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BREEDING BARLEY (*Hordeum vulgarae* L.) FOR ABIOTIC AND BIOTIC LIMITING FACTORS

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Abstract

This paper presents breeding work on malting and forage barley, specifically focusing on increased tolerance to abiotic and biotic stresses. Breeding for yield is generally aimed at improving certain yield components that directly or indirectly contribute to its realisation. Apart from high yield potential, new genotypes should have adequate drought resistance (tolerance) to be achieved by identifying sources of beneficial genes and ways to maintain or improve grain yield in dry years. The long-term traditional selection process and evidence of climate change demand a breeding strategy targeting adaptation to future production conditions in small grains, primarily barley and wheat. Selecting widely adaptable genotypes that produce stable yields and show resistance to economically important diseases and tolerance to different biotic and abiotic factors indirectly contributes to increasing the yield and quality of malting and forage barley.

Key words: *barley, breeding, length of growing season, lodging, drought*

Introduction

Cereals are the most widely grown crops in the world, accounting for about 61% of the total arable land (Leff et al., 2004). Among cereals, wheat ranks first in terms of land area, followed by maize, rice and barley (Takeda et al. 2008). In the first decade of this century, barley was annually grown on 57 million ha, with an average production of 140.8 million t grain and an average grain yield of 2.6 t ha^{-1}.

Since the early work on developing new barley cultivars, the main goal has been to increase grain yield potential. Apart from an increase in yield potential, new cultivars should have increased resistance to lodging (Dencic et al., 1992; Przulj et al., 2000; Przulj and Momcilovic, 2002). In the 1980s and 1990s, grain yield remained a permanent goal in creating new cultivars, with breeding being further expanded to include other traits, primarily quality and resistance to biotic and abiotic limiting factors (Knezevic et al., 2007).

Grain yield also depends on many other factors, such as length of growing season, lodging resistance, cold resistance, disease and pest resistance, etc. Directional selection has resulted in the creation of local cultivars of malting and forage barley belonging to the continental ecotype, which yield grain that exhibits good technological traits even under these conditions. Breeding programmes have involved the use of genotypes originating from Eastern Europe as donors of genes conferring adaptability to semi-arid conditions, as well as the use of genotypes originating from Western Europe as donors of genes providing good quality.

Selection for length of growing season

Earliness is a very important trait in barley adaptation to a production region. Under optimum growth conditions, longer growing seasons lead to increased grain yields. This trait is of greater importance for northern and upland regions located at higher altitudes (1000 m a.s.l. and above) where growing seasons are considerably shorter, with earliness often playing a decisive role in obtaining satisfactory yields. This trait is equally important in arid regions. Although yield is theoretically positively correlated with length of dry matter accumulation, higher yields under Serbian production conditions are produced by short-season cultivars. Early-maturing cultivars manage to produce most of their yield before the dry period, whereas forced maturity and reduced grain yield and quality occur in late-maturing cultivars (Pržulj and Momčilović, 1998). High yields and good grain traits require uniform optimum grain filling. Forced maturity in barley leads to poor starch accumulation, a low percentage of large uniform-sized grains and a higher dry matter content. Even under no-stress growing conditions, long-season cultivars spend a large part of dry matter to form vegetative parts; therefore, their yields may be lower that those of early-maturing cultivars (Borojević and Wiliams, 1992).

However, in any production region, there are external factors constraining plant growth and development and, hence, largely determining the most favourable length of growing season for the particular production region. A certain length of growing season may be favourable for one production region but unfavourable for another. Therefore, breeding for length of growing season should also be adjusted to environmental conditions. Among the environmental factors, the highest effect is produced by temperature, day length, altitude, humidity and soil fertility. Length of growing season in the selection process is generally determined by number of days from emergence until earing.

Among the Novi Sad cultivars of winter malting barley, Novosadski 293 takes the longest to put forth ears (193 days); the growing season of new cultivars is 4-5 days shorter, whereas spring malting barley cultivars have a growing season of about 60 days (Pržulj and Momčilović, 1998).

Selection for drought resistance

Drought is a major environmental stress factor that limits crop production in many countries worldwide. Changes in regional climate are expected to include reduced rainfall, lower soil moisture, reduced water availability and more frequent extreme climate events (drought, heat waves, storms accompanied by precipitation, etc.) during the warm part of the year. Similar changes have been observed at the local level (Dodig 2004). Irrigation is the most comprehensive operation that can help mitigate the adverse effects of drought stress. Yet, only about 5.3% of Serbia's arable land is irrigated (Bošnjak, 1999). Both worldwide and in Serbia, barley is generally grown without irrigation. In order to solve the drought problem, breeding work should result in more resistant cultivars and adaptation of production technology to unfavourable drought conditions. To date, there has been no breeding strategy for drought resistance in wheat and barley in Serbia. Instead, breeding work was focused on developing genotypes showing high yield potential under optimum conditions that subsequently proved suitable for cultivation under dry conditions (Dodig 2004). As emphasised by Quarrie et al. (1999), progress in breeding for drought resistance can be achieved through selection for specific traits to improve plant water supply and, hence, increase water use efficiency and harvest index.

Drought resistance refers to the ability of a plant to adapt to a deficiency of soil water (soil drought) or air humidity (air drought) for some time, without any significant decrease in yield size and quality. Drought resistance, particularly in the early period of plant development, is an important trait in spring barley.

The degree of drought-induced damage is dependent on a number of factors, notably stage of plant development during dry weather, drought intensity and length of drought.

Susceptibility to soil moisture deficiency shows variations across growth and development stages. The highest susceptibility is found in germinated seeds, emerging plants and young plants. Water deficiency at this stage induces poor development of the root system and, hence, the aboveground parts of the plant. Small grains also show susceptibility during earing, resulting in non-uniform earing, flowering and fertilisation, as well as in grain shrivelling.

Selection for drought resistance involves choice of plants that do not reduce their yield under dry conditions. Cultivars highly resistant to drought have been created under frequent long-term drought conditions (e. g. Central Asia). The inclusion of these cultivars in European breeding programmes can contribute to their increased resistance. Being tolerant of drought, some cultivars have relatively good agronomic and technological traits. Drought tolerance is controlled by polygenic inheritance, being determined by complex physiological processes, such as root absorption capacity, cell sap concentration, unbound water amount, etc.

Most barley production regions do not have optimum cultivation conditions due to inadequate water and temperature regimes during plant development and crop growth. Downing (1995) stated that southern parts of Europe would become more deficient in rainfall, whereas northern Europe would become more humid. Putarić (1996) reported a 1-1.5 ^{o}C increase in average temperature in Vojvodina during 1930-1965, and an annual decrease of 1.3 mm in rainfall. Jovanović et al. (1996) observed that the severest droughts in the Republic of Serbia occurred after 1980, with drought spreading into regions where it had not occurred previously. A number of other authors have also observed the effects of climate change in the Serbian region including reduced amounts of available water and increasing temperatures, which forces breeders to create genotypes whose development rhythm will be largely adapted to the present climate conditions. Recently, important results in selecting barley for drought have been achieved using molecular markers. When adapting plant species to agroenvironmental conditions, particular importance is given to development genes since they exert a pleiotropic effect on numerous traits, including stress tolerance, among others (Foster et al., 2000).

Breeding barley for disease resistance

Assessment of disease-induced yield reduction is sometimes made difficult due to the absence of visible symptoms. Some diseases lead to reduced crop density and vigour, which can be partially compensated for by fertilisation and use of intensified cultural practices. Other diseases cause grain shrivelling, reduction in hectolitre weight and/or quality deterioration. Disease-induced losses can be reduced by the use of resistant tolerant cultivars, a higher level of production technology and fungicide applications (Pržulj and Momčilović 1995).

The largest problem in barley selection is a high pathogen variability causing resistant cultivars to rapidly become susceptible. Therefore, the selection process is considered completely successful if the production of a wheat or barley cultivar is maintained for 5-7 years. There are examples of cultivars retaining resistance to certain pathogens for a long period of time. Resistant cultivars exert pressure on pathogens, since only part of the pathogen population harbouring virulence genes for the cultivar are developed on them. This part of the population expands, causing changes in pathogen structure and relationship. In this way, cultivars favour the multiplication of pathogens to which they are resistant and become susceptible to them after several years. Susceptibility also occurs as a result of the emergence of new pathogen strains that are virulent to the cultivar. Therefore, plant selection for pathogen resistance is a long-lasting process (Borojević, 1992).

Table 2. Major resistance genes against 15 fungal pathogens, four virus and two pests in barley (Chelkowski et al. 2003; Weibull et al. 2003)

Gene symbol	Pathogen, Pest & Disease	# of Genes
Rph	*Puccinia hordei* (leaf rust)	17
Rpg	*Puccinia graminis* (stem rust)	4
Rps	*Puccinia striiformis* f. sp. *hordei* (stripe rust of barley)	4
Ml (Mlo, Mla, MILa&Reg)	*Blumeria graminis* f. sp. *hordei* (*Bgh*) (powdery mildew)	23
Rcs	*Cochliobolus sativus* (spot blotch)	5
Rpt	*Pyrenophora teres* (net blotch)	6
Rdg (Rhg)	*Pyrenophora graminea* (barley stripe)	3
Rrs (Rh)	*Rhynchosporium secalis* (scald)	14
Run (un)	*Ustilago nuda* (loose smut)	8
Ung	*Ustilago nigra* (semi-loose smut)	1
Ruh	*Ustilago hordei* (covered smut)	4
Rsp	*Ustilago hordei* (covered smut)	3
Rti	*Typhula incarnate* (gray snow mold)	1
Fb	*Fusarium* ssp. (scob)	1
Ryd	BYDV (barley yellow dwarf virus)	2
Rym	BaYMV (barley yellow mosaic virus) Ba MMV (barley mild mosaic virus)	13
Rsm	BSMV (barley stripe mosaic virus)	5
Rsg	*Schizaphis graminum* (green bug aphid)	3
Rha	*Heterodera avenae* (cereal-cyst nematode)	3

As estimated from more than 15,700 literature references and 3,700 field trials, an average disease-induced yield loss in barley is 10.5 % (Oerke and Dehne, 1997). Jorgensen (1988) published a list containing 83 loci rendering resistance to important barley diseases. Graner (1996) provided an extensive review of molecular mapping of qualitative and quantitative disease resistance loci. Current state of resistance study and breeding for resistance were summarised by Kleinhofs and Han (2002), Chelkowski et al. (2003) and Weibull et al. (2003). Barley plants are mainly susceptible to fungal and viral diseases (Tab. 2). Fungal diseases include powdery mildew, scald, rust diseases (leaf rust, stem rust) and others. Barley is attacked by several viruses, viz. barley yellow dwarf virus, cereal yellow dwarf virus, barley mosaic virus, wheat dwarf virus, etc.

A summary of reported QTL in barley includes 757 QTL which cover the whole barley genome for abiotic stress resistance, agronomic traits, biotic stress resistance (Tab. 2), quality traits and others (Hayes et al, 2003).

The cultivars developed at the Small Grains Research Centre in Kragujevac exhibit satisfactory resistance to major (or important) barley diseases, primarily leaf rust, stem rust and powdery mildew.

Conclusion

Barley breeding through improvement in certain components has resulted in new cultivars that have high yield potential. Today, yield increases are much more difficult to attain than they were before. Breeding should be further expanded to include other traits, primarily quality and resistance to biotic and abiotic limiting factors. Apart from high yield potential, new genotypes should have adequate drought resistance (tolerance) to be achieved by identifying sources of beneficial genes and ways to maintain or improve grain yield in dry years.

The long-term traditional selection process and evidence of climate change demand a breeding strategy targeting adaptation to future production conditions in small grains, primarily barley and wheat. Selecting widely adaptable genotypes that produce stable yields and show resistance to economically important diseases and tolerance to different biotic and abiotic factors indirectly contributes to increasing the yield and quality of malting and forage barley.

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