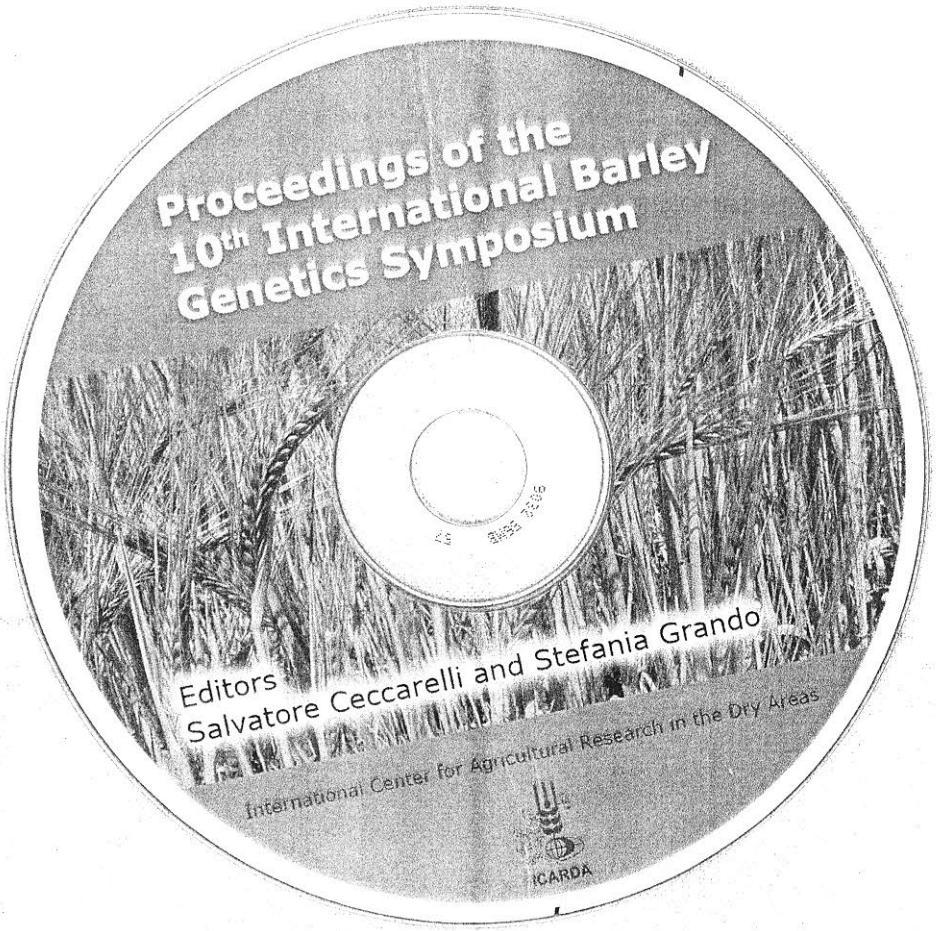

Proceedings of the 10th International Barley Genetics Symposium

Editors
Salvatore Ceccarelli and Stefania Grando

International Center for Agricultural Research in the Dry Areas
Aleppo

Citation:
Ceccarelli, S. and Grando, S. (eds) 2010. Proceedings of the 10th International Barley Genetics Symposium, 5-10 April 2008, Alexandria, Egypt. ICARDA, PO Box 5466, Aleppo, Syria. pp xii + 794.

ISBN 92-9127-246-9

International Center for Agricultural Research in the Dry Areas (ICARDA)
PO Box 5466, Aleppo, Syria
Tel: +963 21 2213433, 2213477
Website www.icarda.org

The evolution of barley in Brazil: contributions of Embrapa in 30 years of research and development

E. Minella
Embrapa Trigo, Caixa Postal 451, Passo Fundo, RS, 99001-970, Brazil.

Abstract

Increased beer consumption since 1920 has challenged scientists and farmers to establish malting barley production in Brazil. The major challenge has been adapting barley to give an economic yield under the natural acid soil and wet and warm growing conditions of Brazil. Currently, malt consumption is 1.1×10^6 t/yr while production is 0.3×10^6 t/yr. Barley production increased substantially from 20 to 70% of the supply needs of the malt industry. The increasing trend is attributed to yield and quality improvements that have established barley as a competitive crop. This competitiveness is mainly due to the results of 30 years of research and extension at Embrapa (Brazil Agricultural Research System). The widespread use of Embrapa's technologies, including varieties, the "No-Till" Production System (NTPS), crop agronomy and protection since the early 1990s have increased yield from 1500 kg/ha in the 1980s to 2500 kg/ha today. Since the release of BR 2, Embrapa varieties have gained grower preference, taking up 70% of the acreage. Varieties resistant to net blotch, a very limiting factor, have reduced fungicide use. Current modern short, lodging-resistant, varieties (e.g. BRS 195, BRS Greta) are more competitive in the NTPS, where improved soil properties and production technologies boost the yield of barley to 6000 kg/ha in favorable seasons. Varieties Embrapa 127 and BRS Borema match closely the quality of known elite malting cultivars under Brazilian environmental conditions.

Introduction

Barley was firstly introduced into Brazil in 1586, but became a crop only in the 20th Century, when commercial production started in 1930, although only production for malting has been competitive in economic terms. The only barley used for feed is the amount produced annually that does not meet malting quality. Production has evolved but is still concentrated in southern Brazil in regions where cool springs favor malting quality. Major growing areas are between latitudes 24° and 31° S, in the highland plateaus (400 to 1100 masl) of Rio Grande do Sul, Santa Catarina and Parana states. The regional climate is classified as a Koppen's cfa (humid subtropical), with rainfall well distributed throughout the year and a mean temperature in the warmest month of >22°C. Barley is sown in late autumn to early winter, following a summer crop of soybean or maize, in the traditional double cropping system area. The crop cycle is completed in 110–140 days, depending on the variety, location, planting date and seasonal temperature and rainfall regimes. Harvesting takes place from late October to early December. Subsoil acidity causing aluminium toxicity is a recurrent problem; the originally acid soils restrict root growth beyond the limed layer, making barley more vulnerable to moisture stress than the more acid-soil tolerant crops such as wheat and oats. Rainfall during the growing season averages 700 mm. High seasonal and regional variability in the amount and distribution of rainfall are the major limiting

factors affecting yield and quality. Excessive rainfall during the reproductive stage, particularly in El Ninho Southern Oscillation (ENSO) years, is the most unfavorable environment for malting quality. Seasonal drought or temperature stresses (heat, frost) at critical stages, and fungal and virus diseases, are other major limiting factors. Since 2000, a small amount of malting barley has been produced under irrigation in tropical Brazil in the states of São Paulo, Goiás and Minas Gerais.

The objective of this paper is to present 30 years of effort by and research results of Embrapa in attempting to tailor barley to be a competitive crop in the acid soil and high rainfall growing conditions of southern Brazil.

Barley production

Since the beginning of commercial barley production in Brazil it has been produced under contract between farmers and the malting-brewing industry. The malting industry provides seed of varieties they want to malt and buy the production that meets the quality standards established in the contract. In the beginning, and for some time, the seed distributed by the industry was imported, mainly coming from Argentina. Local production was small and confined to the Rio Grande do Sul, Santa Catarina and Parana states, in areas where forest had been cleared for agricultural production by settlers of European origin, mainly German, Italian and Russian. Until the end of the 1950s, barley was produced manually or using animal power and only on high-pH, fertile soils, while wheat and rye were grown on poor acid soil lands suitable for mechanization. Locally selected varieties more tolerant to soil acidity/aluminum toxicity allowed barley to grow in the mechanized areas, boosting production during the 1960s, when acreages of up to 40 000 ha were recorded. Average grain yield on-farm was then close to 1 t/ha. Production almost disappeared early in the 1970s due to frequent crop failures and competition from the international market.

The Federal Government barley and malt self-sufficiency plan launched in 1976 boosted both barley production and the capacity of the malting industry. As part of the plan, Embrapa, the Ministry of Agriculture Agricultural and Livestock Research System founded in 1973, was assigned the task of providing the requisite scientific and technical support. Embrapa, through its National Wheat Research Unit, started working with barley in 1976, with the mission of expanding, diversifying and coordinating all the country's research and development efforts on the crop.

The public support for research and production finally established malting barley as a commercial crop in southern Brazil, giving the farmers an alternative winter crop to grow on the stubble of a summer soybean or maize harvest. Rio Grande do Sul and Paraná have since become the major barley and malt producing states, with Rio Grande do Sul leading with an average of 60% of total production. Since 2000, barley has also been produced in small amounts, under irrigation, in Goiás and DF in central Brazil and São Paulo in the southeast.

Publicly-funded support to barley production ended by the late 1980s, leaving the fate of local production to the whim of the malting industry. Higher production costs than for other winter crops, mainly due the susceptibility of varieties to net blotch, then the major disease, and the lower price of imported barley, reduced local acreage to the levels of late 1970s. Domestic production started recovering in 1995, with the release the variety BR 2 by Embrapa, the first Brazilian variety resistant to net blotch. It was widely adapted and highly competitive in grain yield, and suitable for production under the NTPS production system then beginning to be adopted in the region. The increased competitiveness of barley under NTPS, as

well as price increases in the international market, made domestic production interesting again to the brewing industry. Malting barley production in the last decade averaged 310 000 t/yr, supplying 60 to 70% of current malting capacity, which produces around 30% of the country's brewing malt requirement. Brazil is a major malt importer and domestic brewing consumption has steadily increased in recent years, indicating an increased demand for both malt and barley. Current trends indicate a significant increase in local malting capacity in a few years, and a consequent increased demand for malting barley. Considering the current agronomic and quality competitiveness of barley, it can be postulated that there will be a steady growth in both acreage and production of malting barley in Brazil.

Barley research

Public barley research was initiated together with that on wheat in 1920. During the 1930 to 1975 period, research was carried out by the brewing industry, interested in malting barley production, with little or no support from government institutions. Major efforts then were directed to breeding, soil improvement and crop agronomy. Under the leadership of Embrapa, research efforts significantly increased after 1976, with inputs from state research systems, universities and farmer organizations. Besides breeding, during the official support to domestic production, barley benefitted from a substantial amount of research on crop production and crop protection. Unfortunately, cuts in official incentives to the crop negatively affected the resources allocated to barley research from public sources.

Since 1990, Embrapa is practically the sole public institution with significant research inputs in barley. In the private sector, AmBev and Coopertiva Agraria run individual research programs, with major efforts in variety development and crop agronomy. Academic studies on barley are almost inexistent today. Embrapa Trigo runs a malting barley breeding program with formal technical and financial support from the malting industry (currently AmBev, Cooperativa Agraria and Malteria do Vale). Since its onset, Embrapa's breeding program work has integrated with the research and quality analysis capabilities of the malting industry. The varieties obtained from the program are incorporated into commercial production through the partners' seed production and farmer technical assistance apparatus, after intensive agronomic and malting quality evaluation.

Embrapa's barley improvement program was implemented in 1976, at the National Wheat Research Center, located in Passo Fundo, RS (28°15' S, 52°24' W, 687 masl), one of the country's most important barley production regions. Since its beginning, the major goals of the program have been the assembling of an enhanced and broad germplasm pool and developing new barley cultivars adapted to local soil and weather conditions and showing competitive yield, malting quality, and disease resistance. Collecting viable seeds from the locally developed germplasm and from exotic genetic material was the first task of the program. Cultivars and breeding lines made available by the brewing companies Brahma and Antarctica and by the state institutions IAPAR (Paraná) and IAC (São Paulo) became the germplasm base. Crossing work started in 1978, aiming to develop breeding lines by combining the locally-adapted superior malting lines with known sources of disease resistance from the USDA world collection, Australia, Canada, Europe, South America, and USA.

The program has been pursuing the idea that to be competitive under local conditions a phenotype (ideotype) should combine the largest possible number of the following traits: acceptable malting quality; high yield potential (over 3000 kg/ha for rainfed and

5000 kg/ha for irrigated conditions); kernel plumpness over 85%; early maturity (<140 days for rainfed and <120 days for irrigated conditions); short straw (<80 cm); resistance to lodging and to pre-harvest sprouting (PHS); and disease resistance (net blotch, powdery mildew, leaf rust, BYDV, spot blotch and head scab). The methodology applied has evolved from strictly conventional breeding to a combination of the available conventional and modern methods. Nowadays, 30% of crosses made are advanced through Single Seed Descent (SSD) and Doubled-Haploid (DH) methods, and 70% through selected bulks up to the F_4. DHs are produced through anther culture. Using SSD, the materials are advanced by three generations per year. Selection for adaptation to soil and environmental conditions and for disease resistance is made under field conditions, under natural and artificial pathogen infection. Selection for malting quality is delayed until the line selection stage, based on the industry's quality analysis output.

Results

The Embrapa research program has been underway for more than 30 years now, and both the germplasm developed and the knowledge generated have made substantial contributions to the consolidation of a malting barley industry in Brazil, and also, in a wider context, to the knowledge on the performance of the crop in acid soil subtropical/tropical areas (Minella and Sorrells, 1992, 1997, 2002; Peruzzo and Arias, 1996). During this period local barley production experienced significant progress. Compared with the 1970s, when Embrapa started researching barley, average acreage has tripled (304%), production is six-fold (603%) and yield has doubled (207%) (Table 1).

During the 1980s the average farm grain yield increased almost 30% due mainly to improved agronomy and plant protection practices developed by Embrapa and partners. Significant improvements were obtained in the geographical distribution of production (production zoning); seeding time and density; soil fertility increases through liming and P and K amendments; N fertilization; and disease (mainly net blotch) and insects (mainly aphids) control methods. The aphid population that was causing severe cereal crop losses was brought under control through a massive release of introduced natural enemies.

During the 1990s the observed yield increase in farmers field was even greater than during the 1980s, one major factor being the difference resulting from the wide use of Embrapa cultivars, which became available to farmers after 1992 (Tables 1 and 2), and the adoption by most of the producers by the end of the decade of NTPS practices (Silva and Minella, 1996; Minella, 2000).

The release of BR 2, Embrapa's first true malting barley, in 1989 has been credited as a cornerstone in both barley breeding and production in Brazil (Minella *et al.*, 1999) Due to its earliness, short straw, wide adaptation, high yield potential and resistance to net blotch, BR 2 was the leading variety for 12 years (1994 to 2003). It was sown on over 80% of the acreage, peaking at 91% in 1997. Its wide use allowed a reduction of at least one fungicide spray against net blotch, thus lowering both production cost and impact on the environment. The net blotch resistance of BR 2 and derivatives continues to be as effective as it was 20 years ago. It is believed that the use of BR 2 represented a 40% yield increase, bringing back the competitiveness of the local crop in comparison with home grown wheat or imported barley.

Barley production was resumed with the release of the Embrapa cultivars in 1995 and is currently stabilized at around 310 000 t/yr, satisfying on average 65% of the malting capacity. Before the advent of the Embrapa varieties and the introduction of NTPS technology, the country was importing on average 70% of the barley used for malting.

Table 1. Current average acreage, production and yield as absolutes and percentages relative to the 1970s for malting barley in Brazil

	Acreage		Production		Yield	
	(ha)	% of 1970s	(t)	% of 1970s	(kg/ha)	% of 1970s
1970s	42 962	100	50 018	100	1 124	100
1980s	102 947	239	146 884	293	1 459	130
1990s	93 812	218	197 230	394	2 036	181
2000s	138 425	322	311 233	622	2 250	200
Last Decade[1]	130 638	304	301 851	603	2 328	207

[1] Data for 1997–2006.

Table 2. Evolution of the malting barley crop in Brazil in the last 15 years.

Year	Acreage (ha)	Production (t)	Yield (kg/ha)	Embrapa (%)[1]
1992	57 018	117 835	2 067	5.0
1993	62 184	105 702	1 700	30.4
1994	53 269	98 176	1 843	45.6
1995	73 462	117 811	1 654	81.5
1996	83 575	223 981	2 680	89.5
1997	124 909	277 604	2 222	91.1
1998	137 720	310 383	2 253	90.2
1999	123 894	314 895	2 542	86.3
2000	136 664	307 303	2 249	65.0
2001	135 640	274 888	2 027	60.0
2002	145 156	224 403	1 546	51.0
2003	136 971	381 220	2 783	63.0
2004	146 803	395 277	2 692	73.0
2005	127 961	282 245	2 207	72.7
2006	90 661	250 291	2 761	57.6
Last 10 years	130 638	301 851	2 328	71.0

[1] Proportion of the acreage seeded with Embrapa varieties.

In this century, the average yield is 10% higher of that of the 1990s, and this increase has been attributed to the release and wide use since 2003 of the high yielding, short straw and lodging resistant variety BRS 195 (Minella, 2005) and to greater use of nitrogen when growing this cultivar. Because of its superior yield potential and acceptable lodging resistance in areas for several years under NTPS (chemical, physical and biologically improved soils), BRS 195, released in 2002, has been the leading variety in both rainfed and irrigated areas. In general, it yields 1000 kg/ha more than the regular (non-dwarf) varieties. Lodging has become a major problem for regular type varieties in soils with a long history under the NTPS production system.

The average malting quality of Brazilian produced barley has also improved substantially (Table 3), and varieties Embrapa 127 and BRS Borema (Minella *et al.*, 2006) have a malting quality profile competitive with those of world top varieties, such as cv. Scarlett.

Table 3. Progress in malting barley traits in Brazil in the last 30 years

Trait	1970	2000	Change (%) 1970–2000
Grain yield (kg/ha)	1 124	2 250	200
Kernel plumpness (%)	65.0	90.0	138
Barley protein (%)	12.5	9.5	76
Malt extract (%)	79.0	82.5	104

The release of BRS 180 six-row barley in 1999 (Silva *et al.*, 2000), was the starting point for the production of malting barley in the cerrado region (Goiás and Minas Gerais states) under pivot irrigation. Since 2005, there has been limited production for malting in irrigated areas of São Paulo, where BRS 195 has been competitive in yield and also malting quality. Due to the long distance from the irrigated areas of Goiás and Minas Gerais to the nearest malting plant (São Paulo), production in those regions is not yet competitive with imported barley and currently is not happening. Major yield limiting factors in the cerrado have been lodging and occasional occurrence of rice blast caused by *Pyricularia grisea*.

The soil improved production capacity under NTPS has doubled the yield potential of barley and nowadays productivities >6000 kg/ha in the farmer's fields are already common in favorable seasons. The yield potential of BRS 195 under irrigation is >8000 kg/ha. In areas under NTPS for more than a decade, barley has been also much less affected by acidity and/or aluminum toxicity of the subsoil than when soil was tilled. A negative effect associated with the NTPS production system consolidated in southern Brazil, has been the increased occurrence of head scab (*Fusarium graminearum*) and spot blotch (*Bipolaris sorokiniana*) diseases. Reducing losses due to these fungi to acceptable levels is currently the major challenge for barley researchers, mainly plant pathologists, breeders and agronomists. The level of genetic resistance to these pathogens in current cultivars is far below the desired one, and the variability in the germplasm being used is not promising for a genetic solution of the problem.

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