Food Barley: Importance, Uses and Local Knowledge

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Foreword

Barley is a very important crop for poor people in dry, marginal areas. Domesticated more than 10,000 years ago in the Fertile Crescent, it is now grown on about 57 million hectares. More than half of this barley area is in developing countries. Barley is a major staple food in some areas of North Africa and the Near East, in the highlands of Central Asia, in the Horn of Africa, in the Andean countries and in the Baltic States. Food barley is generally found in regions where other cereals grow poorly due to low rainfall, altitude, or soil salinity. It remains the most viable option in dry areas (< 300 mm of rainfall) and in production systems where alternative food crops are limited, such as in the highlands and the mountains.

There is scope for improving the livelihood of the rural population in the regions where barley is a staple food not only by increasing sustainable crop productivity but also by improving nutrition, reducing work drudgery and developing barley-based local industries. Due to the potential nutritional benefits, it is also possible that food barley may be exported to developed countries where the interest in healthy food for the prevention of coronary diseases has increased dramatically in the last two decades. Joint research by ICARDA and national agricultural research systems has identified new cultivars and cropping systems that can improve the productivity of food barley.

The international workshop on "Food Barley Improvement," jointly organized by ICARDA, the Food and Agriculture Organization of the United Nations, and *Institution de Recherche et Enseignement Supérieur Agricole*, Tunisia, and supported by the OPEC Fund for International Development, brought together more than 30 participants from 13 countries, representing most of the areas where barley is largely used as food, to review food-barley-based systems and identify production bottlenecks. The participants agreed to establish domestic and international networks of researchers with a common interest in food barley.

This publication contains the presentations made by the participants during the international workshop. I hope that it will prove useful for researchers interested in improving the livelihoods of the farmers in the dry areas who depend on food barley for their nutrition requirements and family income.

Prof. Dr Adel El-Beltagy
Director General

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Preface

Barley (*Hordeum vulgare* L. emend. Bowden) was domesticated about 10,000 years ago in the Fertile Crescent of the Near East, at sites not far from where today ICARDA's headquarters are located, from wild forms morphologically identical to present day *Hordeum spontaneum*. From this origin, barley is now grown over a broader environmental range than any other cereal from 70°N in Norway to 46°S in Chile. Also, in Tibet, Ethiopia and the Andes, it is cultivated higher on the mountain slopes than other cereals. Today barley is grown on about 57 million hectares, of which 32 million hectares are in the developing countries, including those of Central Asia and the Caucasus.

Barley grain is used as feed for animals, malt, and human food. It was a staple food since its domestication. It was the energy food of the masses, and it had a reputation for building strength. Barley was awarded to the champions of the Eleusian games. Gladiators of the Roman Empire were called hordearii, barley-men, because barley was the main component of their training diet.

Early barley remnants from Mesopotamia and Egypt are much more abundant than those of wheat, and the earliest literature suggests that barley was more important than wheat for human food. The Sumerians had a god for barley but none for wheat. In the Near East and Mediterranean, the shift to wheat as human food came in classical times, and by the first century A.D. barley was already mostly fed to animals. In northern Europe barley remained the main food cereal until the 16th century.

Barley is still a major staple food in several regions of the world: in some areas of North Africa and the 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 the low productive systems. In North Africa, the average yield of food barley is less than 1 t ha^{-1} although the potential is 3 t ha^{-1}. Apart from the abiotic constraints, food barley yields poorly because of poor management and lack of resistance to biotic stresses. Additionally, farmers cultivating food barley do not generally have access to information and improved cropping system technologies. Improved sustainable production of barley can play a significant role in improving food security of this population.

In North Africa, average annual national consumption of food barley in 2002 in Morocco, Algeria, Libya and Tunisia was 36, 15, 13 and 7 kg/person, respectively. Although specific statistics for food barley within countries are lacking, it is accepted that the consumption is much higher in certain areas within the country, e.g. Aures region in Algeria, Tensift in Morocco, Sfax in Tunisia. In the rest of the world, barley is also consumed as food in the highlands of Ethiopia, Eritrea, Peru and Ecuador (13, 4, 4 and 2 kg/person/y, respectively), in East Europe (Estonia, Moldova, Latvia, Lithuania: 13, 20, 20, and 18 kg/person/y, respectively, in 1999) and in the highlands of Central Asia.

Food barley consumption has decreased considerably in the last 40 years with the increase of urban population and, often, the introduction of national policies supporting wheat consumption. This is the case of Morocco where food barley consumption has decreased from 87 kg/person/y in 1961 to 36 in 2002. In the case of Algeria, Libya and Tunisia, food barley consumption in 1961 was 27, 35 and 15 kg/person/y, respectively.

One of the key features of food barley research and development is the urgent need to sensitize policy makers and development agents regarding food barley importance in the economy of limited resources areas. Consequently, they can promote barley use as food and set policies that favor barley development, production and use for human nutrition. This is why ICARDA, FAO and *Institution de Recherche et Enseignement Supérieur Agricole*, Tunisia, organized an international workshop on "Food Barley Improvement," which was funded by the OPEC Fund for International Development and held in Hammamet, Tunisia on 14-17 January 2002. It brought together more than 30 participants from 13 countries, representing most of the area where barley is largely used as food.

The objectives of the workshop were to review food-barley-based systems and identify bottlenecks in production; review present and past research efforts addressing food barley improvement; identify and describe major cultivated food barley varieties, including uses and growing environments; identify quality characteristics desired by consumers; identify constraints and research needs; and discuss and define a regional and global plan of action for research and collaboration.

Participants presented the status of food barley in their respective countries, including descriptions of traditional and new uses of barley, varieties, research activities, and the importance of food barley as compared to feed and malting barley. All participants agreed strongly on the need to establish domestic and international networks of researchers with a common interest in food barley.

They also contributed to the preparation of a global project on food barley improvement with the following components:

- Collection of baseline information and filling of gaps
- Breeding local food barley for quality and sustainable productivity
- Establishment of optimum crop management for sustainable production
- Improvement of storage and food-barley-based diets
- Development of small-scale food barley industry, and
- Seed production and multiplication.

It was agreed that barley recipes will be collected from diverse regions and compiled in a book to promote food barley and to document local knowledge.

Investments in food barley research will have a direct impact on the livelihood of the rural population in the regions where barley is a staple food not only by increasing sustainable crop productivity but also by improving nutritional quality, and developing barley-based local industry. It is hoped that this book will encourage readers to play an active role in this global effort.

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Highlights of the Barley Breeding Program in Egypt

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Introduction

In Egypt, barley is mainly grown under rainfed conditions in the north coastal regions, and under irrigation in the newly reclaimed lands, and in saline soils where irrigation water is limited. The total area under barley cultivation in Egypt fluctuates according to the amount and distribution of annual rainfall. In the Nile Valley, the production area has decreased gradually especially at locations where irrigation is feasible and other strategic crops such as wheat can be grown. The barley production area has increased, however, in the newly reclaimed lands. The barley production area and yield in rainfed areas, newly reclaimed lands and old lands are presented in Table 1.

Table 1. Barley area and yield in rainfed areas, newly reclaimed lands and old lands, 1990/91 to 1997/98.

	Production area (ha)				Yield (t ha^{-1})			
Season	Rainfed areas	New lands	Old lands	Total	Rainfed areas	New lands	Old lands	Average
1990/91	32,741	2,374	29,434	64,549	0.44	1.36	3.15	1.71
1991/92	60,584	10,681	32,783	104,048	1.22	2.33	3.42	2.35
1992/93	17,704	16,641	26,040	60,385	0.79	2.33	3.45	2.20
1993/94	21,415	13,307	19,423	54,145	0.71	1.93	3.48	2.10
1994/95	154,858	11,145	22,065	188,068	1.67	2.71	3.59	2.67
1995/96	10,752	13,747	20,007	44,506	0.49	2.80	3.86	2.68
1996/97	27,854	12,192	17,660	57,706	1.04	2.66	3.64	2.18
1997/98	31,505	9,963	18,531	59,999	2.07	2.74	3.50	2.47

Barley yields have increased gradually from 1.71 t ha^{-1} in 1990/91 to 2.47 t ha^{-1} in the 1997/98 season. In rainfed areas the large variation in yield between years is associated with the variation in the amount of rainfall and its distribution. The increase in barley productivity was mainly due to the release of improved barley varieties (Table 2) and to the application of improved agronomic practices.

Table 2. Pedigree and year of release of improved barley varieties.

Variety	Row type	Pedigree	Area of cultivation	Year of release
Saharawy	6	Baladi 16/Atsel	Rainfed	1955
Bonus	2	Bonus (introduction)	Irrigated	1956
Giza 117	6	Baladi 16/Palestine 10	Irrigated	1958
Giza 118	6	Beecher (introduction)	Irrigated	1963
Giza 119	6	Gem/Baladi 16	Irrigated	1973
Giza 121	6	Gem/Baladi 16	Irrigated	1977
CC 89	6	Selected from composite crosses	Irrigated	1980
CC 163	6	Selected from composite crosses	Irrigated	1980
Giza 123	6	Giza 117/FAO 86	Irrigated	1988
Giza 124	6	Giza 117/Bahteem 52// Giza 118/FAO 86	Irrigated	1988
Giza 125	6	Giza 117/Bahteem 52// Giza 118/FAO 86	Rainfed	1995
Giza 126	6	Baladi Bahteem/SD 729-Por 12762-BC	Rainfed	1995
Giza 2000	6	Cr.366.13.1/Giza 121	Irrigated & Rainfed	2000

Barley Breeding Program

Barley improvement began in 1930 when the following landraces were selected from local materials, produced and distributed as commercial varieties: Baladi 1, Baladi 2, Baladi 7, Baladi 16, Baladi 41, Baladi 44, Baladi 48, Sinai 14, Nabaui 2, Nabaui 3, Giza 24, and Giza 73. The varieties Abyssinia 12, Hungarian 1, Iraqi 9, and Palestine were also introduced.

In 1943/44 the first crosses were made. As a result of the breeding program, the varieties Saharawy, Giza 117, and Giza 118 were released in 1955, 1958, and 1963, respectively. These varieties were high yielding and resistant to the main barley diseases. The number of crosses gradually increased with the introduction of sources of resistance to biotic and abiotic stresses. Giza 119 was released in 1973, Giza 121 in 1977, CC 89 and CC 163 in 1980. From 1988 the barley breeding program released Giza 123, Giza 124, Giza 125, Giza 126, and Giza 2000. These cultivars exhibited good performance under various environmental stresses: Giza 123 in saline soils and in the newly reclaimed lands; Giza 124 under heat stress; Giza 125 and Giza 126 under drought stress. Giza 2000 is characterized by wide adaptability and high-yield ability under various environmental conditions.

Major Research and Breeding Activities in Egypt

Evaluation of genetic resources

The barley program receives germplasm from other breeding program for evaluation under different environmental conditions. The introduced germplasm along with F_5 lines derived from Egypt's national breeding program are being evaluated, and classified according to their yield, and tolerance to biotic and/or abiotic stresses. The selected lines are included in the national crossing program to be used as parents in the breeding program.

Crossing Program and Segregating Populations

About two hundred crosses are made each year at the Giza and Sakha Research Stations. The breeding materials from F_1 to F_5 are grown at Giza and Sakha under irrigation and from the F_2 under rainfed conditions in the coastal region.

Barley breeding program objectives

Drought tolerance

Barley germplasm is being tested and evaluated under rainfed conditions in the northern coastal areas of Marsa Matrouh and Sinai. The average annual rainfall in these areas fluctuates between 130 to 200 mm. The material is planted in observation nurseries and yield trials including on-farm verification trials. The most promising rainfed selections are candidates for inclusion in future breeding cycles as drought-tolerant genotypes.

Salt tolerance

A detailed soil survey of Egypt revealed that over two million acres of cultivated land is affected by salinity to varying degrees and brackish water is likely to be used in irrigation. Development of barley genotypes for cultivation in such conditions would be an efficient and economical way to expand irrigated agriculture that is dependent upon poor-quality water. The available data is encouraging as several barleys showed tolerance to saline conditions.

The salt-tolerance breeding program was initiated in 1976. A combined screening using laboratory, sand culture, and field tests is used to screen and evaluate domestic as well as exotic materials, representing a wide spectrum of genetic diversity. This work is mainly conducted at Giza and the program has also established five sites for evaluation of salt tolerance under field conditions.

Disease resistance

Barley diseases in Egypt are numerous and cause substantial reduction in yield. These diseases are powdery mildew (*Erysiphe graminis* f.sp. *hordei*), leaf rust (*Puccina hordei*), barley leaf stripe (*Helminthorporium gramineum*), net blotch (*H. teres*), dry-land root rot (*H. sativum* and *Fusarium gramineum*), scald

(*Rynchosporium secalis*), covered smut (*Ustilago hordi*) and loose smut (*U. nuda*). Boron toxicity is affecting barley under rainfed conditions and in some areas in the newly reclaimed lands.

Domestic varieties and advanced lines as well as exotic material are evaluated annually for resistance to major diseases. These evaluations are carried out at both the seedling and adult stages. The seedling evaluation is done in the greenhouse using artificial inoculation of major diseases whereas adult evaluation is done in the field under natural infection. Screenings for barley diseases are conducted at Giza (powdery mildew), Sakha (net blotch), Noubaria (leaf rust) and Marsa Matrouh (dry-land root rot).

Powdery mildew is one of the most economically significant barley diseases in Egypt. It causes a reduction in malting quality, kernel weight, and yield and is found in the old lands as well as in the newly reclaimed lands. Resistance to PM was studied during the 1995/96 season using 20 near-isogenic lines to identify the genes that control resistance. The study showed that ML-a6, ML-a7, Ml-a14, and Ml-(La) are the effective genes in Egypt.

Other significant diseases are leaf rust, barley leaf stripe, net blotch, and dry-land root rot. Leaf rust occurs annually under irrigated conditions and in some locations in newly reclaimed land. Barley leaf stripe is found under rainfed conditions in the North West Coast (NWC) and northern Sinai where farmers continually use their own seed. Net blotch is found mainly in the northern parts of the Nile Delta and in some areas in the newly reclaimed lands, such as in Noubaria. The disease has also been found in the NWC under rainfed conditions, especially in wet years. Preliminary surveys for root diseases were conducted during the 1991-1993 seasons. The results indicated that dry-land root rot causes significant reductions (10-27%) in the number of fertile tillers in infected plants, over 10% loss in grain yield, and reduced kernel weight. Prior to these surveys there was little knowledge on the nature and distribution of barley root rot disease in Egypt.

Aphid resistance

Barley in Egypt is infested by several aphid species under both irrigated and rainfed conditions. Survey studies are mainly conducted in Giza, Mallawy, and the rainfed areas. The most dominant aphid species in all barley production areas are *Rhopalosiphum maidis* followed by *R. padi* and *Schizaphis graminum*. Screening techniques consist of both laboratory and field tests. Selected aphid-tolerant genotypes are then used in the national cross-breeding program.

Grain and Straw Quality

Barley grain is used principally as feed for animals, and food for human consumption. Also, barley straw is used for animal bedding, and immature barley plants may be harvested for forage by grazing or by cutting for hay or silage.

Animal feed

The largest use of the grain is for animal feed. Grain protein content ranges from 10 to 15%, depending on the climatic and soil conditions under which the barley grows. High protein content is desirable in barley used for feed. Barley protein is nutritively unbalanced due to a deficiency in the essential amino acid (lysine).

Food

The largest use of barley for food is found in regions where other cereals do not grow well due to low rainfall or soil salinity stresses. Barley is used for food as pearled barley, flour, or malt. Barley is used in baby and other specialty foods. Barley-malt products are used in making breakfast cereals and confectionery products.

In Egypt, the advanced breeding material is tested regularly for grain quality characteristics in cooperation with the Food Technology Research Institute at the Agriculture Research Center. The tests include protein and β-glucan content. In addition to these two characteristics, the 1,000-kernel weight is also tested. Environmental stresses, especially drought stress, cause a decrease in 1000-kernel weight. The Food Research Institute has begun to make various products from barley, such as combining barley and wheat flours to produce *baladi* bread. They have also produced baby food, some pastries, and special foods for patients with high cholesterol levels, kidney, or stomach problems.

Agronomy Research

Along with the development of new varieties, agronomy trials are being conducted to determine the cultural practices used with the varieties nominated for release. These trials deal with:

- Effect of nitrogen, phosphorus, and potassium in poor sandy soils;
- Effect of biofertilizers and different nitrogen sources;
- Effect of irrigation regimes;
- Effect of ploughing and seed depth;
- Intercropping systems of barley and forage legumes;
- Sowing methods in saline soils;
- Nitrogen forms and levels in saline soils.

Maintenance and Seed Multiplication

The main objective of the seed multiplication is to increase the seeds of the newly released cultivars for growing on a commercial scale.

Technology Transfer

The gap between the national yield averages compared with the experimental average is large. It is anticipated that if appropriate technology is applied and production constraints are minimized, over 25% yield gains could be reached in farmers' fields. Technology transfer services are intended to identify the improved technologies (including new cultivars and agronomic practices) and to train both extension staff and farmers in barley production areas on the use of the improved production packages.

Improvement of Food Hull-less Barley in Egypt

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Introduction

In Egypt, the national production of cereals is relatively lower than the consumption demands. It was, therefore, suggested to use barley (*Hordeum vulgare* L.) as a complementary cereal crop to minimize this gap because of barley's ability, compared with other cereal crops, to grow well under the drought-stress conditions common to Egypt.

Barley is the main crop grown under rainfed conditions in Egypt. It occupies about 100,000 ha in the North West Coast (NWC) and about 40,000 ha in North Sinai. The annual rainfall is about 130 mm in the NWC and slightly higher in North Sinai (Frere and Popov 1984), below the lower limit of semi-arid areas (160 mm). Fluctuation of rainfall between seasons and between locations in the same season is one of the main constraints facing barley growers. Therefore, barley cultivars developed for these areas should be drought tolerant and stable for these harsh conditions (El-Sayed et al. 1990; Noaman et al. 1995).

In the newly reclaimed lands, barley is planted on about 60,000 ha. Most of these lands are suffering from water shortage, low soil fertility, and a high level of soil and/or water salinity.

Local landraces of barley, that are low yield and vulnerable to diseases are grown in both rainfed and the newly reclaimed lands.

The grain of the hull-less barley is easily separated from the hulls after threshing. This characteristic could facilitate the use of barley grain for bread making and other nutritional foods. Moreover, barley straw is important as fodder for farm animals, especially during summer months in the deserts where green forage is scarce. This dual usage of naked barley would help the Bedouins with the difficulties of securing both human and animal food in the harsh environments of the rainfed areas and the newly reclaimed desert lands.

In recent years barley is gaining renewed interest as a food component because of its high soluble dietary fiber and β-glucan content compared with other cereals.

Barley grain contains about 20% of dietary fiber (Åman et al.1985; Oscarsson et al. 1996). β-glucan, an important dietary fiber in barley, varies between 3 and 7% (Ullrich et al.; 1986; Åman and Graham 1987; Oscarsson et al. 1996). Martinez et al. (1992) have shown that barley β-glucan has significant blood cholesterol lowering effects. Moreover, barley β-glucan increases the viscosity of digestion in the intestine, slowing down the rate of starch digestion and absorption (Anderson et al. 1990), which is beneficial to diabetics (Pick 1994; Gosain 1996).

There is, however, a large variation in the chemical composition between different barley types. Hull-less barley contains less ash and dietary fiber and more starch, protein and fat than covered barley (Oscarsson et al. 1996; Andersson et al. 1999a).

Objectives of the Project

The objectives of the Egyptian-French hull-less barley project are:

- To develop high yield and disease resistant hull-less barley genotypes adapted to the drought conditions in both the rainfed areas the newly reclaimed desert lands;
- To determine proper crop management techniques in rainfed and newly reclaimed desert areas;
- To disseminate the new varieties and associated management package to barley growers through:
    a. on-farm verification trials;
    b. a strong extension program for transfer of hull-less barley production technology to extension specialists and farmers;
- To identify hull-less barley genotypes suitable for bread making that also have high protein and β-glucan contents for use in the breeding program;
- To test hull-less barley in human nutritional product preparations.

Breeding and Extension Activities

Hull-less barley genetic material screening

The project collaborates and exchanges hull-less barley genetic materials with ICARDA, Institut National de la Recherche Agronomique INRA/France, the United States Department of Agriculture (USDA), and the Bulgarian National Agricultural Research Institute. The national advanced hull-less barley lines and the introduced lines are grown in the hull-less barley screening nursery.

Selection criteria

- Agronomic and disease resistance traits: resistance to Egypt's major barley diseases (leaf rust, powdery mildew, net blotch, boron toxicity, and root-rot); maturity, crop duration, plant height, grain yield, biological yield, grain color, kernel size;
- Food quality traits: protein and lysine content, soluble dietary fibers, β-glucan content, thousand-kernel weight, extraction percentage, and bread-making attributes.

Crossing block
Each year approximately 50 parents of hull-less and 50-100 parents of local hulled barley are used for crosses. Crosses are done in the field and the greenhouse.

Segregating populations testing
Segregating populations are grown yearly at the NWC under rainfed-drought stress conditions and at Sakha Agriculture Experimental Station under irrigation. At Sakha the segregating populations are also exposed to major barley diseases endemic to this specific location.

Yield trials
A series of yield trials, A-Naked (hull-less) Barley Yield Trial (NBYT), B-NBYT, D-NBYT and on-farm verification trials are conducted seasonally. The entries selected from the screening nursery are promoted to A-trial, the selected genotypes from A promoted to B level and the selected from B level promoted to D level.

On-farm trials conducted with promising lines selected from D level trial, are conducted with the participation of farmers in the final selection of new varieties.

New hull-less barley cultivar registration
The project registered in 2001 three new hull-less barley varieties: Giza 129, Giza 130, and Giza 131, for irrigated areas, irrigated and rainfed areas, and rainfed areas, respectively. These are the first hull-less barley varieties released in Egypt.

New cultivar dissemination
Extension fields of the three registered varieties have been established for the 2002 season in all barley production areas. Extension activities include demonstration and dissemination of the new hull-less barley varieties to farmers and the training of both extension personnel and farmers in large-scale production technology.

Food Technology Activities

Evaluation studies on eleven promising hull-less barley lines were conducted in collaboration between the Egyptian-French Hull-Less Barley Project and the Food Technology Research Institute, Agricultural Research Center, Egypt. The results are shown in Tables 1, 2, and 3.

Hull-less barley (Table 1) lines have a low ash content value, while fat and protein content is high. Protein content of hull-less barley lines ranged between 13 and 14% of total composition. These results are in agreement with Andersson et al. 1999a and 1999b.

Table 1. Grain chemical composition of promising hull-less barley genotypes.

Line/Variety	Moisture (%)	Protein (%)	Ash (%)	Other extracts (%)
LHB93/1	11.61	13.01	1.541	2.73
LHB2000/1	11.50	13.45	1.5887	2.73
LHB2000/4	11.56	13.23	1.5462	2.10
LHB2000/5	11.78	12.92	1.4702	2.53
LHB2000/6	12.24	14.13	0.9674	2.64
LHB2000/8	11.64	13.92	1.6908	2.73
LHB2000/10	11.21	13.39	1.1139	2.09
LHB2000/11	11.7	13.28	1.6639	2.26
Giza129	11.88	14.41	1.5138	2.45
Giza130	12.01	13.52	1.7491	2.44
Giza131	11.64	13.13	1.0066	2.41
Sakha 69 (Wheat)	9.2	12.51	1.98	2.09

Genotypes LHB2000/8, LHB2000/1, LHB2000/10, and LHB2000/6 (Table 2) had the highest β-glucan values, while covered barley and wheat had the lowest values. These results are also in agreement with Andersson et al. 2000.

Table 2. Grain β-glucan content of promising hull-less barley genotypes.

Line/Variety	Total β-glucans (%)	Soluble β-glucans (%)	Insoluble β-glucans (%)
LHB93/1	5.62	3.04	2.58
LHB2000/1	6.87	3.71	3.16
LHB2000/4	3.10	1.64	1.46
LHB2000/5	6.35	2.62	3.73
LHB2000/6	6.25	2.77	3.48
LHB2000/8	6.95	3.29	3.66
LHB2000/10	6.50	3.12	3.38
LHB2000/11	5.94	3.22	2.72
Giza129	3.12	1.59	1.53
Giza130	4.60	2.50	2.10
Giza131	4.44	2.40	2.04
Giza123 (Hulled barley)	3.01	1.87	1.14
Sakha 69 (Wheat)	1.80	0.97	0.83

Table 3 lists the flour and bran percentages of 11 promising hull-less barley varieties.

Table 3. Extraction ratio of promising hull-less barley genotypes.

Line/Variety	Flour (%)	Bran (%)
LHB93/1	90.0	10.0
LHB2000/1	91.2	8.0
LHB2000/4	91.0	9.0
LHB2000/5	87.0	13.0
LHB2000/6	91.0	9.0
LHB2000/8	87.0	13.0
LHB2000/10	87.3	12.7
LHB2000/11	85.0	15.0
Giza129	88.0	12.0
Giza130	90.8	9.2
Giza131	91.0	9.0

Bread was prepared using 20% hull-less barley flour mixed with 80% wheat flour (82% extraction). The produced bread had good morphology and nutritional quality.

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Status of Food Barley in the Libyan Arab Jamahiriah

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Introduction

Food has social, physical, and psychological as well as political significance, thus a country's development plans aim to raise the standard of living, which correlates indirectly with a higher nutritional level.

The human body obtains energy from food by burning carbohydrates. Cereal crops are the major source of carbohydrates, wheat and rice being the most widely consumed. Other cereals, such as barley, are consumed as food in mainly arid areas. In Libya, people like and use barley for food preparation.

Libya is located on the central coast of North Africa, which is one of the driest regions in the world, with a total area of 176 million hectare of which 1.3% of the total is arable land. Approximately 300,000 ha are irrigated, and 800,000 ha are rainfed. According to the topographic and climatic conditions the country is divided into the following zones:

The coastal zone, extending from the Egyptian to the Tunisian borders, has an annual precipitation range from 100 to 500 mm with an average rainfall of 200 mm;
The western steppe zone, a strip south of the coastal zone, has an average annual precipitation range between 150 and 200 mm;
The *jabal* zone plateau includes the Nefusa mountains in the west with an average annual precipitation range between 100 and 250 mm, and Al Jabal Al Akhdar mountain in the east, where annual precipitation is between 200 and 400 mm;
The predesert zone includes various regions occupying the southern slopes of the plateau beyond the steppe with a low annual precipitation of approximately 70 mm;
The desert-oases zone comprises the largest area of the country, with no precipitation.

Barley and wheat are cultivated under rainfed and/or supplementary irrigation conditions in the first three zones and under full irrigation in the desert zone. Barley is the dominant crop in all zones (Table 1).

Table 1. Area and production of barley and wheat, 1990/91-1998/99.

Season	Area ('000 ha)		Production ('000 t)	
	Barley	Wheat	Barley	Wheat
1990/91	256	165	183	98
1991/92	453	114	198	90
1992/93	225	82	156	60
1993/94	179	18	80	44
1994/95	253	12	117	23
1995/96	170	19	124	28
1996/97	93	24	119	27
1997/98	213	37	217	47
1998/99	288	61	306	69

Source: Technical Department and Production, General Public Committee of Agriculture, Ministry of Agriculture, Libya

Health Considerations

Libyans use food barley not only for its nutritive value, but also as a remedy for certain diseases. It is common knowledge that barley can be effective in the treatment of diabetes, stomach and colon problems, and kidney problems.

Social Considerations

Local barley meals are not only a food, but are a public cultural expression. The main local barley preparations are: *koubz* (bread), *bazin, zummeta* (used mainly for breakfast), *dshesha, harisa,* and *couscous.* The consumption rate of these traditional foods, although decreasing among the younger generations, is higher in rural areas than in cities. However, for certain social occasions, such as gatherings for marriages and funerals, barley preparations are preferred, particularly *bazin.*

Economic Considerations

The annual consumption of feed and food barley in Libya is estimated at about 700,000 tonnes. The needs for human consumption are about 100,000 tonnes with the per capita consumption of bread wheat, durum wheat, and barley at 130, 70, and 20 kg year^{-1}, respectively. Local production of barley covers human needs (Table 1), but feed barley is imported. Local barley production is not subsidized, so the price is higher than wheat, which of course affects the prices of barley food end products. The barley food sector comprising milling, processing, and bread making is privatized.

Germplasm Improvement

There are no specific barley varieties cultivated for food uses. Mainly covered barleys are cultivated in Libya and farmers favor the six-row type. Consumers, however, prefer two-row barley for its plump kernels. The national germplasm needs more attention through the collection of local landraces for evaluation and screening to determine their potential use as food barley. The national program collected three landrace varieties of naked barley from the desert oases:

1. Tarida Swoda
2. Tarida Bieda (2-rows type)
3. Tarida Bieda (6-rows type)

These varieties, however, are characterized by low drought tolerance, susceptibility to lodging and powdery mildew, and low productivity. In an effort to improve Libyan barley production, germplasm from ICARDA has been introduced.

One source of germplasm was the hull-less barley special nurseries introduced from ICARDA. The preliminary screening showed the following characteristics:

- Low tolerance to drought;
- Susceptibility to spike breakage;
- Susceptibility to smut disease;
- Susceptibility to lodging;
- Higher yielder than local varieties under rainfed and irrigated conditions.

Table 2. Barley performance under rainfed and irrigated conditions, 1998-2000 seasons.

Trait	Rainfed (Sofiet station)		Irrigated (Barjoj project)	
	Hull-less	Hulled	Hull-less	Hulled
Days to heading	86	69	71	75
1000 kernel weight (g)	27	35	30	40
Plant height (cm)	53	60	91	86
Yield (t ha^{-1})	1.7	3.0	4.6	6.0

Hull-less barley germplasm was also introduced through a North African barley project, using a decentralization breeding approach. Crosses were made at ICARDA between hull-less types and drought tolerant varieties. The selection was carried out under local conditions in environments specific for each barley growing zone, thus resulting in a number of new naked types.

There is a need for more collaboration in quality testing to screen the local genotypes for use as human food.

Constraints to Barley Cultivation

Major constraints in barley cultivation are:
- High price of local production;
- Lack of policies to encourage barley use for human consumption;
- Lack of quality parameters;
- Shortage of improved varieties for food barley;
- Lack of grain standards for food barley;
- Lack of quality research on food barley;

Recommendations for Improved Barley and for Higher Usage

- Establish quality standards for the national program;
- Activate germplasm exchange;
- Improve barley germplasm for food barley;
- Improve quality parameters for food barley;
- Issue booklet of barley recipes in other barley-growing countries;
- Issue food-barley newsletter.

Use of Barley Grain for Food in Morocco

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Introduction

Barley (*Hordeum vulgare* L.) is ranked as the world's fourth crop in terms of acreage and production and its cultivation is the most widespread grown species across different agroclimatic zones. Barley grain has multiple uses as malt, as food, and as feed.

Barley has always occupied the largest land area among the crops grown in Morocco. Throughout history barley has played a significant role in household food security and as a major feed source. The successive dynasties since the *Mourabitine* in the beginning of the second millennium have based their food security and safety against famine on the development of large storage facilities, *makhazene.* The Moroccan kings ensured their security and popularity through the safeguarding of barley grain stored in the *makhazene* (Rosenberger 2001). Powerful rural households stored barley while urban ones stored wheat, thereby creating systems that identified the distinguished "notables" throughout Moroccan history. These two rural-urban notable systems contributed significantly to food security during food shortages, drought, and epidemics in Morocco. The use of barley and other cereals in the Moroccan political system brought food security issues to the notables' attention.

Until the middle of the last century, barley and durum wheat were the predominate grains consumed by households.

Evolution of Barley Acreage, Production, and Yields

In Morocco barley occupies on average 46% of the total cereal production area and contributes 38% to total cereal production. It is grown in all agroclimatic zones but 70% of its growing area is located in the arid and semi-arid regions and 10% in the mountains.

The average barley area is estimated at 2.2 million hectares and during the period 1980-1990, this increased by at least 200,000 hectares (Table 1). However, some of the barley-growing lands in both high rainfall areas as well as in semi-arid zones have been replaced by bread wheat cultivation. This has pushed most of the barley into arid zones that have harsh growing conditions.

Table 1. Barley distribution in Morocco ('000 ha).

	1961-1970	1971-80	1981-1990	1991-2001
Total cereals	4,230	4,610	4,940	4,840
Total barley	1,830	2,110	2,300	2,210

Source: FAO 2001

The grain production and yield are low and highly variable (coefficient of variation exceeding 32%) mainly due to the predominance of barley cultivation in the drylands and the lack of inputs. In fact, most farmers consider barley as a low risk aversion crop (Benaouda 1992). During the period 1981-2001, the average production was 2.11 million tonnes with a variation coefficient of 48%. Grain yield averaged 0.81 t ha^{-1} with a variation coefficient of 53%.

Morocco was self-sufficient in barley grain production until 1988 and had sometimes even exported barley. Since then Morocco has needed to import an average of 378,000 tonnes of barey grain annually, subsidized by the government, and used mainly for livestock feed (Figure 1).

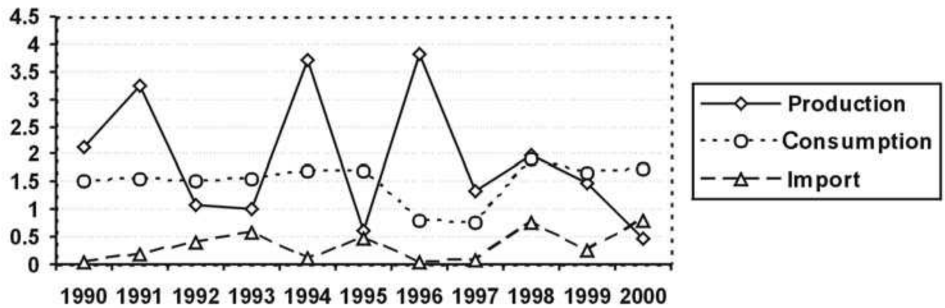

Figure 1. Moroccan barley production, consumption, and import (million tonnes). Source: FAO 2001

Barley Grain Uses in Morocco

Barley is grown by the majority of farmers in all agroclimatic zones and plays an important role as feed for animals. For use as forage from December to February, *aglass* is practiced by farmers on small parcels. This type of barley can be grazed continuously or left to produce grain, it can also be clipped at the heading stage. Barley straw is highly valued by farmers and contributes significantly to livestock feeding. An average of 80% barley grain production is used as animal feed on farms and the remaining 20% is used as food. However, household cereal consumption surveys covering the period 1976 to 1985 showed that this latter usage dropped to 14%. (Belhadfa et al. 1992). Worldwide, Morocco is ranked first in food-barley consumption with the estimated average of 54.8 kg per capita consumed annually (Belhadfa et al. 1992; FAO 2001).

Barley's contribution to daily human caloric requirements is already significant as shown in Figure 2. Long-term projections indicate that consumption levels may increase due to expected prolonged drought conditions in Morocco.

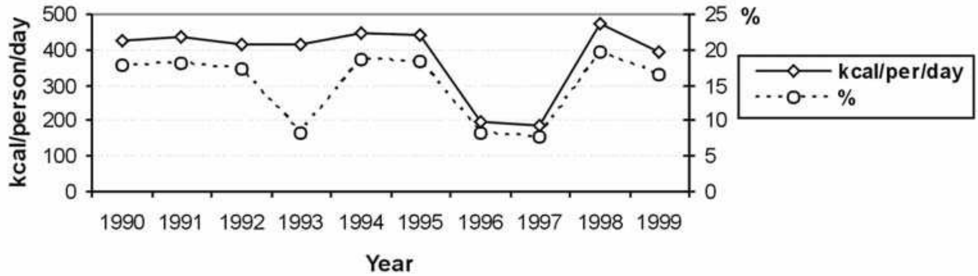

Figure 2. Contribution of barley to energy intake. Source: FAO 2001

The consumption of barley as food varies with the season and with the region. This consumption is highest during dry years and lowest in seasons with more rainfall when wheat is more heavily consumed. During the last decade (1990-2000) barley consumption fluctuated with drought conditions. However, an increase in barley production is associated with a decrease in its consumption. This is because good years for barley production are also good years for other cereals, and barley surplus can be sold allowing consumers to purchase the preferred cereal, usually wheat. Barley grain is mainly used as food in the rural mountain and southern areas of Morocco with an average consumption of 54 kg/per/year compared with 5.5 kg/per/year in the cities (Belhadfa et al. 1992). In the last decade (1990-2000) interest in using barley for food has been noticed to increase in cities and a number of specialized barley mills have been established.

A variety of dishes are made from barley-grain products including soups, bread, potages, and couscous.

Until 1985 a small amount of the grain, produced under contract with farmers, was purchased by the brewing industry. Since then the industry has turned to malt imports.

Research Efforts Promoting Barley for Food

Barley breeding began in 1924 with the selection of lines from domestic landraces. These landraces have been used for both animal feed and human food. In the 1960s, two-row barley varieties were introduced from Europe. Many varieties were selected with higher yield than the predominant local landraces. Twenty-four varieties were released as of 2002.

Tests for assessment of food quality have not been introduced to the barley improvement program in Morocco. For the registration in the catalogue of new varieties, only a few quality parameters have been used, such as protein content, specific weight, 1000-kernel weight, and milling yield. For this last parameter, two-rowed barley varieties have been found to be superior to six-rowed barley varieties (Table 2).

Table 2. Moroccan barley varieties and some quality characteristics.

Variety	1000-kernel weight (g)	Milling yield (%)	Flour yield (%)
Aglou	42.8	86.3	67.3
Asni	41.6	86.9	67.6
Tiddas	46.4	86.1	66.8
Tissa	44.3	86.5	65.9
Acsad 60	44.8	85.9	66.2
Acsad 68	45.3	86.5	61.6
Acsad 176	47.1	85.9	60.6
Annaceur	45.5	84.9	59.9
Arig 8	45.3	78.8	61.2
Barlis	44.1	78.2	59.1
Rabat 071	43.0	77.1	59.2
Merzaga	41.7	76.2	58.0

Source: Moudden 1997

The percentage of β-glucans in barley has been determined for some varieties, and Moroccan landraces have low to medium levels (Table 3). Bread-making value tests of barley varieties, alone or mixed with bread wheat flour, have also been conducted. An additional program to develop hull-less food barley varieties was initiated in 1985. However, the difficulty of handling the seeds of these varieties has caused them to be eliminated from the catalogue trials because of their reduced seed-germination capability.

Table 3. Composition and nutritive quality of barley varieties.

Variety	Humidity %	β-glucans %	Proteins %
Aglou	8.9	5.4	15.1
Asni	9.9	2.8	12.2
Tissa	9.8	3.6	12.3
Annaceur	10.1	5.4	12.9
Rabat 071	9.8	5.9	12.3
Acsad 60	10.1	5.4	12.9

Source: Boujnah 1998

The Cereal Program of the Institut National de la Recherche Agronomique (INRA) has given high priority to food barley research. In this regard, the barley breeding program in Morocco started testing for quality parameters including β-glucan content and bread-making tests.

Conclusion

Barley will remain an important crop in Morocco and can play an increasing role in food security if it is given a greater valorization. Barley, because of its adaptation to harsh environments, will allow better buffering of cereal production under the successive droughts experienced in Morocco during the last two decades. Efforts are needed to develop quality-assessing parameters to be used in breeding barley for food. Knowledge accumulated by local communities could help significantly in achieving this goal.

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Barley-based Food in Southern Morocco

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Barley's Place in Morocco

Throughout the history of Morocco, to this day barley has a unique and important place in the country's agriculture and development. Morocco is considered one of the major centers of diversity for cultivated barley (*Hordeum vulgare* L.). This is evidenced by the large genetic variability found between and within barley landraces and by the presence of numerous wild *Hordeum* species including populations of the wild progenitor of cultivated barley (*H. vulgare* ssp. *spontaneum*) collected in the low Atlas region (Molina-Cano, et al. 1982; 1987). This genetic variability has been used extensively and the North African germplasm will continue to contribute valuable characteristics for barley improvement programs around the world.

Among crop species, barley has the greatest range of adaptation across varying climatic conditions as well as to harsh environmental and low input agricultural systems. Because of its short growing cycle it is well adapted to Mediterranean dryland areas where late droughts are frequently experienced. In Morocco, barley is grown in all agroclimatic zones. However, 70% and 10% of the average 2.3 million hectares sown annually, are planted in the semi-arid/arid and mountainous zones, respectively (Benhadfa 1989). At most farms, barley cultivation is often reserved for harsh conditions and shallow, rocky soils. It frequently follows wheat and is considered by most farmers as a minimum-risk crop that will not require additional inputs

In Morocco, the importance of barley is mainly due to the multiple functions it plays at the farm level. Most farmers practice grazing on barley fields close to their houses. Barley straw and most of the barley grain are used as the preferred animal feed with approximately 20% of the production used as human food, which makes the country a leader in the use of barley for food (Amri 1994). However, with the spread of bread wheat cultivation in Morocco in the second half of the twentieth century, the consumption of barley as food decreased significantly because of wheat flour subsidies and increased urbanization. As a result barley has been consumed mainly in the arid zones and mountainous regions.

Morocco's Institut National de la Recherche Agronomique (INRA) has given a top priority to the improvement of barley productivity through breeding, agronomy, and valorization of the research efforts (Amri 1990). Research and development plans consider barley as a key element in food and feed security in the country (Amri 1994). With Morocco's predominating pattern of dry seasons, barley can play a major role in stabilizing cereal production and in supplying feed for animals. Also, the dietetic benefits of barley are beginning to gain favor in affluent urban households. If this trend continues, the increasing consumption of barley by the population will help to limit the imports of bread wheat.

This chapter illustrates the importance of barley use as food in the Souss and Haha regions of southern Morocco through the variety of dishes prepared from barley grain and flour.

Methodology

We conducted surveys of ten women from the Souss region (Tiznit and surrounding areas) and seven women from the Haha region (Tmanar and El-Dimsirn), with ages ranging from 35 to 90. The goal of the research was to quantify the amount of barley used and the dishes prepared at the household level, currently and historically. The intention of the survey, therefore, was not to produce statistical results, but rather to document the usage of barley as food. Open discussions were held and data collected on the details of processing and dish preparation. Some special dishes were prepared during the surveys. In this chapter we present the processes and the main barley dishes in Morocco.

Main Barley Dishes in Southern Morocco

There are popular sayings from the surveyed regions that testify to the importance of barley as an adapted and multi-function crop such as, "barley is the owner of the farm and wheat is only a guest," "barley is the father crop in the farm," and "the house is empty without barley grain and straw".

Although all the surveyed women acknowledged the importance of barley as a key element in food security at the household level, the decrease in the quantity of food barley consumed by households has also been reported. Historically, barley grain has been the most widely used cereal grain in the survey regions, along with corn and occasionally durum wheat. Usage ranged from 25 to 80 kg/person/year/, but with the introduction of bread wheat and the wheat flour subsidy, consumption has dropped to 20 kg. While some families now use barley grain and flour only occasionally, one family in the Haha countryside stated that barley is still widely used in the mountainous regions and is still consumed at an average of 80 kg/person/year. The surveyed women over 50-years old reported the existence of hull-less barley varieties used for food called *tahardidt,* in Berber meaning naked barley. They also recalled durum wheat and a species of wheat called *tizikirt,* with vitreous grains, but thinner than those of durum wheat. Bread wheat was only known after 1945.

Barley grain in the two survey regions is consumed as food in different forms, guided by the timing of the harvest and by the grinding and cooking processes. In general, barley is used as flour, as semolina, and as whole-dehulled grain. The main dishes are described in the next section.

Azenbou

Most of the farmers in the survey regions harvest small quantities of barley (approximately 50 to 150 kg) at physiological maturity when the grain is still green. The grain is threshed, steamed, and dried. If a family is out of this type of grain or did not harvest it at the appropriate time, they take the barley grain harvested at usual time, soak it in water overnight, and then proceed to the steaming and drying processes. The grain is then medium dry fried to prepare *azenbou* semolina, called locally *ibrine azenbou* or well dry fried to prepare *azenbou* flour called *agourn azenbou.* A small amount of ground salt is added in the flour preparation. The flour and semolina is produced in stone mills by feeding the mill with small or large quantities of grains depending on the type of products to be obtained.

Azenbou flour recipes

- *Labsiss* is a dish that can be prepared quickly. It is eaten at any time of day, but is preferred in the morning and afternoon. Hot water is combined with *smen* (clarified butter, often salted, spiced, or herbed), or olive or argan (*Argania spinosa*) oil, salt, four or five eggs, and flour is added while mixing until soup is thick. *Labsiss* can also be prepared by mixing flour with *smen* and honey to make balls that are then dried. It can be conserved for over six months and is used by travelers and pilgrims on long trips.
- *Toumit* is another quick food prepared by adding *azenbou* flour to cold water and olive oil, and mixing until smooth paste. The olive oil can be added to a depression made in the middle of the paste.
- *Lamriss* is prepared mainly in the summer. It is made by mixing the flour with cold water or buttermilk, and a little salt.
- Soup can also be made from*azenbou* flour by adding the flour to boiling water with oil, cumin, black pepper, and salt.

Azenbou semolina recipes

- Soup can be made by adding the semolina to boiling water; a small quantity of milk can also be added at the end.
- *Tagla* is prepared by mixing the semolina with boiled water; continue mixing until it is thick; serve with olive or argan oil, or with smen or butter in a depression made in the middle of the preparation.

- *Ibrine azenbou* is similar to *couscous* and as the durum wheat *couscous* can be prepared with legumes or in different styles.

Aballagh

Flour and semolina produced from barley grain stored underground for over three years has a special odor and is called *aballagh.* The flour is used exclusively for bread making and the semolina for couscous making.

- *Aftal* is a type of couscous prepared from barley semolina coated by barley flour to make large and round particles.
- *Bouffi* is a special dish prepared by adding flour to one cup of boiled water, one cup of olive oil, and a small quantity of salt; it is mixed until most of the liquid is absorbed and the flour mixture is almost dry.

Dishes from fully mature barley grains

Most of the dishes made from wheat in the survey regions are also made from the flour and semolina of barley grain. Risen bread and flat bread *(toughrift)* are made with only barley flour or in combination with wheat flour. Soup is also made with this type of barley flour and semolina as described for *azenbou* flour and semolina.

Barley flat bread

Over seven types of *couscous* dishes are made from barley semolina. The three most common recipes are couscous with meat, carrots, pumpkins, onion, tomatoes, and turnips; couscous with turnip leaves; and couscous with turnips and dried faba beans.

Some special dishes described in the survey were:

- *Tiberkouksine* is a soup made from semolina to which milk, caraway, and *mhamsa* (large particles of wheat semolina) or a small pasta, are added.
- *Tagla* is a paste made in the same manner as described for *tagla* made from *azenbou* described earlier.
- *Belghmane* and *bouffi* are prepared by adding flour to boiled water and mixed until solid; served with butter, olive, and argan oil.
- *Tiharblattine* is prepared by adding pieces of barley paste to boiling water with olive oil and salt. This dish can also be made as a stew with pigeon and chicken.
- *Birkoukss* is prepared with large-particle *couscous* steamed with oregano and mixed with a small amount of wheat grain; it is served with *smen* or argan oil added to the depression in the mounded couscous.

Barley *couscous*

Whole barley grain dishes

Whole barley grain is often consumed like popcorn. Other popular snacks are:

- *Tijmirout*, made by roasting the mature spikes of the whole harvested barley plants over a fire.
- *Tounjifine* or *tiroufine,* whole grain misted with water, decorticated, and fried until the grains crack. This dish is recommended for bone development of children.

Special dishes prepared with this type of barley grain are:

- *Ourkimne* is made by combining whole-wheat grain, decorticated barley, corn cobs, faba bean, peas, sorghum, carob, small amounts of chickpea and lentils, dried turnips, and various spices. The whole mixture is cooked with a leg of veal for at least ten hours. This dish is often prepared by a group of families and is shared with neighbors during the Ashoura festival.
- *Tagla n'Ikikr* is a soup of barley prepared with the seed of the date palm during the Ashoura festival. The person who first finds the seed is responsible for the livestock for the year.

Conclusions

Barley has played a significant role as food throughout history in Morocco and while per person consumption has declined over the past half century, the diversity of traditional dishes found in the surveyed regions has shown that barley is still important. In urban areas, barley bread and couscous are now also being produced commercially and are increasingly consumed in the cities.

Barley could play a major role in food security in Morocco. To this end the government has allowed the mixing of up to 15% barley with wheat flour for bread making. If this usage continues, wheat imports could be significantly reduced and value-added to this neglected species. More research is needed to develop highly nutritive barley varieties and valorization processes that will increase its use as food in Morocco.

Acknowledgments

We would like to thank the women from Souss and Haha regions who kindly agreed to share their long experience in the uses of food barley. Some participants prepared some of the cited dishes.

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Food Barley in Tunisia

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Barley Systems in Tunisia

Barley status in Tunisia is historically based on its phylogenetic origin in the region where wild relatives and progenitors are still present and cohabit with domesticated and improved cultivars. Tunisia is a secondary center of diversity for barley and durum wheat (Vavilov 1951). Over the centuries, early domestication and local knowledge have generated diverse barley landraces used for feed and for food. Barley is mainly cultivated after wheat as secondary crop. Considered as a low input and marginalized crop, barley yields remained very low during the last century.

Barley landraces are cultivated in all regions of the country. From the northern to the southern zones, many local barley cultivars adapted to the environment and to consumer preferences, are grown. In semi-arid regions (central and southern zones), barley is mostly cultivated by sheep owners and is grazed once or twice as a winter linkage crop when forage and pasture are not available. It is also grown for grain production in intermediate zones and, in areas where oats are not available, for hay intercropped with a forage legume crop (vetch). Improved barley varieties are essential to increase the grain yield and biomass volume as an important component in feed strategies, especially in harsh environments (El Felah 1998; Medimagh et al. 2000).

Martin, Rihane and local barley landraces are the primary barley varieties grown. Martin, a six-row genotype, was selected in the 1930s. It gives a medium grain yield, is late maturing, and is susceptible to late drought, lodging, and the main foliar diseases (net blotch, powdery mildew and scald). Rihane, a six-row variety, was selected in 1987 in collaboration with the International Center for Agricultural Research in the Dry Areas (ICARDA). Rihane is now sown in more than 50% of the barley growing area. Local barley cultivars are still grown essentially for use both as feed and food. The most widely grown barley landraces are Souihli, Ardhaoui, Frigui, Beldi and Djebali, while Sfira and Djerbi are cultivated in limited areas in the south. The latter two are essentially used to prepare special recipes by rural communities on the island of Djerba. In the 1990s, Manel, a new six-rowed barley variety, was officially registered and released for subhumid areas. Momtaz, a drought tolerant genotype, was proposed for official release in 1999.

The two-rowed material is not well accepted by Tunisian farmers compared with the six-rowed genotypes. The local landraces are six-rowed.

Role of Barley in Food Security

Barley is used for both feed (85%) and food (15%) with the local landraces preferred for food preparations rather than the improved cultivars. Early rural domestication focused on primitive barley landraces and their wild ancestors and generated many barley food uses. Barley soup, barley bread, and 'Malthouth' were probably the first barley-based foods in the south Mediterranean area, easily processed from barley grain. With the first invasions to the southern Mediterranean area by the Punic and Roman civilizations, there was an impact on the evolution of food barley. As the people moved from a transhumant lifestyle to a more settled culture they began to use the roasting process brought by the invaders and to produce flour from the roasted barley grain. Over time local knowledge presented barley as a high energy and healthy food and barley also came to be used as a meal to break the fast during the holy month of Ramadan.

Production Potential and Constraints

Barley cultivated areas varied from 450,000 to 800,000 hectares in the last century. Barley is mostly grown in the semi-arid and arid regions in the center and the south of the country. In the favorable northern zones, its area does not exceed 200,000 hectares, whereas in the unpredictable central and southern areas cultivation is linked to early autumnal rainfall and to the previous year's yield. In 1989, farmers cultivated about 450,000 hectares in the semi-arid areas, but the yields were very low (0.2 t ha^{-1}). As a result, for the next two seasons (1990/91 and 1991/92) they cultivated no more than 300,000 hectares in spite of good yields (0.8 t ha^{-1}). In addition to rainfall distribution, the level of barley imports also plays an important role in farmers' decision-making process on their investment in barley cultivation each season.

Research and Extension Activities

For many years farmers grew barley landraces domesticated centuries ago. These cultivars are primarily six-row, tall genotypes that are late maturing and susceptible to foliar diseases, lodging, and shattering.

The cereal improvement program began in 1893. The barley program was initiated with yield trials and on-farm demonstrations. The germplasm was constituted of domestic and introduced material. The first barley crosses were made in 1923 with the objectives of improving grain yield and resistance to disease and lodging.

In the 1970s Tunisia determined that to become self-sufficient in meat and milk, the country would need an increase in feedstocks and an improvement of the rangelands. A collaborative program with ICARDA, initiated in 1981, strengthened the barley program. Fifteen barley varieties have been officially registered and widely grown. Although both two-row and six-row barley cultivars are available to farmers, they favor the latter because of its early production of biomass that in the intermediate zones can be grazed twice.

In the last decade there have been bread-making trials using barley mixed with wheat flour. Over the years, advances in processing, marketing, and advertising seems to have made barley usage for food products more accepted.

The barley improvement program was reorganized in 1999 as a Federative Barley Project with objectives to:

- Improve barley varieties for adaptation to subhumid and semidry areas;
- Improve insect and pest management;
- Improve agrophysiology and genetic resources;
- Improve disease tolerance;
- Improve biotechnology capability.

Food Barley Economic and Social Importance

The names of local barley are sometimes related to tribal rituals or to a region of the country. Djebali's origin is in the high altitudes of the northern mountains Kroumirie and Mogods. Frigui is related to the transhumant nomads and to Tunisia historical name 'Ifriquia'. Ardhaoui, grown in the southern zones, may be assumed to have originated with a Berber dynasty's ritual poem and folkloric dance (Boeuf 1911).

A questionnaire for a food barley study by Medimagh et al. (2000) included questions on people's age, job, education, and their knowledge of food barley. Women showed higher attention to barley uses than to wheat uses. From region to region, the barley processing methodologies change according to the standard of living as well as the urban or rural status of the people. All people interviewed used cracked barley to prepare barley bread or *kisra, malthouth, d'chich, mermez,* or *fric.* Meals prepared from the barley flour include *bazine, assida, b'sissa, hail, and dardoura* (Figure 1).

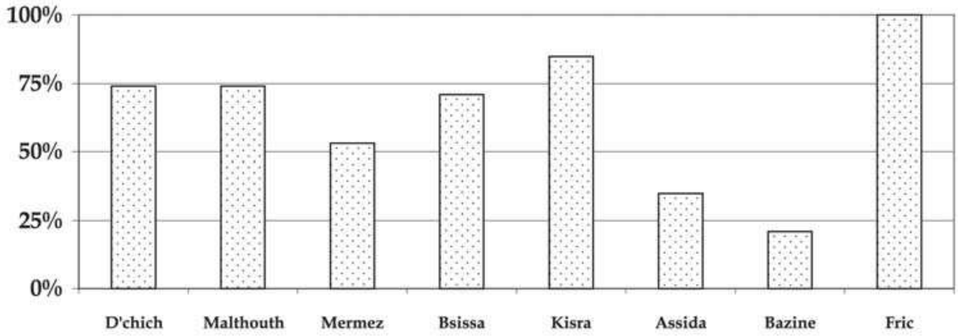

Figure 1. Barley use frequency responses. Source: Medimagh et al. 2000

The local barley landraces are characterized by a gradient of endosperm color, shape, and size (Figures 2, 3, 4). The food barley survey revealed that 91% of Tunisians preferred the white-to-yellow barley grain endosperm, whereas 9% of them choose the gray barley (Figure 2). Traditional and industrial processors preferred elongated (50%) to the round (38%) or oblong (12%) shapes (Figure 3), and they favored the large grains (59%) to the medium (29%) grains (Figure 4).

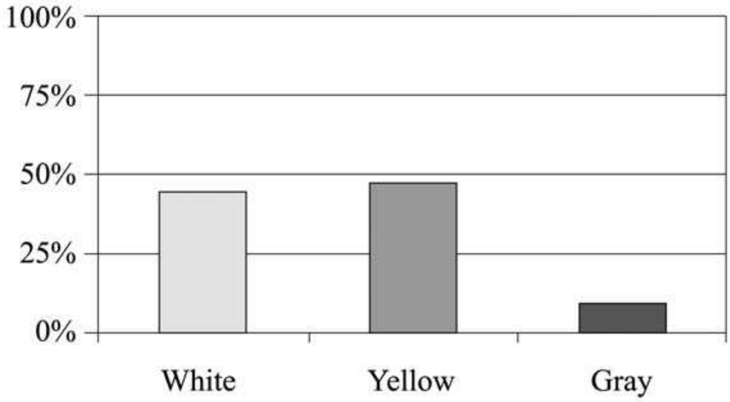

Figure 2. Barley grain color frequencies. Source: Medimagh et al. 2000

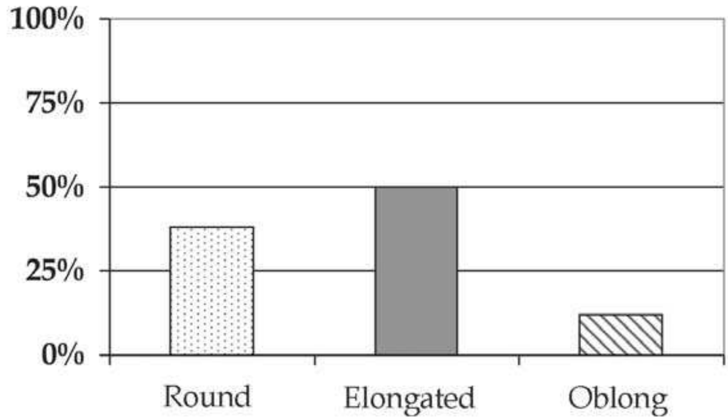

Figure 3. Barley grain shape frequencies. Source: Medimagh et al. 2000

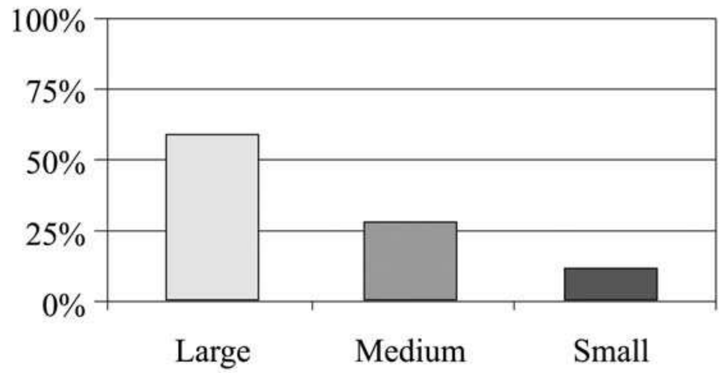

Figure 4. Barley grain size frequencies. Source: Medimagh et al. 2000

Consumer preferences can possibly be traced to the early Tunisian Berber dynasties.

Barley bread is made from white cracked grain in the Kasserine mountain areas to yellow grain in the coastal areas. For *malthouth* grey barley cracked grain is preferred. In the southern region, *bazine* (salty and hot) is a kind of porridge made from a white flour produced from roasted grains of Ardhaoui, a local barley landrace.

Barley Preparations

Whole cracked-barley grain preparations	Ingredients/Preparation
Kisra (Local name for barley bread)	Medium-coarse cracked barley, warm water, salt, yeast; ferment for 3 hours then knead and bake in traditional oven *(tabouna)*.
Malthouth (Local name for barley couscous)	Dampen cracked barley grain, add salt and place in top part of couscous pot; in lower part of pot, add olive oil, vegetables, salt, water, and lamb or octopus; simmer for 1 hour; serve with liquid, vegetables and meat ladled over *malthouth*.
T'bikha	Whole barley grain cooked with vegetables in oil, onion, salt, and water.
Fric (Barley soup)	Combine in a pot onion, oil, tomato, green pepper, fish, and water. Bring to boil. Add cracked barley and simmer 45 to 60 minutes. Serve hot with a squeeze of lemon juice.
Mermez	Barley soup prepared with barley grain harvested at physiological maturity when the grain is still green, then roasted and cracked into medium-coarse pieces.
D'chich	Barley grain cracked into small pieces, used to prepare barley soup or barley bread.
Barley flour preparations	
Bazine	Add barley flour to boiling water; simmer and add olive oil until mixture thickens; complete sauce by adding black pepper, olive oil, tomato, onion, garlic, and mint.
Assida	Barley flour mixed with water and cooked under low heat. Simmer until thick. Served hot with olive oil and honey.
B'sissa	Roasted and cracked whole barley grain mixed with cumin, fennel, coriander, lentil, faba bean, chickpea; all ingredients are roasted and ground.
Dardoura	Barley flour mixed with olive oil, water, and sugar; preferred on hot days.
Hail	Barley flour mixed with olive oil and eaten with *chriha* (fig preserve) in cold weather.

Conclusions

The food barley survey mentioned earlier revealed how important food barley is in Tunisia. Barley preparations are based essentially on the socio-ethnologic origin of communities. The results of the study showed a high diversity of local food barley uses based on the grain processing, the endosperm color, and the size and shape of the grain.

Food barley genetic resources should be managed following socio-economic and agronomic strategies with a participatory and decentralized breeding program aiming at *in situ* conservation, farmers' property rights, and poverty alleviation.

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Barley Farming Systems and Types of Barley End Uses for Human Consumption as Described by Farmers in Eritrea

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Introduction

Barley is the second most important cereal crop in Eritrea. It ranks second to sorghum in total cereal grain production and in total area of cereal crops cultivation. Barley is cultivated in the central highlands and green belt agro-eocological zones. It is food and drink to human beings and the straw is feed to livestock. Barley production in Eritrea has been based on local landrace populations. Eleven landrace populations have been reported of which 10 were collected and preserved. The average annual barley grain production in Eritrea is about 30,000 tonnes from 45,000 ha.

The Ministry of Agriculture conducted a survey on barley farming systems and types of barley end uses for human consumption in Eritrea in 1999. Barley farming systems, farmers' description of varieties, and the end uses are presented in this chapter.

Methodology

Ten villages were selected for the survey. These villages were considered as representative of barley growing areas in the country. Five farmers were interviewed from each village.

Barley Farming Systems

Barley production in Eritrea is based on farmers' traditional production systems. Farmers plough their land with oxen; some farmers use modern fertilizers like urea and di-ammonium phosphate (DAP), while the majority does not apply any fertilizers. Weeding is done by hand and farmers do not apply any disease or pest-control chemicals. Barley is often grown in a mixture with wheat, in a proportion of 75% barley and 25% wheat, known as *hanfetz* (mixed in Tigrigna) often refer to Abat as *"segem"*, meaning barley. This is an indication that Abat has become the most important landrace in the region. Farmers' grow the barley-wheat mixture because barley protects wheat from rust diseases, wheat protects barley from lodging, weeds are suppressed, and barley-wheat bread quality is better than single-grain bread.

Variety Descriptions

All the cultivated varieties are landrace populations.

Yeha

Yeha is a two-rowed barley landrace grown for its earliness in maturity. It is found in the northern and northwestern parts of the central highlands. It is of short-to-medium height, with small-to-medium grains, ranging from gray to tan, and is reported to have a high grain weight. This landrace can tolerate drought both at early and later stages of the growing season, but is susceptible to water logging. Farmers grow this landrace on light soils with a low water-holding capacity. Yeha produces a relatively white flour (although darker than Kulih) and is used for bread, *injera* and other dishes. It is harder to process than Kulih, and thus "is not for lazy women" as one male farmer reported during the survey. The straw of this landrace is thin and highly palatable to animals (preferred over both Dessie and Quinto). The grain can be stored for up to a year under the traditional storage system. Compared to other landraces (such as Kulih, Quinto, and Dessie), it is low yielding. Yeha is reported to be susceptible to shoot fly, but resistant to rust.

Kulih

Kulih is a tall, two-rowed barley landrace grown in the northern, northwestern and southwestern parts of the central highlands. It requires a relatively low temperature, thus it is mainly cultivated at high altitude. It grows best in loamy soils, reaching maturity in 3-to-3½ months. The stem is dark, and the grain is long and rather thin. The flour of Kulih is whiter and is considered of better quality than Yeha and Abat flour, and nearly as good as Atsa flour. According to farmers "the white flour makes the lazy women happy" because it is easy to process. Kulih grain can also be stored for up to a year under traditional storage. In spite of its adaptability, it seems to be a rapidly disappearing landrace.

Atsa

Atsa is two-rowed barley grown in areas with relatively high rainfall. While it is cultivated to some extent in all barley-growing areas, the majority is found in the Senafe region, especially in the southernmost part. In southern and western Senafe, Atsa is found in dispersed fields or as a few plants within a field of other landraces. Many farmers in these areas describe Atsa as a landrace having a nice appearance. The stem is tall and dark, the spike is 'hairy' with large kernels. Two rows of empty glumes running along the two rows of grain give the hairy look.

This trait is reported to partially protect Atsa from bird attacks. Atsa is medium-to-late maturing, prefers loamy and clay soils with higher moisture content, and tolerates water logging quite well. The grain can be store well for up to a year. The flour is white and can be used for various typical barley recipes and food products. Some survey participants said that Atsa is not the best-suited barley for *injera*, but has to be mixed with wheat flour. One female farmer reported that in her *hanfetze* system, she increased the ratio of Atsa to wheat.

Quinto (Gunaza)

Quinto is one of the two six-rowed barley landraces grown in Eritrea. It is cultivated in the areas north of Asmara under the name of Quinto, and in the Senafe area under the name of Gunaza. In neighboring areas of Adi Keih and Dbarbwa, Quinto was mentioned by farmers, but was not physically found. It is definitely a landrace disappearing from these areas. In the Senafe area, the decreasing rainfall is believed to be the main reason for its disappearance.

Quinto grows well in areas with high rainfall. It prefers fertile, loamy soil with good water-retention capacity, but is also cultivated on sandy soil with a high content of organic fertilizers. The plant is tall with tan stem, and late maturing (over 120 days). The spikes are long with large grains, and the thin glumes are also tan. Quinto has white flour that is highly appreciated for bread and *injera.* The thick stem is not very palatable to animals and therefore not as good for fodder as Yeha. Again, under traditional storage, Quinto stores well for a year.

Demhay

Demhay is a two-rowed, late-maturing barley that needs a relatively high rainfall and gives a high yield. There are three types of Demhay: yellow, green and black grains. It prefers clay soil with a high content of organic fertilizers. Demhay is of medium height with a tan stem. The grains have a shape similar to wheat grains. A special characteristic of Demhay is that the grain is covered with only very thin glumes, and is, therefore, sometimes called "naked barley". The thin glumes can be easily removed during threshing, which makes it easy for processing. The straw is highly suited for fodder. Demhai normally brings a higher market price than other barley landraces. Storage capability is similar to other barley types. Farmers appreciate the processing and the taste qualities of the three types. Yellow Demhai is considered to be the best for bread, *tihni,* and *injera.* Black Demhai is very good for *kollo* and *siwa.* Preferences for green Demhai use were not reported.

Abat

Abat is a two-rowed, short-to-medium tall barley landrace grown in dry areas. Most probably, this landrace is the oldest grown by farmers in areas with moisture stress. Abat tolerates drought and matures earlier than both Atsa and Kulih. It has the ability to grow on soils with low fertility, but the yield is low. The stem color either pure-stand barley fields or in *hafetze* fields. In these areas, the farmers often refer to Abat as *"segem"*, meaning barley. This is an indictaion that Abat has become the most important landrace in teh region.

Abedaray

Abedaray is a tall, two-rowed barley. It grows well on clay-loam soil and high rainfall is required for optimal growth. Abedaray matures at the medium term. The landrace has long, compact spikes, grains are large and the stem is tan. The flour of Abedaray is very white and is highly appreciated for *injera* and bread. Storability does not differ from other landraces of barley. A special characteristic of Abedaray is that the awns fall of the mature spikes during good rain seasons, that allowed for a long growth.

Kontsebe (Tsaria)

Kontsebe is a tall, two-rowed type, which grows well on light, loamy soil with good drainage. Similar to Yeha, it matures early and tolerates drought to some extent. The spike is of medium length. The grain size is small to medium. The flour color is rather dark and yet it is used for preparation in most of the common dishes. Apart from one incidence west of Mendefera (Kontsebe found in a *hanfetze* field with other barley landraces and with wheat), Kontsebe is only cultivated in the areas of Senafe and Adi Keih. The name of Kontsebe is interchanged with the name of Tsaria, and it is not clear from which area each name originates.

Tsellimo

Tsellimo means black, and Tsellimo (also called *Tsellim segem*) is the most explicitly black of the barley landraces grown in Eritrea. It is a tall, two-rowed type grown on loamy to clay soil. It is not very drought tolerant and needs good rain for optimal growth, in which case the yield is high. The stem color is dark and the grain is rather small and black, very much like a dark version of Kontsebe (Tsaria). Because the flour is also dark, it is mainly used for the preparation of the local beer (*siwa*). Tsellimo is found in the area around Mendefera and in the green belt area northeast of Asmara, but is most widespread in the southeast (Senafe and Adi Keih areas). Being used for quite restricted purposes, Tsellimo is nowhere the dominant barley landrace, but pure stand fields of Tsellimo are found that are intended for sale or for direct large-scale production of siwa.

Atena

Farmers consider this landrace as a two-rowed barley. However, Atena has the unique characteristic of the basal part of the spike being six-rowed and the rest being two-rowed. The plant is tall with a high tillering ability. It requires a high amount of moisture for its germination. Light to loamy soil is suitable for this landrace, but yields are significantly higher with good manuring. The spike is of is tan and the flour is darker compared with Kulih and Atsa. Grains are used for the typical barley dishes. Abat is grown in the area around Mendefera, especially to the northwest of Mendefera. It is often grown mixed with Kulih or Atsa in length and the grain is big and grayish. It is a late maturing variety that must be planted very early (i.e. during the month of May) to mature well. Storage capability is similar to the other landraces and the white flour is used for all of the typical dishes. Only one sample of Atena was made, and the landrace is rare.

Dessie

This landrace is only grown in the area north and northwest of Asmara. It was apparently introduced from Ethiopia a few decades ago but its cultivation has diminished considerably. Dessie, like Quinto, is a six-rowed barley, it is a relatively late maturing and high yielding barley, later and higher than Quinto. It demands fertile soils and it tolerates water logging. The spikes are short and compact, the grain is dark, as is the flour. Dessie is especially suitable for production of *siwa*, the straw is considered of average quality for fodder, though less digestible than Quinto, which is more highly preferred.

Barley End Uses for Human Consumption

The major uses of barley for human consumption are reported in Table 1.

Barley Production Constraints

The main barley production constraints are disease such as net blotch, scald, and smuts; insect pest outbreaks of armyworm, grasshoppers, locusts, and shoot fly; a lack of improved agronomic practices; and a lack of high-yielding cultivars.

Research and Extension

Food-barley improvement research was initiated in 1999 with the idea of exploiting the landrace diversity through the participation of farmers. Three villages (Adi Keih, Embaderho and Tera Emni) in addition to Halhale research station were selected as experimental sites. High yielding lines have been identified and should soon be available to subsistent farmers. These lines will also be used as parents for crossbreeding.

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Table 1. Barley usage for human consumption.

Local food name	Description	Method of processing	Alternative cereals used
Injera (taita)	Large, fermented pancake	Barley flour is processed into a paste that is left to ferment for 1-3 days. The paste is then baked on one side for 5 minutes on a large clay pan over a fire. For the first minutes the pan is covered by a lid of straw or clay. Barley *injera* can be preserved for 1-3 days. It is served with different sauces.	Wheat (but only in mixture with barley), taff, sorghum, pearl millet, finger millet
Kicha	Bread	This flat, round bread is made of flour paste, roasted on an iron pan. It is served with sauces, and as a snack between meals.	Wheat, sorghum, pearl millet, maize.
Geat	Porridge	Flour is cooked with water into a stiff porridge. It is the most common dish among the Tigre people.	Sorghum, pearl millet, maize, finger millet.
Kolo	Roasted whole grains	Whole grains roasted in a pan are consumed as a snack, sold at markets and on the road-side (often by children)	Wheat, maize, sorghum.
Tihni	Flour of roasted grinded grains	The grains are first roasted, then grinded. It is processed by mixing with butter and salt in boiling water. It is used as condiment for main dishes with sauce	None
Tihilo	Small balls of *tihni*	*Tihni* flour is processed into a stiff paste, and then formed into small balls that are cooked in water. It is eaten with sticks with sauce	None
Birkutta	Bowls of baked, grinded powder	The grinded powder is baked at the fireplace on a hot stone and eaten while hot with butter	Wheat
Titiko	Whole grains	Prepared by pounding and boiling and eaten with salt	Wheat, sorghum, maize
Shirba	Porridge	Mashed grain is boiled with water. This is prepared for certain religious feasts	None
Siwa	Beer	Grain is baked in an iron pan and mixed with fermented *gesso* (germinated barley)	Sorghum, wheat finger millet, pearl millet, (often in a mixture)

Source: Ministry of Agriculture, Eritrea 1999

Effect of Varietal Mixtures of Barley (*Hordeum vulgare*) and Wheat (*Triticum aestivum*) in the *Hanfetz* Cropping System in the Highlands of Eritrea

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Introduction

A typical cropping system in the Central Highlands of Eritrea is mixed cropping of barley (*Hordeum vulgare*) and wheat (*Triticum aestivum*); it is called *hanfetz* (Tigrigna word for mixture). This is a unique cropping system practised in very few locations in Africa but not elsewhere in the tropics.

Most mixed cropping systems contain a legume, because in those cases there will be a clear benefit of mixing crops. In Eritrea, this is not always the case, as the prevailing stresses will condition the choice for crop mixtures. The benefits of mixed cropping such as yield advantage, yield stability etc. can still be realised by growing mixtures of cereals. In the period of 1994 until 1999, the mean area under barley and wheat mixtures was slightly above 7,160 hectares, which corresponded to 28% of the area under wheat and 16% of the area cultivated with barley. The mean production reached around 6, 200 tons annually. This is 30% and 14% of the production of wheat and barley respectively. On average, yields per hectare of *hanfetz* are estimated as 20% and 11% higher than the yields of monocultures of wheat and barley, respectively (Table 1).

Table 1. Estimates of mean total area, production and yield per hectare of the mixtures over the period 1994-99 in the highlands of Eritrea.

	Mixture	*Mixture* % of wheat	*Mixture* % of barley
Area	7,160 ha	28% of wheat area	16% of barley area
Production	6,200 t	30% of wheat production	14% of barley production
Yield	0.84 t ha^{-1}	20% > wheat monoculture	11% > barley monoculture

Source: Ministry of Agriculture, Eritrea (1994-1999)

The mixtures are sown from the end of June until the first week of July. The amount of seed used per hectare ranges from 80 to 250 kg. The amount of seed required for a mixed crop is lower than that of barley monoculture crop, as farmers consider wheat to be stronger in tillering. This amount of seed provides a suitable be ground cover for competing with weeds and with adequate number of spikes. The crop ratio used by majority of farmers ranges from 67 per cent for barley and 33 percent for wheat. The period of harvest lasts from the end of October until mid November. Harvesting is done when the barley crop has reached full maturity and when wheat is physiologically mature, changing its canopy colours. Farmers usually harvest early in the morning when it is humid to avoid shattering. The advantages of cultivating *Hanfetz* is due to the yield advantage, yield stability, food quality, animal feed and resistance to diseases, weeds and insects (Araya, 2000; Araya and Struik 2000).

Genotype composition is one of the factors affecting productivity of barley and wheat mixtures. Farmers in Eritrea indicate that some landraces of barley and wheat are better combiners than others (Araya and Struik, 2000). The component crops should exploit different ecological niches and complement each other in morphology, architecture, phenology and development, thus making better overall use of resources when growing together than when growing separately (Natarajan and Willey 1980). Better exploitation of resources can also take place over time, by growing component crops differing in maturity. Selecting component crops or genotypes differing in maturity may help the component crops to complement each other rather than compete for the same resources. Such a situation may also occur in barley and wheat mixtures (Araya and Struik 2000).

Several studies on mixed cropping have been able to identify suitable genotype combinations of various crop species. Examples can be found for cowpea and pearl millet (Reddy et al. 1990); pearl millet and cluster bean (Bhadoria et al. 1992) and many others. Such studies are not available for barley and wheat mixtures. Hence this study was conducted to evaluate the performance of barley and wheat varieties or landraces in pure and mixed stands under rainfed conditions in the highlands of Eritrea.

The objective of this study was to:

- Identify genotype combinations with higher yield;
- Asses which genotype combination has a better yield advantage compared to the control;
- Study the stability and competition ofmixed cropping compared to mono cropping.

Materials and Methods

Location

The study on mixed cropping of barley and wheat was conducted during the rainy seasons of 1997 and 1998. The trial was conducted at Halhale Research Station, Eritrea, at an altitude of 1997 m above sea level. The annual rainfall during the two growing periods was 580 mm in 1997 and 656 mm in 1998. There were a total of 16 mixtures (4´4) and 8 sole crops (4´2).

Treatments, design, and data collection

The genotypes (or genotype mixtures) tested were Yeha, Kuunto, Ardu 12/60 and IARH 485 (for barley) and Mana, Kenya + Mana, K 6290 and HAR 416 (for wheat) in all possible combinations. A mixture of Yeha + Mana (most common mixture in farmers' practice) was taken as a control. Seed was broadcasted at the end of June at both locations in the standard ratio of barley 67%: wheat 33%. A basal dressing of fertiliser at the rate 100 kg ha^{-1} di-ammonium phosphate (46% P_2O_5 and 18% N) and 50 kg ha^{-1} urea was applied and incorporated in the soil at planting.

All experiments were laid out in a randomised complete block design with 4 replications and a plot size of 3.0 m^2. Data were analysed by a standard analysis of variance using MSTAT-C and by a least significant difference test for comparing the means.

The grain yield of each genotype of the component crop in the mixture was added to get the total grain yield of the mixture. Plant height (cm) was measured from the ground level up to the top of the plant or ear. Measurements of plant height were made from the sole crop and component crop in mixtures at 20,30, 50, 70, 90 and 100 days after sowing. Other data collected includes biomass, days to heading, days to maturity, spike size, number of grains per spike, thousand seed weight, harvest index and lodging.

Yield advantage analysis

Yield advantage for grain yield was estimated using the Relative Yield Total (RYT).

$$RYT = RY_1 + RY_2 = Y_{12} / Y_{11} + Y_{21} / Y_{22}$$

where species 1 is barley and species 2 is wheat; Y_{12} and Y_{21} are the grain yields of component crops in mixtures; Y_{11} and Y_{22} are the grain yields of the sole crop. When RYT is equal to 1, the same yield of the mixtures of each species may be obtained from the sole crop. When RYT > 1, the genotypes of the two crops are complementary in resource use which implies that they have collected and shared their resources in such a way that a yield advantage occurred relative to their sole crops. When RYT < 1, the genotype combination in mixtures is disadvantageous.

Yield stability analysis

The stability test analysis used permits quantitative estimates of adaptability and thus makes it feasible to identify superior performance of a genotype or cropping system over a wide range of environmental conditions. The stability parameters considered were the regression coefficient of the relation between mean grain yield of each location and the mean grain yield of each genotype or cropping systems (b), the coefficient of determination (r^2) and the standard deviation (Sd) of the mean (Eberhart and Russel 1966). Mean grain yield at each location was used as the dependent variable (X axis) and the mean grain yield of each genotype combination, density and crop ratio or cropping system as independent variable (Y axis). Stable genotypes are those that have relatively better mean grain yield, a regression coefficient b=1.0 and standard deviation (sd) as small as possible.

Competition and niche differentiation

The competitive ability of the crops in mixtures and the Niche differentiation index was estimated from the density and crop ratio experiment done at Halhale Research Station in 1997 and 1998. Both replacement and additive series crop ratios were used in the experiment.

A non-linear regression model was used to estimate competition which was

$$Y_{12} = N_1 / (b_{10} + b_{11} N_1 + b_{12} N_2)$$

Final biomass and grain yield data were analysed using a slightly re-written version of the equation

$$Y_{12} = N_1 \times (1 / b_{10}0) / (1+ b_{11} / b_{10} (N_1 + (b_{12} / b_{11}) N_2))$$
$$Y_{12} = N_1 \times W_{10} / (1 + a_{12} (N_1 + (1/c_{12}) \times N_2))$$

in which N_1 is the plant density of the component crop (plants m $^{-2}$); W10 is the apparent weight of an isolated plant ($1/b_{10}$) in g plant^{-1}; a1 is a parameter characterising intra-specific competition (b_{11}/b_{10}) and c_{12} is the relative competitive ability (b_{11}/b_{12}) describing how many individuals of species 2 are equivalent to each individual of species 1. The maximum attainable yield can be estimated as the reciprocal of b_{11} ($1/b_{11}$) (Watkinson 1981).

Alike for species 2:

$$Y_2= N_2 \times W_{20}/ (1+a_{21} (N_2+(1/c_{21}) \times N_1))$$

The non-linear regression procedure of SPSS was used to fit both version of the model in order to determine the parameter values b_0, b_1, b_2, w, c and a.
By deriving this ratio for the two-component crop species of a mixture the niche differentiation index can be estimated.

$$NDI = (b_{11} / b_{12}) \times (b_{22} / b_{21})$$

This index represents the ratio between intra- specific (b_{11} and b_{22}) and inter-specific (b_{12} and b_{21}) competition. If NDI > 1, there is niche differentiation indicating that the intra-specific competition exceeds inter-specific competition. Plants in the mixtures are sharing resources better than plants of a sole crop, which means that competition for the same resources is less. If NDI= 1, the two species are competing equally for the same resources, whereas a NDI < 1 suggests that the species are hampering one another (Spitters et al. 1989).

Results and Discussion

Grain yield

The results of the grain yield at Halhale are shown in Tables 2 and 3. There was significant variation in grain yield among the barley genotypes grown as sole crop and grown in mixtures in both years. The only exception was found for the genotypic differences in total mixture yields at Halhale in 1998. At Halhale, Kuunto was one of the best in grain yield, averaged over two years both in sole cropping and in mixtures (Table 2).

Table 2. Grain yield (kg ha^{-1}) of barley and wheat genotypes grown in sole crop or mixtures at Halhale Research Station, Eritrea, 1997 and 1998.

Genotype	Sole cropping			Average total mixtures		
	1997	1998	Mean	1997	1998	Mean
Barley						
Kuunto	1,250 a	1,550 a	1,400	1,439 b	1,648	1,544
Ardu 12/60	1,393 a	717 b	1,055	1,799 a	1,193	1,496
Yeha	727 b	1,167 a	947	1,534 ab	1,297	1,416
IAR 485	1,213 ab	647 b	930	918 c	1,430	1,174
Mean	1,146	1,020	1,083	1,424	1,392	1,408
LSD 5%	507	447	NS	347	NS	NS
CV%	36.4	27.4	30.3	15.6	18.8	12.7
Wheat						
Mana	607	1,843	1,225	1,534	1,437	1,486
Kenya+Mana	1,070	1,627	1,349	1,588	1,352	1,470
K 6290	893	1,687	1,290	1,282	1,475	1,379
HAR 416	997	837	917	1,292	1,304	1,298
Mean	892	1,499	1,196	1,424	1,392	1,408
LSD 5%	NS	NS	NS	NS	NS	NS
CV%	38.9	35.2	27.6	26.4	18.5	12.8

Source: Araya 2000

The grain yield for mixtures with Kuunto was higher than the grain yield of a sole crop of Kuunto. The same holds for all barley genotypes. They all had higher average total mixture yields than sole crop yields. There was no variation in grain yield among the wheat genotypes either in sole cropping or in mixed cropping at Halhale except in 1998, when significant variation among the wheat genotypes was observed in the wheat component yields in the mixtures (Table 3). The combination of Ardu 12 + Kenya + Mana gave the highest yield when averaged over 2 years (2009 kg ha^{-1}). Yeha + Mana (farmer's practice) was out yielded by the other genotype combinations.

Table 3. Selected genotype combinations in the Hanfetz mixed cropping sytem tested at Halhale Research Station, Eritrea, 1997 and 1998.

Genotype combination				
Barley	Wheat	1997	1998	Mean
Ardu 12/60	Kenya+Mana	2,590 a	1,427 abcd	2,009 a
Kuunto	Mana	2,044 ab	1,610 abc	1,827 ab
Kuunto	HAR 416	1,583 bcde	1,883 ab	1,733 abc
Ardu 12/60	K 6290	2,143 ab	1,010 cd	1,577 abcd
Ardu 12/60	Mana	1,677 bcd	1,367 abcd	1,522 abcd
Yeha	Kenya+Mana	1,687 bcd	1,307 abcd	1,497 abcd
Yeha	Mana	1,570 bcde	1,280 bcd	1,425 bcd
Yeha	K 6290	1,163 cde	1,420 abcd	1,292 cde
IAR485	K 6290	933 cde	1,546 abcd	1,240 cde
Mean		1,710	1,428	1,569
LSD 5%		810	633	523
CV%		34.8	35.2	26.2

Source: Araya 2000

The aim of selecting appropriate landrace combinations is to minimise or reduce intercrop competition and maximise complementary effects. Attention should be given to differences in morphological characters when identifying complementary genotypes. Barley was taller and grew faster during the early growing period up to 70 days after sowing. Wheat was suppressed during initial stage but later on it grew taller and took over barley utilizing the relatively scarce rainfall during the final part of the growing season when barley approached maturity (Figure 1). This difference in plant growth could result in demand of resources at different periods allowing sharing of resources.

In this study barley genotypes matured within 90 to 95 days while the wheat genotypes matured within 100 to 105 days. Barley matured earlier than wheat. When barley matures earlier than wheat, it leaves the soil resources for wheat to continue growth. The late maturing crop species in mixtures as one of the component crops can complement the early maturing component crops rather than compete for the same resources.

The plant characteristics providing the best prediction for grain yield were harvest index (r= 0.62*), biomass (r= 0.64*) and thousand-grain weight (r= 0.58*). Plant height (r= 0.60*) was positively correlated with biomass (Table 4).

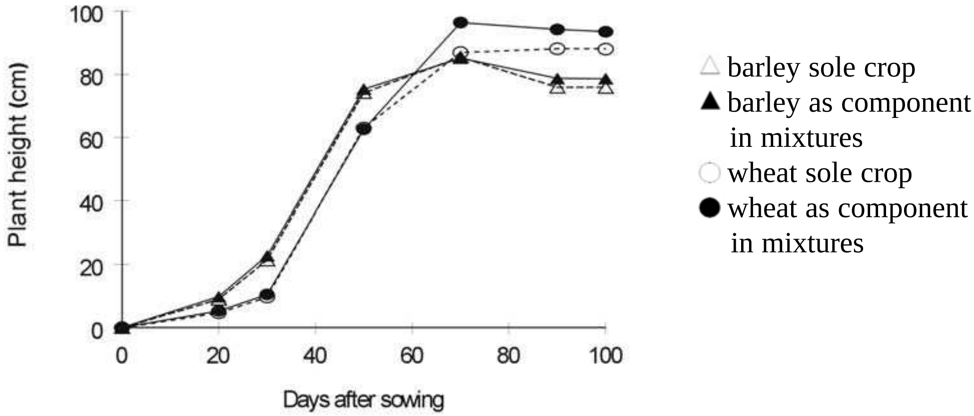

Figure 1. Changes over time of plant height (cm) for barley and wheat as sole crops and component crops in mixtures at Halhale Research Station, Eritrea in 1997. Source: Araya 2000

Table 4. Regression analysis for the relationship between mean agronomic characters, biomass and grain yield of the mixtures of barley and wheat genotypes at Halhale Research Station, Eritrea, 1997-1998.

Parameter	Biomass yield			Grain yield		
	1997	1998	Pooled	1997	1998	Pooled
Stand cover	0.62*	0.63*	0.72*	0.26	0.55*	0.44*
Plant height	0.56*	0.57*	0.60*	0.21	0.50*	0.10
Days to heading	-0.29	0.12	0.29	-0.52*	0.63*	0.22
Days to maturity	-0.13	-0.11	0.09	-0.17	0.46*	-0.07
Ear size	0.46*	0.47*	0.30	0.49*	-0.01	0.31
Ear m^{-2}	0.68*	-0.23	-0.22	0.53*	-0.06	0.05
Kernels ear^{-1}	-0.43*	0.03	0.15	-0.30	0.10	-0.18
TGW	0.20	0.35	0.39	0.23	-0.10	0.58*
Kernels m^{-2}	0.68*	-0.13	-0.30	0.54*	0.11	0.18
Biomass	-----	----	-----	0.71*	0.24	0.64*
Harvest index	0.33	-0.50*	-0.039	0.75*	-0.23	0.62*

Note: * significant at 5% level
Source: Araya 2000

Yield advantage

The results of the Relative Yield Total or yield advantage based on grain yield, 1997-1998 are shown in Table 5. There was a significant difference in RYT grain yield in both years. Yeha + Kenya and Mana (RYT= 2.22) and Yeha + HAR 416 (RYT=1.68) showed very high increases in grain yield over their monocrops. RYT was extremely high for certain varietal mixtures and this is based on relatively very poor performance of the sole crops. The lower the yield of the sole crop or the higher the yield in mixtures, the higher will be the yield advantage (Table 5).

Table 5. Relative yield advantage based on grain yield of selected genotype combinations in barley and wheat mixtures at Halhale Research Station, Eritrea 1997 and 1998.

Genotype combinations				
Barley	Wheat	1997	1998	Mean
Yeha	Kenya + Mana	3.51 a	0.93 defg	2.22 a
Yeha	HAR 416	2.34 b	1.02 cdefg	1.68 b
Ardu 12/60	Kenya + Mana	1.93 bcd	1.21 bcdef	1.57 bc
Yeha	Mana	2.24 bc	0.85 fg	1.55 bc
Kuunto	Mana	1.85 bcde	0.98 cdefg	1.42 bcde
Yeha	K 6290	1.56 defg	1.07 cdefg	1.32 bcdef
Kuunto	HAR 416	1.28 defghi	1.32 bc	1.30 bcdefg
Ardu 12/60	K 6290	1.63 cdef	0.88 efg	1.26 bcdefg
Kuunto	K 6290	0.74 hi	1.23 bcde	0.99 efg
Ardu 12/60	HAR 416	0.65 i	1.29 bcd	0.97 fg
Kuunto	Kenya + Mana	1.01 fghi	0.75 g	0.88 g
Mean		1.70	1.05	1.38
LSD 5%		0.67	0.37	0.44
CV			31.9	21.9
22.9				

Source: Araya 2000

Yield stability

A major reason for the predominance of barley and wheat mixed cropping in the central highlands of Eritrea is that it can give greater yield stability over different environments. There are several mechanisms that could explain the improved yield stability. The main mechanism is that if one component crop (wheat) fails or grows poorly due to stress, the other component crop (barley), which is drought tolerant, makes (to some extent) use of the resources that are available and thus partly compensates for the yield loss. This compensation cannot be realised if the crops are grown separately.

Both monocrops were not stable under varying environmental conditions. The higher mean grain yield (1744 kg ha^{-1}) and regression value equal to 1 (b=0.995; Sd=0.277) showed that mixed cropping was more stable than either barley or the wheat monocrops (Table 6).

Table 6. Stability parameters of barley and wheat monocropping and mixtures (n=6 environments).

Parameters	Sole crops		Mixtures
	Barley	Wheat	
Mean yield (kg ha^{-1})	1,511	1,283	1,744
Slope (b)	0.769	1.336	0.995
Standard deviation (Sd)	0.192	0.303	0.277
r^2	0.640*	0.682*	0.536*

Note: Coefficient of determination (r^2) is significant at 5% level
Source: Araya 2000

Competition and niche differentiation

The relative competitive ability was higher for barley than for wheat in both years. At Halhale, the competitive ability for barley was higher in biomass during the year 1997 as compared to 1998. Taking as an example grain yield at Halhale 1997, for barley, one barley plant was able to compete equally with about two (2.4) wheat plants. For barley, the presence of one barley plant feels as strong as the presence of eight wheat plants. For wheat, two wheat plants were equal to about one barley plant (0.523; 1/2). The influence of barley plants relative to the influence of wheat was at least two times greater (Table 7) (Woldeamlak 2000; Woldeamlak et al. 2001).

There was niche differentiation for both total biomass and grain yield at both years. The degree of niche differentiation was higher for grain yield than for biomass at both locations. In general, the niche differentiation in barley and wheat mixtures can be explained in time and in resource use. Barley is early maturing and can escape periods of moisture deficit by maturing before the onset of the period with low rainfall. Difference in height could help the crops to utilise resources at different times in a better way (Figure 1). Barley is sensitive to lodging under sole cropping but in mixtures it is physically supported by the more robust wheat allowing it to get enough solar resources. Inter-specific competition was higher than intra-specific for barley and intra-specific competition was greater than inter-specific for wheat. Any wheat plant suffered less competition from other wheat plants than from the barley plant while barley plants suffered more from barley than from wheat. Thus if the more competitive species has a higher yield potential, the comparison of a mixture with pure stands will be in favour of the mixtures (Table 7).

Table 7. Competition and niche differentiation in barley and wheat mixtures.

Environment/Location	Barley b11/b12	SE	Wheat b11/b12	SE	NDI
Biomass yield					
Halhale 1997	3.049	0.102	0.330	0.117	1.010
Halhale 1998	1.970	0.290	0.998	0.200	1.970
Grain yield					
Halhale 1997	2.379	0.228	0.543	0.170	1.292
Halhale 1998	2.010	0.460	0.986	0.250	1.990

Note: NDI= Niche Differentiation Index
Source: Araya 2000; Araya et al. 2001

Conclusions and Recommendations

The genotype combinations such as Ardu 12/60 + Kenya + Mana (2009 kg ha^{-1}) and Kuunto + Mana (1827 kg ha^{-1}) were the best in grain yield when rainfall was normal. The experiments showed that the best genotype combinations differ from what farmers currently use. Two of the best mixtures including the control (Yeha + Mana) need to be tested in on-farm verification trials at a diversity of locations before they can be released to farmers. There was a yield advantage of the mixture relative to the sole crops. This yield advantage could be explained by complementary use of resources during the growing period. The difference in morphology and phenology among the component crops can contribute to the demand of resources at different times during the growing period, which, leads to yield advantage compared to sole cropping. The traditional combination, Yeha + Mana, was surpassed in yield by other genotype combinations.

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Food Barley in Ethiopia

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Introduction

Barley (*Hordeum vulgare* L.), which appears to have been grown by the ancients long before other cereals were mentioned in recorded history (Kipps 1983), is also believed to have been cultivated in Ethiopia as early as 3000 B.C. (Gamst 1969). The country has diverse climates, soils, topography, social environments, vegetation cover, and animals. The long history of barley cultivation and the diverse agro-ecological and cultural practices have resulted in a country renowned for its large number of farmers' varieties (landraces) and traditional agricultural practices. All three barley groups distinguished by their caryopsis type are prevalent: hulled, hull-less, and partially hulled (Asfaw 1989). Hulled barley is dominant in the area, provenance, number of morphological types and the most diverse category that include: six-row, two-row, irregular forms, dense, lax, hooded, long awn, short awn, rough awn, and smooth awn. Hull-less barley types have a low prevalence and have restricted distribution unlike the hulled types (Asfaw1988, 1996). Two-row, six-row, lax, and dense forms of hull-less barley are prevalent and partially-hulled barley constitutes a diverse group of two-row barley with lax, and dense forms (Asfaw 1988, 1996). In addition, the existing landraces also vary in their characteristics such as maturity, seed color, seed size, seedling vigor, straw strength, and in disease and insect pest resistance. As of 2001 the total number of barley germplasm holdings in the Institute of Biodiversity Conservation and Research (IBCR) is 14,592 (IBCR 2001) and their characterization is under way.

In accordance with the diverse agro-ecologies of the country, farmers in barley cultivation are exercising different traditional cultural practices. The diverse traditional recipes that are prepared from barley and the strong barley consumption habit of the population signify the importance of the crop in Ethiopia.

However, despite barley's long history of cultivation, diverse farmers' varieties, traditional practices, and its valuable uses, the improvements made to boost the productivity of the crop have been low. Research efforts to improve the production and productivity of the crop were started a few decades back in 1955. The purpose of this chapter is to highlight the importance, the production systems, the research efforts made so far, and the direction of future research on food-barley in Ethiopia.

Importance

In Ethiopia, barley is produced mainly for human consumption and is one of the most important staple food crops. The share of malting barley production is quite low (about 2%) and most is used for making the local bread, *injera*. Barley grain is also used in a diversity of recipes and deeply rooted in the culture and tradition of people's diets. Furthermore, barley straw is a good source of animal feed especially during the dry season, and it is also a useful material for thatching roofs of houses and for use as bedding.

Barley is cropped twice a year. The main cropping season, known locally as *meher*, relies on June-September rainfall, while the minor cropping season, known as *belg*, is during the short rainy season, March-April. Barley is the most suitable crop for *belg*-season production and it accounts for about 30% and 28%, respectively, of the total major cereal areas and total cereal production during this season (Table 1).

Table 1. Estimates of area, production and yield of major cereal crops in belg-season (1990/91-1999/2000).

Crop	Area ('000 ha)	Production ('000 t)	Yield (t ha^{-1})
Barley (*Hordeum vulgare* L.)	184.3	135.1	0.73
Tef (*Eragrostis tef* (Zucc.) Trotter)	41.6	21.3	0.51
Wheat (*Triticum* spp.)	37.9	23.3	0.61
Maize (*Zea mays* L.)	308.8	289.0	0.94
Sorghum (*Sorghum bicolor* L. Moench)	31.9	21.9	0.69

Sources: Central Statistical Authority (CSA) 1993, 1996a, 1996c, 1997b, 1998b, 1999b, and 2000b

In the period from 1990/91 to 1999/2000 cropping seasons the average cultivated area was 914,900 ha with total average annual production of 908,778 tons from both *meher* and *belg* seasons (Table 2). This accounts for about 15% of the total growing area of major cereal crops and about 13% of the total annual cereal production in Ethiopia.

Table 2. Total estimates of area, production and yield of major cereal crops grown in meher and belg seasons (1990/91-1999/2000).

Crop	Area ('000 ha)	Production ('000 t)	Yield (t ha^{-1})
Barley (*Hordeum vulgare* L.)	914.9	908.8	0.99
Tef (*Eragrostis tef* (Zucc.) Trotter)	1877.2	1608.8	0.86
Wheat *(Triticum* spp.)	819.1	1020.7	1.25
Maize (*Zea mays* L.)	1455.5	2290.1	1.57
Sorghum (*Sorghum bicolor* L. Moench)	962.1	1227.2	1.28

Sources: Central Statistical Authority (CSA) 1991, 1992, 1993, 1996a, 1996b, 1997a, 1997b, 1998a, 1998b, 1999a, 1999b, 2000a, and 2000b

Food Barley Production Systems

Late-barley production system

This is the most dominant system, is important in the high-altitude areas of Ethiopia and is practiced during *meher*, or the main rainy season (June to October). Two variants of this system are recognized based on the planting dates, *Genbote* and *Sene gebs*. In South Gonder, North Welo and northwest Shewa, *Genbote* is planted in May and *Sene gebs* is planted between mid-June to early-July. Different farmers' varieties are grown in the two sub-systems (Yirga et al. 1998a, 1998b). Baleme in Shewa, Necheta and Tikur gebs in North Welo, and Abat gebs in North Gonder are among the farmers' varieties grown in this system. These varieties require five to six months to mature. Grain yields for this system vary from 0.6 to 2.0 t ha^{-1} (Yirga et al. 1998a).

Barley production system with guie (soil burning)

This is a *meher* season system, which is important in the highlands of north and northwest Shewa where waterlogging is a major hindrance to barley production. To alleviate this problem farmers use *guie* (soil burning) which involves three to five plowings of fields that have been left fallow for at least five years. The practice is very tedious. Early maturing farmers' varieties, Demoye and Magie, are used in this system. Grain yield is higher in the first year (about 2.0 t ha^{-1}) but dramatically declines in subsequent years. Other cultural practices are similar to the late barley production system (Yirga et al. 1998a).

Early-barley production system

Also a *meher*-season system and is important both in the mid- and high-altitudes of Gojam and Gonder (Northwest Ethiopia) and some parts of Shewa. Early farmers' varieties such as Semereta in Shewa and Gojam, Belga in North Gonder and

Tebele in South Gonder require 3.5 to 4 months to mature. The varieties are planted from mid-May to June and harvested in the period between early September to early October. Important early barley varieties are Aruso in Arsi and Bale and Saesa in Tigray (Negusse 1998). In Welo farmers' varieties such as Ehilzer and Tebele, two-row types, are important for early growing areas (Yallew et al. 1998). The yield of early barley in a normal year varies from 0.7 to 1.5 t ha^{-1} (Yirga et al. 1998a).

Belg barley production system

This system is practiced in North and Northwest Shewa, North Welo, Bale and a few areas in Arsi. *Belg* barley is planted in February and/or early March and harvested in early July. Early maturing farmers' varieties that require three to four months to mature are usually cultivated. In this system farmers do not apply fertilizer. Moisture stress and Russian wheat aphid *(Diuraphis noxius)* are the major threats to barley in this system. The yield of *belg* barley in a normal year varies from 0.8 to 1.2 t ha^{-1} (Yirga et al. 1998a).

Residual moisture barley production system

This system is important in some parts of Gojam, North and South Gonder and West Shewa. Early maturing farmers' varieties, Belga in North Gonder and Semereta in Gojam, are important in this system. Planting is done between September and October, immediately after harvest of the main-season barley crop. The seed of the main-season barley is resown in the same field, in the main-season fallow field, or in any other field where the main-season crop has failed. Fertilizer is not generally applied in this system. Harvesting is done from December to February. Grain yield from this system is generally low, less than 1.0 t ha^{-1} (Yirga et al. 1998a) and it is mainly used as seed for the next season.

Role of Barley in Food Security

In addition to its significant share in the annual grain production of cereals, barley has a number of advantages that testify to its role in food security.

- Barley has a wide range of adaptation and can be grown in altitudes of over 3,400 m asl, on steep slopes, degraded soils, and in stressed areas with occasional drought and frost where other cereals fail to grow. In such areas barley is the only source of food, homemade drinks, animal feed, and cash.
- The annual production of barley grain is better distributed across seasons, agro-ecologies, and production systems than any other cereal crops, as it can be grown in different seasons, offers an early harvest in the main season, and can be cropped in different production systems and agro-ecological environments. Eighty-five percent of the annual barley production is harvested between September and February, while the balance is harvested in July when there is a critical cereal grain shortage. Therefore, in a country like Ethiopia where storage and transportation facilities are poorly developed, having the

total annual production distributed across locations and seasons has a great relevance in food security.

- Barley is a low input crop requiring relatively low investment. Its cultivation can be/is being practiced by the majority of small-holder farmers for subsistence (Yirga et al. 1998a).
- Barley yield stability is far better than the other cereals, making it a dependable source of food in bad seasons (Lakew et al. 1996).
- Barley with its long history of cultivation is deeply rooted in the consumption habits of the population as it can be utilized in more diverse forms than any other cereals.
- Barley straw is an important feed source during the dry season.

Utilization of Food Barley

In Ethiopia, the total annual barley grain production is almost wholly destined for human consumption and is the major staple food in the highlands. It has deep roots in the consumption habits of the population and can be utilized in a greater diversity of traditional recipes than other cereals.

Among the traditional recipes prepared from cereals, some recipes such as *besso, zurbegonie,* and *chiko* have a long shelf life and can only be prepared from barley grain. Other barley recipes such as *genfo, kolo,* and *kinche* are the most popular but they can be prepared from other cereals also. Barley, after tef, is the preferred grain for making the traditional bread, *injera,* which can be made either solely or in combination with tef flour or other cereals. *Dabbo* (bread), *kitta* or *torosho, atmit* or *muk,* and *wot* can also be prepared with only barley or blended with other cereal flours. Among local beverages *tella, borde,* and *areki* are the prominent. The most preferred *tella* and *borde* are from barley grain.

Eshet is the name given to any grain harvested at milk or dough stage. Although maize *eshet* made by roasting or boiling the ear harvested when the grains are at milk or dough stage, is the most important, unripe barley spikes or ripe and dry spikes are also roasted over fire and the grain is eaten. This is called *eshete* or *wotelo* if the spikes are unripe or *enkuto* if the roasted barley spikes are dry. However, *eshete/wotelo* and *enkuto* are not very common, and they are mainly prepared by shepherds in the rural areas.

Almost all of the important cereal-based (barley, tef, wheat, maize, and sorghum) traditional recipes, with the exception of *nifro,* can be prepared with barley (Table 3).

In addition to the traditional recipes, efforts are being made to discover and introduce other uses for barley. These include research into the best proportions for blending barley flour with other cereals to improve recipe quality (Kerssie and Goitom 1996) and also the best blends of barley flour and pulses that will provide an improved nutritional value in specialized foods such as those used for weaning (Wondimu 1996).

Table 3. Cereal-based traditional dishes and drinks prepared from major cereals.

Type of Recipes	Major cereals				
	Barley	Tef	Wheat	Maize	Sorghum
Dishes					
Injera	S/B	S/B*	B	S/B	S/B
Genfo (porridge)	S*	S	S/B	S/B	S/B
Dabbo (bread)	S/B	-	S*	B	B
Kitta/Torosho	S/B	-	S/B	S/B	S/B
Kinche	S*	-	S[1]	S	S
Atmit/Muk	S/B	-	B[2]	-	-
Wot (Sauce)	S	S	-	S	-
Eshet/Wotelo	S	-	S	S*	-
Kolo	S/B*	-	S/B	S/B	S/B
Besso	S*	-	-	-	-
Chiko	S*	-	-	-	-
Zurbegonie	S*	-	-	-	-
Shorba (Soup)	S*	-	S	S	S
Nifro [3]	-	-	S	S	S
Drinks					
Tella	S/B*	B	S/B	S/B	S/B
Bequre	S/B*	-	-	S/B	-
Borde	S/B*	-	-	S/B	-
Areki	S/B	B	S/B	S/B	S/B

[1] durum wheat (*Triticum turgidum* var. *durum*)

[2] emmer wheat (*Triticum dicoccum)*

[3] Nifro: made with boiled maize or other cereals prepared either alone or mixed with pulses such as faba bean *(Vicia faba* L.), field pea (*Pisum sativum* L.), chickpea (*Cicer arietinum*), or other beans (*Phaseolous* spp.) and usually served as a side-dish or snack (Yetneberk 1993)

S = sole, B = blended, S/B = sole or blended with other cereals

* The most popular and preferred

Sources: Kebede and Menkir 1988; Tesema 1988; Tolessa 1988; Asfaw 1990; Gizachew et al. 1993; Ketema 1993; Yetneberk 1993; Kerssie and Goitom 1996; Yallew et al. 1998

Preparation of Major Barley-Based Traditional Dishes and Drinks

Traditional dishes

The preparation of most barley-based dishes and drinks are more tedious and strenuous than preparations with other cereals because of the additional effort needed to remove the husk. Barley-based traditional recipe preparation is categorized in two groups: those that are prepared with raw-grain flour and those that are prepared with mildly-to-well-roasted grain flour.

Raw grain flour-based recipes. Depending on the type of recipe, coarse or fine barley flours are prepared preferably from white-seeded barley grains following the schematized general procedure shown in Figure 1. The flour is then used to prepare diverse traditional recipes.

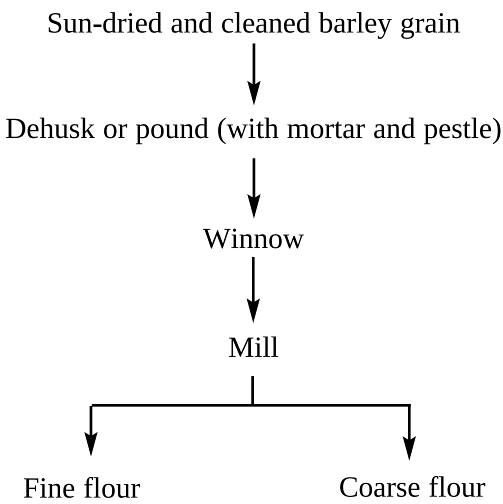

Figure 1. Procedures for the preparation of raw grain flour.

Sources: Asfaw 1990; Kerssie and Goitom 1996; Molla and Abebaw 1998; Yallew et al. 1998

Injera. This is a leavened, thin, and spongy pancake-like local bread served with a sauce *(wot)* that might be prepared either from pulses, vegetables, or meat, usually served as the principal food at lunch and/or dinner. It is a staple food in most parts of the country. Injera made from barley is next in preference to tef. Barley-based injera can be prepared either from only barley or blended with other cereals such as tef, wheat, maize, sorghum, or other cereals.

To prepare injera the fine flour of raw barley grain is sieved well to remove remnants of the husk and the purified fine flour is then kneaded with cold water into a dough and allowed to ferment for two to seven days. The fermentation time depends on the climate. When the climate is hot the fermentation period is shorter than when it is cool. The fermented dough is then liquefied with hot water and again set aside to initiate further fermentation. After it has risen the dough is then baked on a hot, circular clay pan. Injera can be prepared from any barley variety but varieties with a high flour yield, high water absorption capacity, and white-seeded grains are the most preferred (Molla and Abebaw 1998; Yallew et al. 1998).

***Dabbo* (Bread).** This is a leavened, thick bread made with a fine barley flour. *Dabbo* from wheat flour is the most preferred, but it is also common to prepare this bread from only barley or barley blended with wheat or other cereals. All flours are sieved, kneaded with warm water, mixed with leaven, and left overnight to initiate rising (Molla and Abebaw 1998).

Kitta/Torosho. This is an unleavened, thin, dehydrated bread made with a fine flour. Fine barley flour is sieved twice, kneaded into dough with hot or cold water, and flattened until thin. It is baked on a hot, circular iron or clay plate and is turned until it is dry and brittle (Molla and Abebaw 1998). In some areas of the country it is commonly served for breakfast, snacks, and as a side-dish during coffee ceremonies (Molla and Abebaw 1998). In other areas *kitta/torosho* made with barley and/or other cereals is served as a principal food at lunch or dinner with milk and sauces of different types. White-flour barley varieties are preferred for kitta (Yallew et al. 1998).

***Wot* (Sauce)**. Although not an important barley product, in some areas *wot* is prepared from barley flour, or other cereals, when people are short of pulses or other usual *wot* ingredients (Yallew et al. 1998).

***Shorba* (Soup)**. It is a soup-like gruel made from coarsely ground barley grain. The coarse flour is boiled with water until it is well-cooked and then mixed with boiled milk, oil, or butter.

Roasted or lightly roasted grain flour-based recipes. Depending on the type of recipe, lightly or well-roasted barley grain is prepared as shown in Figure 2. The grain or the fine flour obtained from the process can be used to prepare diverse traditional recipes.

Kolo. This is a well-roasted, dehulled, and cleaned barley grain that is served alone or mixed with roasted legumes such as chickpea (*Cicer arietinum*) and field pea (*Pisum sativum* L.) and oil seeds such as safflower (*Carthamus tinctorius*) and niger (*Guizotia abyssinica* (L.f.) Cass.). *Kolo* has a long shelf life if kept dry and is commonly served as a breakfast, snack and as a side-dish during coffee ceremonies. Plump and semi-hull-less barley varieties whose husk can easily be removed are usually preferred (Yallew et al. 1998).

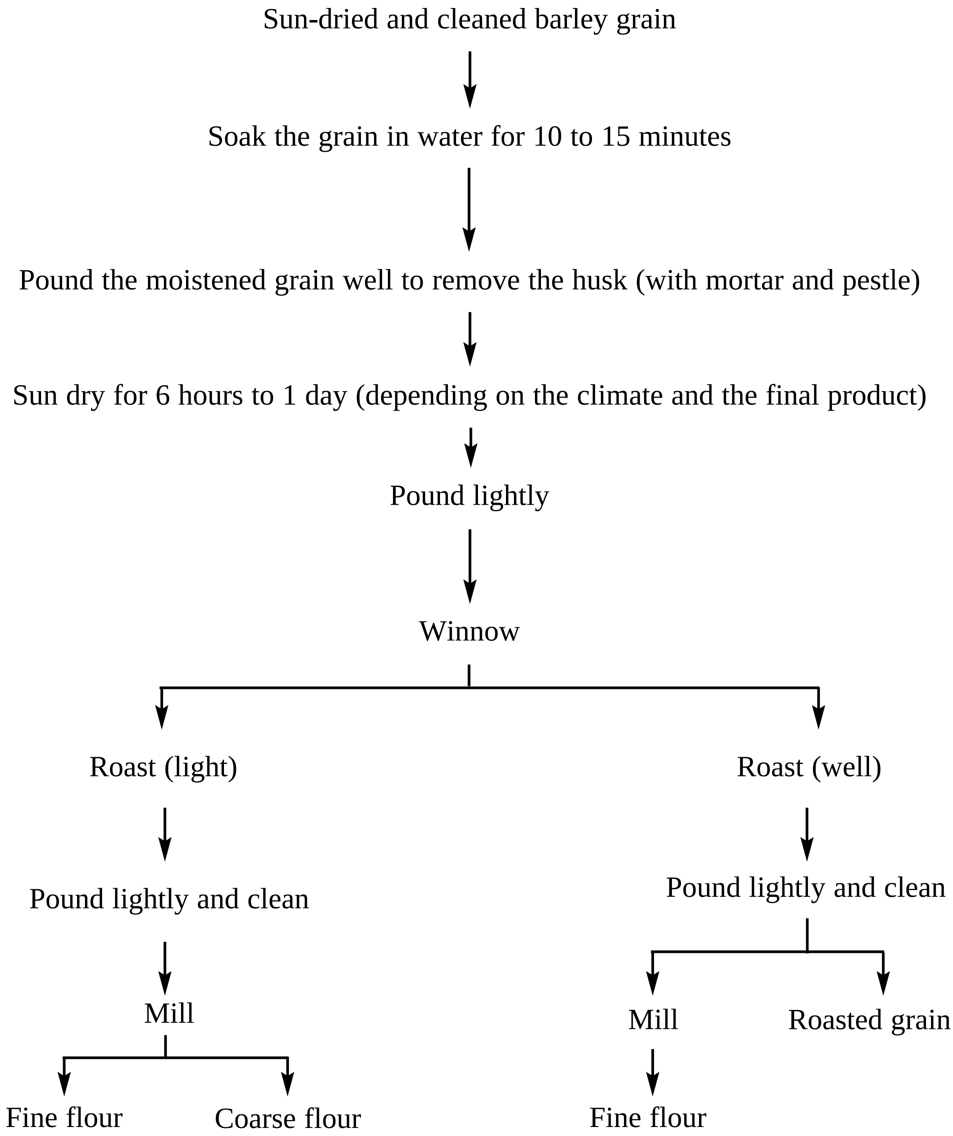

Figure 2. Procedures for the preparation of roasted or lightly roasted grain flour and roasted grain. Sources: Asfaw 1990; Kerssie and Goitom 1996; Molla and Abebaw 1998; Yallew et al. 1998

Besso. This is made with a fine flour of well-roasted barley grain. The flour is moistened with water, butter, or oil and lightly kneaded (Molla and Abebaw 1998). *Besso* is among the recipes known for a long shelf life if kept dry and is used by travelers and as a military ration during wartime. White-seeded barley or white-floured barley are preferred for besso (Kerssie and Goitom 1996; Molla and Abebaw 1998; Yallew et al. 1998).

Zurbegonie. This is a fine flour of well-roasted barley grain taken in liquid form (Kerssie and Goitom 1996). The same type of flour is used for the preparation of both *zurbegonie* and *besso.* A few spoons of the flour and some sugar are dissolved in cold water and drunk whenever needed. As long as the flour is kept dry it has a long shelf life.

Chiko. This is prepared from a fine flour of well-roasted barley grain soaked with butter. The flour is well sieved and depending on the amount of butter available is soaked with butter and lightly kneaded. It is then compacted and kept in a container. It has a long shelf life and is served by cutting off small slices.

Genfo. This is a thick porridge made from a lightly roasted fine flour of barley grain. Water is boiled, usually in a clay pot, salt is added and the sieved flour is stirred in gradually to avoid lumping. After enough amount of the flour is added, stirring continues to avoid burning until it is well cooked and stiff. The stiff mass is served with butter and hot chilli powder. It is usually served to mothers after they have given birth. White seeded barley varieties are preferred for *genfo* (Molla and Abebaw 1998).

Kinche. This is an extremely thick porridge made from lightly roasted, coarsely ground barley grain. The coarse flour is boiled with water and mixed with boiled milk, oil, or butter. It is served with milk, butter, or oil, preferably at breakfast. White seeded varieties are preferred for *kinche* (Molla and Abebaw 1998). Such recipes can also be prepared from durum wheat, maize, and sorghum although the most popular and preferred is from barley.

Atmit/Muk. This is a soup-like gruel made from fine flour of lightly roasted barley grain. Its preparation involves mixing of the sieved barley flour with cold water and pouring the mixture into a pot of boiling water and stirring continuously until it is well cooked. Salt or sugar is added and it is served with or without butter. In some areas emmer wheat (*Triticum dicoccum*) flour is mixed with barley flour for *atmit/muk* preparation. It is one of the important foods for mothers after childbirth (Molla and Abebaw 1998).

Traditional drinks

The major traditional drinks made from barley are *tella, areki,* and *borde.*

Tella. This is a fermented and undistilled homemade beer. The preparation procedure for *tella* differs from place to place, but generally the main ingredients are dried and pounded hops leaves, locally made malt from barley, *abshillo* (pancake prepared from a 4- to 15-day-old dough of barley flour), and *derekot* (flour from barley grain roasted until black). After these ingredients are mixed sequentially and allowed to ferment, *tella* of different ages can be prepared. *Tella* in most parts of the country is indispensable at festivals, and in some areas, at social labor-pooling gatherings (Yallew et al. 1998). Black-seeded barley varieties are preferred for brewing *tella* for it purifies quickly (Molla and Abebaw 1998).

Areki. This is a distilled homemade spirit made from fermented ingredients. The preparation of the fermented ingredients for *areki* are more or less similar to that of *tella,* except that *areki* is a distilled extract from the fermented ingredients with a higher alcoholic percentage. Black-seeded barley varieties are preferred for brewing *areki* (Molla and Abebaw 1998).

Bequre. This is a thin drink of unfermented or slightly fermented flour of roasted grain and malt (Kerssie and Goitom 1996). White-seeded or barley varieties with white flour are preferred as for *besso.*

Borde. This is a thick drink of mildly-fermented flour of roasted grain and malt (Kerssie and Goitom 1996). White-seeded or barley varieties with white flour are preferred as for *besso.*

Nutrition

Barley is mainly used as a source of carbohydrates, although the protein content is also important (Kerssie and Goitom 1996). Barley protein is composed of 19 amino acids, but low in lysine and methionine (Matz 1959). This might be the reason why most traditional barley recipes are prepared or eaten along with legumes or animal products to supplement the deficient amino acids (Kerssie and Goitom 1996). Although the composition of barley depends on the variety and the environment where it is grown, chemical analysis has indicated that barley is as nutritious as the other major cereals and even better in its fiber content (Table 4).

Table 4. Chemical composition of major cereals.

Composition	Barley	Wheat	Tef	Maize	Sorghum
Energy (Cal)	334.0	339.0	336.0	356.0	338.0
Moisture (%)	11.3	10.8	11.1	12.4	12.1
Protein (g)	9.3	10.3	10.5	8.3	7.1
Fat (g)	1.9	1.9	2.7	4.6	2.8
Carbohydrate (g)	75.4	71.9	73.1	73.4	76.5
Fiber (g)	3.7	3.0	3.5	2.2	2.3
Ash (g)	2.0	1.5	3.1	1.3	1.6
Ca (mg)	47.0	49.0	157.0	6.0	30.0
P (mg)	325.0	276.0	348.0	276.0	282.0
Fe (mg)	10.2	7.5	58.9	4.2	7.8

Source: Agren and Gibson 1968

In addition to its nutritional value, barley is believed to be beneficial for its dietary fiber that is mainly composed of β-glucans responsible for the reduction of serum cholesterol. Because consumption of barley as food in most developed countries has been abandoned, its merits for health improvement may enable it to regain its importance in human nutrition as in the developing countries.

Straw

Although natural pastures are the principal feed source, they hardly meet the maintenance nutrient requirement of grazing animals, especially during the dry period. Crop residues, therefore, play an important role in fulfilling the deficit. Among the various crop residues, barley straw has a considerable share of the total annual crop residue production (Table 5).

Table 5. Yield and chemical composition of various crop residues on dry-matter basis.

Crop residue	Yield (kg ha^{-1})	Composition (%) DM	EE	Ash	CP	NDF
Barley straw	10,000	92.6	2.3	8.4	4.7	71.5
Tef straw	5,000	92.6	1.9	8.4	5.2	72.6
Wheat straw	9,000	93.1	1.2	9.0	3.9	79.8
Faba bean	3,800	91.7	0.8	10.4	7.2	74.3
Field pea	5,000	91.9	1.2	6.1	6.7	73.6
Natural pasture (hay)	4,100	92.2	1.5	9.5	6.6	73.8

DM = dry matter, CP = crude protein, EE = ether extract, NDF = neutral detergent fiber
Source: Gebre-Hiwot and Mohammed 1989

Although the taller stems left after harvesting the spikes are used in thatching roofs in certain areas, and some are used for bedding, the majority of barley straw is meant for feed. The straw is stored and sometimes the fields are grazed after harvesting.

However, straw low nutrient density, slow rate of digestion, low digestibility and low proportionate rumen fermentation pattern (Bediye et al. 1995) generally limit its utilization. Small-scale farmers are not able to adopt most of the technologies developed in different parts of the world on the treatment of low-quality feed. Hence, looking into readily acceptable alternatives has been among the focuses of research in animal feed and nutrition. Among the various aspects that have been assessed, the influences of the variety and the location on barley-straw quality were researched (Bediye et al. 1995). However, the study revealed that differences were not of an appreciable magnitude and further studies to establish grain yield and straw quality relationships are required (Bedeye et al. 1995).

Since 1996, research has been undertaken around Holetta to improve the straw quality by sowing forage legumes with barley without a significant grain loss (EARO 1998a, 1998b). Although conclusive results are not yet achieved vetch (*Vicia villosa*) was grown successfully with barley without affecting barley grain yield significantly (EARO 1999b). Even if readily acceptable technologies for small-scale farmers have not yet been discovered, barley straw remains an important feed source in the highlands of Ethiopia.

Review of Food Barley Research

In Ethiopia, research on food barley was started in the early 1950s by the former Alemaya College of Agriculture and Mechanical Arts at its branch experimental station in Debre Zeit, with the evaluation of landraces and introduced nurseries. After the establishment of the Institute of Agricultural Research (IAR) in 1966, barley research was transferred from Debre Zeit to Holetta Research Center.

Currently, barley research is coordinated from Holetta Research Center in a strong collaboration with various institutions and organizations. The national collaborations with the federal and regional research centers (at Kulumsa, Ambo, Sheno, Adet, Sirinka, Mekele, and Sinana), the Institute of Biodiverity Conservation and Research (IBCR), the Agricultural Development Department (ADD), the Extension Department of the Ministry of Agriculture, the Ethiopian Seed Enterprise, and the National Seed Industry Agency are among the most important. A multidisciplinary (breeding, pathology, entomology, agronomy, weed science, food science, soil and water conservation, forage and nutrition, agricultural economics, and research and extension), agro-ecological based and participatory research approach is the focus of barley research. Past international collaborations have included the Food and Agriculture Organization (FAO), the United States Department of Agriculture (USDA), and Swedish Agency for Research and Education Cooperation (SAREC). Since the mid-1970s collaboration with the International Center for Agricultural Research in the Dry Areas (ICARDA) has been valuable for the exchange of information and germplasm, and in capacity and capability building.

In the efforts so far made on food barley research, achievements on varietal development, improvement on cultural practices, and extension research activities are worth mentioning.

Varietal Development

To develop enhanced varieties the breeding program utilized local landraces and exotic germplasms, and since 1968 hybridization and selection. Several hulled barley varieties have been recommended for release to farmers, those that are still under production and officially released for commercial production by the National Variety Release Committee (NVRC) in recent years are shown in Table

6. Although some efforts to improve hull-less barley were made, it was found to have a generally lower kernel weight and to be more susceptible to diseases than the hulled barley, and no improved varieties of hull-less barley have been released (Gebre et al. 1996). The work undertaken in the breeding program is highlighted as follows.

Landrace selection

In the 1970s, the 1980s, and the 1990s approximately 3,300, 5,476, and 5,392, respectively, local landraces were evaluated in nurseries. Most of the entries were found susceptible to scald (*Rhynchosporium secalis* Oud.), net blotch (*Helminthosporium teres* Sacc.), spot blotch (*Helminthosporium sativum* Pum.), leaf rust (*Puccinia hordei* Otth.), and lodging. From this effort six outstanding hulled-barley varieties have been identified and released for large-scale production in certain production systems (Table 6). Owing to the numerous and diverse landrace collections and farmers' varieties, the country has landrace improvement activities will still have a great role in improving the productivity of barley.

Evaluation of Exotic Germplasms

Introduced germplasms have been studied and evaluated at Holetta Research Center which serves as a quarantine site (Gebre et al. 1996). Every year exotic germplasms is evaluated for desirable agronomic characters such as grain yield, lodging resistance, maturity, grain color and plumpness, resistance to diseases (scald and net blotch) and insect pests (shoot fly and aphids). Between 1966 and 1993 over 22,000 entries and between 1994 and 2001 about 6,400 entries of introduced germplasms were evaluated. However, most of them were highly susceptible to scald, net and spot blotches, barley shoot fly, and had poor plant vigor and small grains. About 6% were selected for further study. In the early 1970s the major germplasm contributors to these nurseries were the FAO Near East Regional Program, the USDA, and the Arid Land Agriculture Development, and from the mid-1970s until 2001 the International Center for Agricultural Research in the Dry Areas (ICARDA) has also been a principal contributor. Some germplasms were also received from Brazil, Columbia, the former Czechslovakia, Egypt, India, Kenya, Peru, Sweden, and the former Republic of Yugoslavia (Gebre et al. 1996). From these efforts one hulled-barley variety, AHOR 880/61, was released (Table 6) and some other elite lines are being also used as sources of genes for desirable agronomic traits such as grain quality and stiff straw and for disease and insect pest resistance in the national crossing program.

Hybridization and selection

Between 1974 and 2001 over 1,600 crosses (single, 3-way and double crosses) were made between exotic and local, and among local germplasm to improve their resistance to lodging and to major diseases such as scald, net blotch, spot blotch, and leaf rust. F2 progenies have been evaluated at a number of targeted areas in the country. Only one outstanding hulled-barley variety, HB 42, has been identified from this program. It is an outcome of a double cross between single crosses of IAR/H/81 x Compound 29 and Compound 14/20 x Coast. Other than IAR/H/81, a selection from local germplasm, the rest are exotic parent materials. HB 42 is a high yielding and widely adapted variety in relatively optimal environments with good resistance to diseases such as scald and net blotch (Table 6).

Table 6. Released food barley varieties.

Methods	Variety	Year of release	Grain yield (t ha-1) On-station	On-farm	Suitable locations
	IAR/H/485[a]	1975	2.5-5.6	2.0-3.5	Central/Eastern highlands
	ARDU 12-60B[b]	1986	3.6-6.3	1.8-2.0	Central/Eastern highlands
Landrace	Shege[b]	1996	2.3-5.1	2.6-3.4	N & W Shewa, Arsi & NW Ethiopia
selections	Misrach[b]	1998	2.5-3.5	2.3-3.4	North Shewa
	Abay[b]	1998	1.5-3.0	1.8-2.0	NW Ethiopia
	Dimtu[b]	2001	2.0-4.0	1.5-2.2	N & W Shewa, Arsi & NW Ethiopia
Introduction	AHOR 880/61	1980	2.9-4.4	2.0-2.5	Central/Eastern highlands
Hybridization and Selection	HB 42	1984	3.2-5.5	2.0-3.3	N & W Shewa, Arsi & NW Ethiopia

[a] Pure-line selection from a landrace of Shewa

[b] Pure-line selections from landraces of Arsi

Sources: EARO 2002; Gebre et al. 1996; IAR 1996

Improvements on Cultural Practices

Past research has resulted in the identification of optimum sowing dates, seed and fertilizer rates, tillage practices, crop rotation, and weeding times specific to different ecological areas.

Optimum sowing dates of barley largely depends on the agro-ecology and barley production system. *Meher* season sowing is optimal from late May to late July. Around Adet, an early barley producing area, late May to mid-June is best (Liben et al. 1996), while early-to-mid-June are optimum sowing dates for medium-maturing varieties at Holetta and Areka, and for early-maturing varieties at Mekele (IAR 1969, 1970, 1979a). Most other studies made at Bedi, Sheno, Kulumsa, Bekoji, Asela, and for early-maturing varieties at Holetta indicated that the optimum sowing dates range between mid-June to late July (CADU 1969, 1972, 1975; IAR 1969, 1970, 1971, 1972, 1975) and most of the major barley growing areas for *meher* season fall within this category. However, around Sinana the optimal *meher* season sowing dates range between mid-July to early August (IAR 1986, 1989) while for belg season it ranges from March to early April (IAR 1992).

Investigations to determine the optimum seed rate has been undertaken at different locations with levels ranging from 75 kg ha^{-1} to 150 kg ha^{-1} of seed and grain yield differences were not of appreciable magnitude (IAR 1989). However, seed rates of 100-125 kg ha^{-1} for broadcast sowing and 85-100 kg ha^{-1} for drill sowing are found to be optimum for food barley at a number of locations.

Poor soil fertility and low pH are among the most important constraints that threaten barley production in Ethiopia. Since the major barley producing areas of the country are mainly located in the highlands, severe soil erosion and lack of appropriate soil conservation practices in the past have resulted soils with low fertility and pH. Although soil fertility status is dynamic and variable from locality to locality and difficult to end up with a blanket recommendation invariably, some soil amendment studies were undertaken at different times and places. Earlier studies made at Bedi indicated that application of 60 kg ha^{-1} of nitrogen and 26 kg ha^{-1} of phosphorus fertilizers both for red and black soils resulted in good grain yields (Beyene 1987).

However, recent studies made in the central highlands (at Degem and Wolmera) indicated that use of 41/46, N/P_2O_5, kg ha^{-1} is marginally profitable under the prevailing fertilizer and output prices (Yirga et al. 2002). Other studies made in the northwestern part of the country, Bahir Dar Awraja, revealed that application of 46/46, N/P_2O_5, kg ha^{-1} to be profitable (Ashagrie et al. 1992). Some studies made in the northern part of the country, north Welo, indicated that the highest marginal rate of return (MRR) was obtained by using 46/0, N/P_2O_5, kg ha^{-1} (Alemu 2001). In the south eastern highlands of the country, around Sinana, fertilizer rate determination studies made in 1988 and 1989 on farmers' fields showed that a fertilizer rate of 0/46, N/P_2O_5, kg ha^{-1} to be economically an acceptable level for small-scale farmers although mean grain yield and fertilizer use efficiency were highest at 41 kg ha^{-1} of N (Elias et al. 1991). Besides chemical fertilizers, green manuring and crop rotation practices were among the alternatives sought for soil amelioration in the past. In barley production system with *guie*, the traditional way to improve the soil is to leave the fields fallow for at least five years and to burn the soil (guie). On unfertilized pellic vertisol at Sheno, vetch as a green manuring crop, field pea and faba bean as precursor crops were compared with the traditional fallow system and some indications for yield advantages over fallow were observed (Tuluma 1989).

Although conclusive results are not yet attained from such studies, shortening or avoiding the fallow period by generating alternative means or efficient cultural practices for soil amelioration will have a vital role in food security owing to the increasing population pressure. In addition to breaking disease and insect pest built-up in barley monoculturing, crop rotation has a vital role in ameliorating soil if practiced with the inclusion of leguminous crops. At Sheno yields of small grains were found to be significantly depressed after three years of continuous production (IAR 1989) and other studies made in Arsi showed that faba bean as a precursor crop to wheat and barley considerably increased grain yield over the monoculture crop (Gorfu et al. 1991). Holetta Research Center has also investigated the effect of crop rotation on barley yield and found that planting barley after faba bean and/or field pea increased the grain yield of barley significantly (IAR 1972).

To improve soil acidity (low pH), field studies were made at Bedi, Nedjo, and Chencha using different rates of ground limestone ($CaCO_3$). At Bedi and Nedjo red soils, application of 3 t ha^{-1} of limestone was found to be optimum while at Chencha application of limestone at a rate of 6 t ha^{-1} was required to improve the extreme acid conditions (IAR 1970, 1972, 1976, 1984; Beyene 1987).

Barley-cultivation tillage practices largely depend on the agro-ecology, the soil types, and the locality's barley-production system. Seedbed preparation methods studied at Sheno, a waterlogged area, indicated that narrow, camber beds (6m wide) plowed with moldboard and disc plows followed with the application of 60 kg ha^{-1} nitrogen and 20 kg ha^{-1} phosphorus fertilizers increased the yield of barley significantly (IAR 1979b). Other seedbed preparation methods were also studied at Holetta and Mekele research centers although yield differences were not significant among the tested methods. Generally barley requires a fine seedbed prepared by frequent plowing using the local plow, *maresha.*

The effect of weed growth on barley was investigated at Holetta and Mekele and the research showed that a single hand-weeding (25 days after planting or 20 days after emergence) is optimum for barley. Although insignificant, the average percentage of weed dry-matter weight from fertilized plots was higher compared with the unfertilized plots at Altufa, indicating that in fields where weeds are known to be a problem weed control and fertilization better recommended as packages (EARO 2000a). Some chemicals for control of grass and broad-leaved weeds were also identified. Results of recent studies indicated that diclofopmethyl at a rate of 1.5 l ha^{-1} is the most preferred herbicide if the grass weed population consists of *Avena fatua* and *Phalaris paradoxa* (EARO 2000b). Broad-leaf weeds are still well controlled with 2,4 D herbicide at a rate of 1 l ha^{-1}.

As summarized by Haile and Ali (1986), thirty-six barley insect pests in Ethiopia were reported of which the barley shoot fly (*Delia arambourgi*) and the Russian wheat aphid (*Diuraphis noxius*) are the most dangerous. Chaffer grub (*Melolontha* sp.), an important insect pest especially to seedlings in dark-brown soils of Tikur Inchini, has also recently been reported (IAR 1997). Barley shoot fly infestation is severe in the meher season while the Russian wheat aphid is more prevalent in the belg season. Barley shoot fly and chaffer grub can be controlled by seed-dressing chemicals such as Gaucho® (imidacloprid 70% WS) and Marshal® (Carbosulfan 25% ST) (EARO 1999a, 2000b). Use of GuachoR was also found effective in controlling Russian wheat aphid (IAR 1997; Berhan and Gebremedhine 1999). Lines tolerant to Russian wheat aphid were also identified (EARO 2000a).

As of 1996, thirty-six barley pathogens have been reported (Semeane et al. 1996). Although the danger level of barley diseases depends on the agro-ecology and the production system, scald and net blotch are among the most hazardous diseases in the major barley growing areas of Ethiopia. Spray chemicals such as Baylaton at 0.5 kg ha^{-1} against scald and Tilt 200 EC at 0.5 l ha^{-1} against net blotch are effective. Chemical evaluation and optimum application rate determination for the control of some important pests and the search for resistant genes are also underway. Recent germplasm evaluations to identify resistant line for the major leaf diseases such as scald and net blotch resulted in the identification of some materials (EARO 2000a, 2000b).

Generally the attempts made so far by different disciplines to tackle the production constraints of food barley were mainly based on results of baseline surveys, which have played a vital role in identifying production systems and diagnosing and prioritizing constraints. However, the relative importance of the yield limiting factors of barley in the different production systems lack clarity and most past studies mainly dealt with investigations of single yield limiting factors at a time rather than following a holistic approach. Therefore, to understand the relative importance of the yield limiting factors of food barley, some studies were made in the central and northwestern highlands of the country where fertilizer, variety, weeding, seedbed preparation, and aphid control were considered as factors (Molla and Gebre 1992; Liben and Asefa 1998). The results of these studies indicated fertilizer, among others, to be the most important factor where yield advantages of 47.5% and 80-286% were reported from the central and northwestern highland studies respectively over the traditional practice, unfertilized plots (Molla and Gebre 1992; Liben and Asefa 1998). Therefore, this implies the low fertility status of the soils of the major barley growing areas of the country and the need for assessing efficient methods towards soil fertility improvement.

Technology Transfer

Technology dissemination to users has generally been given less attention due to poor linkage between the research system and the Department of Extension of the Ministry of Agriculture. Since the mid-1980s the Institute of Agricultural Research, (IAR) now the Ethiopian Agricultural Research Organization (EARO), established a research and extension office to facilitate technology dissemination in the country. Generally, technology dissemination has been handled in two phases: demonstration and popularization. Some of the activities carried out in recent years are summarized as follows.

Demonstration

Demonstration of two improved food barley varieties, HB-42 and Shege, along with the suggested cultural practices (optimum fertilizer rate, seed rate, and efficient weed management) were carried out in the central highlands of the country for five consecutive cropping seasons beginning in 1996/97 (EARO 1998a, 1998b, 1999b, 2000c, 2001). In 1997/98, HB 42 was demonstrated at Sululta, while the newly released variety, Shege, was demonstrated at the other locations. Grain-yield levels for the demonstration trials from 1996/97 all the way through 2000/2001 cropping seasons at the different localities are summarized in Table 7. The yield levels with efficient practices varied from 1.6 t ha^{-1} at Wolmera in 1998/99 to 3.9 t ha^{-1} at Degem in the same season. The mean yield level across seasons and locations was 2.7 t ha^{-1} as compared with 1.7 t ha^{-1} of the corresponding local practices, giving an overall yield advantage of 52.3% (Table 7). By considering fertilizer as the major variable cost, the average five years marginal rate of return (MRR) was found to be 178%, at least giving a clue for the profitability of the efficient practices (Table 8).

Table 7. Mean grain yield levels of improved varieties, HB 42 and Shege, under two cultural practices: central highlands, from 1996/97 through 2000/2001 cropping seasons.

Cropping season	Location	Practices: Suggested (t ha^{-1})	Practices: Local (t ha^{-1})	Yield advantage %
1996/97	Wolmera	1.68	1.20	40.0
	Ambo	2.85	1.72	65.7
	Sululta a	2.15	1.45	48.3
1997/98	Wolmera	2.67	1.73	54.3
	Ambo	2.15	1.50	43.3
	Addis Alem	3.73	3.15	18.4
	Wolmera	1.56	0.67	132.8
1998/99	Degem	3.89	3.24	20.1
	Addis Alem	2.35	1.26	86.5
	Wolmera	2.57	1.73	48.6
1999/2000	Ambo	2.55	1.82	40.1
	Degem	3.13	1.24	152.4
2000/2001	Sululta	3.15	1.90	65.8
	Mean	2.65	1.74	52.3

[a] HB 42 was the improved variety demonstrated

Sources: EARO 1998a, 1998b, 1999b, 2000c, and 2001

Table 8. Cultivars HB 42 and Shege partial-budget analyses for demonstration trials (from the 1996/97 through the 2000/2001 cropping seasons) and for popularization activities (1996/1997 and 1997/98 cropping seasons) in central highlands.

Item	Demonstration [a]		Popularization [b]	
	Efficient Practice	Local Farmers	Participant Farmers	Non-participant Farmers
Average yield (kg ha^{-1})	2,650	1,740	3,360	2,010
Adjusted average yield (80%) (kg ha^{-1})	2,120	1,392	2,688	1,608
Gross benefit (birr ha^{-1})	2,544	1,670	2,822	1,688
Cost that vary (birr ha^{-1})				
- Fertilizer	314	0	304	0
Net benefit (birr ha^{-1})	2,230	1,670	2,518	1,688
Marginal benefit (birr ha^{-1})	560		830	
Marginal cost (birr ha^{-1})	314		304	
MRR %	178		273	

Average prices between 1996 to 2000 were: white-seeded barley 1.20 birr kg-1, DAP 2.27 birr kg-1, and urea 1.73 birr kg-1. Average prices in 1996 and 1997 were: white-seeded barley 1.05 birr kg-1, DAP 2.14 birr kg-1, and urea 1.79 birr kg-1.

[a] Average of five consecutive years demonstrations (1996/97-2000/2001)

[b] Average of two consecutive years popularization (1996/97 and 1997/98)

Sources: EARO 1998a, 1998b, 1999b, 2000c and 2001.

Popularization

Average barley yield levels of participant farmers in farmer-managed demonstration trials as compared with those of neighboring non-participant farmers in the period 1996/97 and 1997/98 at different localities are shown in Table 9 (EARO 1998a, 1998b). Significantly higher yields were realized by participant farmers, indicating the enormous impact of improved technologies. Trial average yields in individual localities ranged from 2.4 t ha^{-1} at Wolmera to 4.5 t ha^{-1} at Addis Alem in the two seasons. The highest average extra yield was obtained from Wolmera. The percentage yield increase varied from 35.6% at Degem to 164.4% at Wolmera. The overall yield increment averaged 1.4 t ha^{-1}, representing 67.2%. With fertilizer as the major variable cost, the two-years average marginal rate of return (MRR) was found to be 273%, which is even better than the results of the five-year demonstration trials (Table 8).

Table 9. Barley yield levels (t ha^{-1}) of participant and non-participant farmers in farmer-managed demonstration trials: central highlands of Ethiopia (1996/97 and 1997/98).

Cropping season	Location	Farmers Participants (t ha^{-1})	Non-participants (t ha^{-1})	Yield advantage %
1996/97	Wolmera	2.44	1.42	71.8
	Wolmera	3.57	1.35	164.4
1997/98	Degem	2.93	2.16	35.6
	Addis Alem	4.50	3.10	45.2
Mean		3.36	2.01	67.2

Sources: EARO 1998a and 1998b.

Potential Production and Constraints

In Ethiopia where the population growth is rapid (2.9%), ensuring sufficient food supply is a priority concern. Food barley can have a vital role in alleviating food shortages due to its merits for production and consumption.

The annual national average grain yield of barley at about 1 t ha^{-1} is quite low when compared with the yield potential of some of the released food-barley varieties. These varieties, if used in conjunction with the suggested efficient practices in their appropriate niches, have shown the possibility of boosting the production and productivity of the crop. Some of the major food-barley production constraints are summarized as follows:

- low-yield capacity of farmers' varieties (landraces) and an inadequate number of improved varieties adapted to the different production systems and varied agro-ecological zones;
- lack of appropriate production practices (cultural practices and soil fertility management);
- biotic stresses such as disease (scald, net blotch, spot blotch, and leaf rust), insect pests (Russian wheat aphid, barley shoot fly, and chaffer grub), and weeds (broad leafed and grass weeds). In studies conducted at Holetta, scald and net blotch may reduce grain yield by 21-67% and 25-34%, respectively (Bekele 1986). Barley shoot fly may reduce yield by more than 56% and aphids may cause 4% to 79% (Haile and Ali 1986) loss or even total crop failure;
- abiotic stresses such as poor soil fertility, low soil pH, drought, waterlogging, and frost;
- loose linkage between research and extension services.

Future Research Areas and Priorities

The wide range of adaptation of food barley in Ethiopia has resulted in numerous problems and it has not been possible to address even the most important ones in the major barley growing areas. As it has been the case in many parts of the world, past research emphasis was to develop widely adapted technologies for relatively optimal environments, which result in high yields. Food barley research in the country has been handled in a decentralized-participatory system where technology generation and development is based on different agro-ecology and production systems.

In barley-research strategy, areas for research and their priorities are classified for accomplishment in short-term, medium-term, and long-term phases. Although associated problems and their importance differ in different production systems and agro-ecologies, priority constraints that deserve immediate attention include:

- Development of improved barley varieties and agronomic practices suitable for barley production in the different production systems and agro-ecologies
- Identification of resistant genes and appropriate control measures against major diseases (scald, net blotch, spot blotch and leaf rust) and insect pests (barley shoot fly and Russian wheat aphid)
- Intensification of extension services and further characterizations and analyses of agro-ecologies and farming systems.

Research Collaboration

If food-barley research is to successfully boost its impact, both national and international research collaborations are indispensable.

On the national level, the strong collaborations with the Institute of Biodiversity Conservation and Research (IBCR), the Ethiopian Seed Enterprise, the National Seed Industry Agency, Agricultural Development Department (ADD), the Extension Department of the Ministry of Agriculture, and federal and regional research centers need to continue. On the international level, collaboration with ICARDA continues to be vital for the exchange of germ plasms and experience, as well as for capacity and capability building.

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Acronyms

ACPSE	Agronomy and Crop Physiology Society of Ethiopia
ADD	Agricultural Development Department, Ethiopia
ARNAB	African Research Network for Agricultural By-products
CADU	Chilalo Agricultural Development Unit, Ethiopia
CIMMYT	Centro Internacional de Mejoramiento de Maiz y Trigo
EARO	Ethiopian Agricultural Research Organization
ENI	Ethiopian Nutrition Institute
ESAP	Ethiopian Society of Animal Production
FAO	Food and Agriculture Organization of the United Nations
HRC	Holetta Research Center, Ethiopia
IAR	Institute of Agricultural Research, Ethiopia
IBCR	Institute of Biodiversity Conservation and Research, Ethiopia
ICARDA	International Center for Agricultural Research in the Dry Areas
MRR	Marginal Rate of Return
NVRC	National Variety Release Committee, Ethiopia
SAREC	Swedish Agency for Research and Education Cooperation
SIDA	Swedish International Development Authority
USDA	United States Department of Agriculture

List of Amharic and other local language terms

Abshillo	pancake-like sourbread prepared from 4- to 15- days-old dough of cereal flour
Areki	distilled homemade sprit made from fermented ingredients
Atmit (muk)	soup-like gruel made from fine flour of cereal grains
Awraja	subdivision of former administrative regions
Belg	minor cropping season that rely on March-April rainfall
Bequre	thin unfermented slightly fermented drink made from flour of well-roasted grain and malt
Borde	thick mildly-fermented drink made flour of well-roasted grain and malt
Besso	fine flour of well-roasted barley grain consumed by moistening and kneading with water, butter, or oil
Chiko	besso soaked with butter alone
Dabbo	leavened, thick bread made from flour of cereals

Derekot	flour from burnt (roasted until black) cereal grain
Enkuto	broiled ripe and dry spikes of cereals such as barley and wheat
Eshet	grain that can be eaten at milky or dough stage of the grain either raw, roasted, or boiled
Genbote	a variant of the late-barley production system of meher season planted in May
Genfo	porridge
Guie	barley-production system of meher season that involve soil burning
Injera	leavened, thin, pancake-like local bread prepared from flour of cereals
Kinche	thick porridge made from coarsely grounded grain
Kitta (torosho)	unleavened, thin, dry and brittle bread prepared from flour of cereals
Kolo	roasted grain
Maresha	animal-drawn traditional plow (usually oxen and in some cases horses)
Meher	main cropping season that rely on June-September rainfall
Nifro	boiled legumes or cereals grain
Sene gebs	a variant of the late-barley production system of meher season planted in June
Shorba	soup-like gruel made from coarsely grounded grain
Tella	fermented and undistilled homemade beer
Wot	sauce which can be prepared from vegetables, meat, pulses, sometimes from cereals flour
Wotelo	broiled unripe spikes of cereals such as barley and wheat at milky or dough stage
Zurbegonie	flour of besso and water mix taken in liquid form

Barley Production and Research in Yemen

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Introduction

Barley is an important cereal crop grown by farmers in the highland regions of Yemen, mainly under rainfed conditions in different seasons and production systems as an important source of food for human consumption and for animal feed during the dry season.

Barley is grown on about 37,075 hectares (6% of the total cereal production area), produces 42,428 tonnes, and contributes about 6.3% of Yemen's total cereal-grain production with an average yield of about 1.1 t ha^{-1} (Agricultural Statistics Year Book 2000). According to the Central Bank of Yemen Statistics, in the year 2000, 1,675 tonnes of barley grain were imported at a cost of 31 million Yemeni rials.

Barley Production Zones

Barley is grown in three agroclimatic zones within the highland areas at elevations from 1,800 to 3,000 m asl:

- Mountain terraces where barley is primarily cultivated under rainfed conditions;
- Intermountain plains with a mixture of rainfed, irrigated, and supplemental irrigation;
- Wadis with primarily rainfed and occasional irrigated cultivation.

Area, Production Distribution, and Yield in the Highland Regions

In the 2000 growing season, the northern highlands region had the highest cultivated area and production followed by the central highlands. The higher yields per hectare in the southern and the central highlands regions are due to the higher rainfall and the use of irrigation (Table 1).

Table 1. Area, production, and yield of barley in the highland regions in 2000.

Region	Area (ha)	Area (%)	Prod (t)	Prod (%)	Yield (t ha^{-1})
Northern (Sanaa, Hajah, Saddah, Amran, Al-Mahweet)	21,374	57.7	18,296	43.0	0.96
Central (Dhamar, Al-Bida)	10,602	28.6	15,795	37.2	1.5
Southern (Taiz, Ibb)	2,409	6.5	4,771	11.3	1.98
Other Areas	2,690	7.2	3,556	8.5	1.33

Source: Agricultural Statistics Year Book 2000

Barley Production Systems

In Yemen barley is cultivated under three production systems: rainfed, residual moisture, and irrigated.

Rainfed system

This is the major cultivation system in the highland mountain terraces and inter-mountain plain areas in spring and summer.

Spring short rainy season. The short rainy season, locally known as 'Al-Jahry' in the mountain terraces, and as 'Al-Dathy' in the intermountain plains and the wadis, is from March to May. Barley is usually planted at the end of February or early March and it is harvested at the end of May. Three local, two-row varieties are grown in this season. The two predominant varieties are Saklah and Bakor, while the third variety, Habib, a hull-less barley, is not as widely used. These varieties require 80 to 90 days to mature.

Summer main rainy season. The main rainy season, known as 'Al-Serab' in the mountain terraces, intermountain plains, and wadis, is from June to September. Barley is planted in mid-June and harvested at the end of September. The two local varieties, Saklah and Bakor, are primarily grown in the mountain terrace areas, while the three improved varieties, Mobasher, Arifat, and Aswad Mahli are widely used in the intermountain plain and wadi areas. These latter varieties mature in 3 to 4 months.

Residual moisture system

This system is used in high altitude mountain terraces. After a good rainy season the two local varieties, Saklah and Bakor, are planted in early November, using residual moisture from the previous rains, and harvested in January. However, yield from this system is usually very low as compared with the other barley production systems.

Irrigated system

This system is widely utilized in the intermountain plain and wadi areas that have sources of water for irrigation. Barley is planted mainly in the winter season, locally called 'Al-Kiath' (mid cycle) from mid-December to early January and harvested from March to early April. Two improved six-row varieties, Mobasher and Arifat, and two local varieties, the six-row Masdos and the two-row Aswad Mahli, are grown. These four barleys require 3 to 4 months to mature. The two local varieties, Saklah and Bakor are also grown.

Common barley varieties with their growth characteristics are shown in Table 2.

Table 2. Yield, plant height, 1000 kernel weight (kw), and growing period duration of common barley varieties in Yemen.

Varieties	Actual yield ($t\ ha^{-1}$)	Potential yield ($t\ ha^{-1}$)	Plant height (cm)	1000 kw (g)	Growth period (days)
Aswad Mahli	1.6	2.4	70	55	110
Mobasher	1.9	2.4	65	43	110
Arifat	2.1	2.5	80	40	120
Saklah	1.3	1.9	42	33	103
Bakor	0.9	1.5	58	34	88

System Constraints

The major constraints limiting barley productivity are poor rainfall distribution, inadequate water supply in irrigated areas, soil erosion, poor soil fertility, a shortage of production inputs, and a shortage of labor. The result is a decrease in crop yield and low farm income.

Barley Research Background

Since 1990 Yemen's barley research program has included two components, breeding and agronomy.

The breeding program has depended on evaluation and selection of materials introduced from the International Center for Agricultural Research in the Dry Areas (ICARDA) and the Arab Center for Studies of the Arid Zones and Dry Lands (ACSAD). The barley program received early segregating population, observation nurseries, and variety trials for characteristics of early maturity, drought resistance, and high-yield. Most of the trials were conducted at research stations and breeders carried out all selection processes under controlled environments.

The barley research program conducted many levels of trials in order to select new varieties. The selection criteria were determined by the researchers and often these did not match the actual farmers' cultivation results. It had also often taken a long time to complete variety evaluations resulting in a delay in the release of new varieties.

In 1996 the Agricultural Research and Extension Authority (AREA) adopted the farming system approach, and the national program started some barley research activities in farmers' fields via three methods:

- Transferring of promising technologies, such as a high-yield variety, that would solve one or more of farmers' problems;
- Conducting selection of promising barley varieties with farmers participating in the selection process;
- Conducting participatory plant breeding from the early stages of selection.

Barley Production Practices

Production practices used by farmers include:

Seed source and sowing ratio. For local landraces seed is selected from the previous crop, while for improved varieties the seed is procured from the seed multiplication project. The sowing ratio is 100-120 kg ha^{-1}.

Crop rotation. The two principal crop rotation patterns in mountain terrace areas are barley/lentil/dry pea with sorghum and barley/lentil/fenugreek with wheat/faba bean.

Plowing. Plowing is done with oxen and/or donkeys three to four times per season. Plowing frequency depends on the type of previous crop planted and on the soil type.

Manuring. Manure is widely used at the time of plowing.

Fertilizing. Urea is applied at a ratio of 180-200 kg ha^{-1} in high rainfall and irrigated areas.

Harvesting and threshing. Harvesting is done by hand using a sickle, and threshing is done by driving oxen or donkeys over the harvested barley on a circular, well-prepared, piece of ground. Straw is separated by blowing, using large wooden forks.

Barley Utilization

Barley straw is a good source of animal feed during the dry season and barley grain is used to prepare various types of local dishes and drinks (Table 3).

Research and Strategy

As stated earlier, the barley research program in Yemen has two components, breeding and agronomy. The program goals are the development, testing, adoption, and demonstration of improved varieties that are adaptable to the varying rainfall conditions, are drought and lodging tolerant, are resistant to the barley shoot fly and Russian wheat aphid, and are early maturing.

Table 3. Barley usage in rural households, Dhamar governorate.

Food	Ingredients and Preparation
Zoam or Matiat	Barley flour, milk, and water are boiled until slightly thick. Used with bread or *Asid* (porridge)
Alaath	Small amount of barley flour is added directly to Al-marq (meat soup); or flour can be mixed first with a small amount of water and then added to the soup
Maloog (a bread)	Barley flour and wheat flour are mixed with water, with a higher ratio of wheat to barley. If local *(baladi)* wheat flour is used some white wheat flour is added
Fateera (a hard pie)	Barley flour, maize flour, and lentil flour are mixed with water
Matany (a bread)	Barley flour and lentil flour are mixed with water, with a higher ratio of lentil flour
Kaac (a pie)	Barley flour and lentil flour are mixed with milk
Nakia (a drink)	Boiled barley grain

Livestock and Other Usage

Fodder for animals especially donkeys
Bedding for chickens
Mixed with clay for building barns and houses
Mixed with dung to form cakes for use as fuel

The current research methodology being implemented by multidisciplinary research teams focuses on a farming system approach to research and extension employing problem solving techniques; the improvement of relevant genetic materials and strategic technology components from partner institutions including Consultative Group on International Agricultural Research (CGIAR) centers; participatory research with farmers and breeders; integration of crop-livestock systems; and the strengthening of Yemeni human resource capacity.

Barley Improvement in Islamic Republic of Iran: Present Status and Future Prospects

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Introduction

Iran is located in the world's desert belt and considered as an arid and semi-arid region. The annual precipitation is about 250 mm, which is one-third of the average world precipitation. Although the total land area of Iran is 165 million ha, only 18.5 million ha (11.2%) are used for crop production. Of this, 6.2 million ha (34%) are cultivated under rainfed conditions and the rest (66%) is cultivated under irrigated conditions. In the rainfed areas, only 1.2 million ha receive more than 400 mm of rainfall. All precipitation is received in the form of snow or rain during the winter and early spring months. This moisture stress on crop production is further aggravated by thermal stresses caused by low (down to -30°C) as well as high (> 40°C) temperature.

Wheat and barley are the two most important crops in Iran. These two crops account for almost 75% of the calories of people's diet. Almost the entire rainfed area is devoted to the production of wheat, barley, lentil, chickpea, and some oilseed crops (Table 1).

Table 1. Total area and production of cereals and food legumes, Iran 1998.

Crops	Area ('1000 ha)			Production ('1000 t)		
	Total	Dryland	Irrigated	Total	Dryland	Irrigated
Wheat	6,180	3,951	2,229	11,995	345	11,650
Barley	1,825	1,119	706	3,301	1,189	2,112
Lentil and Chickpea	797	763	34	344	305	39

Barley Importance and Uses

The predominant farming system is cereal-livestock, in which barley plays a very important role. Barley (*Hordeum vulgare* L.) is cultivated on 1.83 million ha under diverse and variable agro-climatic conditions and ranks second among the cultivated crops in terms of hectares. It is grown under irrigated and rainfed conditions (Table 1). In spite of extensive and large-scale cultivation of barley, the national average is only 2.5 million tonnes of grain and that does not meet Iran needs. This low production is due to low yield per unit area (0.9 t ha^{-1} and 2.8 t ha^{-1} in rainfed and irrigated conditions, respectively).

Barley is primarily produced and used as animal feed in Iran. It is also consumed as malt, as food in the form of "barley soup," and *ma-ol shaer* (non-alcoholic beer). Besides grain, barley straw is also fed to animals for stall feeding, especially during winter months when other feed resources are either scarce or unavailable. Barley grain is also used for bread (alone or mixed with wheat). About 150 to 200 thousand tonnes is annually used for human consumption in different forms. The largest cultivation of barley occurs in the regions where other cereals do not grow well due to altitude, low rainfall, or soil problems such as salinity.

Being the major source of animal feed, barley plays an important role in the sustainability of agricultural production systems in Iran. The increasing demand for animal feed and human food is being met by imports from other countries and by increasing production horizontally. As a consequence, the marginal areas were brought under cultivation and the pressure on rangelands increased. The present average national grain yield for barley is 1.7 t ha^{-1}. In the rainfed area, representing 60% of the total barley area in Iran, yield is only 0.9 t ha^{-1}, and this contributes only 35% to total barley production in the country.

To relieve the pressure on rangelands and reduce the cultivation of barley in fragile, marginal areas, prone to environmental degradation, the government decided to increase production vertically rather than by increasing the cultivated area. Barley statistics indicate a significant reduction in area under cultivation from 2,348,000 ha in 1981 to 1,100,000 in 2001. However, during the same period, barley production increased from 1.97 to 2.74 million tonnes. Nevertheless, grain yield in the dryland areas is still low, which is attributed to several depressing factors including biotic and abiotic stresses. Moreover, due to severe drought in 1999 and 2000, the cultivated area, production, and grain yield in the dryland areas showed a significant reduction (Table 2).

Table 2. Barley area, production, and yield in the Islamic Republic of Iran, 1981-2000.

Year	Area ('000 ha)			Production ('000 t)			Yield (t ha^{-1})	
	Irrigated	Rainfed	Total	Irrigated	Rainfed	Total	Irrigated	Rainfed
1981	563	1,785	2,348	953	1,015	1,968	1.7	0.6
1982	575	1,266	1,841	1,101	802	1,903	1.9	0.6
1983	673	1,333	2,007	1,241	793	2,034	1.8	0.6
1984	780	1,383	2,163	1,455	838	2,293	1.9	0.6
1985	781	1,303	2,084	1,532	765	2,297	2.0	0.6
1986	710	1,263	1,973	1,563	942	2,505	2.2	0.7
1987	860	1,360	2,220	1,735	996	2,731	2.0	0.7
1988	927	1,648	2,576	2,096	1,298	3,394	2.4	0.9
1989	1,046	1,605	2,651	2,073	774	2,847	2.0	0.8
1990	942	1,687	2,729	2,258	1,290	3,548	2.4	0.8
1991	834	1,324	2,158	2,028	1,073	3,101	2.4	0.8
1992	693	1,393	2,086	1,705	1,360	3,065	2.5	1.0
1993	668	1,292	1,960	1,773	1,285	3,058	2.7	1.0
1994	716	1,041	1,757	1,980	1,065	3,045	2.8	1.0
1995	666	1,086	1,752	1,793	1,159	2,952	2.7	1.1
1996	617	1,057	1,674	1,782	954	2,736	2.9	0.9
1997	628	873	1,502	1,771	728	2,499	2.8	0.8
1998	706	1,119	1,825	2,111	1,189	3,301	3.0	1.1
1999	596	807	1,403	1,579	420	1,999	2.7	0.5
2000	674	936	1,100	1,582	743	1,400	2.3	0.8

Source: Center for Agricultural Statistics, Department of Statistics and Information, Ministry of Jehad-e-Agriculture, Islamic Republic of Iran.

Barley-Growing Areas

Barley is considered a stress-tolerant crop, suitable for marginal areas and as a consequence, is gradually being pushed into those areas where cultivation of wheat is uneconomical. Therefore, a lower priority is given to barley cultivation and minimum inputs are applied. Furthermore, because of climatic diversity and environmental variation, there is no single type of barley that can be successfully grown throughout the country. There is a climatic gradient from very warm to severe cold growing conditions in Iran that warrants the cultivation of barley with different growth habits ranging from short duration spring types to cold tolerant, pure winter types.

Based on the prevalent climatic conditions in the country, five specific regions for cereal cultivation have been recognized. These include:

- Winter cereal region with cold, mountainous climate, mostly rainfed but with some irrigated areas;
- Spring cereal region with warm climate and sufficient water for irrigation;
- Spring cereal region with warm climate and fertile soils;
- Facultative cereal region with low rainfall and shortage of irrigation water;
- Spring cereal region with warm climate and salinity and drought problems.

About 66% of rainfed and irrigated barley are in the cold, high altitude mountainous regions. Grain yield varies between 1,500 and 4,000 kg ha^{-1} for irrigated barley and between 450 and 1,500 kg ha^{-1} for rainfed barley. The range of elevation is 1,000-2,700 m. Average rainfall varies from 100 to 500 mm. The number of frost days varies between 60 and 180, with minimum temperature ranging between -2 and -35° C. Sowing time is between 23 September and 20 November. Heading generally occurs between 15 April and 15 May.

Ongoing Research

Barley research for both breeding and agronomy is carried out at two main institutes, the Seed and Plant Improvement Institute (SPII), Karaj, and the Dryland Agricultural Research Institute (DARI), Maraghah. Until 1993, barley-improvement research was carried out by SPII only, with a major emphasis on development of new cultivars and technology for the high input irrigated areas, and a spillover of that research went for the rainfed, moisture-stressed areas. However, the barley improvement work for moisture-stressed areas of Iran was later mandated to DARI at its establishment in 1993.

Barley improvement work is carried out partly to overcome the yield and production-depressing factors in different ecological zones. A comprehensive plan has been developed to address the problems of barley in Iran, covering all agroecologies. The International Center for Agricultural Research in Dry Areas (ICARDA), which has been associated with DARI since its inception, has provided improved barley germplasm, and additional expertise in research and training in barley improvement. The development of improved, moisture-stress tolerant barley germplasm is one of the major objectives of research in Iran. There are some other objectives, which are of local importance such as earliness in maturity, winter hardiness, and tolerance to heat and salinity.

Due to enormous agroclimatic diversity in Iran, especially in the dryland areas, no single location can cater for the needs of the entire country, and no single genotype can be successfully cultivated in all agro-ecologies. To overcome this limitation, DARI established three major research stations, one each at Maragheh, Sararood, and Gachsaran, as typical testing sites for the cold, moderately cold, and warm areas, respectively, with the objective of developing new varieties and suitable technology for each of these mega-environments. SPII also maintains research stations in each of the three ecological areas.

Most of the breeding efforts have been devoted thus far to improving feed barley. Nevertheless, breeding of hull-less barley for human consumption and of malting barley has been initiated relatively recently, primarily at SPII.

Major Production Constraints

A significant area of barley is grown in high elevation (> 1,000 m asl) areas where cold and drought are the major prevailing stresses. In addition to those stresses, the following constraints have been identified as reasons for the low barley yield in Iran.

Disease

Scald (*Rhynchosporium secalis*); net blotch (*Pyrenophora teres*); spot blotch (*Helminthosporium sativum*); barley leaf stripe (*Helminthosporium gramineum*); powdery mildew (*Erysiphe graminis* f.sp. *hordei*); loose smut (*Ustilago nuda*); septoria leaf (*Septoria nodorum*) and glume blotch (*Septoria passerinii*); Barley Yellow Dwarf Virus (BYDV).

Insects

Sunn pest (*Eurygaster* spp.); aphids (*Rhopalosiphum padi, R. maidis*).

Weeds

Although there are a large number of weed species of broad leaf and grassy plants such as wild oats, and others throughout the dryland areas, the most obnoxious species in south-western Iran are *Glycyrrhiza glabra* L. (vernacular name: *Shirin-bian*), and *Sophora alopecuroides* L. (vernacular name: *Talkh-bian*) of the family Leguminacea.

Heat

At the reproductive stage of crop development heat causes considerable yield loss in certain areas.

Variability

Bad distribution of and variability in rainfall aggravates the drought effect on yield. A special emphasis is placed by DARI on investigating the mechanism by which certain genotypes tolerate or resist the effect of moisture stress better than others.

Inadequate soil

Characteristics such as toxicities from salt and/or boron, deficiencies of various micro- and macro-nutrients such as nitrogen and zinc depress crop growth and production in certain barley growing areas.

Lack of varieties

Suitable food-barley varieties are not available for the different agro-ecological regions.

Inadequate technical expertise

There is insufficient transfer of technology and expertise, although progress is being achieved in on-farm testing and demonstration and in linkages with extension services.

Breeding Strategy

The barley breeding strategy in Iran is based on the use of locally adapted materials in hybridization with exotic elite, trait specific germplasm through single, double, top and back crosses, involving both spring and winter types. A major emphasis is placed on using national landraces and barley-related species. Pedigree and bulk pedigree methods are followed to handle segregating populations.

Efforts were made to procure barley germplasm of spring, facultative, and winter types from the national gene bank as well as from ICARDA for evaluation against various stresses and to identify parental stocks for hybridization. The flow of the breeding material at SPII is shown in Figure 1. Initial breeding steps at DARI are similar to that of SPII. However, to overcome the problem of greater agroclimatic diversity in the rainfed areas, the early generations of segregating populations are evaluated at a number of DARI research stations. After the F6 generation, materials are tested in Preliminary Yield Trials (PYT) with two replications, generally at two or three stations (depending on seed availability). Materials selected from the PYT are entered into Advanced Yield Trials, AYT (three or more stations in each major agro-ecology).

Table 3. Various barley nurseries grown at DARI or SPII stations.

Type	Name
National Nurseries	Crossing Block, Segregating Populations, Malting barley, Forage Barley, Naked Barley Nursery, Salt Tolerance Nursery, Shuttle Breeding, Drought Tolerance Experiments, Disease Resistance Nurseries, Insect Pest Resistance Nurseries, Physiology-breeding, Molecular Marker Breeding.
International Nurseries	Crossing Block, Segregating Populations, Barley Observation Nurseries, Hull-less Barley Screening Nursery (HBSN), International Spring Early Barley Observation Nursery (ISEBON), International Spring Naked Barley Observation Nursery (ISNBON), Barley Yield Trial (BYT), Early Maturity Barley (EMB).

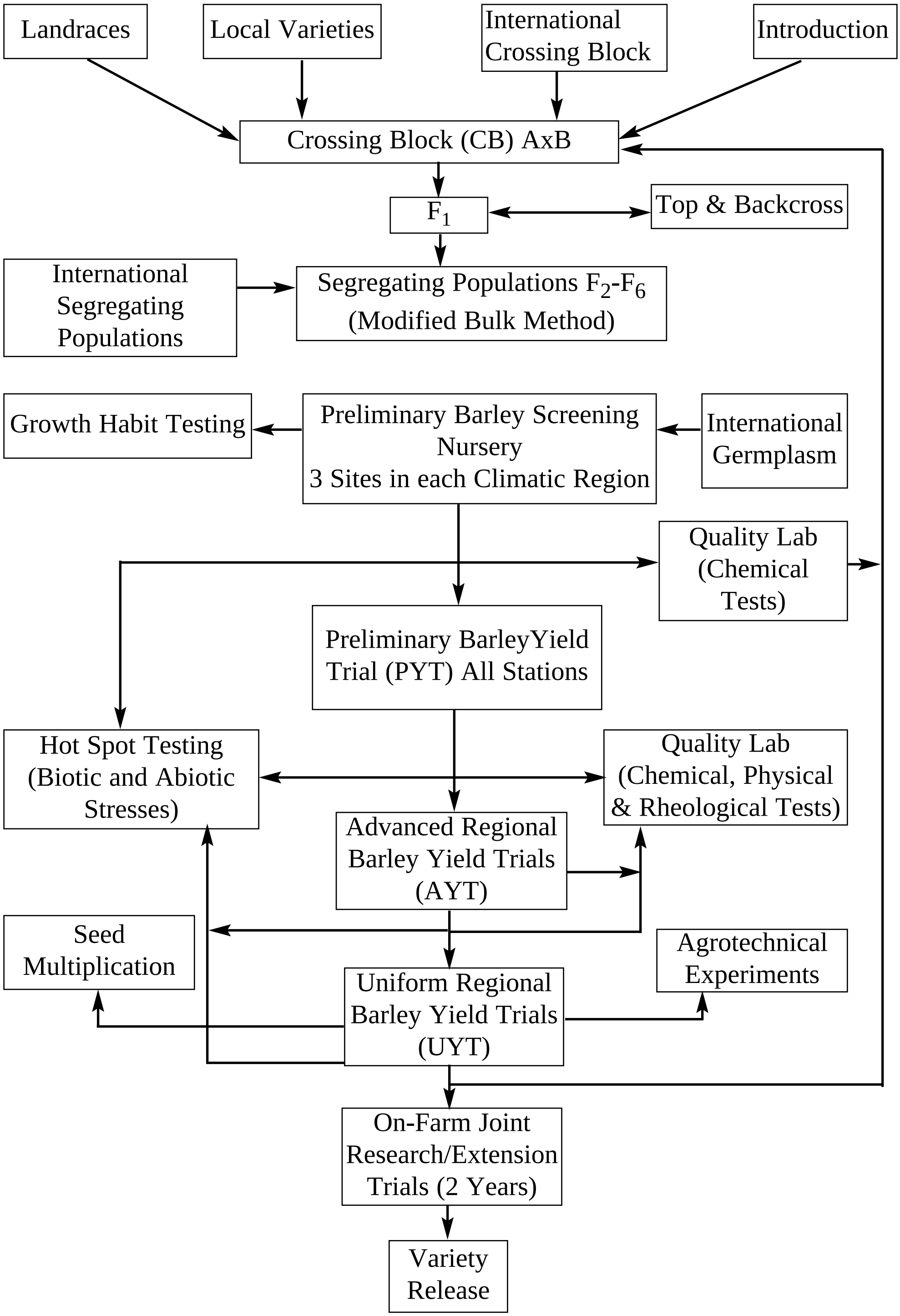

Figure 1. Germplasm movement in barley breeding program at Seed and Plant Improvement Institute (SPII), Iran.

The best entries are selected for the Uniform Regional Yield Trial (UYT), conducted for three years at all stations and usually under two water regimes, supplementary irrigation and rainfed conditions. Table 3 shows the various nurseries grown at DARI or SPII

The interest in barley as a food crop is increasing in Iran. Although breeders responded to this trend, most of the work on breeding hull-less barley has been generally limited to spring barley, despite in Iran the area sown with winter barley is larger than the one planted with spring barley. The majority of hull-less barley lines have poor cold tolerance; therefore, improving the cold tolerance of hull-less barley has been given a high priority. The breeding efforts to improve cold tolerance conducted in collaboration with ICARDA were targeted to find an acceptable compromise between the desirable traits of spring types (early maturity, good early growth vigor, long straw, drought tolerance) and the cold tolerance of winter types. This is being achieved through two avenues: (a) developing winter barley with good early growth vigor and resistance to drought, and (b) improving the cold tolerance of spring barley types.

Widening the Gene Pool

Iran is an important genetic diversity center for barley. The barley gene pool includes different types of landraces and wild relatives that could be utilized as sources for tolerance to biotic and abiotic stresses. Six species of barley are found in Iran: *Hordum vulgare* L. (ssp. *vulgare*, and ssp. *spontaneum*), *H. murinum* L. (ssp. *murinum*, and ssp. *glaucum*), *H. marinum* Huds., *H. bulbosum* L., *H. brevisubulatum* (Trinius) Link (ssp. *violaceum*, and ssp. *iranicum*), and H. *bogdani* Wilensky.

A collection of barley landraces and wild species has been assembled from most areas of the country. This collection, which is preserved at the National Plant Gene Bank of Iran (NPGBI), a section of SPII, comprises 6,500 accessions, including landraces and wild species. At the NPGBI, primary investigations including botanical identification, morphological evaluation, agronomic characterization, and screening for resistance to powdery mildew have been completed for nearly 2,000 accessions including landraces and *H. spontaneum*. As a result, 25 accessions were identified as resistant to diseases. In addition, 500 accessions of barley landraces have been screened in saline conditions. Many accessions of wild barley species *H. murinum*, *H. marinum*, *H. spontaneum*, and *H. bulbosum* were judged valuable sources of tolerance to several biotic and abiotic stresses. A large number of accessions are jointly evaluated by NPGBI, DARI and SPII researchers on an annual basis.

Barley Breeding Program

Iran has a close collaboration with ICARDA in barley improvement. One of the components of this collaboration is the exchange of germ plasm including landraces, segregating populations, fixed lines, and diverse sources of desirable traits. In the 2000/01 cropping season, national and international barley nurseries were evaluated at DARI and SPII stations (Table 4), from which several promising lines or populations were selected for more advanced evaluation or consideration for release. Yesevi, Obruk, ICB11838, and COSS/OWB71080-44-1H are promising lines selected from UYT in the cropping season 2000/01.

Table 4. Total and selected entries from winter barley nurseries at various DARI and SPII stations, 2000/01 cropping season.

Nursery	Total	Selected
Barley Crossing Block (national)	430	430
International Winter Barley Crossing Block-Cold Hardiness-Cold Winters (IWBCB-CH-CW)	149	57
F_1	440	440
Segregating population (national)	4,460	567
Segregating population (international)	2,438	847
Preliminary Barley Yield Trials (PBYT)	1,911	339
Preliminary Hull-less Barley Yield Trials (PHBYT)	536	120
Advanced Yield Trial -A	294	65
Advanced Yield Trial -B	90	39
URBYT	36	36
On-farm trial	6	3
HBYT	56	20
IBYT- CH-CW	24	19
IWPBYT-CH-CW	603	72
AHB	55	22
IBON-CH-CW	1,188	217
Salinity trials	246	Further evaluation

Among SPII released cultivars are Rihane-03 (spring type) and Makoui (winter type) for the high rainfall or irrigated areas. DARI also released new cultivars, through its collaborations with SPII and ICARDA, targeted for the water-stressed environments of Iran. Current barley cultivars used under rainfed and irrigated conditions in Iran are presented in Table 5.

Table 5. Varieties and area under cultivation of barley cultivars under irrigated and rainfed condition in Iran.

Variety	Name/ Pedigree	RT[a]	Gh[b]	Year of release	Condition[c]	Area (ha) Irrigated	Area (ha) Rainfed
Valfajr	CI 108985	6	F	1983	Irr / Rf	236,589	62,110
Makoui	Star	6	W	1990	Irr / Rf	124,055	49,170
Rihane-03	Rihane-03	6	S	1994	Irr	97,200	-
Dasht	Probestdwarf	2	F	1993	Irr / Rf	14,270	49,520
Local Barley (Irrigated conditions)	Landrace	2/6	S	-	Irr	117,855	-
Productive	Productive	6	W	-	Irr / Rf	6,882	25,028
Binam	Unknown	6	F	-	Irr	6,390	-
Zarjo	Selection from Landrace	6	W	1959	Irr / Rf	11,361	21,884
Afzal	Selection from Landrace	6	F	1996	Irr	3,660	-
Karoon	Strain 205	6	F	1979	Irr / Rf	24,742	133,200
Jonoob	Gloria'S/Copal'S	6	F	1997	Irr	6,762	-
Kavir	Arivat	6	F	1990	Irr / Rf	18,347	2,200
Local Barley (Rainfed conditions)	Landrace	6	S	-	Rf	-	527,170
Torkaman	Rihane-04	6	S	1994	Rf	-	12,992[d]
Sararood-1	ChiCm/An57// Albert	2	W	1998	Rf	-	1,951
Sahand	Tokak	2	F	1997	Rf	-	36,131
Jo-Siah	-	2	S	-	Rf	-	5,000
Ezeh	-	6	S	1996	Rf	-	3,000
Gorgan-4	-	2	S	1962	Rf	-	4,350
Others	-	-	-		-	6,267	1,813
Total						668,113	933,706

[a] RT= Row Type

[b] Gh=Growth habit (W=Winter; F=Facultative; S=Spring)

[c] Irr=Irrigated; Rf=Rainfed

[d] This value is area under cultivation of cv. Torkaman together with cv. Rihane-03 in high rainfall areas under rainfed conditions

One recently released variety is Sararood-1 (ICARDA line ChiCm/An57//Albert). This line was identified and released by researchers at Sararood Station, Kermanshah, main DARI station for moderately cold areas. Sararood-1 has a high yield potential. During 10 years of testing, it showed an average yield of 3.1 t ha^{-1} with 18-20% increase over the local checks. Yield average was up to 4-4.5 t ha^{-1} in on-farm demonstrations under rainfed conditions (400-450 mm rainfall). Up to 10 t ha^{-1} was recorded in research fields under supplementary irrigation.

Malting Barley

In its work on malting barley, SPII evaluates its most advanced materials for the following quality traits: kernel weight, uniform germination, absence of dormancy, protein content, beginning saccharification time, duration saccharification time, malt powder moisture percentage, filtration time, and Brix value (percentage of solid matter in the solution). In the year 2000, 200 barley lines were evaluated at six stations, in collaboration with Behnoosh Company (Table 6). Of these, 61 entries were selected based on kernel weight and grain protein content. In the final stage, 20 lines were evaluated for all of the above quality traits, and only a few were selected as malting barley elite lines.

Table 6. Quality characteristics range for 200 malting barley lines.

Characteristic	Range
Thousand kernel weight (g)	40.5-47.5
Hectoliter weight (kg)	75.37-84.10
Protein content (%)	8.40-10.78
Duration saccharification time (min)	4.50-6.00
Filtration time (min)	15.17-29.66
Brix value (%)	7.42-8.53

Future Research

Major research needs for barley improvement in the highlands and other barley growing areas of Iran include:

- Collection and characterization of local types and their uses in hybridization;
- Development of improved hull-less barley cultivars and quality evaluation of hull-less types for use as food barley cultivars;
- Development of new varieties/cultivars with better yield and quality for Iran's varying agro-ecologies;
- Investigation of biotic and abiotic stresses affecting yield and incorporation of related resistant genes into suitable barley cultivars;
- Development of winter barley cultivars with good early growth vigor and resistance to drought;
- Improvement of cold tolerance for fall-planted spring barley;
- Undertaking of epidemiological studies for major diseases;
- Monitoring of diseases, environmental variation, varietal diffusion, yield level and other farm-related factors, with aim of taking appropriate measures to increase yield and reduce yield variation;
- Development of improved production package for farmer adaptation;
- Upgrading competence of barley researchers in modern techniques and technologies.

Status of Food Barley in Nepal

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Introduction

Nepal is a small landlocked country in the southern part of the Himalayas extending from 80° to 88° east longitudes and 26° to 30° north latitudes. Except for Tibet in the north of the high Himalayan region, India surrounds the country on three sides. The elevation of the country ranges from about 60 m above sea level (asl) to the world's highest peak, Everest at 8,848 m asl. The total area of the country is 147,484 sq km and the population is 23 million. Of the total population, 81% depends on the agricultural sector that contributes 40% of gross domestic product to the national economy.

Although Nepal is a small country, it has a wide climate range mainly determined by altitude and longitude. The climate in the Terai, a swampy plain area bordering India, and in the valleys of the Siwalik hills is almost tropical, while in the low-range hills it is subtropical. The climate of the high-hill area is temperate while the climate of high Himalayas, always covered with snow, is tundra or arctic. Nepal is divided into five geographic regions: Terai plain, the Siwalik hills, middle-range hills, high-range hills, and Himalayan high mountains covered by snow.

The Terai and middle mountain areas are more important for agriculture as 80% of the total cultivated area is in these two regions. However, the contribution of the Siwalik valleys to the country's food supply cannot be underestimated. The total cultivated area of Nepal is around 3 million ha of which 30% is irrigated. The production is not sufficient to meet the food requirements of an ever-growing population. Barley occupies 1.0% (Figure 1) of the total cultivated area and is 0.44% of the total cereal production of the country.

Barley (*Hordeum vulgare* L.) ranks as the fifth staple-food crop of Nepal after rice (*Oryza sativa*), maize (*Zea mays* L.), wheat (*Triticum aestivum* L.) and finger millet (*Eleusine coracana* L). Research on barley was initiated by Dr. S. N. Lohani in 1972 and systematic research on finger millet, barley, buckwheat, and amaranth was begun with the establishment of the Hill Crops Research Program (HCRP) in 1987 with the support of the International Development Research Center (IDRC). However since termination of IDRC support in 1993/94, barley research is again falling behind.

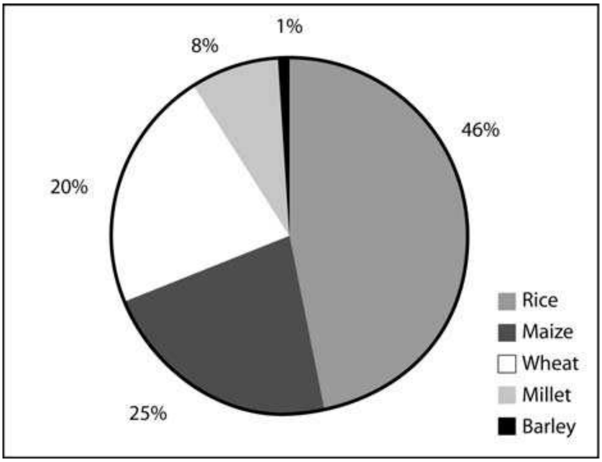


Figure 1. Total cultivated area of major cereal crops, 1998/99.

Area and Production

The area, production, and productivity of barley for the last 10 years (1990/91-1999/00) continued to increase up to 1995/96. The barley growing area increased 33% and production increased 48% in 1995/96 in comparison with 1990/91 (Table 1). However, since 1995/96 the barley area has decreased. As of the 1999/00 season the barley area (28,196 ha) is 5% less than the base year of 1990/91 and 28% less than in 1995/96. In contrast to decrease in area, barley production increased by 11% in 1999/00 as compared with 1990/91. The obvious reason for the increase in barley production in recent years when compared with the base years was the increase in productivity from 940 to 1,093 kg ha^{-1}.

Table 1. Barley area production and productivity, ten year period 1990/91-1999/2000.

Year	Area (ha)	Production (t)	Productivity (kg ha^{-1})
1990/91	29,610	27,840	940
1991/92	29,660	27,640	932
1992/93	29,680	27,610	930
1993/94	37,385	35,157	940
1994/95	39,096	37,108	949
1995/96	39,400	41,340	1,049
1996/97	35,280	36,690	1,040
1997/98	35,590	37,150	1,044
1998/99	31,843	31,798	999
1999/2000	28,196	30,817	1,093

Although, recent barley production is about 25% less than in 1995/96, the productivity is an increasing trend.

Out of the total barley area (28,196 ha), more than 50 % is in the hill region, while 40% is in the mountain region occupy 40% (Figure 2). If we consider the political division of the country, about 80% of the barley area lies in the western, mid-western and far-western regions (Table 2). Almost 40% of the total barley area lies in the mid-western region. Among the geophysical regions, the highest barley area lies in the mid-western hills. The middle-range hills of Nepal have more than 50% of the country's barley area. There is a larger barley area in the western region compared with that of eastern Nepal, mainly because there is heavier winter rain in western Nepal.

Recently, in the accessible hill area farmers have been seeking an alternative to the barley crop as a means of generating more income from their limited land-holdings. Some farmers are using their land for vegetable seed production, such as radish seed. The majority of radish seed is produced in the mid-western hills region; this could be the reason for the decreasing barley area.

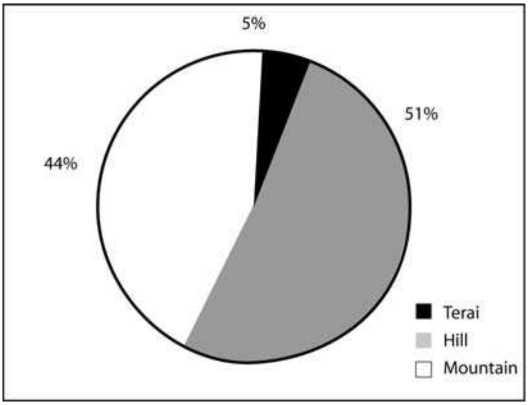


Figure 2. Distribution of barley area in geophysical region of Nepal, 1999/2000.

Barley Importance and Significance

When considering barley area and production, the significance of barley appears to be low, but it should not be forgotten that barley is an important food crop of resource-poor farmers living in the remote and very difficult to reach hill areas. Barley is locally consumed in different forms. In the western high hills (Mustang district), the flour of roasted hull-less barley is usually taken with tea. This is also common in the eastern high hills (Solukhumbu district en-route to Mount Everest), however a thick, barley porridge (hulled or hull-less) is a common recipe from mid-western to eastern Nepal. This porridge is usually prepared by mixing barley flour with tartaric buckwheat (*Fagopyrum tartaricum*) flour in a 3:1 ratio.

Table 2. Geophysical and political distribution of barley, 1999/2000.

Political region	Geophysical									Total		
	Terai plains			Middle hills			High hills					
	Area	Production	Productivity	Area	Production	Productivity	Area	Production	Productivity	Area	Production	Productivity
Eastern	50	60	1,200	934	898	961	897	1077	1201	1,881	2,035	1,082
Central	790	761	963	1,891	1,864	986	1,158	1342	1159	3,839	3,967	1,033
Western	245	261	1,065	4,258	4,482	1,053	731	890	1218	5,234	5,633	1,076
Midwestern	84	91	1,083	5,455	5,806	1,064	5,943	6611	1112	11,482	12,508	1,089
Far-western	162	161	994	1,940	1,930	995	3,658	4583	1253	5,760	6,674	1,159
Total	1,331	1,334	1,002	14,478	14,980	1,035	12,387	14503	1171	28,196	30,817	1,093

Notes: Area: ha; production: t; productivity: kg ha^{-1}

In the mid-western high hills (Karnali region), barley is a very important crop following rice in the irrigated valleys. Due to the low temperature, wheat cannot be adjusted to the cropping pattern as it has a longer maturation period. However, only early maturing barley varieties can be used in the rice-barley system and late high yielding cultivars are planted in the region's rainfed land. People of the mid-western high hills prefer hulled barley to hull-less barley because local breads are better prepared from hulled barley. Barley, often in the east and usually in the west, follows finger millet in the maize-millet system in the middle-range hills of Nepal These fields would otherwise remain fallow as no alternative winter crop can replace barley in this ecological environment. In the upper Mustang, western high hill area, barley is a significant staple food, grown as the most important summer crop.

Barley straw is an important source of fodder for livestock, the main component of the Nepalese hill farming system. As hill farmers have no access to, nor can most of them afford, expensive commercial inorganic fertilizer, farmyard manure (FYM) is the only plant nutrient added to the soil to sustain hill farming.

Barley has a high level of religious significance in Hindu society. It is one of the most important and indispensable items in every religious and ritual ceremony. A small amount of hulled barley is needed daily for orthodox Hindus to conduct their prayers.

Research

Germplasm collection and utilization

With the beginning of HCRP research in 1987, several thousand barley varieties were collected from several national and international organizations and introduced into Nepal. Among the major sources of germplasm were the International Center for Agricultural Research in the Dry Areas (ICARDA), Centro Internacional de Mejoramiento de Maiz y Trigo (CIMMYT), and institutions in India. Additionally several food barley lines were introduced from Canada, Mexico and Korea. Some of the introductions have been maintained in the plant genetic resource unit of the Nepal Agricultural Research Council (NARC) at Khumaltar. Additionally several hundred barley accessions have been collected from various areas of Nepal. High yielding, disease resistant, and superior quality barley germplasms have been tested, selected, and preserved.

Varietal development

In the process of varietal development, desired traits such as high yield, disease resistance, and early maturity have been utilized in the crossing program at HCRP. Progenies of these crosses have been tested in optimum environments of the country and selected for future uses.

Multilocation varietal trials

The Hill Crops Research Program is testing two different sets of materials in observation nurseries, initial evaluation trials and coordinated variety trials (CVT) for high-range hills and middle-range hills environments.

Twelve barley genotypes were tested in the CVT-high hill set at HCRP in Kabre and the Agriculture Research Station (ARS) at Jumla in 2000/01 (Tables 3 and 4). Most of the tested materials produced higher yields at Kabre than at Jumla and all materials matured about 40 days later at Jumla than at Kabre. Local Jau (hulled barley) and Coll#112-14 matured in 176 days at Jumla, where time of maturity is critical under the rice-barley system. Yellow rust (*Puccinia striiformis* f.sp *hordei*) was not found in Coll#112-14 at Jumla but 40MR scoring was given at Kabre. Solu uwa (recommended hull-less barley variety) is a yellow rust susceptible variety, and scored 80S at Kabre and 70S at Jumla. In general, the severity of yellow rust in Nepal was found less in the 1990s than in the 1980s.

Barley genotypes tested in CVT-middle hill set, at four locations showed significant yield differences only at ARS in Surkhat (Table 5). Some food barley lines like B86152-2-2-0-OK (introduced from Canada) as well as 10thVEOLA-3 and 10thVEOLA-13 and some local collection like NB1003-37/903 have shown promising results under different middle-range hill conditions (Table 6).

Table 3. Days from planting to heading, days from planting to maturity, plant height, number of heads m^{-2}, 1000 kernel weight, grain yield, and yellow rust score of twelve barley genotypes tested in the CVT-high hill set, ARS Jumla (2,300 m asl), 2000/01.

Genotype	Heading	Maturity	Plant height (cm)	Head m^{-2}	1000 kernel weight (g)	Grain yield (kg ha^{-1})	Yellow rust (Cobb's scale)
NB1003-37/878	159	187	83.3	226	32.1	1,588	20S, MS
NB1003-37/903	153	186	82.3	250	29.1	2,296	40MR
10thVEOLA-12	158	186	88.0	243	31.7	2,154	30R
10thVEOLA-2	157	190	90.0	233	29.6	2,079	10R
Coll#112-14	144	176	93.7	229	33.7	1,804	40MR
B86115-1-2-0-OK	156	194	96.7	243	33.2	2,315	0
GR-25-85	149	182	101.0	218	37.0	2,024	10S
NB1003-37/1219	158	193	80.0	253	32.4	2,412	10S
10thVEOLA-24	156	194	87.7	198	32.6	1,965	60S, MS
Solu uwa	149	181	101.0	251	31.0	1,903	70S
Local uwa	146	180	102.0	240	27.8	2,267	60MS
Local Jau	145	176	89.0	253	32.7	2,378	80S
F- Test	**	**	**	NS	NS	NS	
CV %	3.82	4.04	9.14	14.5	13.6	20.5	
LSD 5%	4.76	7.89	7.72	61.57	7.77	731.37	

** Highly significant (P<0.01), NS= Not significant

Table 4. Days from planting to heading, days from planting to maturity, plant height, number of heads m^{-2}, 1000 kernel weight, grain yield, and yellow rust score of twelve barley genotypes tested in the CVT-high hill set, HCRP, Kabre (1,740 m asl), 2000/01.

Genotype	Heading	Maturity	Plant height (cm)	Head m^{-2}	1000 kernel weight (g)	Grain yield (kg ha^{-1})	Yellow rust (Cobb's scale)
NB1003-37/878	102	144	86.0	423	42.8	2,768	TR-40NS-S
NB1003-37/903	104	143	97.4	336	45.0	3,555	0, 20MS-S
10thVEOLA-12	98	140	91.4	315	44.6	2,639	0, 10NR-MS
10thVEOLA-2	100	140	103.3	354	42.5	2,315	0, 10MR-60MS
Coll#112-14	87	137	107.0	292	43.9	2,787	0
B86115-1-2-0-OK	95	139	111.4	306	42.3	2,618	20MS
GR-25-85	89	139	94.7	351	43.5	1,646	0, 20MS
NB1003-37/1219	99	143	95.7	295	46.0	2,120	0, 20MS
10thVEOLA-24	97	144	90.7	273	42.7	1,641	0, 20MS
Solu uwa	87	135	91.4	284	44.5	2,044	80S
Local uwa	84	136	89.3	305	42.2	2,003	20MS-90S
Local Jau	95	140	99.1	306	42.9	3,155	0, 30MS-50MS
F- Test	**	**	NS	NS	NS	NS	
CV %	9.0	2.31	10.8	24.68	5.87	42.68	
LSD 5%	21.39	2.905	15.96	123.75	4.63	1,773.3	

** Highly significant (P<0.01), NS= Not significant

Barley genotypes tested in CVT-middle hill set, at four locations showed significant yield differences only at ARS in Surkhat (Table 5). Some food barley lines like B86152-2-2-0-OK (introduced from Canada) as well as 10thVEOLA-3 and 10thVEOLA-13 and some local collection like NB1003-37/903 have shown promising results under different middle-range hill conditions (Table 6).

Table 5. Barley genotypes yield at different middle-range hill locations tested under CVT, 2000/01.

Genotypes	Grain yield (kg ha^{-1})				
	Kabre	Khumaltar	Surkhet	Dailekh	Mean
COQ/K/DESCII	2,133	3,383	1,491	3,922	2,732
10thVEOLA-2	2,999	3,514	2,061	5,139	3,428
NB1003-37/903	2,338	3,528	2,025	4,244	3,034
10thVEOLA-12	2,391	3,356	1,883	4,038	2,917
10thVEOLA-13	2,909	3,248	2,197	4,412	3,192
B86152-2-3-0-OK	3,116	2,720	1,804	3,966	2,902
B86152-2-2-0-OK	3,154	3,629	2,039	3,407	3,057
B86065-1-4-0-OK	2,228	3,159	1,246	3,243	2,469
ACC#1545	2,883	3,071	1,476	3,606	2,759
B86099-2-1-OK	2,848	3,181	1,761	3,527	2,829
Bonus	2,681	3,206	1,692	3,436	2,754
Local check	2,125	2,830	1,630	2,523	2,277
F-test	NS	NS	*	NS	-
CV%	36	16	21	32	
LSD 5%	-	-	931	-	-

* Significant (P<0.05), NS= Non significant

Table 6. Days to maturity and grain yield of top-yielding barley genotypes at various locations in CVT, 2000/01.

Locations	Altitude (m asl)	Genotypes	Maturity	Grain yield (kg ha^{-1})	F-test
Kabre	1,740	B86152-2-2-0-OK	143	3,154	NS
		B86152-2-3-0-OK	143	3,116	
		10thVEOLA-2	144	2,999	
		10thVEOLA-13	139	2,909	
Khumaltar	1,350	B86152-2-2-0-OK	155	3,629	NS
		10thVEOLA-2	157	3,514	
		NB1003-37/903	160	3,528	
		COQ/K/DESCII	160	3,383	
Surket	450	10thVEOLA-13	127	2,197	NS
		10thVEOLA-2	127	2,061	
		B86152-2-2-0-OK	124	2,039	
		NB1003-37/903	133	2,025	
Dailekh	1,350	10thVEOLA-2	152	5,139	NS
		10thVEOLA-13	158	4,412	
		NB1003-37/903	159	4,244	
		10thVEOLA-12	153	4,038	

Recommended Varieties Under Cultivation

In the 1970s, five barley varieties Galt, CI10448, NB1003-11, NB1003-37, and Bonus were recommended for general cultivation in the middle-range hill region of the country. At that time these were high-yield varieties resistant to yellow rust. However, as of 2001 all varieties except Bonus are out of cultivation. These varieties were all hulled types and the majority of people living the high regions prefer hull-less barley (*uwa*) to hulled barley (*jau*), as they mix the flour of roasted kernels in tea. So, the hull-less barley variety Solu uwa, selected from the local variety population was released in late 1980s. Many varieties/lines with the desired characteristics have been tested and selected but have not yet been released.

Varieties' characteristics

- Bonus: this is a two-row hulled barley. It is a late maturing type with high tillering ability and is resistant to yellow rust. It is a Swedish malt barley, but in Nepal it is used as food barley.
- Solu uwa: this is a six-row hull-less barley selected from the local population varieties of the eastern high-range hill region of Nepal. It is an early maturing type and is susceptible to yellow rust.

Extension

Extension activities are conducted at various outreach research (OR) sites. Village-level workshops are one of the extension activities at these sites. Cooperating farmers and local leaders participate by presenting the problems they experience with various crops. Scientists working in the research station(s) take the issues raised in consideration when planning their future research.

A farmers' field day is also organized at the station once during the winter season. Both men and women farmers take part and enthusiastically select the barley varieties of their choice. Women farmers are often more critical when selecting a variety. Such farmers' field days give an opportunity for face-to-face interaction between researchers and farmers.

Elite genotypes of barley are being tested in OR sites to get the farmers' reactions and to evaluate the yield performance under the farmers' systems and management practices. Promising barley genotypes were tested under farmers' field trials (FFT) in middle-range hill environment at the Kabre, Dailekh, and Surkhet research stations in 1999/2000. The average yield of barley genotypes tested at these OR sites ranged from 2,979 to 3,949 kg ha^{-1}, although the yield difference was not statistically significant. Genotype B86152-2-3-OK (Canadian food barley) gave the highest yield but was latest maturing of the tested genotypes (Table 7).

Table 7. Mean days from planting to heading, days from planting to maturity, plant height, number of heads m^{-2}, and grain yield of barley genotypes tested under farmers' field conditions, Dailekh, Surkhet, Kabre, 1999/00.

Genotypes	Heading	Maturity	Plant height (cm)	Heads m^{-2}	Grain yield (kg ha^{-1})
ACC#1545	91	141	104	309	3,481
NB1003-37/1138	88	140	84	277	3,832
10thVEOLA-2	91	137	90	269	3,786
B86152-2-3-OK	88	149	98	297	3,949
10thVEOLA-13	90	143	99	294	3,500
Bonus	93	143	94	448	3,472
Local Jau	91	141	97	414	2,979
CV%	8	13	24	46	28
F-test	NS	**	NS	NS	NS

HCRP is also working in collaboration with various district-level agriculture extension offices. In addition, various international nongovernmental organizations working in remote areas, contact HCRP for recommended seed varieties or elite barley cultivars.

Barley-based Production Systems and Food Security

Although barley is grown elsewhere in the country, it is the most important crop in western Nepal and in the high-mountain areas of the country. Different local cultivars and/or landraces of barley are grown under various systems mostly determined by altitude and irrigation facilities (Figure 3). Hull-less barley is more common in the trans-Himalayan areas of the western region. The flour of roasted naked barley is usually consumed with tea as breakfast or *tiffin* (a light midday meal) and this is a low-cost meal for the poor. As mentioned earlier, another popular preparation is a thick porridge mixed with the flour of tartaric buckwheat in a 3:1 ratio.

The climate of upper Mustang (3,500-4,000 m asl) in the trans-Himalayan western region of Nepal is quite unique with very low rainfall in summer and severe cold in winter. Therefore, only one summer crop can be grown. Hulled barley is not cultivated in this area and although wheat is the preferred crop, farmers plant either hull-less barley, maturing about 15 to 20 days earlier than hulled barley, or bitter buckwheat, maturing 10-15 days earlier than the sweet variety.

At the altitude range between 3,000 and 3,500 m asl, wheat, hull-less barley, and buckwheat are common crops. At this range, either hull-less barley and buckwheat are grown on the south facing slopes, or wheat and buckwheat are grown in a two-year rotation system. So, there is an obvious advantage of hull-less barley over wheat as it allows buckwheat to grow in the same year as barley. At the altitude range of 2,800-3,000 m asl, farmers either grow hull-less barley with buckwheat or wheat with buckwheat. However, farmers used to rotate wheat and hull-less barley in different years to sustain their farm production. Thus, barley has incredible significance on the food security of this highly remote and inaccessible area where it is expensive to transport food from areas of surplus.

In the cropping systems of the eastern high-range hills barley does not grow at an altitude of 4,000 m asl. In the eastern high hill area of the Solukhumbu district (2,600-2,800 m asl), the usual pattern is hull-less barley followed by bitter buckwheat or radish in the same year. In the two-year rotations, the common pattern is potato followed by wheat or hull-less barley, followed by bitter buckwheat or vegetables. However, at the lower altitudes of this region (around 2,400 m asl), early maturing maize follows hull-less barley in a one-year rotation system.

Because barley is so important for farmers' food security, they carefully choose the best varieties for their growing conditions. For instance, women farmers in Poiyan village (Solukhumbu district) select early maturing, tall barley plants with large heads. They prefer tall plants because barley straw in that region is used as fodder. Most of the barley grown in this area is six rowed, hooded, and hull-less. As hull-less barley matures earlier than wheat, it provides an early source of food in the spring, fodder, and some surplus during the time of scarcity.

In the eastern high-hills area with more fertile soil, (around 2,000 masl, in Solukhumbu district) farmers use an intensive and unique, for Nepal, intercropping system to maintain soil fertility and sustain production. They plant potato in early February intercropped with maize in early April, then finger millet is planted with the maize after the potato harvest in late June Application of compost/FYM is common but the amount varies from 10 to 40 t/ha, determined by the number of livestock. The distance between the field and the house also plays a role in the amount of fertilization. Generally, the nearer the field, the more FYM is applied. Moreover, *in-situ* manuring by tethering animals in the field is a common practice to maintain soil fertility. Commercial fertilizers are only applied in small amounts and then only if the farmer is near district head quarters.

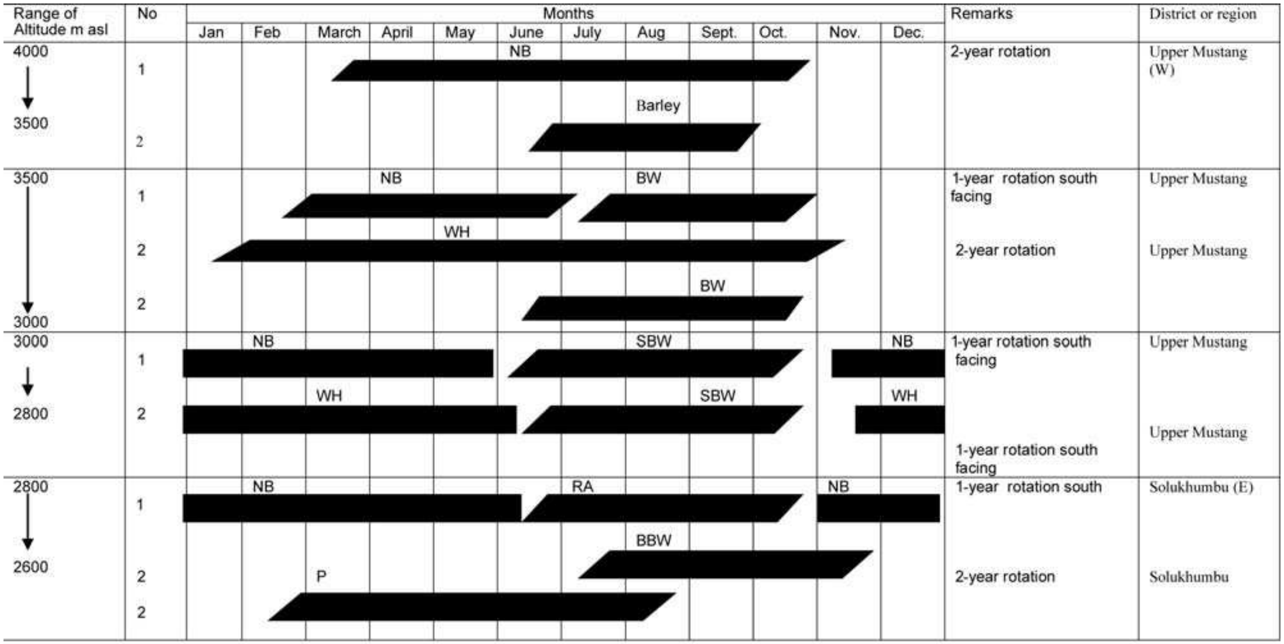
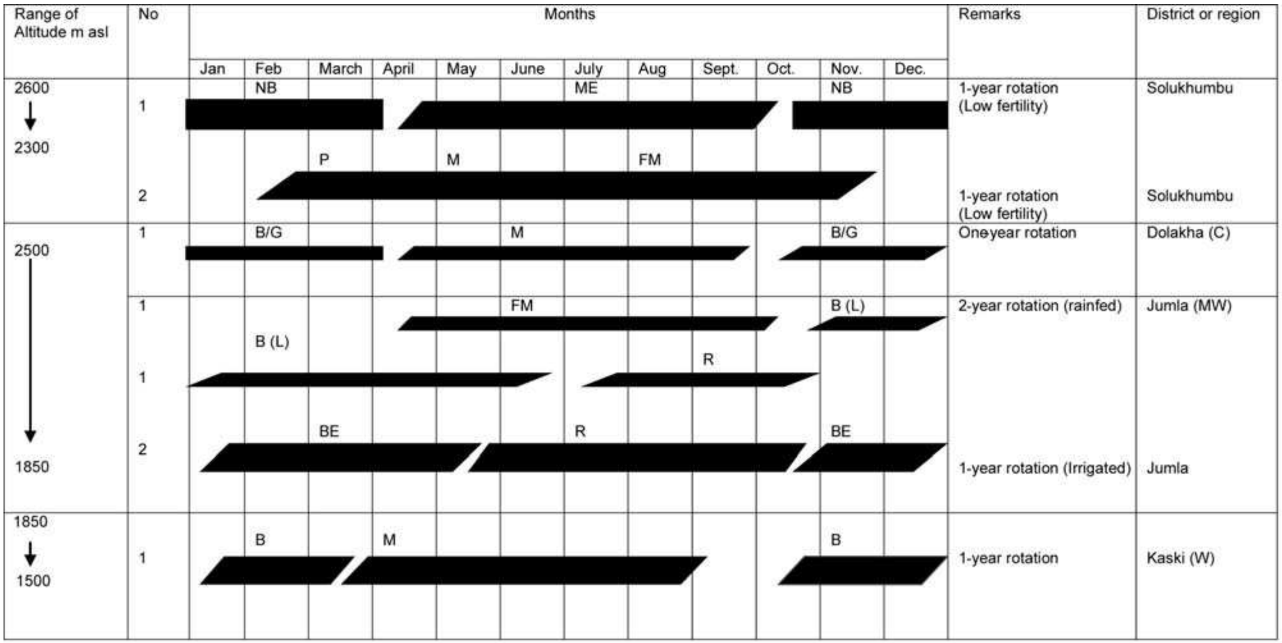


Figure 3. Barley based cropping calendar: altitude and ecological region.

Figure 3 continued



Note: Crop growing period

BW = Buckwheat
BL = Barley late maturing,
BE = Barley early maturing
E = Eastern Nepal
W = Western Nepal

BBW = Bitter buckwheat,
NB = Naked barley,
W = Wheat
C = Central Nepal
MW = Mid western Nepal

FM = Finger millet,
M = Maize, P= Potato,
R = Radish
G = Garlic

Figure 3. Barley based cropping calendar: altitude and ecological region.

The price of hull-less barley (*uwa*) is a little higher than that of wheat and is almost double that of hulled barley (*jau*). The flour of roasted hull-less barley is consumed as *dhido* a thick porridge, or as *saatu* also known as *champa*. However, in this area hulled barley is used to prepare the local beer, known as *chhyang* or bitten rice. Thus, both types of barley play significant roles to sustain the productivity of the hill farming system and to provide food security to the rural poor of the eastern region.

Barley (usually hulled) also follows maize at an altitude of around 2,000 m asl on south facing slopes in a one-year rotation. However, a finger millet-maize-barley cropping pattern is more common in a two-year crop rotation at this altitude.

The cropping pattern and food habits of midwestern Nepal in the Karnali region (2,200-2,600 m asl) are different. In irrigated valleys barley is planted after harvesting of the rice and before the transplanting of the rice of the following season. The system is so tightly scheduled that often farmers harvest barley even before physiological maturity, if it delays the rice transplanting. In this system, locally adapted barley cultivars that mature in about 185 days are used. However to sustain the system farmers replace rice with early maturing finger millet every two years. HCRP Kabre has developed a barley genotype (Coll#112-14) from a local selection that is suitable for this system.

In the rain-fed land of the Karnali area, the usual practice is to grow wheat at a higher altitude than barley. Bitter buckwheat or summer vegetables usually follow hulled barley in this area. Locally grown barley cultivars are high-yielding and late maturing. Most of barley grown both in rainfed and irrigated systems is the six-rowed hulled type. Hull-less barley is rare in this region. The farmers in this area prefer a pancake-like local bread to *champa* or *dhido*. This type of bread is better prepared from hulled barley than from hull-less barley.

At the time of writing, Nepal's barley is grown solely for food and is significant for the food security of the country. The malt quality of barley has not been studied as yet and Nepal's brewing industries procure malt from foreign countries.

Constraints

Most of the barley area lies in remote hills that are fragile, marginal, and inaccessible. Farmers of different agro-economical regions are using diversified landraces that best fit into their complex farming systems. Moreover, the majority of barley areas are marginal lands and the production systems are almost without external input. Under such situations, increasing barley productivity is a difficult task for agricultural research scientists. As farmers are growing different barley cultivars suited for different ecosystems within a certain geophysical region, developing high yielding varieties for such situations will be difficult and may not be cost effective.

As barley is a crop of subsistence farming systems, grown mostly by poor farm communities that cannot afford and have almost no access to external inputs such as inorganic fertilizers, advising barley growers to use fertilizer for increasing productivity will not be a viable technology. Depletion in soil fertility due to loss of topsoil by erosion and a decreasing rate of compost application are also major constraints of barley production. The processing of hulled barley is tedious and time-consuming, so farmers grow hulled barley only if they do not have any other alternative.

Stripe rust (*Puccinia striiformis*) is the most serious disease causing almost 30% yield loss in susceptible varieties, but other diseases like powdery mildew (*Erysiphe graminis* f.sp. *hordei*), barley stripe (*Pyrenophora graminea*), and smut (*Ustilago hordei* and U. *nuda*) also cause problems. Selection and screening for disease resistance to develop resistant barley genotypes is ongoing at HCRP. Success at these efforts can raise barley productivity to some extent. However, the barley research program has comparatively poor linkages with other national and international institutions; if this situation could be improved it would help to strengthen the national program in terms of manpower development, germplasm exchange, and technology generation.

Potential

Selection and/or improvement of local cultivars

Since barley began to be cultivated in the Himalayan region, the tremendous diversity in barley-based farming systems and ecology in which the crop is grown has allowed diversified barley cultivars to evolve through both farmers' selection and the natural process of evolution. The Himalayan region is one of the center of diversity for barley, therefore there is ample scope to collect, characterize and select barley germplasm from the many different systems. Barley varieties selected from among the region's existing germplasm are expected to fit better the many diverse systems than exotic material. For example, barley cultivar Coll#112-14 is a selection from local landraces collected in the Mustang district and is under the process of recommendation for the rice-barley production system of the mid-western region.

Selection from exotic materials

Some Canadian food barleys have shown promising results in grain yield, resistance to major diseases, and adaptation to growing conditions in mid-western high hill (Jumla) and maize-barley cropping system. Canadian barley B86152-2-3-0K has shown exceptionally promising results in a wide range of middle hills.

Selection for early varieties

For the irrigated environment of the mid-western high hills area of Jumla, early

maturing hulled barley is needed to fit into the tight rice-barley rotation system. HCRP is trying to develop varieties for such a cropping system. However, except for Coll#112-14, most of the genotypes tested under coordinated varietal trials are late maturing. In the rainfed environment of Jumla where farmers need high yielding and drought tolerant varieties, the maturing period is not as important, because barley is the main crop. HRCP is also studying the potential for development of cold-tolerant high-yielding hull-less
barley for the high hills of the western and eastern region that would raise the productivity and contribute to food security.

Malt barley

The brewing industry is growing and there is an interest in developing malt barley varieties. At present, the brewing industry imports malt so the development of malt barley varieties would contribute to the nation's economy through import substitution and increase the income of farmers.

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Food Preparation from Hull-less Barley in Tibet

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Introduction

Hull-less barley is the main staple food crop in Tibet. Around 2.1 million people consume barley in the nation. Barley is grown in more than 55% of the total cultivated land and accounts for 56% of the total food production. Since 1980, this proportion has increased from 53% to 56% (Figures 1 and 2), while in most other areas of the world, as living standards improved, barley consumption decreased due to an increased intake of rice and wheat (Bhatty, 1992).

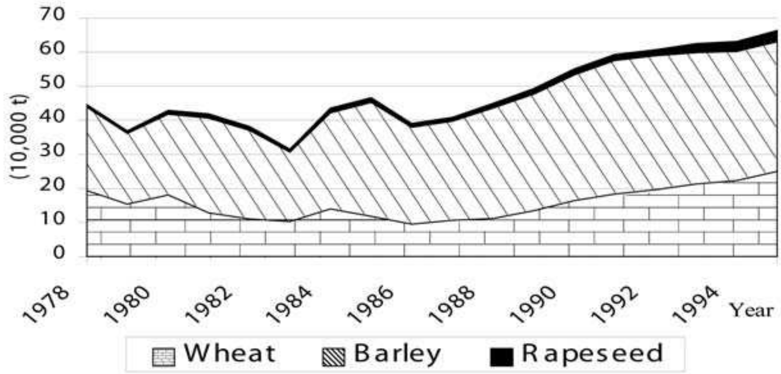

Figure 1. Grain food and oil seed production in Tibet.

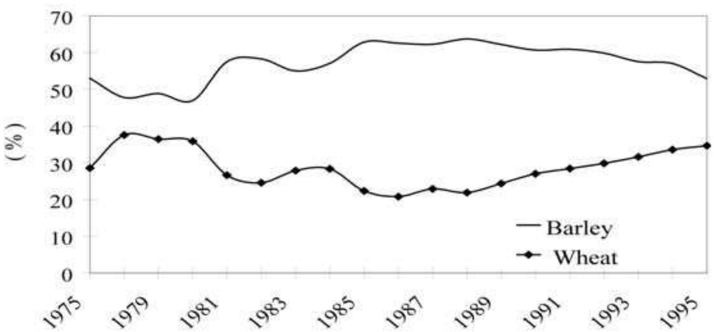

Figure 2. Proportion of barley and wheat in grain production.

The Tibetans' long history of Hull-less barley use has resulted in many unique ways of preparing food products from it. These products are culturally and economically adapted to the primitive mountainous region of the Tibetan plateau. 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. In addition barley is used for cakes, soups, porridge and snack foods.

Barley is cultivated in both the valleys and in the higher mountains of Tibet. In 2003, the total cultivated barley area was about 130,000 ha, which constitutes more than 66% of the total area of grain in Tibet. The total production that year was nearly 640,000 t and the average yield was only 5 t ha^{-1}, though the potential yield was estimated at 6.5 t ha^{-1}. The main reason for this yield gap is the limited area sown to improved varieties. Most of the improved barley varieties are grown in the central part of Tibet, where the average yield is about 6-7 t ha^{-1}, whereas there are rarely any improved varieties of barley in the cultivated area above 4,200 m asl which accounts for 44% of total area under barley). Local traditional varieties that have a potential yield of 3-4 t ha^{-1} are used. Poor crop establishment, such as high seeding rate and seeding depth, poor land management and poor technology for weed control are the factors that limit the barley yield.

Barley was traditionally cultivated only in spring but winter barley is nowadays relatively common. At present spring barley represents 93% of cultivated barley. It is sown in April and harvested in August. The main varieties are Zangqing 320, Zangqing 148, and Zangqing 3179. These improved varieties were produced by the Tibetan Agricultural Research Institute (TARI). However, in spite of their lower yield (3 t ha^{-1}), the landraces Chachu,Yangsun, and Lhazi Ziqingke are also quite popular because of their special food quality.

Winter barley started to be cultivated with the development of frost tolerant varieties by TARI. These varieties are cultivated in the lower land where temperatures are milder. The main varieties are Guoluo, Dongqing 1, and Dongqing 8. Winter barley is sown in October and harvested in July. The longer season results in higher yield than spring varieties (6 t ha^{-1} and 5 t ha^{-1} in winter and spring barley respectively).

All the cultivated varieties grown in Tibet are hulless barley (also called naked barley). The hulled varieties are not accepted by farmers because of their difficulty for cooking and their low quality for Tibetan dishes. Malting barley was cultivated briefly during the 1980s when the Lhasa Beer Factory was built. Around 350 ha were planted in 1986 and 1987, but, because of the high procurement price for barley and the higher cost of the malt processed locally than the imported malt, the enterprise ended. At present, all the malt is imported from provinces near Tibet and no hulled barley is growing in Tibet.

Barley varieties are chosen based on their use. For example, purple barley is preferred for *chang* preparation. Similarly, white or yellow seed barley is used for *tsangpa*. The traditional landraces have special characters that are appreciated by consumers. For example, the cultivar Garsha is regarded as the best for preparing tsangpa and the cultivar Lhazi Ziqingke, that has a purple seed is considered to be the best for preparing *chang.*

Food Products

Preparation of *tsangpa*

The word *tsangpa* means roasted grain flour and the most common flour is made from hulless barley. The grain is carefully cleaned, washed and roasted with fine sand. The sand is needed to distribute the heat evenly and prevents the barley kernels from burning. The sand is heated in a large, heavy pan at about 100-150°C and the grain is then poured into the heated pan and mixed for 2-3 minutes. The sand is sieved off and the remaining roasted barley grain is called *yue*. *Yue* is cleaned again and ground into *tsangpa* using a water mill.

Tsangpa can be eaten in many different ways. It can be added to tea, skim milk, *chang* or even cold water and consumed as a beverage. Many people mix it with sugar and eat it directly. Most commonly, however, *tsangpa* is mixed with a little tea and kneaded into a dough-like ball called *ba*. *Ba* is cooked in various ways and used in many religious occasions where it is tossed into the sky in small amounts.

Preparation of cakes

Chima is made from *tsangpa* mixed with butter, dried cheese and sugar. *Chima* symbolizes happiness and is often made during festivals, particularly the New Year festival. Usually a small amount is made to present to family members and visitors during the festivals.

Magsan is traditionally prepared during the summer time in Central Tibet for picnics. It is made from *tsangpa* mixed with skim milk, dried cheese, and brown sugar, and kneaded to make a stiff dough-like cake. The top of the cake is then dressed with butter and brown sugar.

Tsog is a cake made for religious occasions, presented for worship and eaten as holy food. It is made of *tsangp*a mixed with tea, dried cheese, dried grapes and brown sugar.

Preparation of porridge

Yuetub, widely used in Central Tibet for breakfast, is made from large particles of roasted barley flour mixed with yak or lamb meat and a vegetable. The barley grain is roasted roughly and ground to one fourth the size of the grain. Traditionally nettle leaves are used as the vegetable. Most Tibetans put fresh cheese and sugar on yuetub.

Sanchak tukba is a porridge that is usually prepared around the Tibetan New Year in February. *Sanchak* means steeped and mashed barley grain and *tukba* means porridge. To make *sanchack tukba*, barley grain is steeped overnight and usually mashed by hand. It can be either cooked fresh or dried and stored for several months. *Sanchak* is boiled in water with lamb or yak meat, dried cheese and green beans or peas.

Preparation of soup

Changuel is made from *chang* and *tsangpa*, mixed with cooked rice, dried cheese and sugar. The mixture is boiled for about 10 minutes. *Changuel* is mostly prepared for breakfast with fried cookies.

Tsangtub is made of *tsangpa*, water, beef or yak meat, lamb, peas, dried cheese. Various vegetables are added to enhance both the nutrition and taste.*Tsangtub* is often served for dinner and occasionally for lunch.

Preparation of snack food

Yue, roasted or popped barley, is the most popular snack food among Tibetans. Most make it for daily consumption. Nevertheless, it has not been commercially produced and little is sold in the market. Some Tibetans like to roast barley grain with sugar and a little butter for better taste.

Drubdrub is made from immature barley spikes. People consume the immature seed in small quantities after removing the awns and glumes.

Beverages

Preparation of *chang*

Chang is the major alcoholic beverage in Tibet. The preparation of *chang* begins with cleaning and washing raw barley kernels. Purple barley grain is preferred for its flavor and color. A greater uniformity of kernels is also considered important as this ensures uniform processing. Currently many brewers mix malting barley with hulless barley in a 1:2 ratio. This specially prepared barley grain is called *changdru*. *Changdru* is boiled in water for 2-5 hours. The boiled barley grain is named poub and can be mixed with sugar and butter, and it is consumed in small amounts. When the *poub* is cooled, *changdzi* (powdered yeast) is added and the mixture is allowed to ferment for 3-5 days. There is no free liquid remaining at this point. This fermented barley grain is known as *Lenmar* and is also directly consumed in small quantities or sometimes fried in a little oil and eaten as a delicacy with sugar. *Lenmar* is usually put in an earthenware pot with water and steeped for 6-10 hours; it is then filtered to produce *chang*. The water is added 3-4 times and the alcoholic content of chang depends on the number of times water is added. Alcohol content of the first run of *chang* is usually about 7%, the second is about 5%. People normally drink *chang* at about 5% alcoholic content or less.

Preparation of *sanchang*

Sanchang is a slightly alcoholic beverage brew made from *tsangpa*. *Tsangpa* is mixed with a little warm, clean water and powdered yeast. The mixture is fermented for about 3 days. Half-fermented *tsangpa* tastes sweet and is known as *sanchang*. It is usually cut into square pieces and dried. Many people like it as a snack food, while some steep the pieces in water and then drink it. *Sanchang* is very common in the western Tibetan region where there is limited fuel for boiling barley grain to make *chang* and water boils at around 80°C.

Significance of Hull-less Barley in Tibetan Life

According to Tibetan traditional medicine roasted barley flour *(tsangpa)* has the most *jue* (safety and nutrition), and is a *mengarbu* (white medicine). *Tsangpa* and *chang* are occasionally made from wheat or a mixture of wheat and barley. But Tibetans believe it is not healthy and usually explain that it is made from pure barley grain when it is offered to others. Nevertheless, there is no big difference in their flavor and actually wheat can be grown in most of the major agricultural land. Studies have confirmed that barley has medicinal properties and value. In particular, it has the potential to contribute fiber , particularly ß-glucan, to the diet and to have an inhibitory influence on cholesterol absorption from the small intestine which prevents disease such as colon cancers and heart diseases (McIntosh et al. 1992).

Due to the high altitude and relatively cool temperatures, not many vegetables and fruit trees are grown in Tibet. Therefore, sources of vegetable fibers are limited in most regions. Diary products, especially butter, and meat are widely consumed in Tibet. High cholesterol content in blood and heart disease, therefore, can be easily expected. However, large quantities of hulless barley are also consumed, approximately about 155 kg/person/year, which is the only significant source of dietary fiber. The ß-glucan content in major Tibetan cultivars is higher than that of Harrington, CDC Richard and CDC Buck in Canada and is significantly higher than that of wheat and rice (Tashi 1993). This may be the reason for which heart diseases and colon cancers occur at a lower rate than expected.

The significance of hulless barley is also remarkable in Tibetans' daily life. Atmospheric pressure on the Tibetan Plateau is very low due to the high altitude. Therefore, food can not be cooked quickly. Fuel wood is quite limited in most areas where a major proportion of the land is either barren or pastoral. Tsangpa is a ready to eat food. It is also very convenient for storing and handling as well as for saving fuel wood. The unique ways of processing barley for food such as using sand during the *tsangpa* preparation to distribute the heat evenly and to increase and preserve temperature for roasting, significantly save fuel wood which otherwise cause drastic loss of habitat in shrub land and deforestation. Food in Tibet generally is simple and natural, but is nevertheless nutritious. A typical Tibetan meal usually consists of cooked yak or lamb meat, butter tea (brewed tea mix with a little butter), *chang* and *tsangpa*. It provides all the nutrients needed by the human body. The choice of barley as a staple food crop by Tibetans is part of their adaptation mechanisms that allow them to survive in such harsh conditions.

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Barley in Latin America

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Introduction

Barley was introduced to the New World on the second trip of Columbus. Records show that in 1493 wheat and barley seeds were brought along for cultivation in what is now Isabela, Puerto Rico. On subsequent colonization journeys there were additional introductions of wheat for food and barley for feed. There are records of barley crops in Mexico in 1500, Argentina in 1527, Peru in 1531, Chile in 1556, Brazil in 1583, and in what is now the USA in 1602. The successive introductions increased genetic variability and the cultivations consolidated the local germplasm populations.

Barley Research

The first formal barley-breeding program in Latin America started at La Estanzuela Experiment Station in Uruguay in 1914. Alberto Boerger and Enrique Klein, scientists hired from Germany by the Uruguayan government to carry out cereal research, settled in the experimental station in the western part of the country. From the selection of local landraces, feed and malting varieties were released. Mr. Klein moved to Argentina a few years later to start his own program and using germplasm introduced from Uruguay released the variety Cebada CAPA (Criadero Argentino de Plantas Agrícolas) that is known for its resistance to leaf rust.

In the following years, many Latin American countries established public and private research institutes such as the National Institute of Agricultural Technology (INTA) in Argentina, the Brazilian Agricultural Research Enterprise (EMBRAPA) in Brazil, the National Institute of Agricultural Research (INIA) in Chile, and others. Those research institutions, through intensive training programs at different educational levels, carried out quality research and breeding in barley and other crops, and supplied the cultivars, the agronomic practices, and the extension needed by growers.

Barley Uses

In Latin America two main production regions are differentiated, based on the agro-ecological systems and the final uses of barley. In the Andean countries (Bolivia, Chile, Colombia, Ecuador, and Peru), barley production is carried out in small farms under low-technology conditions. In these regions barley is a crop adapted to high altitudes and is better able to withstand the area's abiotic stresses. Barley is commonly found above 4,000 m asl and in soils under drought, salinity, and aluminum toxicity stresses. Its precocity and tolerance to cold makes it viable for the short, frost-free growing seasons in the high altitudes of the Andes. The main uses of the crop are for human consumption, direct grazing by small ruminants, hay production, and sometimes silage. The exception in the Andean region is Chile, where production of malt is the most important use, followed by the other uses mentioned above.

In the Southern Cone of South America (Argentina, Brazil, and Uruguay) and Mexico, the main use of barley is for malt production for making beer. The practice of animal grazing the crop before heading and harvesting the grain is also used in some production systems. Tradition and the intended end-use determines the type of barley grown in the different countries: German cultural influence has led to mainly two-row varieties in the Southern Cone, while six-row varieties are grown in Mexico as in the United States.

In the countries where barley is an important crop for human consumption, hull-less barley is generally preferred as it has a value-added price in the market. An example is the variety Atahualpa in Ecuador. The lack of hulls and the larger size and light color of the kernels adds almost 10% to this variety's market price.

Physical quality parameters visually assessed during the selection process include the amount of covered kernels, size, color, and shape. Chemical quality traits are also usually assessed in collaboration with the Alberta Department of Agriculture. Near-infrared reflectance technology is used to assess the amount of lysine, the percentage of digestible protein, the percentage of digestible energy, and the total amount of digestible energy. Promising values in those parameters are present in the selected lines in Table 1.

Table 1. Quality parameters of hull-less and covered barley varieties.

Genotype	Lysine content	Protein digestible (%)	Energy digestible (%)	Total digestible energy
Petunia dwarf	7.29	79.67	93.83	3,704.39
Petunia	6.50	79.48	88.96	3,584.28
Bichy	6.20	79.92	93.00	3,493.13
Cabuya (hulled)	4.76	75.14	72.13	2,788.19
Tocte (hulled)	4.53	82.29	71.73	2,816.38

Biotic and Abiotic Stresses

Various diseases affect barley production in Latin America. Yellow rust (*Puccinia striiformis*) has been the most serious disease in the Andes since its introduction in 1975. Scald (*Rhyncosporium secalis*), leaf rust (*Puccinia hordei*), net blotch

(*Dreschlera teres*), Fusarium head blight (FHB) (*Fusarium graminearum*), and barley yellow dwarf virus (BYDV) also cause considerable yield and quality losses. In addition to those biotic agents, aluminum toxicity in acid soils, salinity, and drought also limit production in some areas.

In the Southern Cone the most prevalent diseases are net and spot blotches followed by leaf rust and most recently FHB. The latter has always been present in limited areas, but in the 2001 season it acquired epidemic magnitude in Argentina, Uruguay, and southern Brazil, often causing losses of two-thirds of expected yield. At the time of writing, in 2002 the amount of mycotoxins present in the harvested grain is being assessed. High levels of toxins, such as Deoxynivalenol (DON), can make grain unsuitable for malt production or for feeding monogastric animals.

Production Trends

The total barley area in Latin America has been stable at around 1,000,000 ha since 1991. Within the region, some countries like Chile and Colombia decreased the planted area, whereas in general, the malt-producing region in the Southern Cone increased the area planted (Table 2). The yield per unit of area (Table 3) had a general increase from 1991 to 2001 resulting in an increase of total barley production (Table 4). Barley production for forage and human consumption is expected to become stable in the following years, while barley grown for malt production is projected to increase. Demand for good malt-quality barley has been increasing based on favorable economic and environmental conditions and beer-consumption in Latin America has also been increasing for many years.

Future Research

An increase in cultivation area will depend on the respective support from public and private research. The recent demand of barley for different uses in some Andean countries, such as for malting barley in Bolivia and Peru, will possibly require a restructuring of the present cultivars. In addition, the increased incidence of diseases like FHB and the possible change in races of yellow rust will need to enhance and strength the coordination among Latin America's international and regional research centers, and contacts with advanced research centers.

Table 2. Area of barley harvested in Latin American countries from 1991 to 2001.

Area harvested	Year										
('1000 ha)	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
Latin America & Caribbean	1,035.5	992.0	898.9	707.0	958.5	1,079.7	1,112.6	1,851.0	915.6	1,082.7	1,056.5
Mexico	284.1	290.0	234.2	115.8	246.4	283.3	243.5	267.5	227.0	290.3	260.0
Argentina	233.5	228.7	198.9	149.0	217.9	246.9	323.0	212.2	184.6	246.2	246.2
Peru	113.4	81.8	101.2	112.6	114.8	128.9	130.6	146.7	142.7	155.6	157.1
Brazil	97.4	66.8	67.1	53.6	69.5	84.1	127.6	156.0	136.4	143.8	143.7
Uruguay	82.7	124.8	88.3	73.2	130.9	146.1	118.9	72.8	54.9	88.6	134.0
Bolivia	82.2	75.4	85.8	88.9	83.7	86.9	91.1	86.5	87.3	90.7	90.6
Ecuador	60.3	61.9	63.5	55.7	48.7	60.6	45.2	43.0	48.3	42.3	46.4
Chile	31.7	28.4	22.9	28.2	25.2	23.3	22.0	26.6	26.5	17.2	15.4
Colombia	49.5	33.4	36.2	29.0	20.4	18.7	9.6	6.1	7.0	7.0	7.5
Guatemala	0.8	0.8	0.9	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0

Source: FAO Yearbook 2002

Table 3. Evolution trend in yield in the Latin American countries from 1991 to 2001.

	Year										
Yield (kg ha^{-1})	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
Latin America & Caribbean	1,775	1,907	1,796	1,847	1,737	1,889	1,975	1,783	1,803	2,131	1,999
Chile	3,373	3,843	3,664	3,559	3,600	2,747	3,685	4,331	3,074	3,466	4,259
Argentina	2,456	2,550	2,311	2,313	1,771	2,173	2,866	2,538	2,273	2,922	-
Uruguay	1,680	2,466	1,466	2,425	2,513	2,331	1,670	2,692	2,022	2,542	900
Mexico	2,042	1,897	2,308	2,653	1,975	2,068	1,933	1,933	2,001	2,524	1,923
Colombia	2,069	1,677	2,002	1,989	2,198	2,119	1,984	1,978	2,172	2,143	2,067
Brazil	1,146	1,873	1,640	1,690	1,506	2,489	2,028	1,926	2,311	1,913	2,156
Peru	1,032	842	1,112	1,154	1,143	1,187	1,057	1,130	1,190	1,197	1,144
Guatemala	788	788	839	860	850	850	850	850	850	800	900
Bolivia	763	615	708	724	710	739	762	469	575	709	710
Ecuador	739	725	697	582	651	756	771	832	696	682	686

Source: FAO Yearbook 2002

Table 4. Total barley production in the Latin American countries from 1991 10 2001.

	Year										
Production (t)	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
Latin America & Caribbean	1,838,333	1,891,999	1,614,105	1,305,531	1,664,822	2,039,540	2,197,203	1,816,018	1,650,977	2,307,219	2,112,135
Mexico	580,196	549,966	540,529	307,266	486,636	585,754	470,671	410,766	454,133	732,706	500,000
Argentina	573,360	583,200	459,439	344,692	385,848	536,443	925,790	538,408	419,556	719,500	719,500
Brazil	111,650	125,219	109,952	90,614	104,634	209,215	258,847	300,389	315,064	275,068	309,743
Uruguay	138,900	307,800	129,400	177,500	329,000	340,600	198,600	196,000	111,000	225,200	-
Peru	117,074	68,816	112,499	129,843	131,193	152,939	138,032	165,831	169,817	186,168	179,700
Bolivia	62,669	46,332	60,700	64,359	59,418	64,189	69,381	40,521	50,180	64,310	64,272
Chile	106,959	109,089	83,970	100,289	90,630	64,103	81,131	115,350	81,473	59,639	65,454
Ecuador	44,518	44,908	44,309	32,406	31,683	45,800	34,892	35,777	33,629	28,828	31,866
Colombia	102,400	56,039	72,552	57,702	44,930	39,647	19,009	12,126	15,275	15,000	15,500
Guatemala	606	307	755	860	850	850	850	850	850	800	900

Source: FAO Yearbook 2002

Barley in Ecuador: Production, Grain Quality for Consumption, and Perspectives for Improvement

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Introduction

Barley (*Hordeum vulgare* L.) is after maize, the cereal of widest distribution in the Ecuadorian highlands. In Ecuador the area planted exceeds 40,000 hectares (INIAP 2000), distributed in all highland provinces: Chimborazo, Cotopaxi, Cañar, and Pichincha, followed by the provinces of Imbabura, Carchi, and Loja. There is no defined regionalization for barley cropping in the country. The potential area without ecological limitations is located between 2,500 and 3,500 m asl. According to the Regional Barley and Wheat Program, 70,000 ha of highlands and hills that surround the Andean region could be allocated to this crop.

The social and economical importance of barley is based on its diversified use as human food. In the rural areas, the consumption represents around 46% of the national production that is 20,800 tonnes (INEC 1995), whereas in the urban areas, the annual family consumption (five persons/family) is 34.16 kg. Barley can be utilized as food in different ways. *Machica* (toasted barley flour) and *barley rice* (cracked barley) are the most in-demand products and together they represent 88.3% of total grain consumption.

The increasing relevance of quality in the commercialization of barley and the nutritional aspects, are of great interest to breeders, who try to incorporate positive quality parameters from the trade, industry and nutrition perspectives. Successful commercialization of barley primarily requires that it is disease-free, dry, and clean, but the processors also require genetic characteristics that allow a high quality product to be obtained. To accomplish these goals plant breeding must emphasize selection of high-quality genotypes for agro-industrial processing and for human consumption, guiding the appropriate utilization of selected lines according its characteristics.

Production

In the 1960s, the area dedicated to the barley crop exceeded 100,000 ha. The crop area decreased progressively to 26,000 ha in 1980, due to the incidence of yellow rust, which affected barley production in the entire Andean region. This disease, exotic in the area, eliminated almost all the landraces planted in Ecuador.

After 1986 the growing area recovered (Table 1), but the process was slow, due to the insufficient diffusion among producers of the new, improved varieties, the lack of quick seed supply channels, the high cost of the agricultural inputs, and the low price of barley grain during the harvest season.

In the 1986 to 1991 period, the average cultivated area was stabilized at around

Table 1. Barley area, production, and yield in the period 1986-2001 in Ecuador.

Year	Area (ha)	Production (t)	Yield (t ha $^{-1}$)
1986	68,000	67,700	0.99
1987	64,200	63,900	0.99
1988	63,430	52,647	0.83
1989	56,590	73,567	1.30
1990	56,490	107,331	1.90
1991	60,250	44,585	0.74
1992	65,000	65,000	1.00
1993	67,000	70,350	1.05
1994	68,500	75,350	1.10
1995	69,000	79,350	1.15
1996	54,589	45,800	0.85
1997	45,236	34,892	0.77
1998	43,007	35,777	0.83
1999	48,312	33,629	0.70
2000	42,253	28,828	0.68
2001	40,000	22,590	0.57

Source: Ministerio de Agricultura y Ganadería (MAG), Dirección de Información Agropecuaria 2003

60,000 ha; it recorded a slight increase from 1992 to 1995, and then suffered a drastic decrease since 1996. It is anticipated that the barley crop can increase to 70,000 ha, if yield rises, if price increases in the domestic and foreign market (primarily Colombia) expectations are met, if the availability and quick diffusion of new varieties takes place, and if there is lower protection to imports.

Quality for Consumption

The analysis of the different quality traits are carried out at all stages of selection in the breeding program, i.e. segregating populations, crossing block, international observation nurseries, yield trials, and multiplication plots.

Early Generations

In the segregating generations, objective and subjective kernel traits are evaluated and are related to the performance that it is going to have during processing. The most important attribute is the kernel type, which is related to kernel size, shape, presence/absence of diseases and impurities. The scoring of kernel type is carried

Table 2. Kernel type qualitative scale.

Category	Trait
+	Kernel regular, slender, stained, hard to thresh
*	Kernel good, slender, easy to thresh
*+	Kernel very good, round
**	Kernel excellent, round, husks of light yellow color
***	Kernel excellent, round, husks pale creamy color

Source: INIAP, Programa Regional de Cebada y Trigo 2000

out based on the qualitative scale shown in Table 2.
The kernel shape, related to thickness and fullness, is the most important trait for commercialization. Ulonska (1983) points out that there is a direct association between shape and grain quality. The more round and closed the central scare, the higher the starch percentage and the lower the husk content (lemma and palea).

Advanced Generations

In advanced generations (small plots, international observation nurseries and yield trials), selection is carried out considering not only the kernel type but also thousand-kernel weight (TKW) and aleurone color.

The thousand-kernel weight is a function of kernel size, density, and uniformity. This parameter varies as function of the head density, environmental conditions, and soil fertility where the crop was grown. Kernel weight is a predictor of flour yield, is related to the starch amount and is therefore related to quality. Genotypes with a TKW higher than 37 g are selected.

The aleurone is the posterior layer to the external kernel cover, which is constituted by one or several cellular layers with abundant fat globules and protein. The color of this layer can be white or blue. In Ecuador there is a consumer and processor preference for the genotypes with white aleurone, whereas those with blue aleurone have only forage value. This trait is unwanted for food products, since the consumer relates the blue kernel color with damage and decomposition.

Regional Trials

The lines in the regional trials are testes for grain quality parameters. For the selection the quality parameters are compared with those of standard checks planted in the same location. At the present the varieties INIAP-Shyri 89 and INIAP-Shyri 2000 are used as checks for covered grains and the variety INIAP-Atahualpa 92 for hull-less grains. Their cross and pedigree are reported in Table 3.

Table 3. Name, cross, and pedigree of standard checks.

Name	Cross	Pedigree
INIAP-Shyri 89	Lignee 640/Kober//Teran 78	CMB83A-2561-A-2M-1Y-1LAG-1E-OGH
INIAP-Shyri 2000	INIAP-Shyri 89/Grit	E-93-8891-2E-1E-4E-0E-0E-0E-0E
INIAP-Atahualpa 92	Sutter/Gloria"S"/Come"S"/3/PI 6384/Capuchona	CM86-767-C-2Y-168GH-2M-0Y

The lines in the regional trials, in addition to kernel type, TKW, and aleurone color, are also evaluated for physical characteristics.

Hectolitric weight

This trait is less important in barley trading than it is in wheat and other grains. This trait is related to quality and since the starch has a higher specific weight than the husks, a high hectolitric weight indicates less percentage of husk and higher flour yield. This parameter depends on the shape and grain uniformity. It is affected by moisture, manipulation, diseases, frosts and other weather conditions, and uneven maturity (Kent 1982). Genotypes with a hectolitric weight higher than 40 kg hl^{-1} are desired, although this parameter should be considered together with the grain plumpness and only lines from the same environment and year should be compared.

Plumpness

Kernels are sorted according to their shape and the width of sieves at 2.8, 2.5, and 2.2 mm. The fraction retained above the 2.8 mm sieve is rated first class; second class is the fraction retained above the 2.5 mm sieve, and third class is the portion retained above the 2.2 mm sieve. Kernels with low-starch content and small grains of other crops and vegetable residues are sample impurities and constitute the portion that goes through the 2.2 mm sieve. After cleaning, these latter kernels can be used as forage.

The kernels retained above the 2.8 and 2.5 mm sieves, are considered to have commercial quality. These two fractions determine the percentage of plump kernels. The minimum value accepted for this last parameter is 75%.

Endosperm hardness

This trait can be influenced by genetic factors and by crop management, especially an excess of nitrogen fertilization results in high protein content. On the basis of the endosperm hardness, barley kernels can be classified as:

Floury	< ¼ of the endosperm is vitreous
Semivitreous	> ¼ and < ¾ of the endosperm is vitreous
Vitreous	> ¾ of the endosperm is vitreous and hard

This information is compiled in the floury index, which ranks commercial quality by the endosperm consistency (Coca et al. 1988). The standard floury values for commercial quality are 85%, 10%, and 5% of floury kernels, semivitreous, and vitreous kernels, respectively. A higher percentage of vitreous kernels decreases the milling efficiency and in consequence the yield of flour and *machica* products. Despite this, it has been determined that genotypes with 5% of vitreous grains are suitable for producing *barley rice*. This hardness level avoids the excessive flour production during kernel pearling and crushing.

Kernel germinative energy

The kernel viability is determined by the percentage of seeds that are able to germinate under controlled conditions of humidity and temperature. The germinative energy is determined after three days and does not differ significantly from the germinative capacity that is the percentage of grains that show evidence of germ development 120 hours after soaking. The minimum limit for commercial barley is 85%. This test eliminates samples that do not germinate due to a long storage period.

Kernel purity and health

The main criteria, variable according to local conditions, are:

Storage moisture	< 13%
Minimum germinative energy	> 85%
Varietal purity	> 93%
Kernels smaller than 2.5 mm	< 10%
Other cereals or seed mixtures	none
Microorganisms or parasitic insects	none
Zearalenone (toxin)	< 50 ppb
B1 and C1 (toxins from mold)	< 100 ppb

The germinative energy, purity and health are indispensable requirements, especially when barley is used for seed. The production and storage of barley for human consumption is not very different from that used for seed.

Based on these physical evaluations, breeders make their selections in order to obtain better quality, producers purchase their barley, and trading prices are determined.

Chemical and Nutritional Characterization

Nitrogen, minerals, starch, and fiber are the components of nutritional interest in barley. However, chemical and nutritional evaluations are not used in the parent selection. These elements are considered in the evaluation of lines close to release and are also utilized when giving guidelines that will encourage the use of this cereal, especially among the urban population.

Starch

A biopolymer formed by units of α-D-glucose that are attached to form macromolecules. In plants, starch is in the form of microscopic granules, partially soluble in cold water. It is constituted of amylose and amylopectine, representing 25% and 75%, respectively of the starch in most cereals (Swinkels 1985). The relationships among these elements are genetically controlled and can be changed through breeding to obtain functional properties that are important in food technology. Examples of this usage are in flans, sauces, and various dough products where the structure is dependent in large part on the starch gels.

In waxy barley almost all the starch is in the form of amylopectine, which has a high intrinsical viscosity. Amylopectine solutions form heavy pastes that solidify into hard gels slowly. The starch in this type of barley could be a perfect substitute for waxy maize starch, tapioca, and other such starches. Barley with high amylose content (40%) is recommended for whisky production, because the malt enzymes completely hydrolyze the amylose in glucose, affecting alcohol yield; with a higher amylose content a higher alcohol yield is obtained. Amylose is considered the main responsible for the starch retrodegradation and this is the most significant property of this fraction (Carrasco 1998).

Additionally, starch is an important nutrient, it is the principal source of energy in our diets, and makes it possible to utilize protein efficiently. Therefore, breeding should be oriented to obtain varieties with high starch content without decreasing the protein content. Research has shown that starch content in hull-less genotypes is between 38 to 42% (INIAP 1991).

Protein

The contribution of barley to the diet is significant as an efficient source of protein, rich in glutamic acid, proline, and leucine amino acids, needed as part of the protein molecules of all body tissues. Although the essential amino acids lysine and triptophan are low in non-germinated barley grain, it is possible to overcome this deficit by combining cereals with legumes in the same meal. Nutritionists have found that proteins derived from different sources ingested at the same time, are better utilized than when eaten independently.

The protein content of the grain varies widely with the ecological and soil conditions where barley is cultivated; an equilibrium between starch and protein content is desired, since excessive concentration of one component will cause the deficit of the other as is seen in shriveled kernels, which have high protein and low starch content, brought about through high temperatures that speed grain maturation.

It has also been determined that due to the volume/surface relationship the protein content decreases with larger size and rounder kernels. When kernels are sorted by size, protein content decreases in the higher fractions, reaching the lowest level in the fraction retained above the 2.8 mm sieve.

Fiber

Another important polysaccharide in barley is the fiber or husk, constituted mainly of cellulose, and associated with several hemicelluloses and lignin. The type and extension of this association determines the presence of covered or hull-less genotypes. In the covered kernels, the husk is attached to the pericarp, whereas in the hull-less kernels the husk is loose. The color is influenced by the weathering or by the aleurone color, which can vary from light yellow to pale yellow, light cream to pale cream, or blue-green to blue (Newman and McGuire 1985). Fiber constitutes 6 to 10 % of the kernel, is thick in the basal or germinal region, and decreases it thickness in the distal region.

Due to lower fiber content, minimum nutrient losses during processing and better digestibility (94 %) of its products, the hull-less varieties have higher preference among producers, processors, and consumers (CENAPIA 1992). To satisfy the demand, the Regional Barley and Wheat Program, after several years of research, released the hull-less variety INIAP-Atahualpa 92.

The use of covered barleys as food is being increased through the use of pearling treatment. This process removes the husk and facilitates the processing of flakes, broken kernels (barley rice) and flour. The products obtained are low in fiber and ready for meal preparation. Although during the pearling, part of the aleurone layer and endosperm are detached and some of the nutritive value is lost (Table 4), this is compensated for by the higher acceptability of these products by consumers.

Fiber has a more structural than nutritional function, although lately the physiological and nutritional effects of fiber on intestinal health are being highlighted. The effects on liver acids and steroid metabolism have not been fully clarified, but it is known that fiber facilitates the elimination of biliar acids and contributes to a decrease in blood cholesterol level (Foster 1987).

Table 4. Chemical composition (% of grain dry matter) of barley compared with other cereals.

Cereal	Protein	Fat	Carbohydrates		Ash
			Total	Fiber	
Polished Rice	10.1	2.1	86.4	1.0	1.4
Polished Oat	14.7	8.0	72.0	4.0	2.0
Covered Barley	12.2	1.9	75.9	6.8	3.1
Hull-less Barley	13.3	2.6	80.0	1.9	2.0
Pearled Barley	12.0	1.5	84.3	1.0	1.2
Maize	10.3	4.5	81.5	2.3	1.4
Wheat	13.4	2.4	79.9	2.4	1.9

Source: Yufera 1987; INIAP, Nutrition and Quality Department 1991

There are indications that dietary fiber, including the hemicelluloses, decreases the susceptibility to cardiovascular diseases and colon disorders, especially colon cancer. Likewise, diabetic patients may require lower insulin when ingesting higher-fiber content diets, although the fiber can decrease the absorption of some vitamins and oligominerals in the intestine.

Minerals

Barley kernels, covered and hull-less, have higher percentages of iron, phosphorus, zinc and potassium than other cereals usually consumed in Ecuador (Table 5). For pearled grains, however, there is a decrease of those minerals due to the separation of the husk, which contains around 32% of the kernel total mineral content. Despite the reduction, barley is an important source of zinc (43 mg kg^{-1}), this microelement is part of the insulin, and contributes to wound healing.

The contribution of phosphorus to the diet from the hull-less varieties is 0.47 %. Phosphorus is one of the basic minerals, since is part of the nucleic acids deoxyribonucleic (DNA) and ribonucleic (RNA), of the phospholipids, and participates in the emulsification and transport of lipids and fatty acids. The phosphorus provided by the hull-less varieties is better absorbed in the intestine, due to their lower phytic acid content.

Table 5. Mineral content of barley, compared to other cereals.

Constituent	Polished Rice	Polished Oat	Barley Covered	Barley Hull-less	Barley Pearled	Maize	Wheat
Copper (mg kg^{-1})	4.3	1.1	12.0	13.0	12.0	10.5	5.1
Iron (mg kg^{-1})	34.0	79.0	94.0	72.0	26.0	30.0	44.0
Manganese (mg kg^{-1})	15.0	51.0	24.0	19.0	7.0	20.0	38.0
Zinc (mg kg^{-1})	1.8	22.0	49.0	52.0	30.0	10.4	24.0
Calcium (%)	0.01	0.10	0.05	0.06	0.02	0.03	0.04
Phosphorus (%)	0.23	0.34	0.54	0.47	0.24	0.32	0.34
Magnesium (%)	0.08	0.16	0.12	0.12	0.07	0.17	0.18
Potassium (%)	0.24	0.48	0.65	0.48	0.22	0.35	0.41
Sodium (%)	0.02	0.09	0.10	0.04	0.02	0.01	0.03

Source: Yufera 1987; INIAP, Nutrition and Quality Department 1991

Perspectives for Improvement

Considering the economic, ecological, and social importance of barley for Ecuador's sustainable development and food security, the Regional Barley and Wheat Program is very active in the production of new varieties and technologies through research and participatory selection work. Table 6 shows name and pedigree of the promising lines with potential to be released as varieties.

Table 6. Name or cross, and pedigree of promising lines.

	Name/Cross	Pedigree
Hull-less	Petunia	CMB93-855-M-1Y-2M-0Y-0E-0E-0E-0E-0E-0E
Covered	INIAP-Shyri89/3/Gal/PI6384//ESC-II-72-607-E-1E-1E-5E	E97-9053-3E-0EC-1E-0E-0E-0E
	MS2375/3/Robur/Hor728//F3-Bulk Hip/4/Gloria"S"/Come"S"/5/Cardo"S	CMB91A-11-3E-1E-3E
	Anca/2469//Toji/3/Shyri/4/81S.508/5/MPYT169.1Y/Laurel//Olmo Cardo"S"	CMB93-760-D-4Y-1Y-1M-0Y-0E-0E-0E-0E -

Ecuador is characterized by a high demographic growth rate and by a generalized malnutrition. Not only are the generation of new varieties, seed, and agricultural technologies needed, but also new conservation and utilization techniques are required. Also needed is the development of products that satisfy the urban demand for food that can be prepared quickly, taking into account the alimentary and cultural traditions of the people. Consequently, broadening the food base with barley needs an integrated program of investment, research, and extension, together with the improvement of processing techniques, trade, and distribution. To reach those objectives it is proposed to:

- Adapt and enhance the pearling process for optimal use of products and subproducts (flour and husk) of covered barley varieties;
- Develop and optimize the technology for production from hull-less and pearled kernels of precooked, instant barley flakes ready for consumption;
- Study and evaluate the effect of the malting process on the digestibility and the nutritive value of barley, to promote the use of barley malt in baby food processing;
- Adapt and optimize the process of malt-extract production,for use as a nutrient for convalescents and for flavoring breakfast food products;
- Study the process of amylolytic enzymes extraction (α and β amylase) from malted grain for industrial use;
- Promote the formation of an agro-industrial company for the reception, processing, and trading of barley and it products.

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Barley Genetic Improvement and Research Activities at Universidad Nacional Agraria la Molina, Peru

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Introduction

Barley ranks as the fourth most important cultivated food crop in Peru after rice, potato, and maize. By the year 2000 national production was nearly 150,000 tonnes and the productivity was 1.12 t ha^{-1}. This low productivity is mainly due to the shallow and stony soils with low levels of fertility that are usually found in the steep mountains at altitudes over 3,000 m asl; to frost, drought, hail; and to the cultivation of varieties susceptible to diseases. In addition the farming technology applied to the barley cropping systems is generally low.

Barley production in the past was primarily for family subsistence; but today there is an increasing amount of grain being produced for the local markets and for the food industry. Barley is used as both food and feed. In the highland region, 70% of produced barley grain is used directly for human consumption as pearled grain, flakes, and flour. The brewing industry imports barley and malt to supply the Peruvian beer demand. This cereal is originally an introduced foreign crop, but after many centuries of adaptation it has become a staple food, used mainly by the impoverished peasant communities.

The Cereal Program of the Universidad Nacional Agraria de la Molina has been working on barley improvement since 1968 with the support of the Backus Corporation in cooperation with Malteria Lima S. A. Enterprise and the International Atomic Energy Agency (IAEA) with the collaboration of Centro Internacional de Mejoramiento de Maiz y Trigo (CIMMYT), the International Center for Agricultural Research in the Dry Area (ICARDA), and other institutions.

Breeding Objectives and Genetic Variation

The overall goal of the Cereal Program is to increase barley production in marginal lands and to ensure the quality for the various uses of barley in Peru. The specific objectives are to:

- Improve resistance to diseases;
- Improve resistance/tolerance to adverse environmental conditions;

- Improve adaptation;
- Improve yield potential;
- Improve overall quality.

A large collection of approximately 10,000 accessions of barley genotypes from different sources are available, including more than 2,000 accessions collected in Peru and Bolivia in areas above 3,000 m asl. The germplasm exhibits considerable variation permitting researchers to identify many sources of earliness in maturity, of resistance to diseases, of resistance/tolerance to lodging, hail, and drought, and of other characters associated with high-yield and quality. Continuous introduction of segregating populations and advanced breeding lines with proven adaptation and productivity from the ICARDA/CIMMYT barley program provide other sources of useful characteristics.

Breeding Methods

Hybridization

About 120 crosses are made each year to combine the positive traits of the parents. The F_1 generation is harvested as spikes that are grown as spike-rows in the F_2 generation. Ten to twenty spikes are harvested from the promising rows and grown as spike-rows in the F_3. The spike-to-row planting is continued until the F_6 generation when the material is almost homogenous and is harvested as bulk. Then preliminary yield trials are carried out for four years using commercial varieties as checks.

In the breeding program special attention is paid to resistance to fungal diseases, wide adaptation, yield, and food quality. Multiple disease resistance is a main objective because a large number of barley pathogens are present in Peru. The resistant/tolerant materials are selected from among genotypes showing trace-to-moderate levels of response and severity. The tests to select for grain quality are made beginning with the F_4 generations. The tests include plumpness, 1,000 kernel weight, test weight, and protein content. Three locations are used for selection:

La Molina. This location is on the coast near the Pacific Ocean. The area's climate is determined by the cold Humboldt stream. The barley crop grows under irrigation in temperatures of 14 to 20 °C with high humidity in winter (80-90%). The main diseases are powdery mildew, leaf rust, and spot blotch.

Ancash. This location is in the northern highlands at 2,600 m asl, in a valley. Barley is cultivated during the rainy season with temperatures ranging from 10 to 22 °C. The main diseases are leaf rust, spot blotch, barley stripe, net blotch, scald, smuts, and yellow rust. Usually there are drought and frost problems in the latter part of the growing season.

Junin. This location is in the central highlands above 3,400 m asl and it is very representative of the growing conditions of barley in Peru. The temperature range

is from 5 to 20 °C and the crop is cultivated under rainy conditions.
The experimental station has poor, stony soil, the area has frequent hailstorms, and in the latter part of the season there are frost problems. The main diseases are yellow rust, net blotch, barley stripe, and scald.

Mutation breeding

Seeds of well-adapted improved varieties are exposed to nuclear radiation to induce mutation. Radiation with 20 to 30 Krad of gamma-rays was applied to the Buenavista variety creating a hull-less kernel mutant that was released as UNA La Molina 95 with a yield potential of 3.5 t ha^{-1}. The management of the mutant generation is similar to that described in the hybridization method.

Doubled haploid technique

To reduce the development time of new varieties and to improve the selection process, doubled haploids (DH) are produced using the anther culture method from selected material obtained by hybridization and mutation breeding methods. Two or three plantlets are produced per 100 anthers. A total of 450 DH-lines are grown in yield trials at different locations. The low, green plant regeneration is due to the field growing conditions of the anther donors.

Released Cultivars

Since the breeding program began in 1968, eight cultivars have been released: Zapata (1977), UNA 80 (1980), UNA 8270 (1982), Yanamuclo (1987), Buenavista (1992), UNA La Molina 94 (1995), UNA La Molina 95 (1995) and UNA La Molina 96 (1996). Compared with the older varieties the new ones have a higher yield, a higher level of resistance to diseases such as stripe and leaf rust, and a higher food quality. However, their malting quality traits and resistance to some foliar diseases are not yet adequate.

Research Activities

To investigate heterotic effect in F1 hybrids obtained from crosses of barley mutants, crosses were made between selected Buenavista mutants with the Buenavista parent line. To allow full expression of plant yield potential, all materials are being grown widely spaced with a minimum of three replications. After statistical evaluation of the results, F1 hybrids expressing 20-30% yield heterosis will be selected for further work on production of F1-performing doubled-haploid lines.

Agronomic trials are usually performed to analyze the response of barley to nitrogen fertilizer, sowing density, and to other agronomic practices. Also, to stimulate the use of barley as food tests are made to develop recipes using mixtures of other native grains (*Chenopodium and Amaranthus*) having high contents of lysine and other essential amino acids. In the future the development of the molecular-marker laboratory will permit marker-assisted selection.

Food Barley Quality Evaluation at ICARDA

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Introduction

Barley was one of the first cereal crops to be cultivated and used as human food thousands of years ago in northern Mesopotamia and Egypt. In the Greek and Roman eras, barley bread was widely used and had the reputation of being a "strong" food.

At present, very little barley is used as human food in the developed countries, but the demand for food barley in the West Asia and North Africa regions, and in Latin America is expected to increase.

In response to the request from several national programs, the Barley Improvement Project at the International Center for Agricultural Research in the Dry Areas (ICARDA) began in 1996 to work on the improvement and utilization of barley germplasm as human food. In addition to tests to determine optimum kernel color, size, and protein content, other tests for ß-glucan content, kernel hardness, husk percentage, and cooking time were introduced or developed. This chapter describes the methodologies used at ICARDA's cereal grain quality laboratory to evaluate barley for food consumption (Williams et al. 1988).

Grain Color

Traditionally, white and amber are desired for food barley. For a rapid color screening, ICARDA uses a direct visual color evaluation with scores ranging from 1 to 4: 1 = white/amber, 2 = gray/green, 3 = mixed black/gray/green, 4 = black.

Protein Content

Grain protein content is routinely determined by near infrared spectrometry NIR Systems Model 5000 scanning monochromator instrument. Barley protein calibration has been developed for both whole grain and flour. A total of 200 barley samples were used for calibration based on the Kjeldahl (AACC, 1983) protein determination (N x 6.25), ranging from 7.3 to 19.85% protein. The best equation provided a multiple correlation coefficient of 0.98 and 0.99 and standard error of prediction of 0.38 and 0.26 for whole grain and flour, respectively.

ß-glucan Content

It has been reported by several authors (Bhatty 1993, 1999; Bjork et al. 2000) that the presence of mixed linked (1-3), (1-4)-ß-D-glucans in barley can regulate blood glucose and decrease serum cholesterol levels in humans. Hence, the ß-glucan component could be an important feature of food barley.

ß-glucan in barley varies between 2 and 9%. Waxy, hull-less barley tends to contain higher ß-glucan (> 6%) than no-waxy and hulled barley. Barley with a higher ß-glucan level is considered good for a healthy diet, while barley with a lower ß-glucan content is generally favored for malting. Despite the development in recent years of chemical screening methods, there is no generally acceptable and simple screening procedure for ß-glucan estimation to be used routinely in a breeding program.

In 1996, ICARDA developed several calibrations to predict ß-glucan content using a NIR Systems model 5000. As a reference method, ß-glucan content was also determined using a Megazyme (McCleary method, Megazyme, NSW, Australia) kit. A total of 78 covered-barley samples, ranging from 3.14 to 5.73% ß-glucan were used to develop the NIR calibrations. A multiple correlation coefficient of 0.72 and a standard error of prediction of 0.33 were obtained. This is satisfactory for screening barley germplasm for ß-glucan content.

Kernel Hardness

Hardness is another important characteristic for food barley evaluation. Harder barley is more suitable for roller-milling, while the soft barley is more suitable for soups.

At present, ICARDA uses SMS Texture Analyzer to measure the energy required to cut barley grains. From the resulting curves, the following characteristics can be measured:

- Maximum force used (g)
- Sharing energy: integral of force by distance (g mm-1)
- Grain plumpness (mm)

Because of barley husk thickness and composition, the barley grain is peeled before measuring hardness. This eliminates husk effects on kernel hardness results.

Husk Percentage

Most hulled barley used for human food is pearled before being used. For varieties with thick husks this, of course, increases the grain weight loss.

Husk percentage is determined by pearling 20g of grain in a barley pearler for 20 seconds and then reweighing the sample. The percentage loss in weight is recorded as the husk percentage. In hulled types this includes both husk and bran, while in hull-less barley includes bran only.

Results obtained from trials of hull-less barley grown at Tel Hadya, Syria, during the 1998 and 2000 harvest seasons, ranged from 6.5 to 13.8% of bran, with an average of 9.8% (N=400). In contrast, the husk percentage of hulled barley ranged from 14.6 to 21.9%, with an average of 15.15% of husk (N=250).

Cooking Time

A cooking-time test has recently been introduced to evaluate barley germplasm selected for food use. Cooking time is measured from the starting time of the cooking until at least 90% of the grains are cooked, and ready to eat. ICARDA laboratory uses the LABCONCO crude fiber testing equipment to perform the cooking-time test in the following manner:

> Boil 100 ml water in a beaker, add 6g of pearled barley grain, place the beaker under reflux and record the time. After 30 minutes remove 2-3 grains and press them with a finger to check softness. If the grains are hard, continue boiling. Test grains again after 5 minutes and if still hard, continue boiling until the tested grains are soft.

The cooking-time test is subjective, but with a little practice it is possible to obtain very reproducible results. It is useful to watch for the disappearance of the ungelatinized white patch in the center of the cross section of endosperm as an indicator of the cooking rate. Also, the yellowish color of the liquid indicates that about 80% of grains are cooked.

Early work at ICARDA has shown that pearling of barley grain before cooking reduces cooking time significantly. Hulled, unpearled barley cooking time ranged from 1 hour, 45 minutes to just over 4 hours. After pearling, cooking time was reduced to between 42 and 90 minutes. Pearling also reduced the cooking time for hull-less barley from between 70 and 110 minutes to between 28 and 68 minutes. Storage time after pearling did not seem to cause significant differences in cooking times of the pearled samples.

Plumpness

Plump barley kernels are desirable for some types of processing such as pearling, roasting, and flaking. To identify lines with a high percentage of plump kernels, ICARDA uses the European standard sorting sieve system. This consists of 3 sieves arranged one above the other, the top sieve having 2.8 mm holes, the middle sieve with 2.5 mm holes, and the bottom one with 2.2 mm holes. The test procedure is performed by placing 50 or 100g of barley grains in the top sieve and shaking for three minutes. The weight of kernels in each sieve, and the bottom tray, is recorded, with weights expressed as percentages of the original sample. The samples that contain a maximum amount of plump kernels (>75% in the 2.8 and 2.5 mm sieves) and a minimum amount of small kernels (<6% fallen through to the 2.2 mm sieve) are rated as superior.

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Barley for Development of Functional Foods to Improve Human Health in the Third Millennium

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Introduction

Among cereals, barley is the main cereal grain for the development of functional foods, as it contains two classes of compounds of strong nutritional interest: tocols (vitamin E) and *β*-glucans (soluble fiber) (Figure 1). Functional foods may be defined as any food, in a natural or processed form, that contains, in addition to its nutritional components, substances which favor the good health, physical capacity and mental health of an individual.

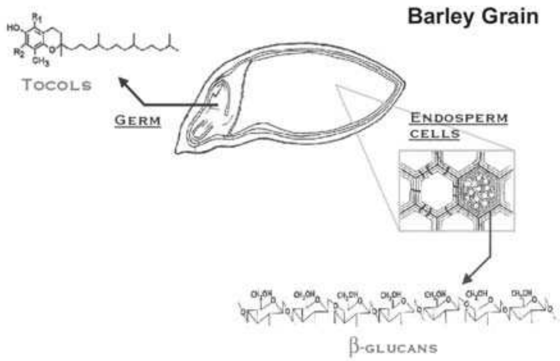

Figure 1. Localization of tocols and β-glucans in the barley kernel.
Source: Jadhav et al. 1998

In recent years we have witnessed a new era in the food science and nutrition fields with an increasing emphasis on the interaction of food and medicine. The practical application of this area of study is known as functional foods. The work in this area involves food components as essential nutrients needed to maintain optimum health and also non-nutritional components that contribute to the prevention or the delay of the onset of chronic illnesses associated with advancing age (Vasconcellos 2001).

The abundant evidence regarding the vital role that nutritional factors play in maintaining health and the role of diet in the occurrence of the major causes of death, including heart disease, cancer, stroke, diabetes, arteriosclerosis and liver diseases, have contributed to the increased interest in functional foods.

Scientific evidence has shown there is a strong relationship between consumed foods and human health, and that there is a beneficial correlation between the function of various food components and the treatment and prevention of specific illnesses (Koide et al. 1996; Aldoori et al. 1998; Anderson and Hanna 1999; Hudson et al. 2000, McBurney 2001). Therefore, consumer interest has focused on a diet with the capability to promote good health and to extend a healthy life span, and this promotes the development of functional foods. Functional foods may be classified in three categories: foods based on natural ingredients; foods which must be consumed as a part of the daily diet; foods that when eaten accomplish a specific task within the human body including an improvement of biological defenses, the prevention or recuperation from a specific illness, the control of physical and mental states, and retarding of the aging process (Vasconcelles 2001).

Tocols

Tocols (tocopherols and tocotrienols) are well recognized for their biological effects, including antioxidant activity (Kamal-Eldin and Appelvist 1996) and reduction of serum LDL-cholesterol (Wang et al. 1993). While tocopherols, mainly α-tocopherol, are considered to have the greater biological activity (Kamal-Eldin and Appelvist 1996), tocotrienols have been the focus of growing research interest as unique nutritional compounds for their hypocholesterolemic action. Among the four tocotrienol isomers, γ-tocotrienol and δ-tocotrienol seem to be more effective than α-tocotrienol. Tocotrienols are reported to be capable of reducing serum LDL-cholesterol in chickens, swine, and human subjects. They may act as inhibitors of the HMG-CoA reductase, a rate-limiting enzyme of cholesterol biosynthesis (Qureshi et al. 1986; Qureshi et al. 1991a; Qureshi et al. 1991b; Qureshi.et al. 1991c). Some studies indicate that the antioxidant potential of tocotrienols is even greater than that of α-tocopherol in certain types of fatty cell membranes and in some brain cells (Suzuki et al. 1993; Kamat et al 1995). Moreover, recent studies suggest that tocotrienols may affect the growth and/or proliferation of several types of human cancer cells (Nesaretnam et al. 1998) with, in some cases, different inhibition power of single tocol isomers (Guthrie 1997).

Cereal grain and certain vegetable oils are good sources of tocols, but the concentration and composition of the eight isomers vary considerably among sources. In cereal grains, tocopherols and β-tocotrienol are mainly concentrated in the germ, while hulls and endosperm have substantial concentration of other tocotrienols (Peterson 1994). Barley grains are a good source of this class of compounds containing both a high concentration of total tocols and a favorable distribution of the most biologically active isomers. For this reason, there have been efforts to increase tocol content in barley flour through milling, sieving, and air-classification in order to include it as an ingredient in functional foods (Wang et al. 1993). There has also been work on extracting the pure compound with new techniques, such as supercritical carbon dioxide extraction to produce high-grade specialty products for the cosmetic and health industries (Colombo et al. 1998). The development of high-tocol barley cultivars would be beneficial for the food industry, however there is a lack of knowledge of genotype potential for tocol productivity, and this has limited the possible application of barley as a primary tocol source. This is particularly true for hull-less barley, investigated largely for its β-glucan content, and seems to be the most promising barley genotype for the food industry (Bhatty 1999), but needs to be compared with the hulled variety for tocol productivity.

Consequently, we evaluated hull-less and hulled barley genotypes, grown in contrasting environments in Italy, for tocol content to study the effects of genotype and environmental conditions, the presence of a location x genotype interaction and the relationships between all isomers and hull-less/hulled trait. The results show that genotype and environment do influence tocol content in barley (Figure 2). Varieties with a significantly higher tocol production were also identified. While the research revealed that a genotype fingerprint is visible in the tocol isomer relative ratio, the environment's impact on tocol concentration is not clearly understood.

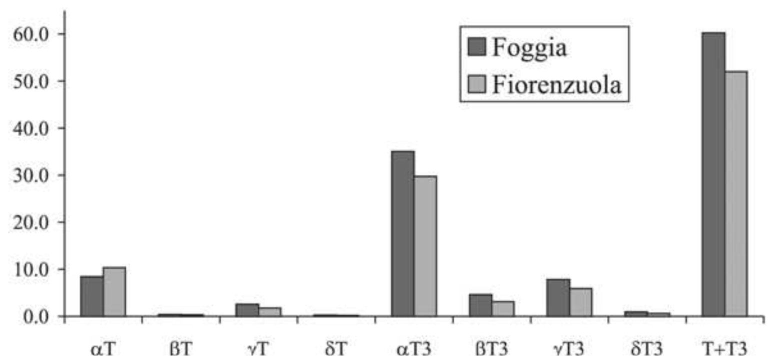

Figure 2. Tocols concentration (mg kg-1) averaged over six barley varieties at Fiorenzuola and Foggia.

The hull-less genotypes examined, in spite of their lower total tocol content, presented a significant amount of the most useful isomers (γT3 and δT3) with the potential to develop high-value genotypes for human nutrition through the establishment of a breeding program from hull-less genotypes with these characteristics. For this purpose additional hull-less barley genotypes will be evaluated to understand the genetics of tocol content in barley.

β-glucans

Barley contains a high concentration, as well as a large range, of the non-starch polysaccharide family (1→3),(1→4) mixed linked β-glucans (β-glucans). This polysaccharide family is the major constituent of barley endosperm cell walls and its viscosity-enhancing property may cause problems in brewing and reduce the value of barley as feed, but it has beneficial health effects on blood cholesterol level, as reported in animal and human trials (Jadhav et al. 1998), and on glycemic response (Liljeberg et al. 1996; Yokoama et al. 1997; Wursh and Pi-Sunyer 1997; Hecker et al. 1998; Bourdon et al. 1999; Kalra and Jood 2000). The hypothesized mechanisms for barley's hypocholesterolemic effect are three: (1) reduced absorption of dietary lipids including cholesterol; (2) reduced absorption of bile acids; and (3) production of volatile fatty acids in the large intestine that are reabsorbed, and act as inhibitors of b-hydroxy-b-methylglutaril coenzyme A (HMG-CoA) reductase in the liver (McIntosh and Oakenfull 1990).

Dietary fibers, such as β-glucans, are defined as the edible parts of plants and analogous carbohydrates that are resistant to digestion and absorption in the human small intestine with complete or partial fermentation in the large intestine. Dietary fiber includes polysaccharides, oligosaccharides, lignin, and associated plant substances (AACC 2001). A diet rich in fiber has health benefits including lowered energy density, prolonged satiety, and effects related to an increase in fecal bulk (Spiller 1994). Foods containing soluble dietary fiber have been shown to lower serum cholesterol levels, postprandial blood glucose, and insulin response (Jenkins et al. 2000).

It is important for diabetics to know the glycemic potential of food carbohydrates. The glycemic index (GI) is a powerful method for nutritional characterization of carbohydrates and has been proposed to diabetic subjects as a tool for managing their diet. Epidemiological data indicates that a diet characterized by a low GI reduces insulin resistance and improves certain metabolic consequences of insulin resistance (Jenkins et al. 1987). This suggests a potential role against both the development of non-insulin-dependent diabetes mellitus (NIDDM) and cardiovascular diseases (Björck et al. 2000). A long-term study of almost 90,000 women and a similar study of about 45,000 men, showed that subjects with a higher intake of cereal fiber-based foods, had about a 30% lower risk for developing NIDDM compared with those having the lowest intake (Salmeron et al. 1997a; Salmeron et al. 1997b).

For this reason, researchers' interest has focused on the use of high-fiber cereals that are rich in β-glucans, such as barley and oats, as potential ingredients for lowering the GI of most cereal-based foods.

The effect of β-glucans on blood glucose and insulin level has been evaluated in a number of studies by testing processed traditional grain products (porridge, flakes, flour) either derived from normal or high-fiber oat and barley genotypes or containing extracted β-glucans fractions (Knuckles et al. 1997; Yokoyama et al. 1997).

A number of techniques have been developed to enrich the β-glucans content of barley flour (Sundberg and Åman 1994; Klamczynski and Czuchajowska 1999). This has provided the opportunity to significantly enhance the β-glucans content of foods prepared from flour blends using barley fractions as a minor ingredient without affecting the sensory characteristics of the traditional wheat-based products (Knuckles et al. 1997; Newman et al. 1998; Marconi et al. 2000). Barley flour fractions, which are rich in β-glucans, have been used with wheat flour and semolina to produce baked products and pasta that have acceptable sensory properties and a lower GI than durum wheat pasta, while containing the same amount of available carbohydrates (Marconi et al. 2000).

Barley Flour Tests for Bread and Pasta

In 2001, at the Experimental Institute for Cereal Research, barley whole-grain flour (BF) and two β-glucan-enriched flour fractions obtained from a hull-less barley variety were evaluated for bread-making quality when mixed with bread wheat flour. The barley fractions tested were: the sieved fraction (SF) produced by processing the BF in an automatic sieve; and a water-extracted fraction (WF) extracted from the SF. Different blends were baked in a pilot plant and each bread was evaluated for sensory attributes and chemical composition. Commercial bread wheat flour (BW) was used as the base flour. To increase the β-glucan content, blends with various levels of bread wheat flour substitution were prepared for each barley fraction. The enrichment in β-glucan concentration in the different barley fractions was successful. The total β-glucan concentration of SF was 1.8 times higher than BF. This increase is due to the elimination of starch with the finer flour fraction (Table 1).

Table 1. Chemical composition of bread wheat flour, barley flour, and barley flour fractions (g/100g db).

Product	Protein (N x 6.25)	Fat	Ash	Total β-glucan	Soluble β-glucan
Bread wheat flour (BW)	16.8	2.1	0.6	0.1	0.1
Barley whole grain flour (BF)	15.5	2.6	2.6	4.6	3.2
Sieved fraction (SF)	17.8	3.2	3.1	8.5	3.7
Water extracted fraction (WF)	17.9	0.9	11.6	33.2	31.9

Source: Cavallero et al. 2002

To keep an acceptable rheological quality with the highest, sustainable β-glucan content, one level of BW substitution was selected for each barley fraction: 50% for SF and 20% for WF. This selection was based on a preliminary farinograph screening and on previous test results (Cavallero et al. 2000). Farinograph water absorption and degree of softness were generally higher in blends as compared to BW only. The increase in water absorption was as high as 29% for 50% SF, 14% for 20% WF, and 11% for 50% BF. Farinograph stability, a property related to protein content, decreased in all bends, confirming the negative effects of β-glucan (Table 2).

Table 2. Flour mixture evaluation for bread making characteristics.

Evaluation parameter	100% BW	50% BF	50% SF	20% WF
Protein (Nx 6.25)	16.8	16.2	17.3	17.0
Total β-glucan (%)	0.1	2.4	4.3	6.7
Farinograph				
- Water absorption, %	58.4	64.9	75.3	67.0
- Stability, min	17.0	2.8	6.6	4.2
- Development time, min	5.7	3.9	6.6	8.2
- Degree of softness, BU	0	80	81	100
Baking test[1]				
- Mixing time, min	3.00 (7.00)	4.45 (7.00)	6.30 (9.00)	n.d.[2] (9.00)
- Bread volume, cm^3	768 (186)	408 (90)	373 (102)	385 (161)

Source: Cavallero et al. 2002
[1] Baking results at the pilot plant are given in brackets
[2] n.d.=not determined

The three blends and one bread wheat tester were baked both in the laboratory according to the American Association of Cereal Chemists method 10-10B (AACC 1995) (with minor modifications to simulate the traditional procedure used in Italy) and in a pilot plant. In the laboratory baking test, dilution of the wheat flour with the barley fractions increased mixing times; for the 20% WF it was not possible to achieve an acceptable dough consistency with the mechanical mixer and manual mixing was necessary. As compared to 100% BW, bread volumes of 50% BF and 50% SF were lower by 46% and 51%, respectively, in the laboratory AACC trials and 51% and 45%, respectively, in the pilot plant baking trials. Bread volume for 20% WF was 49% lower than BW when baked according to the AACC procedure, probably as consequence of the low efficiency of manual mixing, but was only 13% lower when baked in the pilot plant. A bread with high β-glucan content and an acceptable volume was obtained only in this last instance. This confirmed the need to reduce the barley flour fraction in the mixture in order to reach a loaf volume comparable to plain bread wheat bread, because barley depresses loaf volume, (Figure 3).

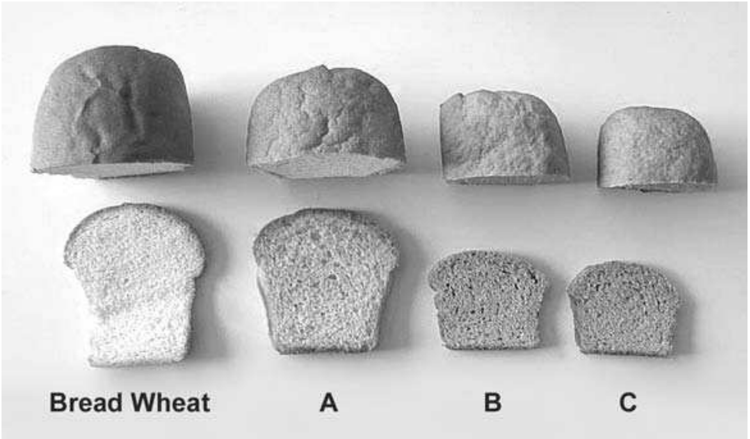

Figure 3. Flour-mixture baking test results.

Notes: Control: plain bread wheat bread A: 80% bread wheat flour, 20% barley water-extracted fraction; B: 50% bread wheat flour, 50% barley flour; C: 50% bread wheat flour, 50% barley sieved fraction.

Moreover, all products were subjected to sensory quality analyses and were judged acceptable, but the 20% WF and the 100% BW reached an acceptability score significantly higher than the other barley breads. So the addition of a high concentrated β-glucan fraction, WF at 20% of the total flour, allowed the production of bread comparable in sensory quality to plain wheat bread, with a lower caloric content and the added value of a high-soluble β-glucan content.

The postprandial glucose response after consumption of the different bread meals has also been determined and related to β-glucan content (Figure 4). The mean peak value of blood glucose was found at 30 minutes for BW bread, whereas for the other experimental breads the peak was reached at 45 minutes However, 30-minute glucose values resulted in significant differences only for 50% SF and 20% WF bread compared with 100% BW bread. Similarly, by indexing the incremental area under the curve of bread, compared with pure glucose or with 100% BW bread (to calculate GI), only WF and BW gave a significant difference (Table 3). Nevertheless, a clear negative trend can be discerned for the GI as a function of the β-glucan content of bread, indicating that barley β-glucans are dose-effective in reducing the blood glucose response to bread.

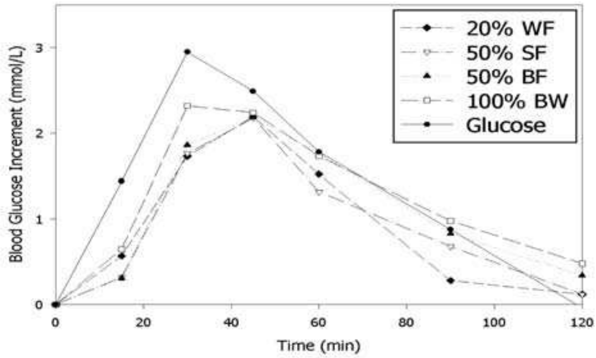

Figure 4. Blood glucose concentration increment in healthy volunteers following ingestion of glucose and different bread meals. Values are means, n=8 (except for 20% WF, n=7).

Source: Cavallero et al. 2002
Notes: WF= barley water-extracted fraction; SF= barley sieved fraction; BF= barley flour; BW= bread wheat flour

Table 3. Mean (± SE) incremental blood glucose concentration and glycemic index in eight healthy subjects after consuming different bread meals and glucose reference meal.

		Incremental Glucose Response			
Time	Ref. Glucose (n=8)	100% BW (n=8)	50% BF (n=8)	50% SF (n=8)	20% WF (n=7)
15 min	1.44 ± 0.32^{a}[1]	0.65 ± 0.23^{b}	0.31 ± 0.38^{bc}	0.32 ± 0.18^{c}	0.57 ± 0.38^{bc}
30 min	2.95 ± 0.23^{a}	2.32 ± 0.35^{ab}	1.86 ± 0.37^{bc}	1.76 ± 0.29^{c}	1.73 ± 0.35^{c}
45 min	2.49 ± 0.44^{a}	2.24 ± 0.44^{a}	2.19 ± 0.33^{a}	2.18 ± 0.33^{a}	2.19 ± 0.32^{a}
60 min	1.78 ± 0.32^{a}	1.73 ± 0.47^{a}	1.76 ± 0.22^{a}	1.32 ± 0.34^{a}	1.52 ± 0.27^{a}
90 min	0.88 ± 0.20^{a}	0.98 ± 0.19^{a}	0.83 ± 0.21^{ab}	0.68 ± 0.26^{ab}	0.28 ± 0.22^{b}
120 min	-0.04 ± 0.18^{a}	0.48 ± 0.34^{b}	0.34 ± 0.32^{b}	0.12 ± 0.06^{a}	0.12 ± 0.20^{a}
		Glycemic Index (120 minutes)			
Reference (G.I. 100%): Glucose	100^{a}	89.49 ± 12.41^{a}	85.42 ± 13.72^{ab}	74.46 ± 15.48^{ab}	69.67 ± 7.19^{b}
Reference (G.I. 100%): BW	-	100^{a}	99.22 ± 12.66^{ab}	81.75 ± 13.65^{ab}	72.20 ± 7.77^{b}

Source: Cavallero et al. 2000
Notes: [1] Means within a row not containing the same superscript are significantly different ($P < 0.05$)

In another study researchers tried to identify the best conditions for a traditional-method preparation of pasta using a mixture of barley flour and semolina, to evaluate the acceptability of the final products by sensory analysis and to define the barley contribution in terms of β-glucans.

Commercial samples of durum wheat semolina were mixed with barley flour in ratios of 85:15 and 70:30. Spaghetti (classified as n°5) was produced on a laboratory extruder and dried in a pilot plant. The spaghetti was cooked for 8 minutes in boiling water (ratio: spaghetti/water=1:10).

The cooking value of spaghetti with 15% barley flour was the same magnitude as the standard spaghetti. This value was lower when 30% barley flour was included in the semolina. Also the sensory evaluations for firmness and stickiness decreased significantly with 30% barley flour in the mixture (Cavallero et al. 2000). The β-glucan content of pasta was not affected by the processing and cooking (Table 4) and was close to predicted values reaching nutritionally acceptable levels with the highest barley flour/wheat flour ratio (Cavallero et al. 2000).

Table 4. β-glucan content and cooking value of spaghetti made with durum wheat semolina and mixture of durum semolina-barley flour: ratio 85:15, 70:30.

	β-glucan content	Cooking value (%)
Spaghetti barley 15%	1.3%	90-92
Spaghetti barley 30%	2.5%	75-80
Spaghetti semolina	0.5%	100

Source: Cavallero et al. 2000

In conclusion, the perspectives to be considered for the near future are to analyze barley variability for β-glucan and tocol contents, to develop fresh strategies for breeding new varieties for functional foods production, and to examine molecular technology as a possible new tool for the development of functional foods. To achieve these goals it will be necessary to foster greater integration between plant scientists and medical scientists. With an energetic exploration of these aspects, barley will be the plant of the future.

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