantage of growing early maturing cultivars in these areas is that farmers can grow a second intermediate crop after barley, like maize for silage or vegetables. This allows for rational use of land resources for farmers.

High-input agricultural systems are becoming unsustainable due to a decrease in the availability of resources such as water, oil and phosphorus, which is further exacerbated by human population growth, which requires increasing levels of agricultural production [31]. Ecological intensification, where crop yield can increase through better use of resources, has been postulated as a possible solution [32-33].

Cultivars from other geographic regions of the world characterized by early maturity have successfully been used for cultivation as well as for barley-breeding purposes in Kyrgyzstan. For example, cultivars from the Baltic and other Soviet countries like 'Kombainieris' (Latvia), 'Doneskij 8', 'Odesskij 100' and Druzhva (Ukraine) have been on the variety list and they were also widely used in the breeding programs as donors for environmental adaptability. Well-studied germplasm gives better chances for the breeders to achieve their breeding goals. Hence, thoroughly characterized germplasm of different origins, possessing a complex of agronomic traits, are valuable sources that should be included as starting material for the breeding programs [34]. The current study forms part of a larger investigation of genetic resources for Kyrgyz barley breeding. The primary aim of this study was to analyze agronomic performance of spring barley cultivars in different agro-environmental conditions in order to seek valuable sources for the Kyrgyz' barley breeding program.

Food supply is a major concern and takes place in a complex global scenario. On one side there is an increasing demand for food, i.e., the human population, projected to be 9 billion by 2050, and on the other side are factors that seriously threaten food production, i.e., climate change and the constant pressure of pests and pathogens, of which the global patterns of infection are also expected to vary due to this changing climate [35-36]. The organic farming sector is increasing in importance and requires varieties with stable yield and adapted to organic growing conditions [37].

Materials and Methods

Plant Material

The material consisted of 18 two-rowed and two six-rowed bred cultivars and nine landraces of spring barley, which were assessed in field trials in 2015 and 2016 (Table 1).

Table 1. Cultivar information of studied material in 2015 and 2016 (Kyrgyzstan and Latvia).

Cultivar	Genebank ID	Origin	Pedigree	Released	Row type
Local 1	18647	Russia, Krasnoyarsk	Landrace	1958*	6
Local 2	18059	Russia, Krasnoyarsk	Landrace	1951*	6
Gibrid 1N35-3E	17021	Russia, Omsk	Landrace	1947*	6
Local 3	4963	Russia, Omsk-local	Landrace	1923*	6
Obyknovenniy 1	11689	Russia, Altay	Landrace	1929*	6
Obyknovenniy 2	11703	Russia, Altay	Landrace	1929*	6
Prostoy 1	11688	Russia, Altay	Landrace	1929*	6
Prostoy 2	16513	Russia, Omsk	Landrace	1939*	6
Local 4	4955	Russia, Omsk-local	Landrace	1923*	6
Jyva	-	Finland	Arve x Verner	2000	6
Lavrance	NGB16727	Norway	Vera//Arve/H82009-1-3	1999	6
Nutans 89	-	Kyrgyzstan	Nutans 7554 x Kaskad	1994	2
Taalay	-	Kyrgyzstan	F2 (Liniya25 x Harpoon) x F2 (Tyasmin x kaskad)	1997	2
Bestam	-	Kyrgyzstan	(Nutans 8884, naryn 27 x K-20431) x (Nutans 4353 x Union) x Odesskiy 100)	2003	2
Nutans 970	-	Kyrgyzstan	Nutans 7554 x Kaskad	1974	2
Odesskiy 100	-	Ukrain	77/74 x Hml 36462	1983	2
Kylym	-	Kyrgyzstan	F3 [F2(Dinat x Azyk) x naryn 27]	2003	2
Naryn 27	-	Kyrgyzstan	Nutans 45 x Nurans 4353	1972	2
Maksat	-	Kyrgyzstan	Nutans 66 x Temp	2006	2
Vladlen	-	Kyrgyzstan	Nutans 3011 x (Nutans 1963 x Nutans 2578)	2010	2
Vatan	-	Kyrgyzstan	Kurier x Jaspis	2008	2
Saana	-	Finland	Kustaa x Hja 60758	1996	2
Mari	NGB1491	Sweden	Mutation selected from X-ray treated Bonus	1960	2
Sencis	LVA00015	Latvia	Rupal/Ofir/Torkel	1994	2
Mette	NGB9275	Sweden	((Ingrid x Ansgar ^2) x Varunda ^2) x	1984	2
Pernilla	NGB1510	Sweden	(Birgitta x Mari) x Gunilla	1979	2
Kinnan	NGB9950	Sweden	Etu x Ida	1992	2
Cecilia	NGB13913	Sweden	PL 1578-87/88045	1998	2
Leelo	EST19	Estonian	Ansgak/Sv2552//Elo	1995	2

* Year of enter in the catalog of N. I. Vavilov Research Institute of Plant Industry

The field trials were carried out in two different agro-environmental climatic zones: one in Priekuli, Latvia (57°19'N, 24°20'E, altitude 20 m a.s.l.) and a second in Issyk-Kul, Kyrgyzstan (42° 3'59.49"N, 76°53'9.59"E, altitude 2000 m a.s.l.). The plant material was obtained from the Nordic Genetic Resource Center (www.nordgen.org), the N. I. Vavilov Institute of Plant Industry (<http://vir.nw.ru>) and from the Kyrgyz Research Institute of Farming (krif@mail.kg). The experiment layout was a randomized complete block design using two replicates and two years in both countries. Each entry was sown in two rows of one-meter length, keeping a distance of 15 cm between rows and 5 cm between plants. In Kyrgyzstan irrigation was applied during the vegetation period in both years, but in Latvia no irrigation was applied.

Evaluation of Agronomic Traits

Phenological observations and evaluations of five agronomic traits were done either directly in the field or in the laboratory after harvest. The five characters were: 1) heading day (HD), the number of days from sowing to the time when 50% of spikes had emerged from the flag leaf sheath; 2) plant height (PH), as measured from the soil surface to the top of the spike, excluding awns; 3) spike length (SL), measured from the base of spikes to the top of uppermost spikelet excluding awns; 4) number of grains per spike (NGS), total number of grains from a single spike; and 5) thousand kernel weight (TKW), was calculated by weighing two samples of 500 seeds.

Analysis of Data

The ANOVA (analysis of variance) for each agronomic trait was performed (Table 2). The relationships between cultivars were assessed using the multivariate PCA analysis for each location and year of

the trial. Minitab 16.0 software was used for statistical analysis (Minitab Release 16 statistical software). For a comparison of agronomic traits between years, a paired t-test was used for each cultivar, whereas between countries for each cultivar was applied by the general linear model ($P \leq 0.05$).

Results and Discussion

Barley cultivation in Kyrgyzstan is practiced throughout the country and thus the growing area is covering a very wide range of agro-environmental zones. Since the agronomic performance of barley is essential for Kyrgyz farmers, breeders have to consider this while developing new cultivars. In breeding programs for specific target areas, studies of genotype x environment interactions can decidedly increase the probability to select for stable genotypes. A critical prerequisite for efficient spring barley breeding is hence to capture wide genetic variation of desirable agronomic traits in the working collection of the breeding program [37-38].

The PCA analysis was made based on all five characters from the field trials according to location (Kyrgyzstan and Latvia) and cultivation year (2015 and 2016). For all cultivars, the first component visualized 37.5 to 42.0 per cent of the total variation, whereas the second component explained 24.9 to 31.9 per cent of the total variation, respectively (Fig. 1a).

The first component distinguished the two- and six-rowed types. In our study with the separation based on row types, two- and six-rowed cultivars were affected mainly by the number of grains per spike (NGS) and heading days (HD). The second component was mainly affected by (SL), (HD) and (TKW). However, the cultivars' responses to environmental conditions in different locations were different, and it can be seen in PCA analysis that the cultivars grouped differently in

Table 2. ANOVA analysis for each agronomic traits based on data from two different years (2015-2016) at two locations (Kyrgyzstan and Latvia).

Source	DF	HD	PH	SL	NGS	TKW
	Mean squares					
Cultivar	28	55,57*	635,70*	5,35*	2351,83*	136,28*
Location	1	2286,71*	85092,5*	87,3628*	6736,39*	2508,75*
Year (Location)	2	118,192*	3874,9*	24,1229*	31,29 ^{ns}	3701,93*
Replication (Location)	4	3,68 ^{ns}	17,90 ^{ns}	0,86 ^{ns}	30,83 ^{ns}	4,33 ^{ns}
Cultivar*Location	28	17,729*	89*	1,0193*	251,02*	81,03*
Cultivar*Year (Location)	56	21,115*	110,5*	0,986*	39,79*	47,83*
Error	112	2,04	8,40	0,34	13,98	3,46
Total	231					

* Significant at 0.001 level, ns-not significant, DF-degree of freedom, HD- heading day, PH-plant height, SL-spike length, NGS- number of grains in spike, TKW-thousand kernels weight.

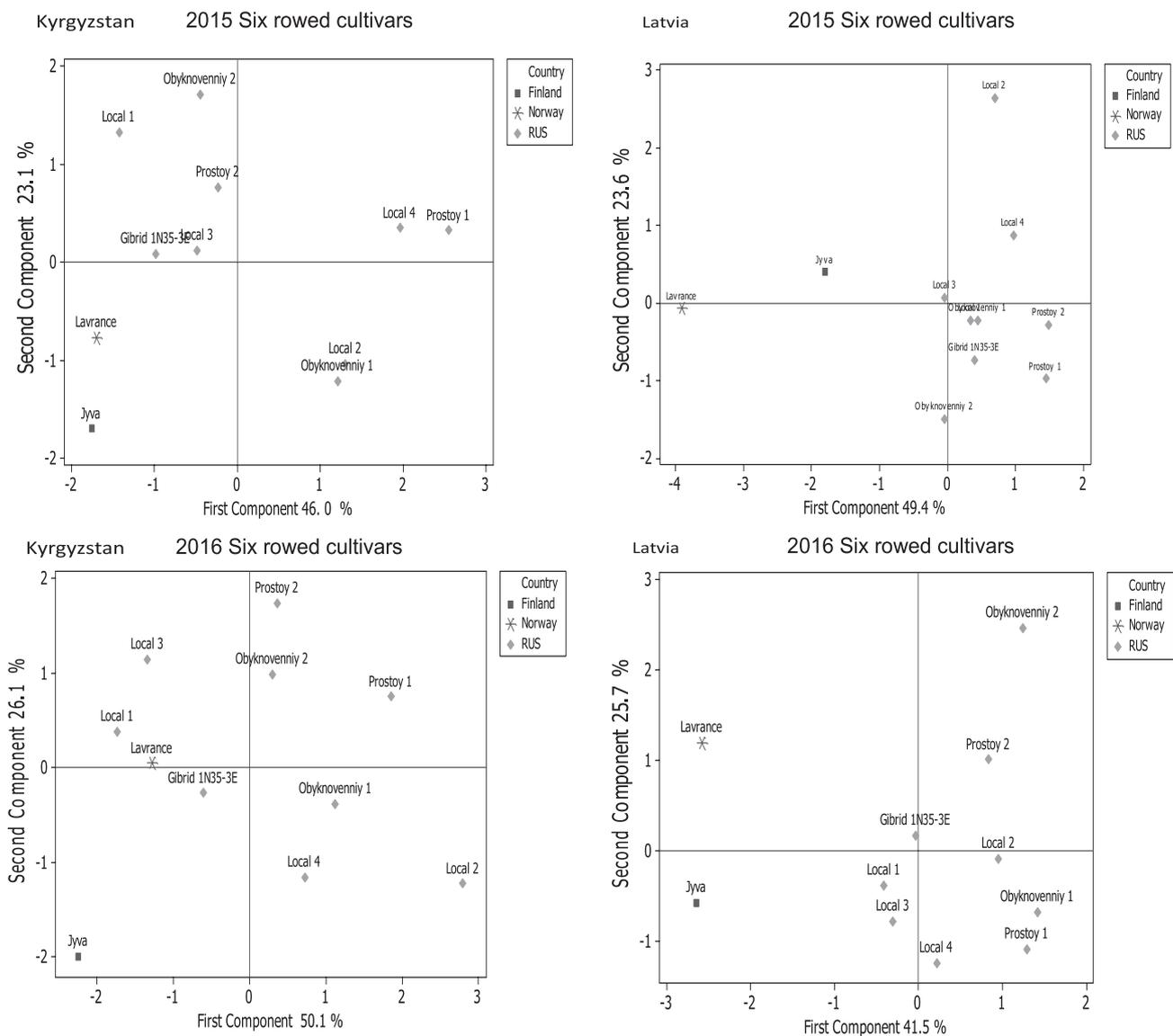


Fig. 1b). PCA analysis based on agronomic traits, six-rowed cultivars, Kyrgyzstan and Latvia (2015-2016).

significant difference between different years within the same trial sites for the NGS trait (Table 2). Bleiderer et al. [38] and Dofing et al. [39] studying advanced bred cultivars of spring barley reported similar results in their studies showing significant interactions for environment \times cultivar in different climatic conditions. One of the reasons for the environmental effect between Kyrgyzstan and Latvia is that there are differences in day lengths. In Latvia the average day from May to September is 15.7 hours, whereas in Kyrgyzstan the average length is only 13.7 hours (Table 3). Thus, the numbers of days to heading (HD) in the Latvian field-trial were significantly lower compared to the corresponding field trial in Kyrgyzstan. The number of days heading for the cultivars in Kyrgyzstan in 2015 varied from 58 to 67 days with an average of 63 days, whereas in 2016 the HD values ranged from 58 to 72 days with an average of 64 days. The heading day values of most cultivars were fairly constant over the

two years. In Kyrgyzstan there was not a significant difference in (HD) for most bred cultivars between 2015 and 2016, but there is a significant difference in response of Russian six-rowed landraces between the two trial years (Fig. 2). This may be due to the fact that bred cultivars have less variation in response to year-to-year variation than landraces. In the Latvian trials there were more differences between the heading day values as compared to the Kyrgyz trial, where only nine accessions did not show significant differences over the two trial years in this trait.

The cultivar 'Mette' showed not only no significant differences in the DH response between years, but also no significant difference ($P \leq 0.08$) between countries. Among the two-rowed barleys the cultivars 'Vladlen', Taalay and 'Naryn 27' were the earliest maturing cultivars in both years (58 and 61 days, respectively), whereas among the six-rowed cultivars 'Gibrid 1N35-3E' and 'Local 3' were the earliest, but

Table 3. Meteorological data for Kyrgyzstan and Latvia 2015-2016 (May-September).

KG 2015	Average temperature °C (min-max)	Average moisture %	Total rainfall, mm	Average day length (Hours)
May	12 (10-17)	58	36	14
June	17 (13-23)	59	40	15
July	19 (14-25)	59	68	15
August	19 (14-23)	61	103	13
September	14 (10-19)	67	100	12
KG 2016				
May	14 (9-19)	71	71	14
June	17 (12-23)	65	55	15
July	19 (14-25)	59	16	15
August	19 (14-24)	56	26	13
September	16 (11-22)	62	12	12
Latvia 2015				
May	13 (9-18)	75	91	16
June	15 (11-19)	77	96	17
July	22 (17-27)	73	76	17
August	19 (15-23)	82	113	17
September	11 (8-15)	85	92	12
Latvia 2016				
May	12 (7-17)	69	67	16
June	18 (13-23)	70	46	17
July	20 (16-25)	75	77	17
August	17 (13-22)	78	115	17
September	13 (10-17)	84	51	12

not in each country. There were differences in rainfall (Table 3) in the beginning of the vegetation period between two years, which could affect the HD. It should be mentioned that in Kyrgyzstan irrigation was applied twice during the vegetation period, which could have reduced the effect of the differences between years (Fig. 2). In Latvian trials no irrigation was carried out and generally the lower precipitation in spring of 2016 resulted in decreased values of HD for the majority of accessions. Some exceptions could be detected, as cultivars 'Saana', 'Kinnan', 'Cecillia', and 'Leelo' had significantly longer periods before heading in 2016 as compared to 2015. Studying genetic diversity of Nordic and Baltic barley cultivars [40] showed that there was a difference between two- and six-rowed barleys in heading days, and that six-rowed barleys were earlier maturing than two-rowed barley. However, in our study also the six-rowed cultivars were separated from the two-rowed cultivars by the characters HD and NGS. The number of days in Latvia 2015 ranged from 52 to 63, with an average of 58 days in 2015 and in 2016

the HD values varied between 44 and 67, with an average of 56 days. Most Kyrgyz cultivars were earlier in heading when cultivated in Latvia but they showed somewhat different responses in the two different years. Several reports have previously mentioned that there are noticeable genotype x environmental interactions for heading values of barley [41]. The interaction between genotype and environment is one of the major problems facing barley breeding programs aimed at achieving the desired breeding targets in new cultivars to be used over larger cultivation areas in different environments [42]. The value heading day is such a determinative trait of adaptation for cultivars to particular environment areas, which defines the crop performance in different agro-environmental conditions [43]. Among the overall studied material, most of the two-rowed cultivars revealed a more stable response to year-to-year variation within the trial site. For example, foreign cultivars from Nordic and Baltic countries 'Mette' ($P = 0.28$, $P = 0.10$) and 'Pernilla' ($P = 0.68$, $P = 0.420$), 'Mari' ($P = 0.18$, $P = 0.26$) from Sweden and 'Sencis' ($P = 0.80$, $P = 0.14$)

Table 4. P-values in comparison of agronomic traits between Kyrgyzstan and Latvia.

Cultivars	Heading day	Plant height	Spike length	Number of grains in spike	TKW
Local 1	0,00	0,00	0,12	0,00	0,05
Local 2	0,03	0,00	0,00	0,00	0,96
Gibrid 1N35-3E	0,01	0,00	0,46	0,00	0,29
Local 3	0,04	0,01	0,30	0,00	0,00
Obyknovenniy 1	0,03	0,01	0,01	0,00	0,00
Obyknovenniy 2	0,05	0,00	0,24	0,13	0,36
Prostoy 1	0,08	0,00	0,12	0,00	0,23
Prostoy 2	0,02	0,00	0,02	0,25	0,19
Local 4	0,24	0,00	0,01	0,00	0,11
Jyva	0,00	0,00	0,08	0,02	0,06
Lavrance	0,00	0,00	0,02	0,33	0,65
Nutans 89	0,01	0,04	0,17	0,05	0,27
Taalay	0,84	0,00	0,02	0,05	0,05
Bestam	0,00	0,00	0,61	0,01	0,25
Nutans 970	0,02	0,00	0,01	0,02	0,93
Odesskiy 100	0,00	0,00	0,23	0,87	0,02
Kylym	0,00	0,00	0,00	0,22	0,89
Naryn 27	0,01	0,00	0,02	0,01	0,69
Maksat	0,04	0,00	0,11	0,13	0,72
Vladlen	0,01	0,00	0,12	0,09	0,12
Vatan	0,02	0,01	0,06	0,04	0,42
Saana	0,39	0,04	0,00	0,39	0,00
Mari	0,02	0,00	0,09	0,83	0,00
Sencis	0,00	0,00	0,02	0,03	0,20
Mette	0,28	0,00	0,04	0,03	0,00
Pernilla	0,01	0,00	0,07	0,42	0,02
Kinnan	0,01	0,00	0,02	0,00	0,38
Cecilia	0,08	0,01	0,06	0,06	0,00
Leelo	0,00	0,00	0,02	0,01	0,01

from Latvia one Kyrgyz cultivar ‘Nutans 970’ ($P = 0.06$, $P = 0.12$) and one Ukrainian cultivar ‘Odesskiy 100’ ($P = 0.77$, $P = 0.09$) are especially promising by showing similar heading day performance within both countries, and there was no significant difference between them over the two years. However, there were few cultivars (‘Mette’, ‘Saana’, ‘Cecilia’, ‘Taalay’) and landraces (‘local 4’, ‘Prostoy 1’ and ‘Obyknovenniy 1’) that showed more stable response of the character in heading days, also when compared between trial sites and years (Table 4). Another important trait is plant height, which in our study is demonstrated by variation over the two years in both countries. Plant height is one

of the traits that can be influenced by the environment, especially by drought [44], which is an abiotic stress that affects plants at various levels and stages of their life. This abiotic stress not only affects plant–water relations through the reduction of water content, turgor, and total water, but it also affects stomatal closure, limits gas exchange, reduces transpiration, and disturbs photosynthesis [45-46]. Differences between cultivars regarding plant height mainly depend on genetic background of the cultivars and it is a highly heritable trait [47-48]. A tall plant is an undesirable characteristic since grain yield can be reduced by lodging [49-50]. In this study, the plant height of cultivars varied between



Fig. 2. Agronomic traits of 29 spring barley grown in Kyrgyzstan a) and Latvia b) 2015-2016; ● = not significant at $P \leq 0.05$.



Fig. 2. Continued.

years of the trials and ranged from 32 up to 119 cm (Kyrgyzstan and Latvia). In general, the PH values were higher in 2016 than in 2015 in Kyrgyzstan. This may be an effect of low precipitation in 2010 (36 mm) during the beginning of the vegetation period (May-June), whereas the rainfall was higher in 2011 during these months (Table 3). Hence, in the case of low moisture content in the soil it is necessary to provide irrigation in order to supply optimum growth conditions. In most provinces it is possible to provide irrigation during the vegetation period, especially during the early stages of plant development. However, in areas where the irrigation water is limited, barley is still cultivated despite rain-fed, unfavorable field conditions. In Kyrgyzstan the plant heights of the cultivars ranged from 69 to 103 cm (average 86 cm) in 2015, whereas the PH value ranged from 75 to 119 cm (average 101 cm) in 2016. Generally, the plants were taller in 2016 as compared to the 2015 with only a few exceptions

among the two-rowed cultivars (Fig. 2a), Appendix 1). The corresponding PH values from the field trials in Latvia ranged from 38 to 74 cm (average 58 cm) in 2015 and they had the same range (average 52 cm) in 2016. The six-rowed Russian landraces were comparatively taller than the Nordic cultivars in both years (Fig. 2b). However, a paired t-test showed that there were a few landraces or cultivars, which showed a sustained performance between years in each country (Fig. 2a-b) but there was a significant difference ($P < 0.05$) between the two countries in plant height. The plant height (PH) character of the cultivars 'Kylym', 'Saana', 'Mette' and 'Kinnan' had rather constant behaviour during the two years at each trial site. In Latvia there were no differences in PH between the two years for cultivar 'Naryn 27' ($P = 0.94$) and six of the Russian landrace accessions. Kyrgyz cultivars 'Kylym' and 'Naryn 27' are recommended for rain-fed cultivation, and also the two Swedish cultivars 'Kinnan' and 'Mette' differed

Cultivars	Kyrgyzstan										Latvia									
	2015					2016					2015					2016				
	days to heading	Plant height, cm	length of spike, cm	Number of kernels in spike	1000 kernel weight, g	days to heading	Plant height, cm	length of spike, cm	Number of kernels in spike	1000 kernel weight, g	days to heading	Plant height, cm	length of spike, cm	Number of kernels in spike	1000 kernel weight, g	days to heading	Plant height, cm	length of spike, cm	Number of kernels in spike	1000 kernel weight, g
Local 1	63	93	9	56	50	62	106	9	67	51	60	66	8	43	28	56	60	8	49	43
Local 2	61	90	11	76	43	69	118	11	85	42	59	57	10	45	38	56	65	9	46	47
Gibrid 1N35-3E	61	82	8	64	46	61	110	9	74	47	58	63	9	38	23	54	64	8	44	54
Local 3	60	81	9	61	42	61	116	9	63	50	58	63	9	45	27	54	61	7	47	42
Obyknovenniy 1	61	87	10	76	39	65	113	10	73	44	59	70	9	49	29	57	67	8	50	36
Obyknovenniy 2	59	93	9	60	52	65	115	9	64	46	58	70	8	40	24	58	70	9	59	56
Prostoy 1	59	103	11	68	36	69	118	10	66	42	59	71	10	35	26	55	68	9	39	45
Prostoy 2	62	96	10	68	54	63	119	10	47	46	60	74	9	39	33	55	74	8	52	50
Local 4	58	99	10	75	43	64	112	11	78	47	59	59	9	33	31	57	53	8	38	47
Jyva	67	76	11	66	49	60	90	10	84	53	55	57	9	57	23	48	45	7	48	51
Lavrance	63	78	7	68	45	61	88	9	63	44	52	60	6	57	28	54	47	6	59	54
Nutans 89	62	69	9	22	44	62	88	10	23	46	58	63	9	21	42	49	38	6	15	54
Taalay	59	86	10	26	51	60	88	10	24	60	61	38	9	20	32	58	52	8	23	58
Bestam	64	84	10	25	56	62	113	8	25	52	60	59	10	22	35	55	52	9	22	57
Nutans 970	63	89	10	23	46	62	110	9	24	44	59	56	9	21	39	51	42	8	20	50
Odesskiy 100	63	85	9	21	38	63	98	10	25	46	54	42	10	25	46	49	66	8	21	57
Kylym	65	90	12	26	49	64	98	10	23	46	61	53	9	20	34	57	48	7	23	59
Naryn 27	61	94	10	24	55	60	108	9	23	51	56	56	9	20	43	46	56	7	17	59
Maksat	63	94	11	26	45	66	110	10	27	48	61	55	11	26	34	51	40	7	19	56
Vladlen	61	81	9	22	52	58	88	9	23	56	56	56	8	22	35	44	40	7	16	57
Vatan	62	85	10	24	46	67	101	10	30	48	58	64	9	22	41	50	39	6	15	50
Saana	65	72	8	23	58	61	75	7	22	54	60	46	8	21	32	63	41	8	20	43
Mari	67	86	11	26	56	65	111	10	27	63	55	61	10	28	38	61	51	9	26	41
Sencis	65	93	11	27	52	64	108	11	27	56	58	67	10	26	40	54	55	8	21	58
Mette	66	70	8	21	44	66	78	9	26	49	63	41	7	20	32	63	40	7	21	41
Pernilla	65	89	10	24	54	61	95	10	27	54	58	63	10	24	45	58	52	8	23	52
Kinnan	67	85	8	26	41	72	78	8	22	42	62	42	8	21	26	67	32	7	14	48
Cecilia	65	87	11	28	53	66	95	11	29	56	57	68	10	25	47	66	40	10	24	42
Leelo	65	84	9	25	56	70	84	10	27	51	59	57	8	21	37	65	40	7	18	44
Max	67	103	12	76	58	72	119	11	85	63	63	74	11	57	47	67	74	10	59	59
Min	58	69	7	21	36	58	75	7	22	42	52	38	6	20	23	44	32	6	14	36
Average	63	86	10	41	48	64	101	9	43	49	58	58	9	31	34	56	52	8	31	50

from other cultivars having a shorter plant height (32-42 cm). Concerning the response of the six-rowed cultivars to environmental conditions there was a difference between the two years, but most cultivars were relatively consistent compared with plant heights in Kyrgyzstan. The barley cultivation in Kyrgyzstan often has unfavourable conditions and always with low input, like low soil nutrition content. Other poor agricultural practices could likewise influence plant height.

Appendix 1

The spike length values varied between the two years and locations, supposedly as a response to different environmental conditions. In Kyrgyzstan the spike length values ranged from 7 to 12 cm (average 10 cm) in 2015, and from 7 to 11 cm (average 9 cm) in 2016 (Fig. 2a). All two and six-rowed cultivars and landraces showed relatively stable SL values over the two years except for a few cultivars. In Latvia the spike length ranged between 6 and 11 cm (average 9 cm) in 2015, and between 6 and 10 cm (average 8 cm) in 2016. Most advanced cultivars were stable in spike length comparison with landraces (Fig. 2b, Appendix 1). Two cultivars, i.e., 'Cecilia' from Sweden and 'Sencis' from Latvia, differed by having long spikes and constant behaviour (11 cm) during both years in Kyrgyzstan. However, four cultivars ('Cecilia' 'Pernilla' 'Mari' and 'Saana') and one landrace ('Prostoy 1') were stable in spike length in each county for both years. There were

no differences between countries (the P-value was greater than at 0.05 level; Table 4). The number of grains per spike (NGS) is highly dependent on spike type. It is well-known that six-rowed barley has a clear advantage over two-rowed barley by having a higher number of grains per spike, but also the disadvantage that the grains are smaller in size and have lower weights [51-52]. In this study, the NGS values of two-rowed cultivars were comparatively constant over the two years and in both countries, whereas six-rowed cultivars showed distinct responses to the environmental conditions. In Kyrgyzstan the number of grains per spikes of two-rowed cultivars ranged from 21 to 28 (average 24) in 2015, and from 22 to 30 (average 25) in 2016 (Fig. 2a, Appendix 1). The NGS values of six-rowed cultivars ranged from 56 to 76 (average 68) in 2015 and from 47 to 85 (average 69) in 2016 (Fig. 2a, Appendix 1). In Latvia the number of grains per spike in two-rowed cultivars ranged from 20 to 28 (average 22) in 2015 and from 15 to 26 (average 20) in 2016 (Fig. 2b). In six-rowed cultivars the NGS values ranged from 33 to 57 (average 44) in 2015, and from 38 to 59 (average 48) in 2016 (Fig. 2b). Among the landraces (Obyknovenniy 2, Prostoy 2) as well as six-rowed (Lavrance') and two rowed cultivars ('Nutans 89', 'Taalay', 'Odesskiy 100', 'Kylym', 'Maksat', 'Vladlen', 'Saana', 'Mari', 'Pernilla' and 'Cecilia'), there were no significant differences at the 0.05 level when the comparison done between countries in NGS over both years.

Grain size was measured as thousand kernel weight (TKW), and it is commonly known that low TKW values lead to barley harvests [53-55]. The thousand kernel

weight is genetically a very complex heritable trait and environmental factors always influence the development of grain size and weight [56-60]. The TKW values of cultivars ranged from 36 to 58 g (average 48 g) in 2015, while in 2016 it ranged from 40 to 63 g (average 49 g) in Kyrgyzstan (Fig. 2a). In Latvia the TKW values ranged from 23 to 47 g (average 34 g) in 2015, whereas the range was from 36 to 59 g (average 50 g) in 2016 (Fig. 2b, Appendix 1). In Latvia in 2016 the cultivars had a markedly higher TKW value compared to 2015. In contrast, the TKW of seven cultivars and six six-rowed landraces in Kyrgyzstan were much more similar between the two years and without any obvious trends. However, in Latvia there were only two cultivars – ‘Cecilia’ and ‘Mari’ (Swedish), plus one landrace ‘Obyknovenyi 1’ (Russian) – that differed by having a consistent TKW in both years (Fig. 2a-b). The TKW of Kyrgyz cultivars was comparatively stable when the two countries were compared, and only three Swedish cultivars had a constant TKW.

Conclusions

Evaluation of breeding material through different eco-environmental conditions allows for a better understanding of the studied material in order to reveal new sources of useful adaptive traits for breeding programs. In our study the response to various environmental conditions was different depending on each agronomic trait. The TKW and NGS were comparatively stable in advanced cultivars than landraces. There are some superior cultivars, including ‘Saana’, ‘Sencis’, ‘Cecilia’, ‘Mari’ and ‘Mette’ from (Sweden and Latvia), which can be preferred as suitable material for the Kyrgyz barley breeding program for earliness, plant height, spike length and number of kernels, whereas among the six-rowed cultivars, ‘Jyva’, ‘Lavrance’ and ‘Local 2’ can be used for earliness, spike length, and NGS.

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Conflict of Interest

The authors declare no conflict of interest.

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