ADVANCED TOPICS IN SCIENCE AND TECHNOLOGY IN CHINA

Guoping Zhang
Chengdao Li
Editors

Genetics and Improvement of Barley Malt Quality

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ADVANCED TOPICS
IN SCIENCE AND TECHNOLOGY IN CHINA

ADVANCED TOPICS IN SCIENCE AND TECHNOLOGY IN CHINA

Zhejiang University is one of the leading universities in China. In Advanced Topics in Science and Technology in China, Zhejiang University Press and Springer jointly publish monographs by Chinese scholars and professors, as well as invited authors and editors from abroad who are outstanding experts and scholars in their fields. This series will be of interest to researchers, lecturers, and graduate students alike.

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Preface

Barley is ranked second in the industrial use of grain and is projected to total 27.4 million tonnes in 2008. A significantly high value use of barley is for malting to produce malt as a raw material for the production of beer. Obviously, malting quality is the primary objective of various barley research and breeding programs around the world as there is a premium for malting quality in many markets. Conventional approaches to the improvement of malting quality have been very successful in the last decade and this is especially true for Australia. Recently, releases of new malting barley varieties Baudin, Hamelin and Flagship resulted in a quantum leap in Australian malting barley quality. Knowledge of the physiological processes, the biochemistry of the pathways involved and the genetic control of these processes and their interaction with the environment has made a great contribution to the development of new malting barley varieties with excellent malting quality.

The world malting barley market keeps expanding constantly and it may be expected that the global demand for malt will increase by 27% to reach 19 million tonnes by 2010. At the same time, brewing style tends to be diversified significantly in order to meet different market requirements. As such, there are different quality requirements for different brewing styles. In addition to the traditional malting quality parameters, including malt extract, malt protein, soluble protein, Kolbach Index, free amino nitrogen, diastatic power, apparent attenuation limit, wort viscosity, alpha-amylase, beta glucanase and wort beta-glucan, new requirements for mouth-feel, flavor, haze, foam head retention and antioxidants have increased the complexity of malting quality improvement. It is one of the objectives for us in writing this book to address these challenges based on current knowledge.

The improvement in malting quality appears to have peaked in some countries. Lack of genetic variation in the current germplasm presents a major challenge for further quality improvement. Chapter 2 provides a comprehensive overview of the genus Hordeum, the relationships of the species among the genus, the origin and evolution of cultivated barley, and utilization of barley germplasm in breeding, including some successful examples and the potential for improvement of cultivated barley. The information about the Qinghai-Tibetan Plateau barley should be interesting to some readers. Diastatic power (DP) has long been used as an indicator for starch degrading enzymes and fermentability. Recently, a new DP enzyme analysis method was developed and a better model for prediction of fermentability was proposed.

In Chapter 6, a new malting paradigm was thus outlined where selection of the appropriate barley variety, growing location and malting conditions was described, providing the maltster sufficient latitude to produce malt within an appropriate range of fermentability characteristics to satisfy brewers varying requirements.

The endosperm cell wall can have direct and often detrimental effects on various processes in the brewery and on the quality and shelf life of the final beer. The same wall components can have indirect effects on other quality characteristics, such as malt extract and fermentability. Chapter 7 provides updated information on the chemical composition, the structures of individual constituents, synthesis and metabolism of cell walls. Most of genes/QTLs controlling malting quality have been mapped. Marker-assisted selection (MAS) has evolved from selection of single gene/traits toward multiple traits/loci and the whole genome. Simple and rapid DNA extraction methods as well as high-throughput MAS systems make marker assisted selection more efficient and cost-effective for malting barley breeding, as presented in Chapter 9.

Chapter 8 outlines how the new genomics data and approaches may enhance our understanding of malting quality. The chapter detailes two genomics platforms and how these technologies can potentially be applied to address malting quality traits. Both platforms are excellent examples of international collaboration in barley research. China is the world's largest and fastest growing beer market. It is also the largest malting barley importer. Australia is the largest malting barley supplier for China. This book is a symbol of collaboration between Australian and Chinese barley researchers. We deeply believe such collaboration to be not only of benefit for both countries but also to the whole barley industry around the world. We'd like to thank China's National Natural Science Foundation and the Australian Grain Research and Corporation for their support on the specific projects.

This book is divided into nine chapters, including barley production and consumption, germplasm and utilization, chemical composition, protein and protein components, carbohydrates and sugars, starch degrading enzymes, endosperm cell walls and malting quality, genomics and malting quality improvement, and marker-assisted selection for malting quality. We hope that the information present here will be especially useful to barley breeders, malsters, brewers, biochemists, barley quality specialists, molecular geneticists and biotechnologists. This book may also serve as reference text for postgraduate students and barley researchers. The authors for each chapter are the experts and frontier researchers in the specific areas. We appreciate their great efforts in providing updated information and sharing their specialist knowledge. We would like thank the authors for their outstanding and timely work in producing the chapters.

Guoping Zhang, Hangzhou, China
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Feb. 28, 2009

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1

Barley Production and Consumption

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1.1 Introduction

Barley (*Hordeum vulgare*) is a very important grain in the world today. It ranks fourth in both quantity produced and in area of cultivation of cereal crops in the world. The annual world harvest of barley in the late century was approximately 140 million tonnes from about 55 million ha. It is very versatile in every way and has well adapted through its evolution. In fact, it is the most adaptable cereals. Much of the world's barley is produced in the regions where cereals such as maize and rice can not grow well. It extends into the arctic or subarctic. Some species approach the subtropical Zone. *Hordeum* species are found in most areas with Mediterranean climate. The genus is also represented in zones with an oceanic as well as a continental climate (Rasmusson 1985). Barley also has a very good resistance to dry heat compared to other small grains. This feature allows it to grow near desert areas such as North Africa.

Barley is a cereal. It belongs to the grass family. There are three types of barley: 1) *Hordeum vulgare*: a six-rowed type of barley that has a spike notched on opposite sides with three spikelets on each notch. At each notch, there is a flower or floret that later develops into a kernel. 2) *Hordeum distichum*: a two-rowed type of barley that has central florets producing kernels and it has lateral florets that are sterile. 3) *Hordeum irregulare*: the least cultivated, with fertile central florets and varying proportions of fertile and sterile lateral florets.

Barley has a very debatable origin. Egypt or China is most likely the centre for the origin of cultivated barley. Barley cultivation is also evident in other parts of the world at later times. For example, north-western Europe is estimated to have been cultivated barley around 3000 BC. Since barley is so old and records of trade were non-existent, the real answer for the origin of barley will probably never be known. The pathways for the domestication of barley also have some points in doubt. The earliest known and most probable ancestor of barley was the two-rowed variety. Most indications point to *spontaneum* as the most probably immediate ancestor of cultivated barley, and all the six-rowed forms are the results of accumulated mutations and hybridization. The ancestor of *spontaneum* was a form with more or less developed lateral spikelets, perhaps male-fertile like *H. murinum* and *H. bulbosum*. Barley cultivation probably originated in the highlands of Ethiopia and in Southeast Asia in prehistoric times. It is believed to extend back to 5000 BC in Egypt, 3500 BC in Mesopotamia, 3000 BC in north-western Europe, and 2000 BC in China. Barley was the chief bread plant of the Hebrews, Greeks, and Romans and most Europeans through the 16th century.

Barley has many economic uses today. Barley is produced primarily as animal feed. For example, over half of the barley is used for livestock feed in the United States. Barley as feed has the same nutritive value as corn. Barley is high in carbohydrates, with moderate amounts of protein, calcium and phosphorus. It also has small amounts of vitamin B. The entire barley kernel is used as feed after it has been steam rolled or gone through a grinding process. By products from the brewing process and malt sprouts are also used in livestock feed. The two-rowed barley is most often used for animal feed because it produces higher weight and superior kernel production. Barley is also used in the production of beer and some wines. About 25% of the cultivated barley in the United States is used for malting, with about 80% used in beer production, 14% used in distilled alcohol production, and 6% used for malt syrup, malted milk, and breakfast foods. A small amount of the barley is used for human food in the form of pearl barley or flour for porridge. Sometimes, barley is grown as a hay crop in some areas. Only the smooth varieties and awnless varieties are used in hay production. Winter barley also can be used for hay if pasteurized before the stems start to elongate. The amount of barley used for ethanol has been increased significantly in the last decade, especially in some EU countries (www.biofeulreview.com).

1.2 World Barley Production

Barley production traditionally has been important in the world. The total area harvested each year is around 50~80 million ha and ranked 4th after wheat (~200 million ha), rice (120~150 million ha) and corn (100~150 million ha) (Fig. 1.1). In the recent two decades, the area has been declining from more than 80 million ha to around 55 million ha. Among the major barley production countries, Russia and other countries from former USSR, United States, India, China are the major countries showing the significant decrease in barley cropping area (Fig. 1.2). The production area in the USSR has decreased from around 30 million ha in the 1980s to around 17 million ha recently with Russia being one of the major countries showing a significant decrease (from more than 16 million ha in the 1980s to around 10 million ha in the 2000s). In the United States, the production area has reduced from around 5 million ha in the 1960s to around 1.4 million ha recently. Barley was replaced by more commercially attractive corn and feed wheat in the feed mix. The Chinese barley production area has reduced from more than 5 million ha in the 1960s to less than 0.8 million ha today. India showed a similar trend to China, from more than 3 million ha to less than 0.8 million ha, but the decrease in the barley production area is mainly due to the significant increase in the wheat production area (from 13 million ha to 28 million ha) while the Chinese wheat production area has been relatively consistent or even reduced slightly. In contrast to the above major barley production countries, Australia showed a significant increase in production area, from 1 million ha in the 1960s to 4 million ha in the 2000s, mainly due to the total increased cropping area.

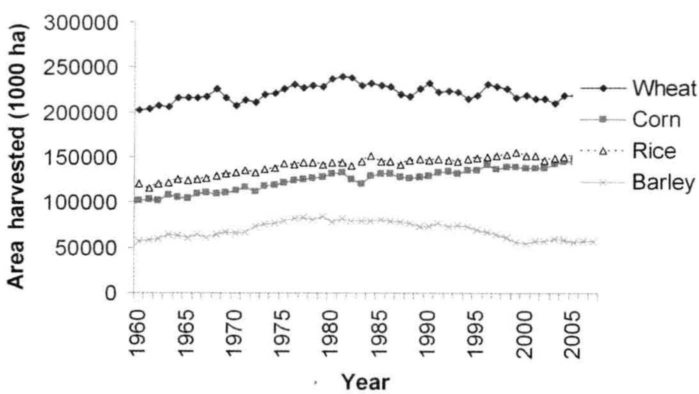

Fig. 1.1. World production of corn, rice, wheat and barley: area harvested

The average yield of the major cereal crops has been continuously increasing since the 1960s (Fig. 1.3). The increasing rate in the average yield for corn was much higher than that for other crops with the average yield of corn being increased by nearly 1.5 times (from 2.0 tonnes/ha in the 1960s to nearly 5 tonnes/ha in the 2000s) in the last 45 years. Even though the average yield of barley had increased from 1.4 tonnes/ha in the early 1960s to 2.4 tonnes/ha in the 2000s, compared to other crops barley showed a lower increasing rate in the average yield, mainly due to the fact that relatively less resource was allocated to barley variety improvement. The EU has a consistently higher yield than other countries. But China is closing the gap with the fastest increasing

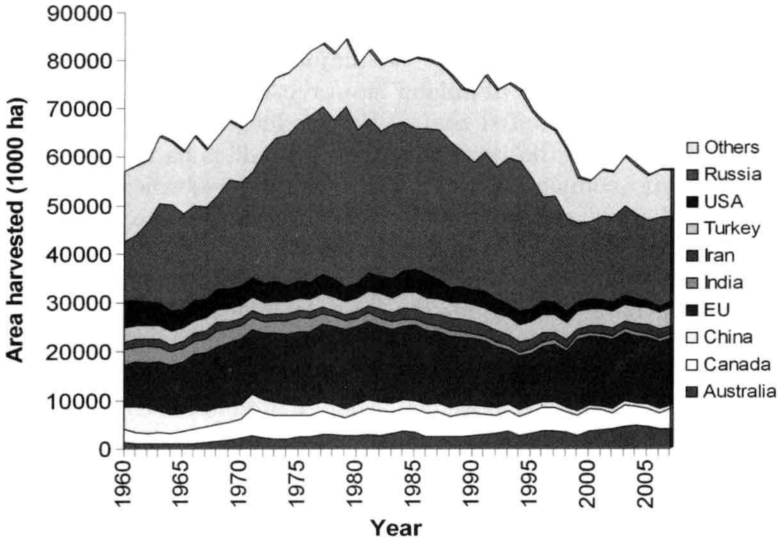

Fig. 1.2. World production of barley (including major barley production countries): area harvested

rate. The average yield of barley in China, increased by nearly 3 times in the last 45 years, from 1 tonnes/ha in the 1960s to 4 tonnes/ha in the 2000s (Fig. 1.4). The slight decrease in world barley yield in the last couple of years was caused by severe drought in some countries such as Australia with its yield dropping from 2.15 tonnes/ha in 2005 to 0.95 tonnes/ha in 2006 (Fig. 1.4). Of the other major barley production countries shown in Fig. 1.2, USA and Canada showed a slightly higher yield and increasing rate than the world average, while USSR, Turkey, Iran and India had similar yields to Australia and all below the world average.

World barley production increased from about 100 million tonnes in the 1960s to more than 170 million tonnes in the mid-1980s and decreased to 140 million tonnes in the 2000s. In contrast, the total production of wheat, rice and corn has been increasing continuously with production in the recent years, being nearly three times that in the early 1960s. For example, corn production was 200 million tonnes in 1960 and it has increased to 768 million tonnes in 2007 (Fig. 1.5). The increase in the total production of barley is mainly due to the increase in yield (Fig. 1.4) since the production area was relatively steady or even decreased in recent years (Figs. 1.1, 1.2). Among the major barley production countries, USSR, USA, India and China all showed a significant decrease in total barley production due to decreased production area (Fig. 1.2). In contrast, the total production in the EU, Turkey, Iran and Australia has been increasing and was quite steady in recent decades. The decreased