Relationship between Grain Yield and Agronomic Traits in Winter Barley

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Summary: Grain yield is one of the most important and complex traits in cereal breeding and depends upon a combination of different plant traits. Therefore, an effective breeding program requires a proper understanding of the relationships between grain yield and agronomic traits. The objectives of this study were the evaluation of two-rowed winter malting barley genotypes and the perceiving of relationships among grain yield and their agronomic and quality traits. The trials with 19 two-rowed winter malting barley genotypes were conducted during three years. The relationships among plant lodging, height, thousand kernel weight, hectolitre mass, grain protein content and grain yield, were studied by PCA biplot analysis. The results showed that the influence of year, genotype and genotype by year interaction on barley grain yield were significant. Further, results indicate that two-rowed winter malting barley grain yield can be improved by selecting plants of average plant height with thousand kernel weight above 41.0 g and grain protein content of about 11.0 g 100^{-1}g dm.

Keywords: agronomic traits, barley, biplot, genotype, grain yield, *Hordeum vulgare*, PCA, quality

Introduction

Barley (*Hordeum vulgare* L.) is one of the most important small-grained cereal crops, placing fourth in world cereal production, after maize, rice and wheat (FAOSTAT 2014). In Serbia, barley production occupies between 90,000 and 100,000 ha across the country and it is used for livestock feed, malt, food and seed production (FAOSTAT 2014). Climate conditions in the Pannonian plain show large and unpredictable variations across different cropping seasons (Pržulj & Momčilović 2012). Moreover, Olesen et al. (2011) predict that climate change will increase the occurrence of undesirable years for crop production. As a response to these changeable environmental conditions, it is necessary to define selection objectives and identify a winter barley ideotype which would be used as a model for the creation of new advanced cultivars. The barley ideotype should possess good tolerance to drought and harsh winter conditions and additionally tolerate variations and extremes in temperature and precipitation. The ideotype should also be suited to diverse conditions of cultivation (Rasmusson 1987).

Modern barley breeding is largely directed towards the development of genotypes characterized with increased yield potential, wide adaptation and high responses to agronomic inputs (Pržulj et al. 2014). Although yield is the universal breeding objective, an effective breeding programme requires a proper understanding of the essential traits and the relationships among them (Yan & Kang 2003). Several agronomic and technological traits such as lodging (LOG), plant height (PH), thousand kernel weight (TKW), hectolitre mass (HM) and grain protein content (GPC) have significant influence on barley grain yield and quality. LOG is a major constraint limiting the yield and quality of barley (Jedel & Helm 1991). Certain plant characteristics such as long and thin stems and excessive vegetative growth make plants susceptible to lodging. Despite the fact that HM and TKW have lost significance in the past decades, they are still important indicators of barley quality. TKW has a positive relationship with starch content which is desirable for brewers since it is a source of fermentable sugars (Savin & Molina-Cano 2002). Furthermore, numerous recent studies found positive relationship between HM and malt and feed quality (Fox et al. 2006, Fox et al. 2007).

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Considering the presence of reverse correlation between GPC and malt extract, GPC is one of the most important traits influencing malt quality (Wright 2000). Often as result of the competition for photo-assimilates, increase of one trait tends to be followed by change in other trait (Slafer et al. 1996), and therefore, it is necessary to correctly understand interrelationships between them.

Different statistical analysis, such as correlation, path coefficient and principal component analysis (PCA) can be used to reveal associations between yield and other agronomic traits. PCA has been widely used in plant sciences for reducing variables and grouping genotypes (Eticha et al. 2010). This method has been exploited to identify trait interrelationships in different varieties of spring barley (Žáková & Benková 2006), maize (Kamara et al. 2003) and wheat (Mladenov et al. 2012).

The objective of this study was the evaluation of winter two-rowed malting barley genotypes across three

growing seasons and assessing the relations among their agronomic and quality traits.

Materials and Methods

The genetic material for this study consisted of 19 two two-rowed winter malting barley genotypes (G1-G19) developed at the Institute of Field and Vegetable Crops, Novi Sad, Serbia (Tab. 1). The experimental plot size was 5 m², with the sowing rate of 400 kernels per m². The plots were 1.0 m wide and 5 m long, with 0.1 m spacing between rows. The trials were conducted during three growing seasons (2009/10, 2010/11 and 2011/12), arranged in randomized complete block design with three replications, at Rimski Šančevi experimental field near Novi Sad (45°20´N and 19° 51´E). Standard agricultural practices were applied in all trial seasons.

Table 1. Genotype abbreviation, pedigrees of the tested genotypes and relative maturity

Genotype abbr.	Pedigree	Relative maturity
G1	Irla/Novosadski 525	E
G2	Posanee/NS 523	ME
G3**	Novosadski 535 – L. 107-87/Sladoran	ME
G4	Belivia/Novosadski 525	ME
G5	Novosadski 525/Sonja	ME
G6	Astrid/ Novosadski 529	ME
G7	Novosadski 333/Alpha	ML
G8	Sonate/Novosadski 331	L
G9**	Novosadski 595 – Sonate/Novosadski 525	E
G10	Korten/Novosadski 293// Novosadski 525	ML
G11	Rex/3/Astrid/Novosadski529//Novosadski 525	E
G12	Obzor/Novosadski 293//Novosadski 519	ME
G13	Novosadski 331/Sonate	ML
G14	Novosadski 331/Amethyst	ME
G15	NS 509/Alpha	E
G16	Novosadski 525/Jagodinac	ML
G17	Alpha/Astrid//Sladoran	ME
G18	Marylin/Sonate//NS 541	ME
G19	NS 507/Vanesa//Boreale	ML

*E, early; ME, medium early; ML, medium late; ** standard variety

The severity of LOG (%) was recorded as a percentage of the plot lodged at the stage of anthesis. TKW (g) was determined from measuring three sets of 300 grains per plot and expressed as the weight of 1000 grains. HM (kg hl^{-1}) was determined by measuring a known volume of the natural seed sample. Grain nitrogen concentration was obtained by Kjeldahl analysis and GPC expressed on dry weight basis was estimated by multiplying grain N by 6.25 (Yuen et al. 1953). YLD (t ha^{-1}) was determined for combine-harvested plots in each of the three replications. Moisture content was determined using a grain analysis computer (Model GAC2100, Dickey-John, Auburn, IL) and grain yield was corrected to 140 g kg^{-1} moisture.

Data were processed using two-way analysis of variance, with software STATISTICA 10. Means were compared using Duncan's multiple range test (Steel & Torrie 1980). Principal component analysis (PCA) was used to determine interdependence between the traits.

Results and Discussion

This study showed that the year (Y) was mainly responsible for variation of studied traits (LOG, PH, HM and YLD) in two-rowed winter malting barley (Tab. 2). Further, genotype (G) and genotype by year interaction (G × Y) effects explained the highest percent of TKW and GPC variations, respectively.

In Table 3 LOG, PH, TKW, HM, GPC and YLD means for the 19 genotypes across three growing seasons are presented. Duncan's test showed existence of significant difference between these means in all examined traits (p<0.01). The highest lodging rate was observed in the 2009/10 growing season. Among tested genotypes, G1 was resistant,

while G8 was susceptible to LOG. In PH, 84.1% of total variation was accounted for by Y effect and their interactions with G. According to different authors (Pržulj et al. 2010, Gholipoor et al. 2013), optimum PH for modern barley cultivars ranges from 90 – 105 cm. Across years and genotypes, average PH value of 100.9 cm was within this range. Genotype G12 had the highest average PH, while G17 had the lowest one. Across growing seasons, genotypes G4, G10 and G19 had the highest TKW, while the lowest TKW was recorded in G18. As reported by Pržulj et al. (2014), cultivars with medium-sized grains (41-44 g) are more suitable for malting, because they soak uniformly and rapidly. Average genotype HM across years varied from 73.4-76.6 kg hl^{-1}, with G19 showing the highest value.

Due to the presence of the high G × E interaction, one genotype can have low GPC in one year and high GPC in another (data not shown), which complicates selection of barley genotypes with desirable GPC (Falconer & Mackay 1966). The permitted range of GPC for production of European lager beer ranges from 9.5 to 11.5% (Pettersson & Eckerster 2007). Accordingly to this range, G6, G11, G13, G14 and G15 are not suitable for beer production, and they should be excluded from further malting barley trials and redirected to feed production.

More than half of the variation in barley YLD was under the effect of Y (57%), while G explained one fifth of variation (21%). High percentage of total variation explained by Y indicates that climate conditions varied considerably between different seasons. The genotypes G4, G10 and G19 had the highest, and G8 had the lowest YLD across the years. Across cultivars, the lowest YLD value was recorded in 2009/10 and the highest in 2010/11.

Table 2. ANOVA mean squares and percentage of variance components for lodging (LOG), plant height (PH), thousand kernel weight (TKW), hectolitre mass (HM), grain protein content (GPC) and grain yield (YLD)

Source of variation	df	LOG (%)	PH (cm)	TKW (g)	HM (kg hl^{-1})	GPC (g 100^{-1}g dm)	YLD (t ha^{-1})
G	18	405.72**	39.63**	41.51**	9.92**	2.34**	2.39**
Y	2	61486.78**	3687.98**	157.94**	585.42**	15.93**	58.32**
G × Y	36	390.13**	27.33**	15.50**	8.29**	1.18**	1.01**
Residual	114	42.19**	7.64**	0.26**	0.26**	0.04**	0.08**
% of variation							
G		4.90	7.17	45.25	10.64	34.70	21.00
Y		82.46	74.17	19.13	69.79	26.24	57.00
G × Y		9.42	9.89	33.81	17.79	35.04	17.71

** significant at 0.01 probability level

Table 3. Average values of lodging (LOG), plant height (PH), thousand kernel weight (TKW), hectolitre mass (HM), grain protein content (GPC) and grain yield (YLD) in 19 advanced barley genotypes

Genotype	LOG (%)	PH (cm)	TKW (g)	HM (kg hl^{-1})	GPC (g 100^{-1} g dm)	YLD (t ha^{-1})
G1	16.7[g]	98.0[gh]	42.2[d]	75.5[cd]	11.1[ghi]	9.14[bcd]
G2	33.9[abc]	104.0[ab]	42.8[bc]	74.9[e]	10.1[l]	8.38[hi]
G3	23.9[def]	99.9[defgh]	38.7[gh]	75.3[cde]	11.4[e]	8.74[ef]
G4	28.9[cd]	101.2[bcdef]	43.5[a]	76.1[b]	11.2[fgh]	9.58[a]
G5	25.2[def]	98.5[fgh]	39.9[f]	75.0[de]	11.3[efg]	9.27[bc]
G6	30.8[cd]	101.6[bcde]	41.2[e]	73.6[fgh]	11.7[d]	9.27[bc]
G7	37.7[ab]	101.4[bcdef]	40.0[f]	73.4[h]	11.0[hij]	8.61[fgh]
G8	39.6[a]	101.4[bcdef]	35.8[i]	73.6[fgh]	11.0[ijk]	7.78[j]
G9	21.7[efg]	100.4[defgh]	41.5[e]	74.1[f]	10.9[jk]	8.96[de]
G10	15.6[g]	98.5[fgh]	43.5[a]	76.08[b]	11.1[ghi]	9.62[a]
G11	24.9[def]	103.0[abc]	42.2[d]	76.6[a]	12.4[a]	9.43[ab]
G12	29.6[cd]	105.0[a]	41.3[e]	75.2[cde]	11.2[fgh]	8.49[ghi]
G13	28.3[cde]	102.2[abcd]	40.4[f]	75.7[bc]	12.0[b]	8.50[fghi]
G14	32.8[bc]	99.1[efgh]	42.4[cd]	75.0[de]	11.8[d]	9.03[cd]
G15	38.0[ab]	102.0[abcde]	39.1[g]	75.3[cde]	11.9[bc]	8.72[efg]
G16	27.8[cdef]	103.5[ab]	41.3[e]	73.9[fgh]	11.1[ghi]	8.30[i]
G17	26.9[cdef]	97.4[h]	38.3[h]	74.1[fg]	10.8[k]	9.39[ab]
G18	30.7[cd]	99.8[defgh]	37.6[i]	73.6[gh]	11.4[ef]	8.69[efg]
G19	20.9[fg]	100.9[bcdefg]	43.2[ab]	76.6[a]	11.1[fgh]	9.59[a]
Year						
2009/10	65.8[a]	102.7[b]	39.0[c]	71.3[c]	11.8[a]	8.13[c]
2010/11	5.9[c]	107.9[a]	41.1[b]	76.2[b]	11.3[b]	10.06[a]
2011/12	12.5[b]	92.1[c]	42.3[a]	77.3[a]	10.8[c]	8.57[b]
Average	28.1	100.9	40.8	74.9	11.3	8.92

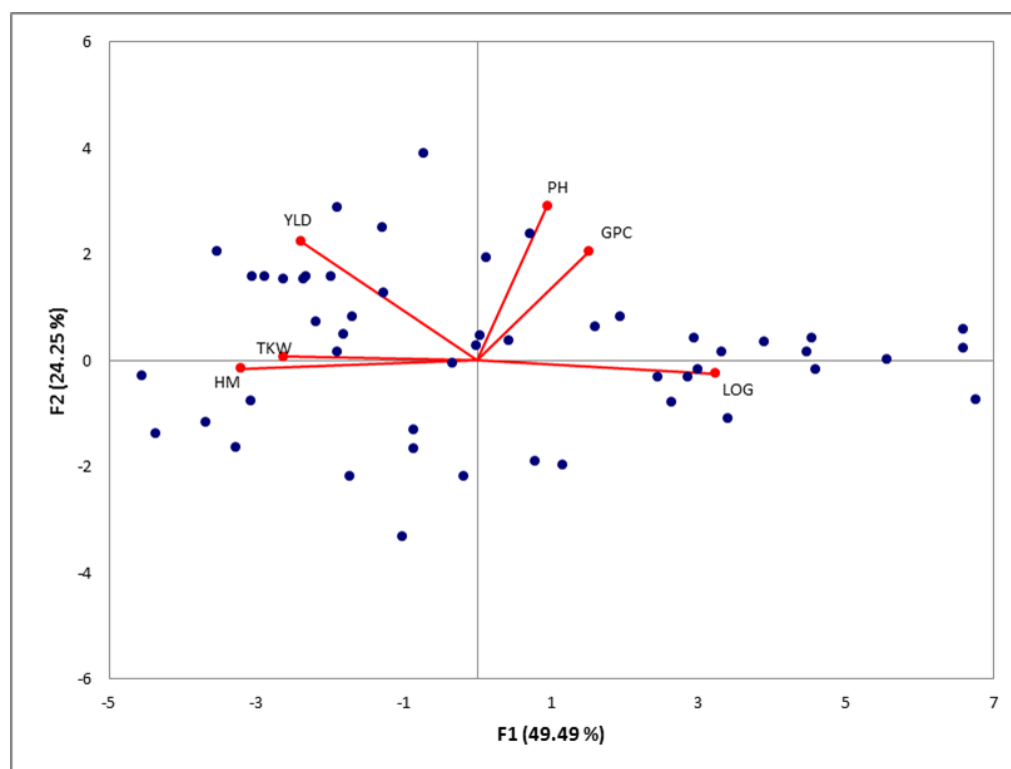Different letters indicate significant difference at $P < 0.05$ level.

Figure 1. PCA analysis of trait relationship (lodging – LOG. plant height - PH. thousand kernel weight - TKW. hectolitre mass - HM. grain protein content -GPC and grain yield - YLD) in winter barley across three growing seasons

The biplot of the principal component analysis illustrates relationships between the studied barley traits for all three growing seasons pooled together (Fig. 1). First PCA explained 49.5% of total variation, while second PCA explained 24.5%. Together, both axes accounted for 73.7% of the total variation in the data. According to the biplot, PCA1 relates predominantly to TKW, HM and LOG, while PH was mostly related to PCA2.

YLD is one of the most important and complex traits in cereal breeding and its continuous improvement remain the top priority during the development of new varieties worldwide (Yan et al. 2007). YLD depends upon a combination of different yield components and plant traits, such as TKW, HM, PH, LOG (Pržulj et al. 2014). Therefore it is important to reveal relationship of these traits and YLD. Moreover, the identification of important traits for selection and the phenotypic expresion of desired traits are also essential for the development of the two-rowed winter malting barley ideotype.

According to Figure 1, YLD had a positive relationship with TKW and HM. On the other hand, Deniz et al. (2009) reported that TKW had negative direct effect on barley grain yield. TKW was negatively associated with GPC. Similarly, Pržulj & Momčilović (2008) reported significant negative correlation between these two traits. Since high protein level result in unacceptable malt quality (Chen et al. 2006), malting barley breeding programs should focus on the selection of genotypes with increased TKW.

PCA showed that YLD had no relationship with PH. The absence of relationship between YLD and PH can be explained by the observation that taller plants potentially have an increased capacity to store assimilates in vegetative organs for the re-translocation to grains during grain filling period (Slafer et al. 1996), however these plants are more susceptible to lodging, leading to decreased yield (Inostroza et al. 2009).

Breeding for lodging resistance represents an important goal during the development of new varieties, since susceptibility to lodging often results in yield and quality reduction (Jedel & Helm 1991). LOG had a strong negative relationship with YLD, HM and TKW. Thus, genotypes susceptible to lodging had low yielding potential and should be excluded from breeding trials (Fig. 1). In agreement with this study, Pearson et al. (1989) and Berry et al. (2004) showed that besides the significant grain yield loss, LOG reduces grain HM, TKW, percent plump kernels, kernel numbers and increased percentage of thin kernels. Further, Jadel & Helm (1991) reported that barley YLD loss depends from the growth stage when LOG occurred. Lodging before grain filling results in partial seed development, while lodging at maturity disables mechanized harvest and exposes plants to disease attack. Since factors that cause lodging may occur at different stages of plant development in different seasons, it is difficult to develop lodging resistant cultivars in field (Pržulj & Momčilović 2012).

Conclusions

This study showed significant effects of Y, G and G × Y interaction on barley yield and other agronomic traits. Three genotypes, G10, G19 and G4, can be distinguished because of their increased TKW and high yield potential. Biplot analysis revealed positive relationship between grain yield and TKW and HM, while LOG and grain yield were negatively associated. Conducted experimentation shows that the grain yield increase in winter two-rowed malting barley can be achieved by selecting plants with optimized/indifferent plant height more resistant to lodging with higher TW (above 41.0 g), lower GPC (about 11.0 g 100^{-1} g dm) and also by acknowledging analogous connection to cytolytic and proteolytic malt degradation. Also, selection should be directed against plant lodging.

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Povezanost između prinosa zrna i agronomskih osobina ozimog pivskog ječma

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Sažetak: Prinos zrna je jedna je od najznačajnijih i najsloženijih osobina u procesu oplemenjivanja strnih žita koja zavisi od većeg broja svojstava biljaka. Uspešni programi oplemenjivanja zahtevaju pravilno poznavanje povezanosti između prinosa i različitih agronomskih osobina. Cilj ovog ispitivanja je bila ocena genotipova ozimog pivskog ječma i asocijacija između pojedinih agronomskih osobina i prinosa zrna. PCA biplot analiza je korištena za proučavanja povezanosti između poleganja, visine, mase hiljadu zrna, hektolitarske mase, sadržaja proteina i prinosa zrna kod 19 genotipova ječma. Rezultati su pokazali značajan uticaj godine, genotipa i interakcije genotip-godina na ispitivane osobine ječma. Takođe, utvrđeno je da se prinos zrna ozimog pivskog ječma može unaprediti odabirom biljaka optimizovane visine otpornih na poleganje sa višom masom hiljadu zrna (preko 41,0 g) i nižim sadržajem proteina u zrna (oko 11,0 g 100^{-1}g dm).
Ključne reči: agronomske osobine, biplot, genotip, *Hordeum vulgare*, ječam, kvalitet, PCA, prinos zrna