An analytical overview of the multiple uses of barley in the development of agro-food industries

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Abstract

Currently, the human population is constantly increasing and agricultural systems are facing a major challenge to ensure food security. This situation is part of a failing agricultural context characterized by impoverished soils, limited water resources and climate change that increasingly threaten crops. The selection of plants which present a good flexibility of adaptation compared to these constraints could be the adequate strategy to face such a situation. Indeed, the choice of crops that are less sensitive to the different types of stress and less demanding proves to be a favorable path to sustainable agriculture. Among these crops, barley (*Hordeum vulgare* L.) which is a plant which is not demanding and which has a very good flexibility of adaptation and which presents enormous prospects and challenges in several fields, such as industrial and agro-food. Through this chapter which is entitled: uses of barley between industrial and nutritional perspectives, the study is oriented towards the virtues of barley. Indeed, a detailed analysis has been carried out in order to show the situation of barley cultivation in the world and to reveal its importance from an economic, industrial and nutritional point of view.

Keywords: barley, production, industrial use, nutritional use, health benefits.

Introduction

Barley (*Hordeum vulgare* L.) is one of the most important cereal crops on a global scale, its production being estimated at 157 Mt [1], it represents 15% of the world consumption of cereals [2] Most of this production is devoted to animal feed and the production of malt [3]. Indeed, animal feed is the main outlet for barley, in the European Union for example, it represents two-thirds of production. On the other hand, industrial uses, mainly the manufacture of malt for brewing, absorb between 15 and 20 %. This cereal contributes to increasing the energy concentration of the rations that animals with increased production capacity or which are driven intensively must receive. Consequently, the British developed a beef production system based on a ration rich in barley grains, 90 % of the total ration, called “barley beef” [4]. In Spain, poultry feed has undergone some changes, the most important among them has been the replacement of corn by barley [5], because the contribution of barley in the diet of laying hens is increasing very the feed conversion ratio and the egg weight are important, in fact, the presence of 64 % barley and a contribution of 14 % soybeans optimizes laying [6]. In Germany and the United Kingdom, as well as in Benelux and Portugal, the manufacture of beer accounts for a quarter of domestic use. Thus, barley intended for brewing must have sufficiently large grains, more than 2.5 mm, high germination power (95 %) and protein content of less than 11%, for the record, 0.15 kg of barley makes one liter of beer [7]. In China and Japan, packaged barley is part of the diet of the population, in the Far East about 80% of edible barley is used for human consumption [8] pearled barley is used to make soup in the U.S.A; in Canada and China [9]. Barley was mixed with bread wheat in England during the 1940s (10 % in 1943) [10]. Its use in baking at percentages of 20 to 30% has been reported by Kiger [11]. Therefore, barley flour like rye flour has, when mixed with wheat flour, the particular property of preventing the extraction of gluten [12]. Barley bread has the particularity of giving a crumbly and cohesionless dough: the nitrogenous fraction which corresponds in barley to gliadin, hordein, has no plastic properties [11]. In addition, barley flour is sometimes used in small amounts in infant foods [11-13]. In 1977, Munk [13], pointed out the importance of a barley which has an amino acid composition very favorable to human growth, after smoking (steaming), grinding and vitamin and mineral supplements, this barley gives a food very practical baby food, where all the proteins and all the carbohydrates would come from barley. Currently, barley is attracting the interest of several researchers who have suggested that it can be integrated into several food products such as: yogurt, noodles, bread, cookies and muffins, etc... [14-18]. In addition, this cereal has caught the attention of health professionals for its fiber content which is beneficial for weight reduction, lowering blood pressure, blood cholesterol, and blood sugar in type II diabetes. as well as, preventing colon cancer and boosting the body's immune system [19-23]. In Algeria, a return to the traditional manufacture of barley products such as couscous, bread (elkasra) and mermeze has been observed, after the observation of its health benefits. This chapter provides an overview of growing barley and its many uses. Initially, the research begins with a presentation of barley species and will be followed by a detailed analysis of the state of barley cultivation in the world, based on a study of the agricultural, political-economic. Thus, part of this document will be devoted to the promotion of the cultivation of barley by highlighting the chemical composition of the vegetative parts and the seeds of barley, and this composition gives it an important value either at the industrial level: transformations microbiological and beverage production or at the nutritional level: the multiple uses in animal and human food while demonstrating the health benefits of barley. Finally, the last point of this chapter will be devoted to the revaluation of barley cultivation in Algeria and the return of Algerians to the traditional barley-based diet.

1. Presentation of barley

Cultivated barley (*Hordeum vulgare* L.) is as old as the origins of agriculture itself. Two-row barleys dating back to the Neolithic period (7000 BC) have been found in the Fertile Crescent, Middle East [24]. They are considered to be the oldest cultivars of cultivated barley. *Hordeum vulgare* originated from wild forms of *Hordeum spontaneum* which was first discovered in Turkey by the German botanist Carl Koch and described by him as a distinct species still found today in the Middle East [25]. According to Jestin [26], *Hordeum spontaneum*, two-row barley, is recognized as the ancestral form of cultivated barley. Moreover, they are perfectly inter-fertile [27]. It is an annual plant, in the herbaceous stage, it is mainly distinguished from other cereals by its light green foliage, the presence of a very developed ligule, glabrous auricles and a strong herbaceous tillering. The inflorescence is a spike, most often bearded. The rachis bears on each article three single-flora spikelets, one median and two laterals. The grain is covered by glumellae which do not separate during threshing, which increases the crude fiber content. This plant diploid monocotyledon (2n=14) belonging to the Poaceae family and the Festucoideae subfamily, [28]. Despite its limited chromosomal complement, the size of the H. vulgare genome is considerable since it is estimated at 5.44 x 103 Mb [29]. Its classification is based on the fertility of the lateral spikelets, the density of the spike and the presence or absence of awns [30]. Indeed, two subspecies are distinguished, depending on whether the ear bears two or six rows of grains [31]. In two-row barley, *H. vulgare ssp.* Distichum, each node of the rachis has three spikelets of which only one is fertile [32]. Alternating knots on either side of the rachis produce a two-row ear. In six-row barley, *H. vulgare ssp*. Hexastichum, the three spikelets of each node contain fertile flowers which give rise to three rows of seeds on each side of the rachis, [33]. Barley can also be classified according to its vegetative cycle, that is to say according to whether it is sown in the fall or in the spring. Winter barley has a vegetative cycle of 210 to 270 days, for a sum of 1900 to 2000 vegetative degrees, with a germination zero close to 0°C. The vegetative cycle of spring barley varies between 90 and 150 days, depending on the genotype, climate and latitude, which corresponds to a sum of 1500 to 1700 degree-days [34]. This species is cultivated in a wide range of environments, it adapts to very fertile areas with high production but also it fits well in environments characterized by great climatic variability [35]. This adaptation is linked to a short development cycle and an appreciable growth rate, at the beginning of the cycle [36].

2. Situation of barley cultivation in the world

According to the classification of cereal crops carried out by the Food and Agriculture Organization of the United Nations [1], barley ranked fourth in the world, both in quantity produced (157Mt) and in sown area (51 Mha). From 2017 to 2018, world production of barley was estimated at 144 Mt, about 30% of that of maize, [1]. Barley could be a source of food for millions of people, although today it is mainly used for animal feed and making malt. Indeed, recently, more than 70% of the barley harvest has been used for animal feed; around 21% was destined for the malting, brewing and distilling industries; less than 6% was consumed by the human population [37]. The importance of barley as a food is mainly due to its potentialities in the production of healthy foods, as an excellent source of dietary fiber and as a functional food ingredient such as β-glucan [38]. In addition, the growing interest in renewable energy has led to a modest use of barley grain for the production of fuel ethanol [39].

2.1. World agricultural context of barley cultivation

Barley is one of the most important cereal crops on a global scale, its production being estimated, in 2020, at 157 Mt of which Europe is the first producer followed by Asia. According to FAO data, it accounts for 15% of global cereal consumption, just behind maize (1162 Mt), wheat (760 Mt) and rice (504 Mt) (Figure 1). Over the last 50 years, although harvested areas have been reduced, production has increased thanks to improved yields, which have increased from around 1.4 in 1960 to 3 t/ha in 2020. From 1960 to in the late 1970s, barley harvested area showed a markedly increasing discontinuous trend. Over the past 30 years, the area harvested has increased from nearly 80 million hectares to about 50 million hectares (Table 1).

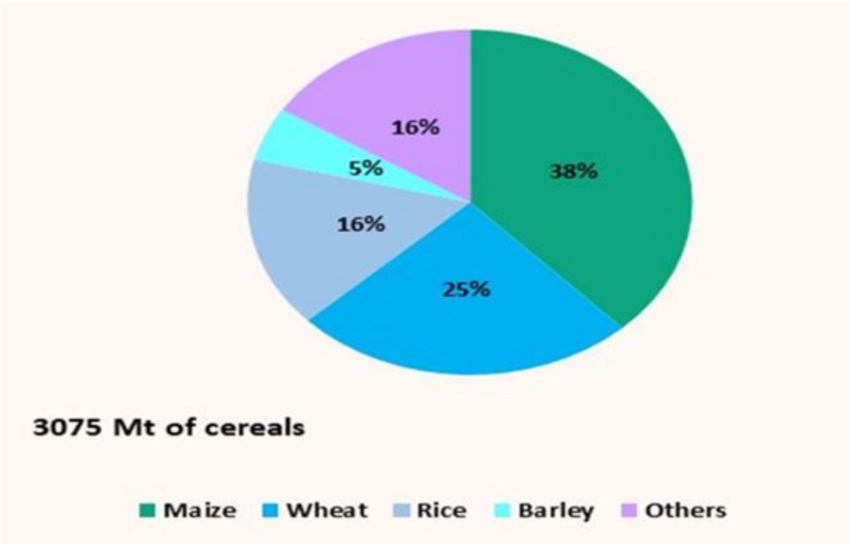

Figure 1. Breakdown of world cereal production in 2020

This trend is mainly due to the significant decrease in barley acreage in major barley-producing countries such as Russia (including all countries of the former USSR), the United States, India and China [40], [41].

Table 1. Gradual evaluation of barley production areas and yields in the world

BARLEY	AREA (10^6 HA)	PRODUCTION (10^6 T)	YIELD (Q/HA)
1960	54,51	072,41	13,282
1970	66,12	119,37	18,054
1980	78,44	156,70	19,977
1990	73,71	178,07	24,157
2000	54,41	133,11	24,464
2010	47,40	123,31	26,012
2011	48,44	132,74	27,402
2012	49,84	132,22	26,528
2013	49,77	143,48	28,825
2014	49,72	145,09	29,178
2015	48,72	147,41	30,252
2016	47,66	145,78	30,588
2017	47,00	147,40	31,356
2018	47,81	139,83	29,240
2019	51,01	158,46	31,060
2020	51,60	157,03	30,430

On the other hand, barley production continues to increase, this gap between the increase in barley production and the reduction in harvested areas is due to improved yields. Indeed, in terms of annual yield, the period considered from 1960 to 2020, is characterized by an increasing discontinuous trend, and it has increased over the last six decades (Table 1). This improvement is mainly due to the introduction of technological innovations such as irrigation, soil management without tillage or the introduction of new varieties that are much more productive than in the past [42].

2.2 Global Political-Economic Context

Barley is considered one of the most adaptable cereals. It is cultivated and used all over the world. It is used in different economic sectors such as animal feed, alcoholic beverages, food products, and recently and particularly in Europe in the production of biofuels [43]. The European Union and Russia still represent the best barley producers in the world reaching over 58 and 20 Mt, respectively. However, the United States of America and Canada have decreased their production over the years, probably due to the low income from this crop compared to other crops such as corn. On the contrary, Australia, Turkey and Argentina greatly increased their barley production, reaching more than two to eight times that of the 1960s [39]. In particular, Germany and France are the first and second European producers of barley with 1.07 and 1.03 Mt, respectively. They harvested about 1.6 and 1.8 Mha with an annual yield equal to 6.7 and 5.4 t/ha. These countries are followed by other major producers such as Spain (7.9 Mt harvested from 2.8 Mha cultivated) and the United Kingdom (6.6 Mt harvested from 1.1 Mha cultivated). These four European countries together contribute over 35% of total EU production and each of them is among the top 10 barley producers in the world [1, 41], (Table 2).

Table 2. The main barley producing countries in the world

COUNTRY	PRODUCTION (10^6 t)	AREA (10^6 ha)	YIELD (t/ha)
EUROPEAN UNION	58,23	12,50	04,65
GERMANY	10,73	01,60	06,69
FRANCE	10,30	01,89	05,43
SPAIN	07,97	02,80	02,85
UK	06,65	01,12	05,93
DENMARK	03,94	00,70	05,59
RUSSIA	17,99	08,13	02,21
AUSTRALIA	09,25	04,12	02,24
CANADA	08,99	02,39	03,49
UKRAINE	07,34	02,48	02,95
TURKEY	07,00	02,60	02,69
ARGENTINA	05,06	01,20	04,19
KAZAKHSTAN	03,97	02,51	01,57
UNITED STATES	03,32	00,80	04,16

According to (Table 2), the international barley trade therefore represents less than 34% of world production, which corresponds to a value of more than 9 million US dollars (MUSD). World barley trade has grown from 20 Mt in 1990 to 38 Mt today. The main barley exporting countries are the EU (16 Mt), Australia (5.8 Mt), Argentina (3.2 Mt) and the Russian Federation (2.8 Mt). Together they represent less than 92.5% (28 Mt) of total barley exports. EU exports represent approximately 9 Mt, or 15% of its total production (58 Mt) and a trade value of less than 1.7 million dollars (MUSD). Among the EU exporting countries, the Netherlands, Belgium and Germany are the main countries totaling an amount of 5 Mt equal to 56% of world European exports and about 1% of world exports [1].

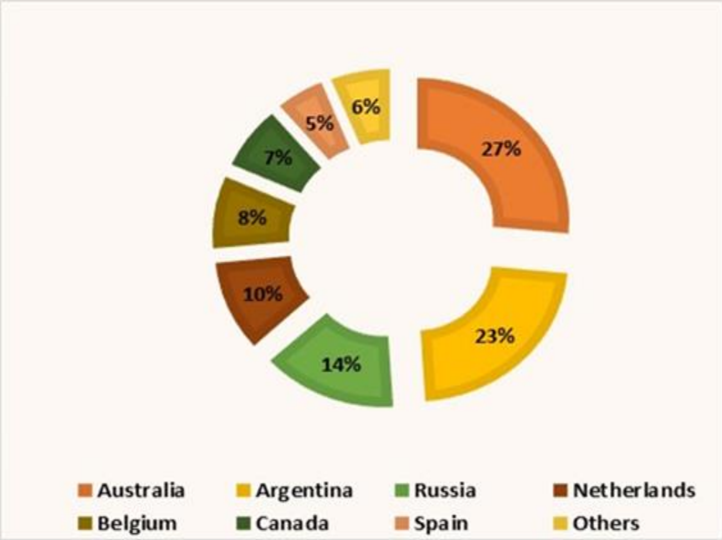

Figure 2. Economic value of barley in the world

The EU changed its role in the international barley trade since it was until 1975 one of the main importers, then in the 1980s it became one of the main exporters. In addition, Russia, Ukraineµµ and Kazakhstan (former Union of Soviet Socialist Republics) and Australia have increased over the past two decades as their barley exports have become one of the largest exporting countries in the world. world after the European Union, (Figure 2). Finally, Canada and the United States have greatly reduced their export activities from the 2000s [39, 41]. China and Saudi Arabia are the main barley importers with 8.1 Mt each, which represents less than 50 % of total barley imports. Saudi Arabia's barley demand is almost entirely met by imports, due to the country's low water reserves. The barley imported by Saudi Arabia (more than 80 %) is intended for livestock feed, mainly sheep, camels and goats. Its use instead of fodder depends on its price and competitiveness [44]. Additionally, barley is also used to prepare traditional Saudi dishes during Ramadan fasting and as a food ingredient. The price of barley has always been lower than that of other cereals. Between the 1980s and the mid-1990s, it was below 100**$/t**, while it then increased to a price above 200$/t in 2012 [42]. In recent years, robust global demand coupled with weak global production has led to declining stocks and consequently higher barley prices in all major exporting countries [40].

3. Promotion of barley cultivation

In cereals, it is usually the seeds that we use for food and feed. The rest of the plant is valued in animal feed, either in the dry state in the form of straw, or in the fresh state or in silage.

3.1. Chemical composition of barley grains and vegetative parts

Physiologically, the grain of barley plays the role of a fruit containing a seed, so it must protect the germ during the waiting period and nourish the seedling during germination [45]. This explains on the one hand that the grains have their periphery formed of dry and hard envelopes, essentially made up of cellulose, on the other hand that the cotyledon which represents 82 to 85 % of the grain, it contains all the necessary nutritive substances [46], carbohydrates represent a rate of 70 to 82 %; proteins with a rate of 10 to 13%; lipids with 2 to

2.5%; mineral substances with a content of 2.7% and finally, vitamins [47-49]. The chemical composition of barley grains varies depending on the genotype, cultural practices as well as environmental conditions [49-51]. Barley grains are naturally little hydrated indeed, their water content varies with the humidity of the air, the balance is between 16 and 13 % depending on the temperature and the ambient humidity [52]. This dryness offers the advantage of ease of transport, conservation and the possibility of treatment by dry process [46]. In the green state, we consider the whole plant at various stages of grain-forming evolution. At the stage of the pasty grain, which is the most advanced stage for the use of the whole plant, the soluble carbohydrates and the starch in formation represent only about a third of the dry matter whereas the parietal constituents contain nearly half. At the same time, the quantity of minerals is about three times higher than in the grain, the other constituents have contents of the same order of magnitude as in the ripe grains [39].

3.2. The microbiological transformations of barley

There is growing interest in the use of barley for food production due to its various health benefits, such as blood cholesterol lowering, glycemic index regulation, and antioxidant activity, [53]. Indeed, the fractionation of barley makes it possible to obtain many valuable products. Barley malts, extracts and syrups are used in small quantities in food products to improve certain organoleptic characteristics such as flavor and color, to breakfast cereals, fermented and unfermented baked goods [39]. Malt extract is a source of soluble sugars, protein, and amylase in dough and promotes yeast activity for many best baked goods in terms of texture and volume. Therefore, β-glucans, tocols (such as tocotrienols and tocopherols), polyphenols (such as phenolic acids, proanthocyanidins and catechins) and others are the functional components of barley responsible for many benefits to human health [53].

Barley has been used to formulate various “healthy” food products such as pasta and bread [54]. The major component of barley grain is starch which can make up more than 70 % of the dry weight [52]. Therefore, the quality of starch can be expected to greatly influence the quality of products intended for human or animal consumption. Starch is also a by-product of the barley fractionation process for the production of β-glucans [55]. Understanding the properties of starch provides a foundation for value-added processed products containing barley. New starches newly made from genetic mutants such as the “amylose-only” genotype offer various possible applications for the food and other industries [56]. A systematic review of various aspects of starch is needed to support the current exploitation of barley as a sustainable crop.

3.3. Barley in beverage production

The best known and most widespread use of barley, for food purposes, is related to the production of malt. Malting which requires the acquisition of good quality barley grains. In fact, the water content of the grain must not exceed 12 %, to avoid the growth of moulds; the grain must also maintain its viability and have a germination rate of 98 % [57-58], this ensures uniform germination; protein content is an important attribute for assessing grain quality, according to Martin and Bamforth [59], for six-row malting barleys, the acceptable protein content is 11.3-12.5 %. During the fermentation process, low protein content may not satisfy the needs of yeasts while high protein content decreases the starch volume of the grain, [49].

Moreover, barley carbohydrates are particularly well suited to malting [39]. The malting process breaks down carbohydrates into sugars which provide unique flavors and fuel for fermentation. Malt beverages are classified according to their alcohol content: alcoholic beverage with a rate greater than or equal to 12 %; low alcohol drink with 0.5 to 1.2 % and non-alcoholic drink when the amount of alcohol is less than or equal to 0.5 %. In fact, starch fermentation products are also distilled into pure grain alcohol for vodka-type products, as well as industrial ethanol sold primarily to the pharmaceutical industry. Modest amounts of soft drinks made from barley and malt are consumed worldwide [46]. Among the non-alcoholic beverages are malted beverages often in the form of "malted milk" in which the malt extract is mixed with milk; Barley infusion (coffee substitute); Barley water and barley tea [39].

3.4. Barley in animal feed

Barley has long been a benchmark for animal feed, the kilogram of barley has been used to define the Feed Unit (FU). Barley grain can be used to feed cattle, pigs and in some cases poultry [38]. Winter barley can be grazed when it is in the tillering stage. Barley is also sometimes harvested green at heading, alone or in association with common vetch. Forage barleys can be two-row or six-row varieties which are very competitive indeed, they can be harvested as forage in about 58-65 days [38, 59]. Additionally, barley can be planted, in some environments, for dual cropping. The opportune moment of forage harvesting corresponds to the milky-pasty stage of the grain indeed, the stage of harvesting has a significant impact on the quality of the forage. Harvesting in the milky stage is recommended for optimum quality although the mushy stage may yield a little more forage while still providing relatively good quality [60]. The aerial part of barley is cut and allowed to dry to adequate moisture, then chopped and stored for use as silage. Rosser et al. [61] noted that the digestibility of whole barley silage decreases as the maturation stage progresses. Feed barley or mixed stands of barley and vetch can also be harvested as dry hay [59]. Mixing barley and vetch improves forage yield and increases protein content [38]. Barley straw can be used as fodder when well supplemented. Compared to corn, barley grain contains more protein, methionine; cysteine; lysine and tryptophan [39] This information highlights the potential contribution of barley to meeting the protein requirements of high-producing ruminants [60]. In addition, compared to other cereals, barley contains the highest levels of neutral and acidic detergent fibers and the lowest levels of starch and fat. Barley is the richest in potassium and vitamin among other cereals [38]. Barley grain contains five times more calcium than oats [39]. With twice the copper and molybdenum and more than twice the manganese, barley is superior to corn. However, barley is lower in zinc than corn. Vitamin C and vitamin B 12 are among the nutrients missing in barley [60]. It should be noted that there are few differences in the nutritional composition of two-row and six-row barleys. Pigs got more energy from barley than other animals, while cattle used less energy from barley. Barley usable energy correlations between broilers and other animals were 0.77 for layers, 0.56 for pigs, and 0.09 for cattle [59]. However, barley grain is a useful feed for several classes of beef cattle. When properly processed, mixed, and supplemented, barley makes an excellent forage grain [60]. It can be used in grower and finisher diets for feeder cattle, as a supplement in forage rations for replacement heifers, and as a source of energy and protein for pregnant and lactating cows [59]. Barley processing requires careful attention in order to maximize digestive efficiency and maintain stable rumen function [60].

4. Development of barley cultivation in Algeria

In Algeria, barley is often considered a secondary cereal unlike wheat, although it has enormous similar potential. Indeed, treated and maintained like wheat, barley can achieve equivalent yields. On the other hand, barley is recognized for its agronomic and socio-economic importance. It is a species very adapted to the cropping system practiced in arid zones; semi-arid or even salty or at altitude [39]. This adaptation is linked to a short development cycle and an appreciable growth rate at the start of the cycle [61]. Because of its hardiness, barley tolerates poor soils and low temperatures [62]. Because of these characteristics, this crop fits well into environments characterized by great climatic variability where, along with sheep farming, it constitutes the bulk of local agricultural activity [63]. The multiple uses of this cereal, green, stubble, straw or grain, give it a strategic value in animal feed, it is a reference fodder since 1 kg of grain is the equivalent of fodder unit containing 75 g of nitrogenous matter [64]. It represents the alternative where substitute fodder is very poorly represented [33]. Indeed, the entire production estimated at 91,990,700 q in 2020 is intended for livestock feed [65]. The rest is intended for human consumption [66]; barley is a popular food that can be stored for long periods of time and transported over long distances. This speculation plays a determining role in the behavior of all animal feed markets [67]. In addition, barley allows farmers who have little land to exploit fodder for their livestock and grain for their own consumption or for their animals [68].

5. The multiple uses of barley in Algeria

Barley most often has mixed uses, it is almost the only resource on farms, it is offered to animals in the form of grain, straw, depressed barley for grazing in winter and stubble in summer. Barley offers in these ecosystems the advantage of flexible use depending on what the climate of the countryside will be, this explains the attachment of farmers to this crop, although its yields are often low [64]. In Algeria, barley is used in sheep feed with a rate of 90 % and the remaining 10 % is used in human food [69] Barley is also a source of early green fodder and thus represents a link between straw (hay) and fodder concentrates, as it can be grazed for a short period before being left to produce grain and straw. Barley straw is highly valued and demanded by breeders as well as quality fodder [70]. We are seeing a return to the traditional production of barley products such as: couscous; bread and elmermeze. For the record, barley bread (elkesra) served as a staple food for Algerians during colonization [71], moreover, in rural areas the daily meal consists of barley pancake and couscous [61].

Conclusion

We have seen through this chapter that barley is one of the ancient grain crops, grown and used all over the world. Thanks to its great adaptability, this plant grows in a wide range of environments. Since the 1970s, areas planted with barley have declined, particularly in producing countries such as Russia, the United States, India and China, probably due to intensive agricultural policies. Indeed, this situation was compensated by the improvement in yields, consequently, they went from about 14 q/ha during the 1960s to 30 q/ha in 2020, which increased barley production. , it went from 79 Mt during the 1960s to 157 Mt in 2020. The entire production is dedicated to animal feed with 70% and the remaining 30% is mainly intended for the manufacture of beer ingredients and a small quantity to other human food applications, moreover, the microbiological transformations of barley which can open, for certain countries, favorable paths in the field of biofuels. In Algeria, barley is grown in marginal areas on small areas that do not exceed ten hectares per farmer. Indeed, the situation of barley in Algeria, the evolution of sown areas, production and yields is identical to the world situation. On the other hand, the use of barley in Algeria is much more based on animal feed indeed, only 10% is intended for human consumption.

This chapter has presented some interesting aspects of barley cultivation, particularly with regard to the economic importance and its multiple uses in a global context. Indeed, the promotion of the development of barley production reveals prospects and challenges at several levels: on the economic level, to better exploit this crop in the industrial and nutritional sector, on the agronomic level, to enhance the virtus of this culture in the face of climate change issues, as well as on the socio-cultural level, to show the benefits of barley on health and encourage the population to return to barley consumption.

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