

Chapter 1

Barley production and consumption

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1. Introduction

Barley (*Hordeum vulgare*) is a very important grain in the world today and it ranks the 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 hectares. It is very versatile in every way and has been well adapted through its evolution. In fact, it is the most adaptable of the cereals. Much of the world's barley is produced outside of the regions where cereals such as maize and rice can 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 that belongs to the grass family *Poaceae*. 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; and 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 also seems to have been evident in other parts of the world at later times. For example north-western Europe is estimated to have cultivating barley around 3000 BC. Since barley is so old and records of trade were non-existent back then, 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 probably of the two-rowed variety. Most indications point to *spontaneum* as the most probable 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 of much of Europe through the 16th century.

Barley has many economic uses in today. Barley is produced primarily as animal feed. For example, over half of the barley grown in the United States is used for livestock feed. 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 the B vitamins. 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. It is found that 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% being 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 produced barley is used for human food in the form of pearl barley or in the form of flour for porridge. Sometimes barley is grown as a hay crop in some areas. Only the smooth varieties or 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).

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). 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 (including all the countries from former USSR), United

States, India and China are the major countries showing the significant decrease in barley cropping area (Fig 2). The production area in USSR has decreased from around 30 million ha in 1980's to around 17 million ha recently with Russia being one of the major countries showing significant decrease (from more than 16 million ha in 1980's to around 10 million ha in 2000's). In United States, the production area has reduced from around 5 million ha in 1960's to around 1.4 million ha recently. Barley was replaced by commercially more attractive corn and feed wheat in the feed mix. The Chinese barley production area has reduced from more than 5 million ha in 1960's to less than 0.8 million ha today. India showed the similar trend with 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 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 above major barley production countries, Australia showed significant increase in production area, from 1 million ha in 1960's to 4 million ha in 2000's, mainly due to the total increased cropping area.

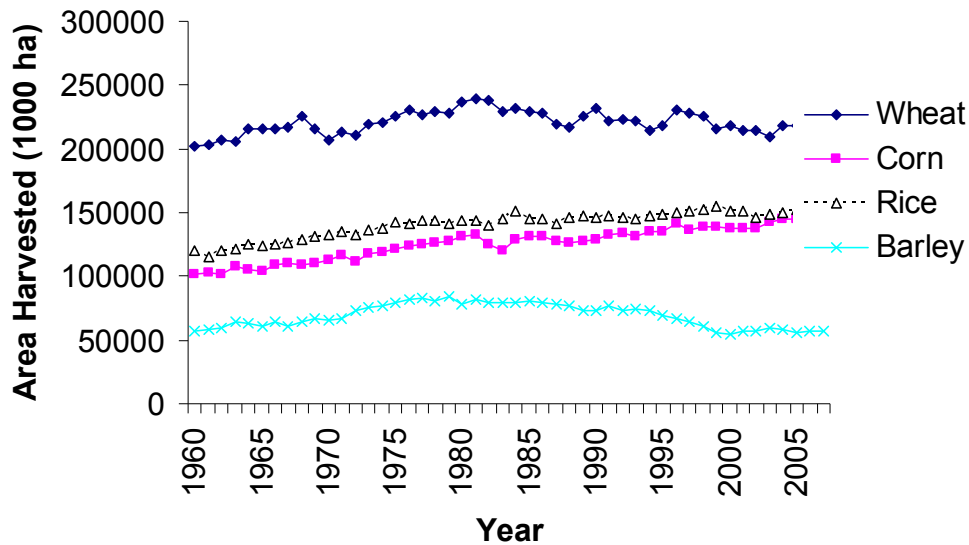


Fig 1 World production of corn, rice, wheat and barley: area harvested (Statistics from United States Department of Agriculture)

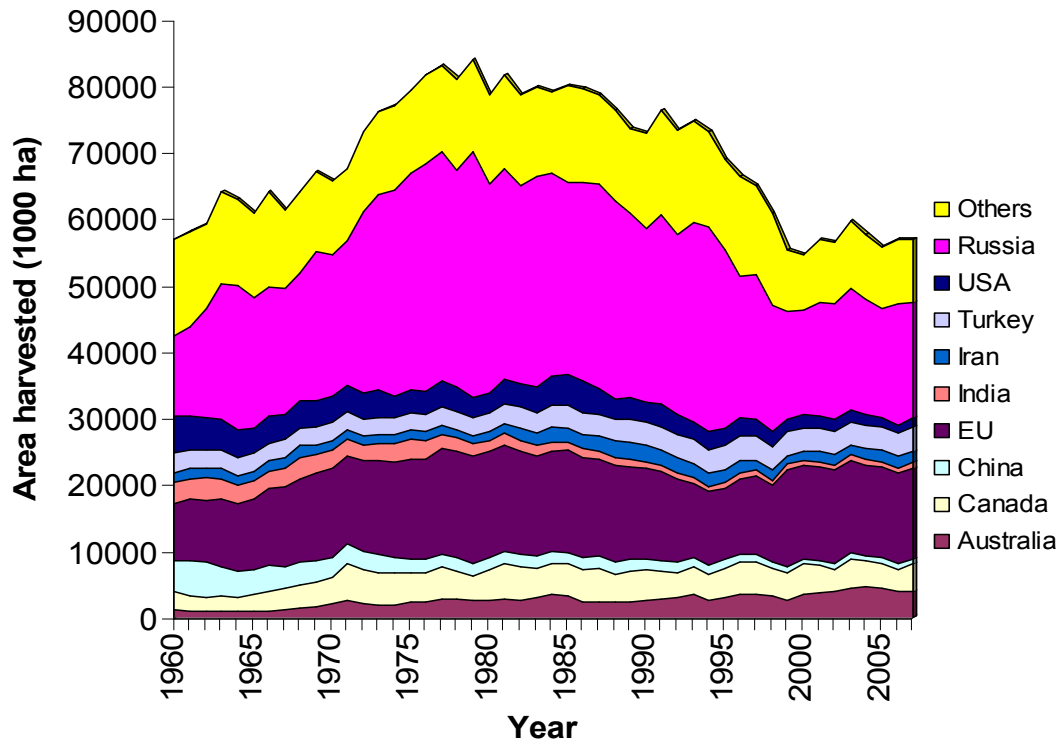


Fig 2 World production of barley (including major barley production countries): area harvested (Statistics from United States Department of Agriculture)

The average yield of the major cereal crops have been continuously increasing since 1960s (Fig 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 ton/ha in 1960's to nearly 5 ton/ha in 2000's) in the last 45 years. Even though the average yield of barley had increased from 1.4 ton/ha in early 1960s to 2.4 ton/ha in 2000s, compared to other crops, barley showed a lower increasing rate in the average yield, mainly due to that relatively less resource was allocated to barley variety improvement. EU has consistently higher yield than other countries but China is closing the gap with fastest increasing rate, which saw the average yield of barley in China being increased by nearly 3 times in the last 45 years, from 1 ton/ha in 1960s to 4 ton/ha in 2000s (Figure 4). The slight decrease in world barley yield in the last a couple of years was caused by severe drought in some countries such as Australia with its yield dropped from 2.15 ton/ha in 2005 to 0.95 ton/ha in 2006 (Figure 4). Of the other major barley production countries shown in Figure 2, USA and Canada showed slightly higher yield and increasing rate than the world average, while USSR, Turkey, Iran and India had similar yield to Australia and all below the world average.

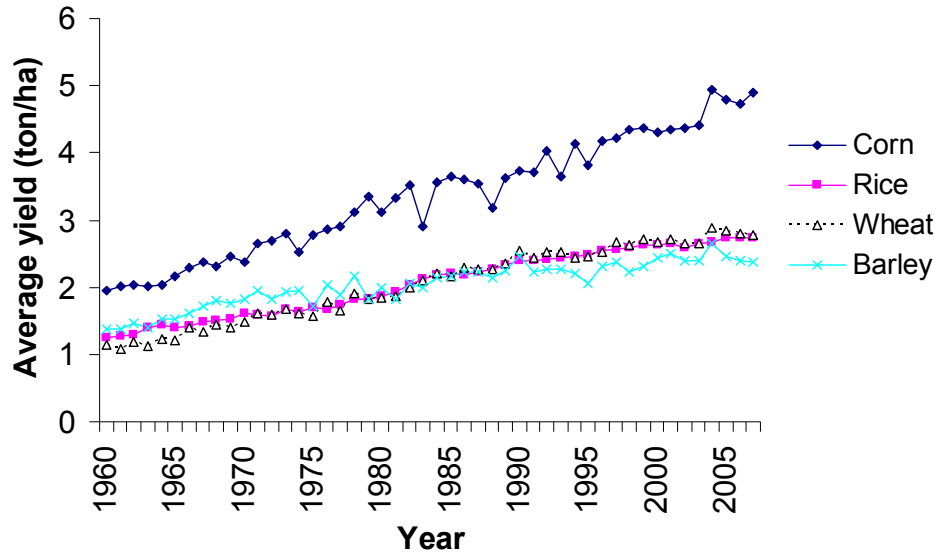


Fig 3 Average yields of corn, rice, wheat and barley (Statistics from United States Department of Agriculture)

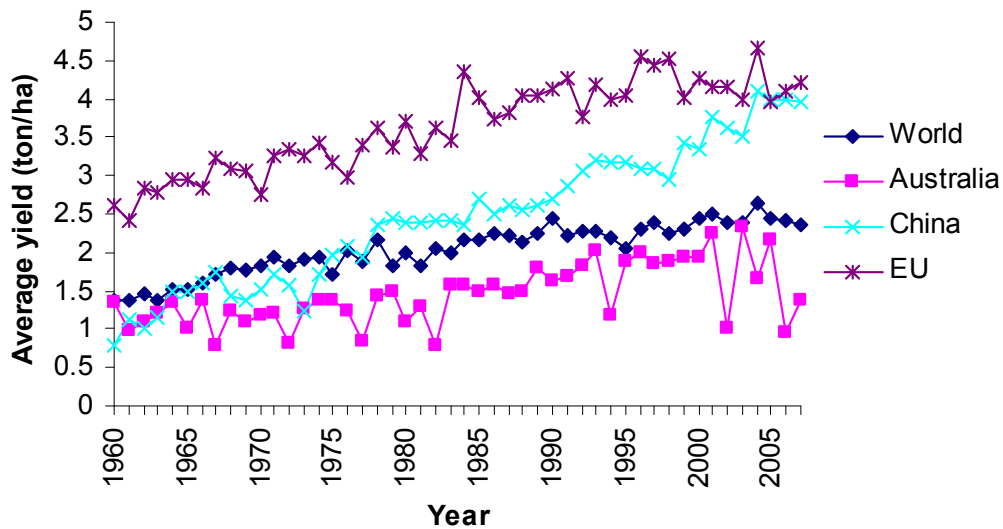


Fig 4 Average yields of barley in Australia, China, EU countries and worldwide (Statistics from United States Department of Agriculture)

The world barley production increased from about 100 million tonnes in 1960's to more than 170 million tonnes in mid-1980's and decreased to 140 million tonnes in 2000s. In contrast, the total production of wheat, rice and corn has been increasing continuously with the production in the recent a few years, being nearly three times of that in early 1960s. For example, corn production was 200 million tonnes in 1960 and it has increased to 768 million tonnes in 2007 (Fig 5). The increase in the total production of barley is mainly due to the

increase in yield (Fig 4) since the production area was relatively steady or even decreased in the recent years (Figs 1, 2). Among the major barley production countries, USSR, USA, India and China all showed significant decrease in total barley production due to decreased production area (Fig 2). In contrast, the total production in EU, Turkey, Iran and Australia has been increasing and was quite steady in the recent a few decades. The decreased production in Australia in 2002 and the recent two years was mainly caused by severe drought (Fig 6). Heat and dryness were also contributed to the decreased production of barley in USSR in 2007, especially in Ukraine which saw its total production reduced from 11.4 millions tonnes to 6.2 million tonnes.

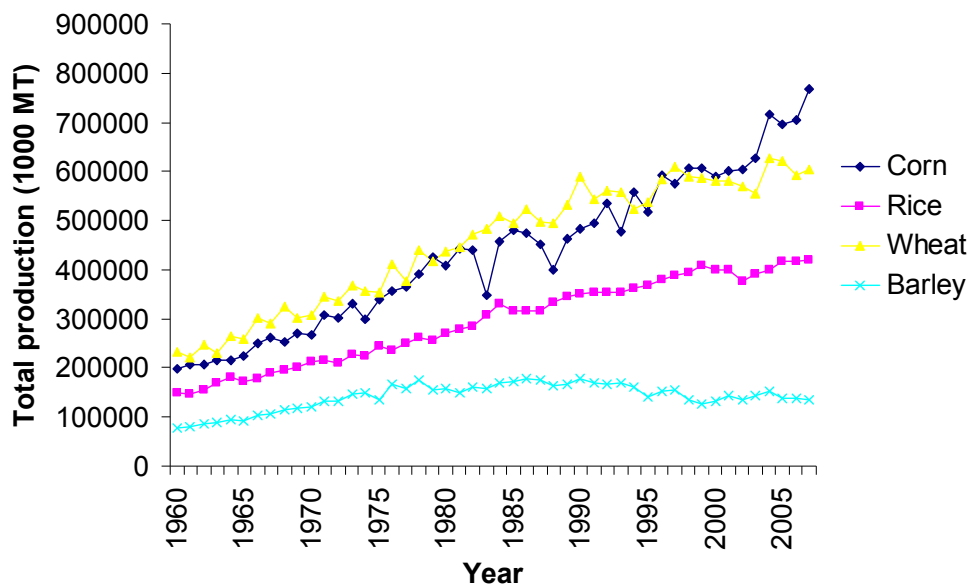


Fig 5 World production of corn, rice, wheat and barley: total production (Statistics from United States Department of Agriculture)

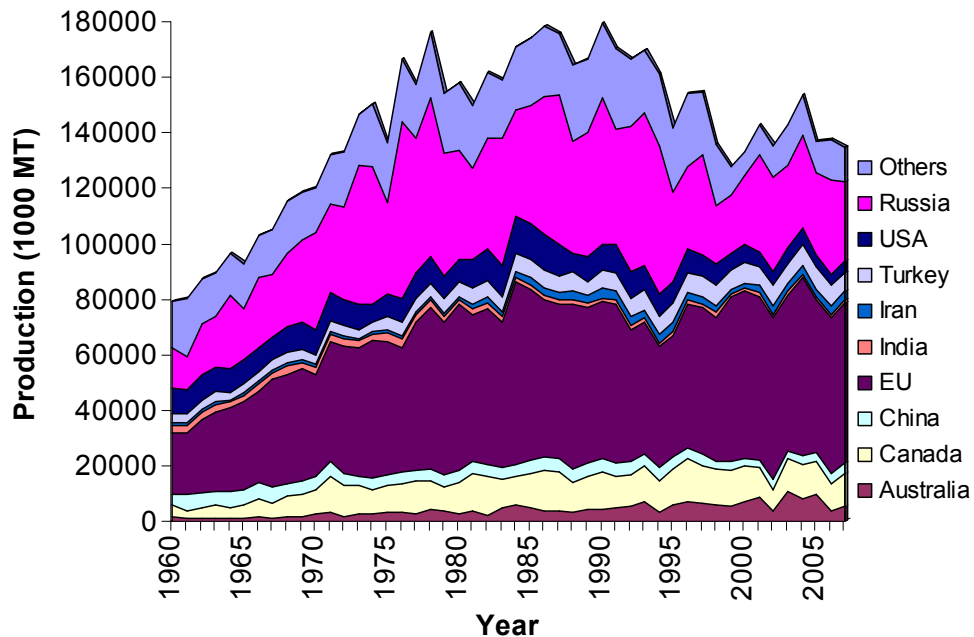


Fig 6 World production of barley: total production, including major barley production countries (Statistics from United States Department of Agriculture)

3 World barley trade

Barley trade accounts about 7% of total production before mid-1980s and increased to about 11% after mid-1980s (Fig 7). The total amount of barley traded had passed 20 million tonnes in 1990 and is now around 15 million to 18 million tonnes (Figs 8 and 9). The major exporters are EU countries, Australian, Canada, USA and recently joined by USSR (including Russia and former USSR countries) which became the largest exporter in the last several years (Fig 8). Saudi Arabia, China and Japan are currently the major barley importers. In the last two decades, the world barley trade market has been boosted by the huge increase in the imports by Saudi Arabia, which comprises more than 40 percent of the total world barley imports. In 2005, Saudi Arabia imported nearly 7 million tonnes which included 2 million from Ukraine, 1.4 million from Australia, 1.2 million from Germany and 1 million from Russia (USDA, GAIN report: SA6002). The EU countries used to be the major importers in the 1960s and 1970s but became the major exporters since 1980s (Fig 9). The significant decrease in world barley trade is mainly caused by draught in the major exporting countries such as Australia with its total exported barley from as high as 6 million tonnes in 2003 to 2 million tonnes in 2006 (Fig 8).

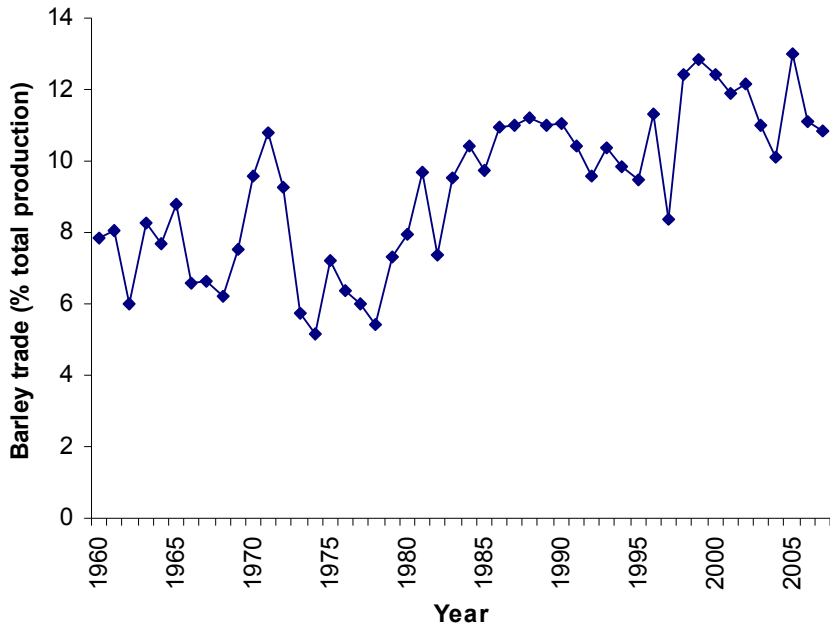


Fig 7 World barley trade (average value of total imports and total exports, statistics from United States Department of Agriculture)

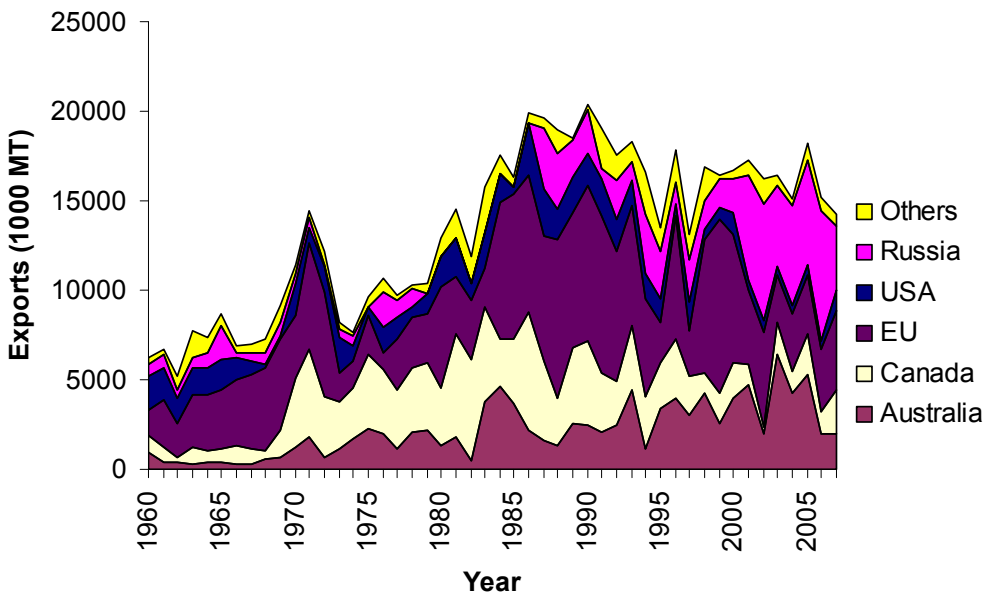


Fig 8 World barley exports (Statistics from United States Department of Agriculture)

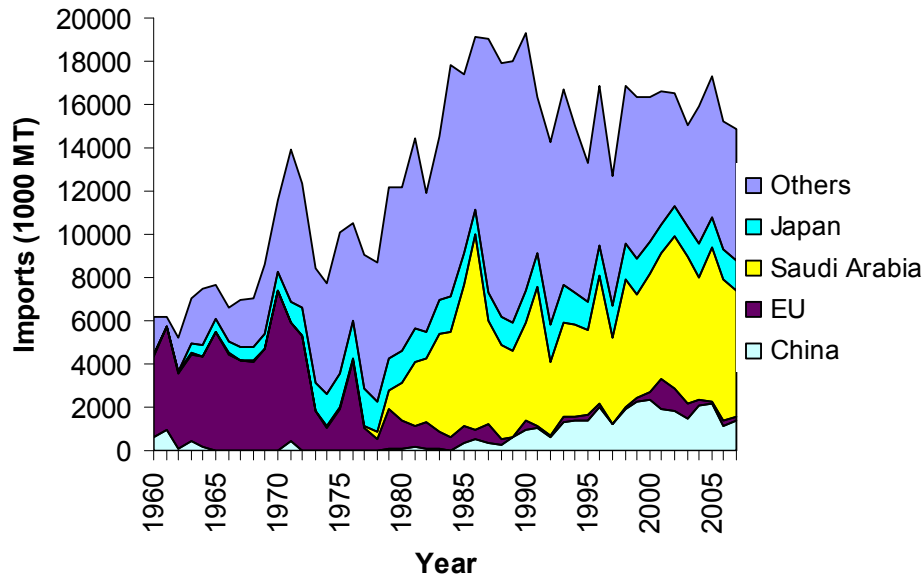


Fig 9 World barley imports (Statistics from United States Department of Agriculture)

4 World barley consumption

The total barley consumption in the world shows the similar trend with the total barley production (Figs 6 and 10). Barley is used commercially for animal feed, to manufacture malt, which is primarily used in beer production, for seed and for human food applications. Feed comprises about 70 percent of barley use. About 16 percent of barley is used for malting, seed or other industries and 14 percent is used for food (Fig 11). Most of the barley consumed in China and USA was as malting production (more than 70%) while more than 85% of barley consumed in Canada is used as feed.

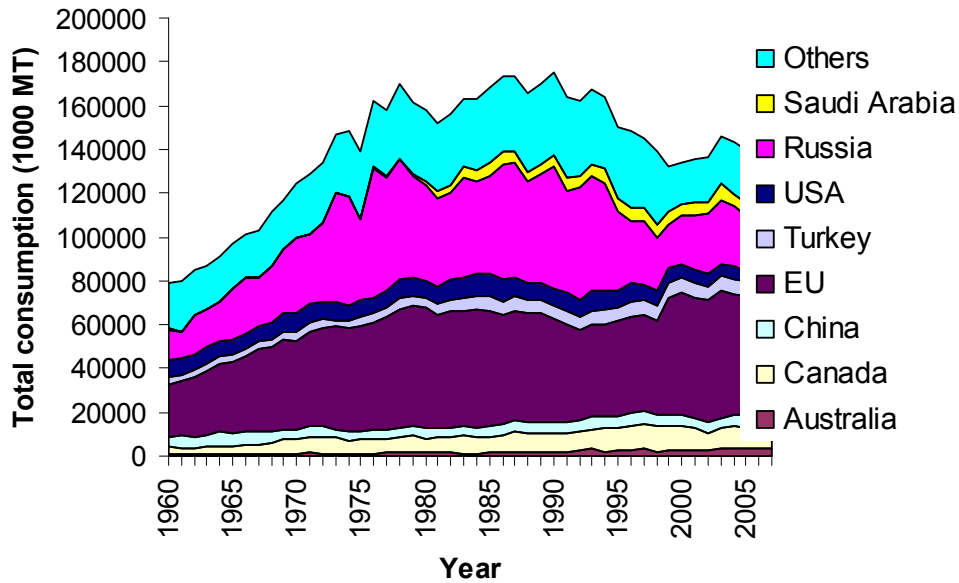


Fig 10 World barley consumption (Statistics from United States Department of Agriculture)

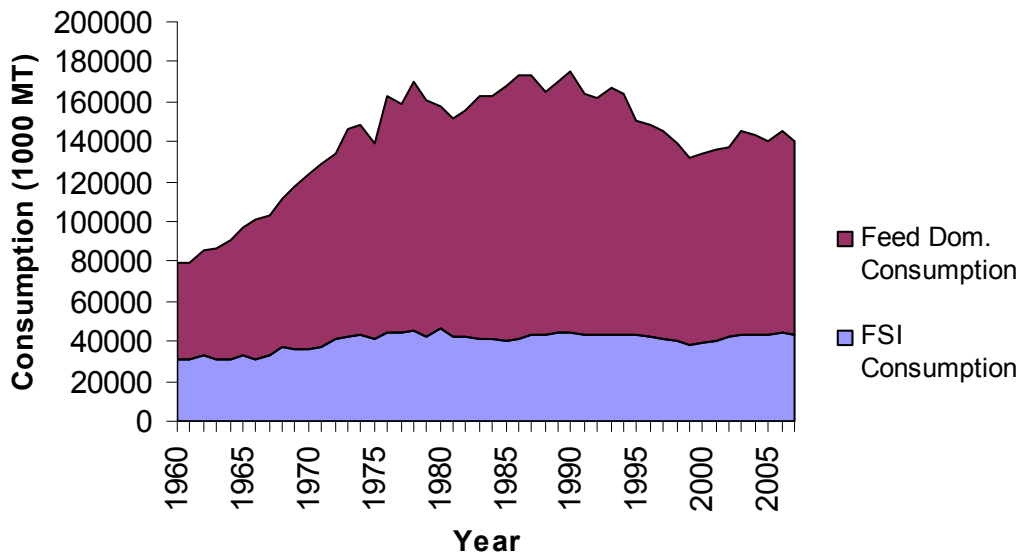


Fig 11 World barley consumption (Statistics from United States Department of Agriculture)

EU countries are the major consumer of barley (Fig 10). More than one third of world total barley was consumed in EU. Russia is another major barley consumer, which consumes nearly 20 percent of the barley. Other major consumers include Canada, Turkey, China, USA, Iran, Australia and India. In the last two decade, Saudi Arabia showed huge increase in the use of barley, from less than 0.1 million tonnes before mid-1970s to more than 6 million

tonnes since mid-1980s, which saw them become the fifth largest barley consumers after EU, Russia, Canada and Turkey. Nearly all of the barley consumed in Saudi Arabia is for animal feed.

4.1 Feed consumption

Barley is one of the four major feed grains (corn, barley, oats and wheat) and is widely used as a feed for livestock. The grain may be used as a major source of energy, protein and fibre for ruminants, and a major source of energy and protein for swine. In Australia, barley and wheat are the grains most commonly used by Australian livestock industries which, when combined, represented around 60% of all cereal grains fed. Oats (20%), sorghum (10%) and triticale (10%) made up the other cereal grains used by the livestock industries. Approximately 40% of the barley was fed to feedlot cattle, 34% to dairy cows, 20% to pigs and 6% to grazing ruminants. Less than 1% was used for poultry. In USA, corn is the most commonly used feed grain, with the amount of tonnages being increased from 80 million in 1960's to 140 million in 2000's and comprising more than 90% of all cereal grain feed, followed by wheat, sorghum, and oats. The amount of barley used for feed has reduced from 5 million tonnes in 1960's to 1 million tonnes in recent years.

The percentage of barley used for livestock feed in different countries varies from below 50% to as high as 90%. As shown in Fig 12, EU countries and Russia are the major feed barley consumers, followed by Canada, Turkey and Saudi Arabia. Since the amount of barley used for food, seed and industrial consumption was relatively consistent, feed barley consumption was more closely related to the total barley production (Figs 6 and 12).

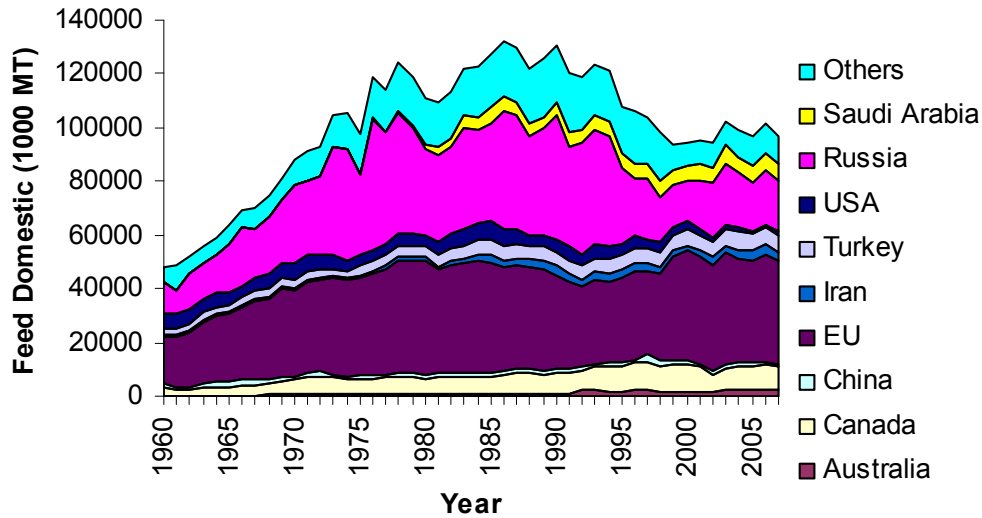


Fig 12 World barley domestic consumption (Statistics from United States Department of Agriculture)

4.2 Malting barley consumption

The second largest use of barley is for malt. Barley is the primary cereal used in production of malt. Historically, this may have resulted from its availability compared to that of other cereals, but there are several sound reasons for its use. Although wheat and rye also produce α - and β -amylase, which together are more efficient than either alone in hydrolysing starch, only barley has tightly cemented lemma and palea. These structures protect the embryo during grain handling as well as the coleoptile during malting, resulting in more uniform germination. In addition, the lemma and palea, or hulls, serve as an aid for filtering the brewing mash. Finally the steeped barley kernel has a firmer consistency than wheat and rye and it can be handled at high moisture levels with less risk of damage (Burger and LaBerge, 1985).

The amount of barley for food, seed and industrial uses (FSI) is relatively consistent in the last thirty years compared to that for feed uses which is largely depend on the total production (Fig13). More than half of the FSI consumption was for industrial uses. Barley ranked second in industrial use of grain, projected to total of 27.4 million tonnes in 2008, against 26.5 million tonnes in the previous year (Fig 14). Most industrially used barley is for malting. The total amount of barley for industrial uses is quite steady with only around 1-3% annual increase, which is very small compared to the annual increase in the industrial uses of corn (more than 10% in recent years). However, it is expected that by 2010 global demand for

malt is expected to increase by 27% to reach 19 million tonnes and world trade to expand by 8%. Most demand growth for malting barley and malt during the next five years will be in countries with rapidly expanding beer production, e.g China (18% growth), Russia and Eastern Europe (17% growth), South America (17% growth) and Africa (21% growth) (http://www.pir.sa.gov.au/grains/grain_value_chains/malt_and_beverage).

The growth of malting barley demand has not been proportional to growth in beer production, especially in recent years. For example, in China, the demand for barley malt is estimated at 2.62 million tonnes for the production of 291 Mhl of beer in 2004 while in 2000, 2.64 Mt of malt was needed for the production of 220 Mhl of beer. Two reasons are responsible for the lower usage of barley malt and malting barley. Firstly, the substitution of adjunct for barley malt has increased. Chinese breweries have the tradition of using rice or, to a lesser extent, corn as an adjunct in beer production. This creates a special taste favoured by local consumers and, at the same time, reduces barley malt usage and input costs. In recent years when malting barley supplies were short, and malting barley prices were high relative to rice prices, breweries adjusted their production techniques to incorporate more rice in substitution for barley malt. In the last couple of years when rice prices increased more than malting barley prices, substantial amounts of corn and even grain syrups were used as a substitute for barley malt. Secondly, the original gravity of beer, defined as the amount of malt and adjunct as a percentage of water in wort, has decreased significantly, from 11-12% to 6-7% in recent years. Thus more beer is produced from a given amount of malt and adjunct. Consequently, the ratio of barley malt to beer is estimated to have decreased from more than 13 kilogram of barley malt for one hectolitre of beer (Kg/Hl) in the 1980s to 12 Kg/Hl in the 1990s and 9 Kg/Hl over the last four years (Agriculture and Agri-Food Canada 2005).

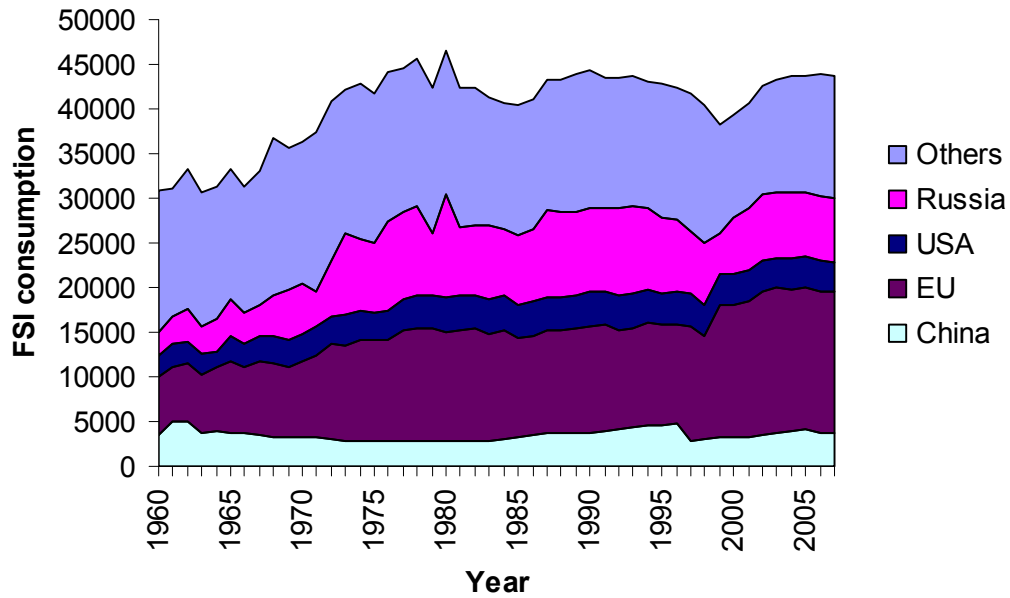


Fig 13 World barley food, seed and industrial consumption (Statistics from United States Department of Agriculture)

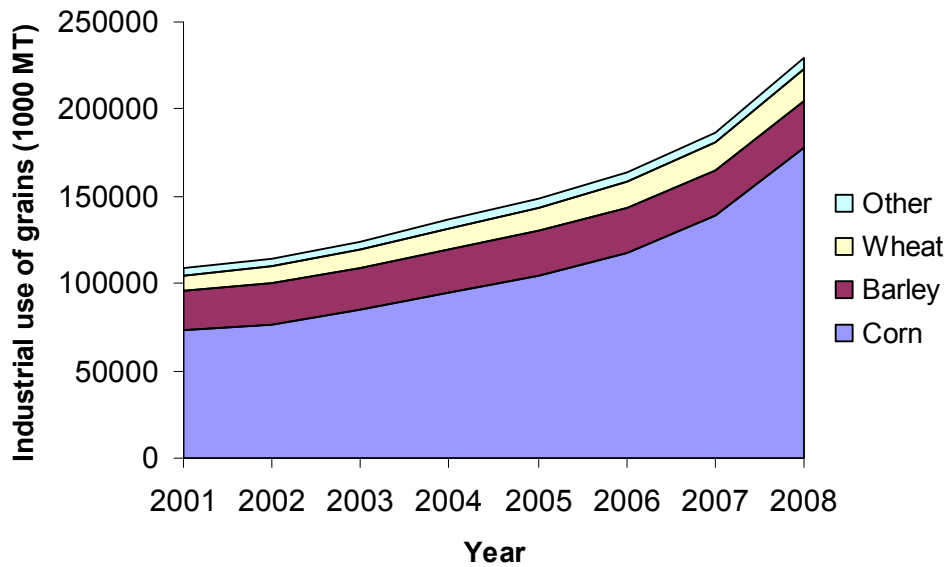


Fig 14 World grain industrial consumption (Sosland, 2007b)

4.3 Food consumption

Barley is still a major staple food in several regions of the world: in some areas of North Africa and Near East, in the highlands of Central Asia, in the Horn of Africa, in the Andean countries and in the Baltic States. These regions are characterised by harsh living conditions and are home to some of the poorest farmers in the world who depend on low productive

systems. At present, very little barley is used as human food in developed countries. However, in the last two decades we have seen a rediscovery of food preparations with barley with a significant increase in the total amount of barley used for food, from 17.3 million tonnes in 1990 to 23.7 million tonnes in 2005 (Fig 15). China has the biggest increase in barley used for food, from 2 million tonnes in 1990 to 4 million tonnes in 2005. Other countries saw the significant increase in the food use of barley include Russia, Ethiopia and Saudi Arabia, from nothing in 1990 to more than 1 million tonnes in 2005.

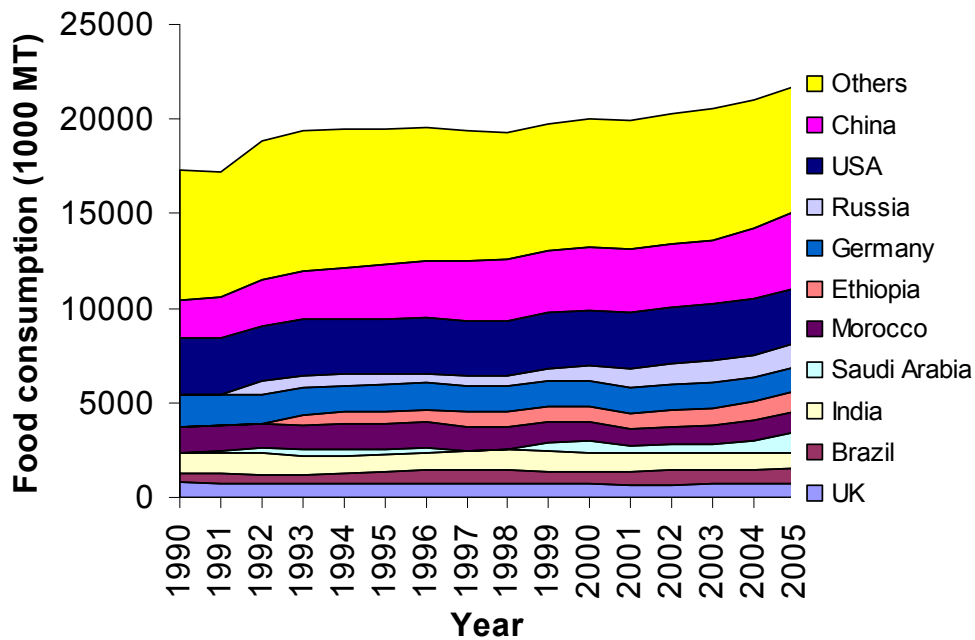


Fig 15 World barley food consumption (Statistics from FAO)

From the FAO statistics in 2005 (Fig15), China is the largest consumer of barley as food (4.0 million tonnes), followed by USA (2.9 million tonnes), Russia, Germany, Morocco, Ethiopia and Saudi Arabia (1 million to 1.3 million tonnes). In China, most of the barley was consumed in Tibet, where it accounts for 56% of the total food production, and about 2.1 million people consume barley. The main product of hull-less barley is a roasted barley flour known as *Tsangpa*; *Chang* brewed from hull-less barley is the major alcoholic beverage. Barley is also used in many other countries in traditional dishes such as *Kasha* in Russia and Poland, *miso* in Japan, and *sattu* or popped barley in India. In Korea, barley is the second most important food crop after rice. In the West Asia-North Africa region, much of the barley is consumed as pearled grain in soups, flour in flat bread, and ground grain in cooked

porridge. In the Western countries small quantities of barley are used in breakfast cereals, soups, stews, porridge, bakery blends, and for baby foods.

Barley products utilized for traditional food preparations can be classified in: a) Whole grain; b) Cracked grain; c) Raw-grain flour (fine and coarse); d) Whole roasted grain; e) Roasted-grain flour (fine and coarse). Barley products are suitable for use in many food preparations, including different types of bread, pasta, rice extender, and for baby foods, although most of the use has been largely confined to pot or pearled barley in soup and to flakes in breakfast cereals. Roasted barley can be used as coffee-substitute. 'Barley coffee' is very popular in Europe. In Italy, known as *Caffè d'orzo*, is commonly used as a breakfast drink for children, often mixed with milk. Barley is eaten in soups or as porridge after been popped, blocked, or pearled and is sometimes used as a rice extender, which needs a longer cooking time than rice.

Among the 10 major consumers shown in Figure 15, Saudi Arabia and Morocco have the highest average consumption (more than 35 kg per person), followed by Germany, Ethiopia (around 14 kg per person), UK, USA, Russia (about 10 kg per person), Brazil, China (3-4 kg per person). India has the lowest average annual consumption (0.7 kg per person).

There has been a renewed interest in food barley as healthy food in general and as a source of soluble fibre implicated in hypocholesterolemia and hypoglycaemia in non-insulin-dependent diabetes. The beta-glucan content of whole-grain barley is equivalent to or greater than that found in whole-grain oats. In a weight-for-weight comparison, whole-grain barley is lower in fat, protein and calories, and higher in total dietary fibre than whole-grain oats. A comprehensive review of the scientific evidence suggests that increasing whole-grain consumption can reduce the risk of coronary heart disease and diabetes, and can help with weight maintenance (<http://www.health.gov/dietaryguidelines/dga2005/document/pdf>).

The potential benefit of soluble dietary fibre such as the β -glucan in lowering the cholesterol level and postprandial blood glucose and insulin response has been reported by several authors (Brennan and Cleary 2005). Tocols (tocopherols and tocotrienols) are also reported to lower the total cholesterol and the low density lipoprotein cholesterol (Wang et al. 1993). Barley grain is a good source of both β -glucan and tocopherols.

4.4 Other industrial uses

Barley native starch and starch derivatives are extensively used in the food industry. The waxy starches from barley cultivars containing waxy or glutenous and high-amylose starches have specialised uses due to their high swelling power and colloidal stability (Greenwood, 1988). Barley has been used in some countries for the production of glucose, maltose syrups and beta-amylase. High-maltose syrup has special properties for use in food and pharmaceutical industries. Beta-glucans may be extracted and purified from barley or its beta-glucan-enriched bran fraction (Bhatty, 1993). Isolated beta-glucan has potential as a thickening agent in foods, as industrial hydrocolloid, and in pharmaceuticals. Hydrolyzed beta-glucan has been suggested as a bulking agent for replacement of sucrose (Cowan and Mollgaard, 1988).

The total grain used for various industries has been increased significantly in the last several years, from 124.6 million tonnes in 2002 to 186 million tonnes in 2007 (Fig 14, Table 1). The major increase was in the amount of grain used for biofuel production. The production of biodiesel has nearly doubled in EU in the last 12 months, from 3.2 million tonnes in 2005 to 6.7 million tonnes in 2007 (Lyndon, 2007). In 2006, the US became the world's largest ethanol producer, turning out 20 billion litres, an increase of nearly 25% from the year before, and overtaking Brazil, which produced an estimated 17 billion litres (Sosland, 2007b). The ethanol production is expected to reach 6 billion gallons in the US in 2007 (Donley, 2007). Currently China produces more than 1 million tonnes of ethanol and the new project would increase fuel ethanol production by more than 10 million tonnes (Biofeuls news digest, 2007). In contrast to the US, where most ethanol is produced from corn, EU countries use a wider range of materials, with half from cereal grains, mainly wheat, corn, barley and rye. Barley used for bioethanol production would represent 25 per cent of the total grain production in Finland and 29 per cent of barley production (www.biofeulreview.com). However, since regular hulled barley can not be converted to fuel ethanol using a conventional corn-to-ethanol process without significant modifications, the use of this feedstock is problematic and current processes for conversion to fuel ethanol are not cost competitive today in the U.S. versus the use of corn. The abrasive nature of hulled barley, the high viscosity of barley fermentations, and the low starch and high fibre content lead to high production costs, low ethanol yields, and a distillers dried grains with soluble (DDGS) product that can't be fed to monogastric animals. A multidisciplinary research effort at the Eastern Regional Research Center, ARS, USDA in Wyndmoor PA, in cooperation with research partners, has been

initiated to solve these technical problems. The research approaches include 1) development of high-starch, hulless barley varieties specifically bred for ethanol production; 2) development of pre-fermentation barley fractionation processes to remove non-fermentables from hulled and hulless barley to produce a starch-rich feedstock for ethanol production; and 3) use of new beta-glucanases to decrease viscosity of mashes, increase yields of ethanol, and decrease levels of residual beta-glucans in DDGS.

Table 1 Global industrial use of grain (million tonnes) (Sosland, 2007a)

	2002-03	2003-04	2004-05	2005-06	2006-07
Ethanol	29.4	34.9	41.0	50.2	65.3
Starch	61.8	64.9	68.2	72.8	79.0
Brewing	27.6	29.2	29.7	30.7	31.3
Other	6.7	8.0	9.1	10.1	10.3
Total	124.6	137.0	147.9	163.6	186.0

There are lots of potential uses of the whole-crop of barley. Petersen and Munck (1993) illustrated the possible industrial uses of whole barley plant, which includes barley grain and straw. The industrial uses of barley grain have been discussed above. Barley straw can be used as ruminant feed. Straw can be chemically treated to improve the feeding value, in which treatments with ammonia or sodium hydroxide are commonly used. The treatment with ammonia increases the content of crude protein in addition to the digestibility (Petersen and Munck 1993). Before 19th century, most paper was produced from annual plants. There still exist a few straw-based cellulose factories, most in the developing countries. According to Petersen and Munck (1993), 1 ha of barley crop producing 5 ton of grain and 5 ton of straw would potentially yield 3.1 ton of starch and 1.6 ton of cellulose. The yields of paper pulp would be about 2.4 ton. The internode chips of barley straw are ideal for the production of particle boards because of their high physical strength properties (Petersen and Munck 1993).

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