Chapter 2

Economic Analysis of the Barley Market and Related Uses

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Additional information is available at the end of the chapter

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Abstract

Barley is an important cereal worldwide cultivated since about 10,000 years. Barley crop is the fourth most important cereal in the world, after wheat, corn, and rice. It could be a food source for millions of people even though today it is mainly used as animal feed and brewing. So, recently, more than 70% of barley crop has been used for feed; about 21% has been intended to malting, brewing, and distilling industries; lesser than 6% has been consumed as human food. In addition, a growing interest in renewable energy has led to the modest use of barley grain for the production of fuel ethanol. The prominence of barley as food is mainly due to its potentialities in the production of healthy food, as an excellent source of dietary fiber, and a functional food ingredient such as β-glucan. The purpose of this chapter is to carry out an analysis of barley market and to present, in summary, its principal uses.

Keywords: barley, barley grain, barley market, barley feed, barley food

1. Introduction

Barley (*Hordeum vulgare* L.) is one of the ancient grain crops cultivated and used worldwide [1, 2]. Its botanic origin is still well unknown although some studies affirm that the region were barley born could be identified in South-Eastern Asia, including China, Tibet, and Nepal [3, 4]. Also, the pathways for its domestication have some points in doubt. However, the first examples of barley cultivation date back to about 10,000 years ago [5]. In fact, several archeological discoveries occur in South-Western Asia in the Fertile Crescent area (also known as the "cradle of civilization"), which indicate that the crop was domesticated about

8000 BC. At later times, barley has been widely cultivated all over the world principally due to the commercial traffics. Thus, it grew in 5000 BC in Egypt, and successively, in 3500 BC, it diffused in Mesopotamia, then in 3000 BC in North-Western Europe, and 2000 BC in China. This plant was used to prepare the bread for the Hebrews, Greeks, and Romans and until the sixteenth century much throughout Europe. The introduction of other cereals in the human nutrition such as wheat, rice, and maize has led to a severe decrease of barley uses and cultivation [6].

Currently, barley is one of the fourth most important cereals in the world in terms of both quantity produced and cultivated areas. On average, the annual world harvest of barley is more that 140 million tons (Mt) obtained from nearly 50 million hectares (Mha) [7]. Moreover, barley is one of the most versatile cereals known to be well adapted to the different global climates through its genetic evolution [8, 9]. In fact, this plant grows outside the regions where the other cereals live (i.e., maize, wheat, and rice) such as arctic and subarctic zone to subtropical region. The barley's ability to adapt to the diverse conditions is supported by a rich genetic diversity being studied in order to identify new characters that can help improve the sustainability of the crop. This feature is mainly linked to the presence of genetic factors that allow synchronizing the vegetative cycle of the plant with the environment. This allowed to have early spring varieties suitable for environments with a prolonged cold weather and short spring-summer seasons and tardive winter varieties able to fully exploit all the productive potential of temperate climates. The good resistance to drought has also allowed the species to adapt to environments such as those of North Africa and the Middle East. In fact, the barley has a vast area of cultivation, from the humid regions of Europe to South America and the arid areas of Africa and Asia [10, 11]. Depending on climate conditions, soil characteristics, agricultural practices (i.e., irrigation), but also a variety of cultivated and technological innovations, barley's yield has changed during the time starting from 1.39 (in 1960) to 2.99 t/ha (in 2017). At present, the best yields are recorded in Zimbabwe, New Zealand, Chile, and Switzerland with about 7.5, 7.05, 6.50 and 6.17 t/ha, respectively [12].

Barley (*Hordeum vulgare* L.) is one of the most important cereals used, preceded only by wheat, rice, and maize. Barley is a versatile crop. Since ancient times, it has been used as food or for the production of beverages, and currently, it is mainly intended for the feeding of livestock [13]. Most probably, in the past, the first use was as food which then evolved into a feed, malting, and brewing, and its uses have changed throughout history and in different geographical area [14]. Currently, it is used in industrialized countries as a fodder and as a staple food in developing countries; however, the most significant use from an economic point of view is represented by malt and beer. It represents an important crop subsistence in the Andean and Himalayan regions and in Ethiopia. In Canada, instead, it is used for swine feed [10].

According to the FAO data, nowadays, about 70% of barley crop has been used for feed; 21% has been intended to malting, brewing, and distilling industries; 6% has been consumed as human food; in addition, a growing interest in renewable energy has led to the modest use of barley grain for the production of biofuels [15]. In 2017, the world production is around 141 Mt. Europe is the largest producer followed by Asia.

2. International barley market trend

Barley is considered one of the most adaptable cereals; it is cultivated and used worldwide. It is used in different economic sectors such as animal feed, alcoholic beverage, food, and recently and particularly in Europe in biofuels production [16]. This ancient crop is the fourth most important cereal in the world; in 2017, its production was approximately equal to 141 Mt after corn (1060 Mt), wheat (749 Mt), and rice (741 Mt) (**Figure 1**) [1, 2, 7, 14]. During the last 50 years, although the harvesting area is decreased, the production was increased owing to the yields improving from about 1.4 in 1960 to 3 t/ha in 2017.

Moreover, European Union (EU) and Russia still represent the best world barley producers, reaching more than 58 and 20 Mt, respectively, in 2017. However, United States of America and Canada during the time have decreased their production probably due to the low income deriving from this culture with respect to others such as maize. On the contrary, Australia, Turkey, and Argentina have highly increased barley productions, reaching more than two to eight times than in 1960s. For instance, Australia showed one of the most significant increases in the total cropping area, from less than 1 in 1960s to 8 Mha in 2017 [12] (**Figure 2**).

In 2017, the total area harvested was around 50 Mha and ranked fourth after wheat (~220 Mha), maize (~183 Mha), and rice (~162 Mha) [7, 12] (**Figure 3**).

From 1960 to the end of the 1970s, barley harvested area has shown a substantially increasing discontinuous trend. In the last 30 years, the harvesting area has been declining from almost 80 million ha to around 47 million ha. This trend is principally due to the significant decrease in barley cropping area of the major barley production countries such as Russia (including all the countries from former USSR), United States, India, and China (**Figure 4**).

In terms of annual yield, the period considered, from 1960 to 2017, is characterized by an increasing discontinuous trend, and it has increased in the last six decades from 1.3 in 1961

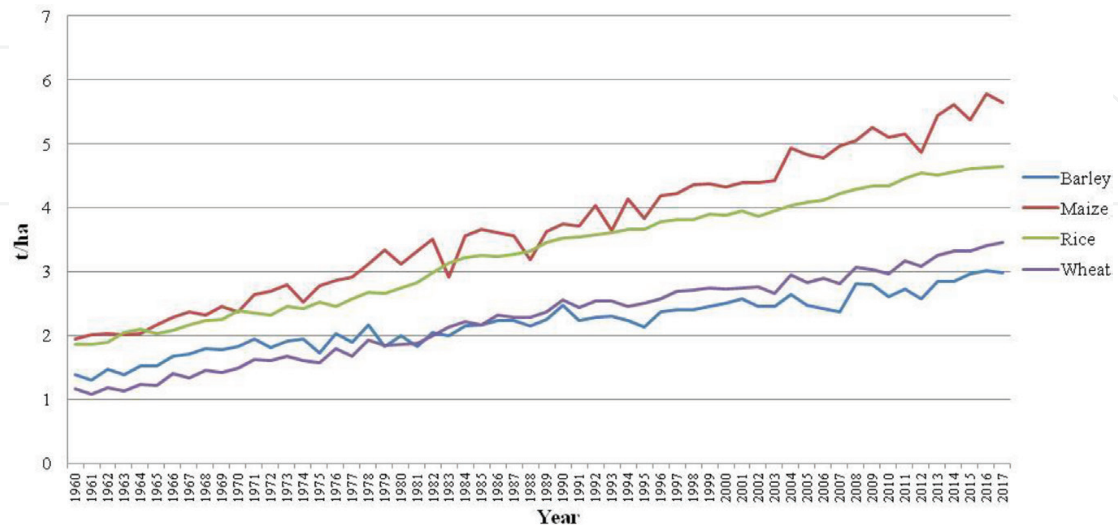

Figure 1. Trend of world production of barley, maize, rice, and wheat from 1960 to 2017 (source: elaborated from [7, 12]).

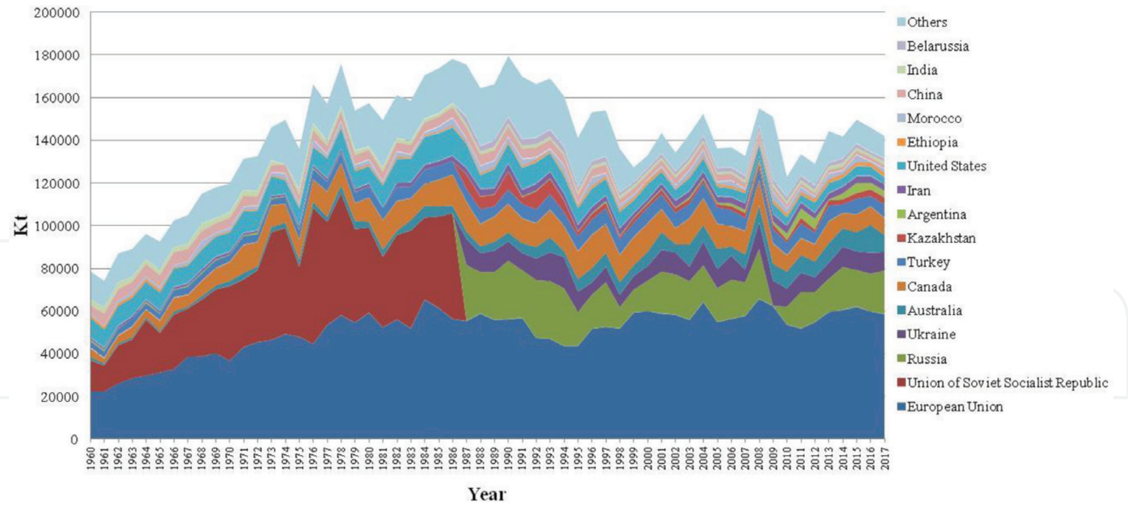

Figure 2. Trend of world barley production (including major barley production countries) (source: [12]).

to 3.01 t/ha in 2017 [12]. As this discrepancy is underlined already between the increase in barley production and the reduction in harvested area, it is due to the improvement of yields. Furthermore, this trend is similar to the other cereals, since maize yield is raised, in the last six decades, from 1.9 (in 1961) to 5.65 t/ha (in 2017), rice from 1.9 to 4.6 t/ha, and wheat from 1 to 3.46 t/ha [12]. This enhancement is mainly due to the introduction of technological innovations such as irrigation, no tillage soil management, or the introduction of new varieties much more productive than in the past.

In 2016, among the 106 barley country producers, only 10 contribute for the 65% (91.8 Mt) of the global production (141 Mt) and the 60% (28.6 Mha) of the total barley harvested area (**Table 1**).

As shown in **Table 1**, the leader, in terms of production and area dedicated, is EU. In 2017, EU barley production was about equal to 59 Mt, which accounts for more than 40% of the global one, 25% (11.5 Mha) of global barley harvested area (47 Mha) and with an average yield

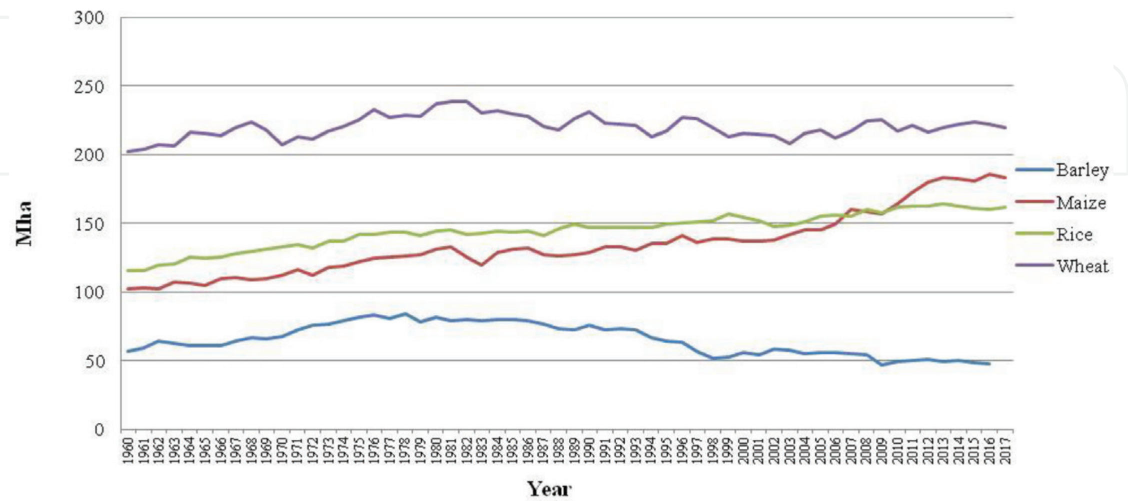

Figure 3. Trend of world harvested area of barley, maize, rice, and wheat from 1960 to 2017 (source: elaborated from [7, 12]).

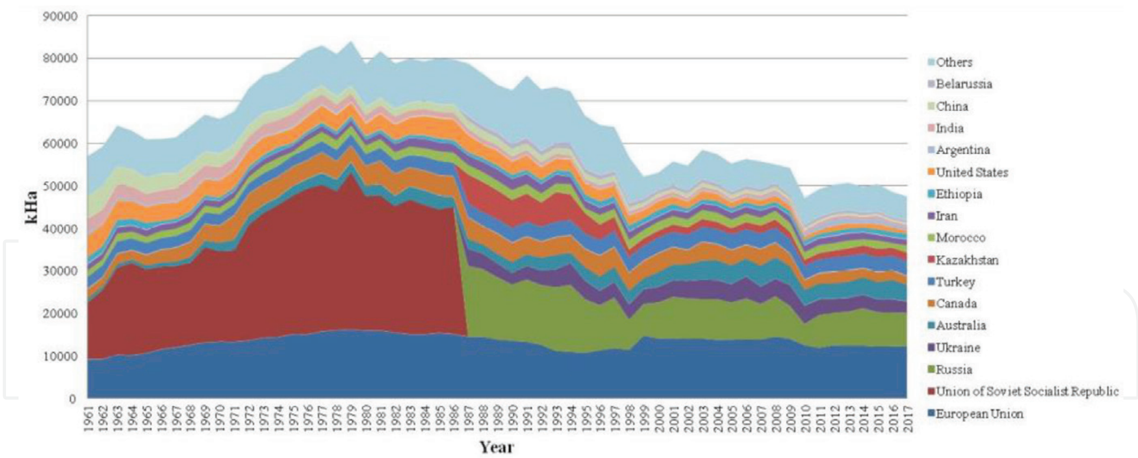

Figure 4. Trend of world barley harvested area (including major production countries) (source: elaborated from [7, 12]).

approximately equal to 4.5 t/ha. In particular, Germany and France are the first and second European barley producers with 1.07 and 1.03 Mt, respectively, harvested approximately 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 important producers such as Spain (7.9 Mt cultivated in 2.8 Mha) and United Kingdom (6.6 Mt cultivated in 1.1 Mha). These four European countries, together, contribute more than 35% of the total EU production, and each of them is included in the top 10 world barley producers [7, 14].

Russian Federation is the second world barley producer with 17 Mt (12% of global production) and 8 Mha (17% of total harvested area) recorded a low average yield equal to 2.1 t/ha. Following the main barley producers list are Ukraine and Australia with their barley production, respectively, equal to 9.4 and 8.9 Mt. Different are their annual yields (3.3 and 2.19 t/ha, respectively) and consequently the total dedicated area (2.8 and 4.1 Mha, respectively). As concerning the other producers, United State of America, Canada, Argentina, and China recorded

Country	Yield (t/ha)	Hervested area (ha)	Production (t)	Country	Yield (t/ha)	Hervested area (ha)	Production (t)
European Union	4.65	12507489	58233580	Iran (Islamic Republic of)	1.80	1611423	2907572
of which				Ethiopia	2.11	959273	2024922
Germany	*6.69*	*1605000*	*10730500*	China, mainland	4.31	412781	1780355
France	*5.43*	*1899615*	*10306008*	India	2.55	590000	1505000
Spain	*2.85*	*2800628*	*7979590*	Belarus	2.78	450814	1252690
United Kingdom	*5.93*	*1122000*	*6655000*	Mexico	2.97	329745	978349
Denmark	*5.59*	*706900*	*3949600*	Azerbaijan	2.62	355129	928923
Russian Federation	2.21	8133765	17992517	Algeria	1.30	706429	919907
Ukraine	3.30	2859200	9435710	Uruguay	3.57	190000	678000
Australia	2.19	4107648	8992274	Norway	4.57	137185	626900
Canada	3.72	2336800	8704300	Morocco	0.51	1207615	619919
Turkey	2.48	2700023	6700000	Syrian Arab Republic	0.57	879086	500001
United States of America	4.19	1035200	4338850	Cyprus	2.00	14655	29300
Argentina	3.80	870213	3308384	Other Countries		5493877	15054283
Kazakhstan	1.71	1894068	3231268	***Total***		***46923218***	***150743004***

Source: [7].

Table 1. World barley yield (t/ha) and production (t) in 2016.

higher world average yields (4.19–3.72–3.80–4.31 t/ha, respectively); on the contrary, those in Kazakhstan, Iran, and Ethiopia are below the world average one (1.71–1.8–2.1 t/ha, respectively).

Regarding the import and export trade of the data available, more update is referred to 2016. So, the international barley trade accounts for less than 34% of global production, corresponding to a value of more than 9 million of US dollars (M US$). The global barley trade has passed from 20 Mt in 1990 to current 47 Mt. Leading barley exporters are EU (16 Mt), Australia (5.8 Mt), Argentina (3.2 Mt), and Russian Federation (2.8 Mt); together, they represent less than 92.5% (28 Mt) of the total barley exported (**Table 2**).

EU exports approximately are equal to 9 Mt, representing 15% of its whole production (58 Mt) with a trade value of less than 1.7 M US$. Among EU exporter countries, Netherlands, Belgium, and Germany are the principal ones totalizing the amount of 5 Mt equal to the 56% of the global European exportation and approximately 1% of world one. Germany, in 2016, was the second barley producer, the second importer and the third exporter (**Table 3**).

A long period trend of barley exports is shown in **Figure 5**. EU has modified its role in the international barley trade, since until 1975, it was one of the main importers, whereas after 1980, it became one of the principal exporters. Moreover, Ukraine, Russia, and Kazakhstan (former Union of Soviet Socialist Republic) and Australia have increased in the last two decades, their barley exportation becoming one of the largest world exporter countries after EU. Finally, Canada and USA have highly reduced their exportation activities starting from 2000s (**Figure 5**).

Country	Net weight (t)	% on world production	Trade Value (MUS$)	% on trade value	Country	Net weight (t)	% on world production	Trade Value (MUS$)	% on trade value
Australia	5808572	4.111	1131059	26.25	Belarus	36130	0.026	4273	0.10
Argentina	3227439	2.284	599701	13.92	Croatia	35850	0.025	6777	0.16
Russian Federation	2862500	2.026	424390	9.85	Latvia	35463	0.025	5470	0.13
Netherlands	2001543	1.416	361639	8.39	Hungary	34833	0.025	7397	0.17
Belgium	1706453	1.208	324492	7.53	United Arab Emirates	31692	0.022	8701	0.20
Germany	1272915	0.901	253227	5.88	Bulgaria	25068	0.018	4634	0.11
Canada	1207325	0.854	293356	6.81	Serbia	23795	0.017	4944	0.11
Spain	1102736	0.780	200324	4.65	Slovenia	22117	0.016	4128	0.10
Kazakhstan	780557	0.552	109052	2.53	Azerbaijan	13854	0.010	2571	0.06
Italy	731741	0.518	135382	3.14	Malta	12538	0.009	2282	0.05
Romania	480421	0.340	78041	1.81	Lithuania	6150	0.004	1418	0.03
Portugal	365521	0.259	67497	1.57	Turkey	5573	0.004	1399	0.03
Austria	182467	0.129	33465	0.78	Israel	4841	0.003	1210	0.03
Greece	179721	0.127	33253	0.77	Estonia	4504	0.003	989	0.02
Cyprus	170991	0.121	31157	0.72	USA	2499	0.002	23942	0.56
Poland	127977	0.091	21820	0.51	Chile	2275	0.002	739	0.02
United Kingdom	125478	0.089	39448	0.92	Lao People's Dem. Rep.	1841	0.001	344	0.01
Rep. of Moldova	114129	0.081	15554	0.36	TFYR of Macedonia	1765	0.001	296	0.01
Ireland	90563	0.064	16442	0.38	India	1661	0.001	616	0.01
France	60901	0.043	13785	0.32	State of Palestine	1635	0.001	303	0.01
Czechia	45392	0.032	9325	0.22	Finland	1104	0.001	323	0.01
Slovakia	44105	0.031	10180	0.24	Luxembourg	911	0.001	389	0.01
Uruguay	41516	0.029	12583	0.29	Other Countries	2518	0.002	1573	0.04
Denmark	36625	0.026	9064	0.21	***Total***	***23076205***	***100***	***4308954***	***100***

Source: [7].

Table 2. Global barley trade: export in 2016.

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Country	Net weight (t)	% on world production	Trade Value (MUS$)	% on trade value	Country	Net weight (t)	% on world production	Trade Value (MUS$)	% on trade value
France	5868270	17.40	1067796	16.17	Finland	184765	0.55	29399	0.45
China	5004888	14.84	1141938	17.29	Russian Federation	158441	0.47	20343	0.31
Saudi Arabia	3667337	10.88	713082	10.80	Lebanon	156997	0.47	27018	0.41
Germany	2887398	8.56	499384	7.56	Latvia	148539	0.44	24104	0.37
United Kingdom	1796240	5.33	313030	4.74	India	141757	0.42	29474	0.45
Romania	1310986	3.89	214964	3.26	Netherlands	130298	0.39	28534	0.43
Japan	1161549	3.44	261218	3.96	Canada	130087	0.39	28250	0.43
Morocco	976845	2.90	179065	2.71	Viet Nam	115432	0.34	22297	0.34
Jordan	956201	2.84	190100	2.88	Oman	109086	0.32	30462	0.46
Algeria	879215	2.61	153413	2.32	Austria	108124	0.32	24749	0.37
Tunisia	711213	2.11	121604	1.84	Peru	106535	0.32	33433	0.51
Denmark	693665	2.06	142768	2.16	Poland	94377	0.28	15423	0.23
Brazil	653779	1.94	169296	2.56	Spain	47890	0.14	14700	0.22
Hungary	640382	1.90	100532	1.52	Lithuania	45390	0.13	7953	0.12
Czechia	501108	1.49	86171	1.31	Ireland	29604	0.09	5810	0.09
Sweden	479847	1.42	96871	1.47	Portugal	25768	0.08	5003	0.08
United Arab Emirates	466826	1.38	103364	1.57	Luxembourg	18567	0.06	3341	0.05
Bulgaria	412266	1.22	70023	1.06	Croatia	7030	0.02	1367	0.02
Kuwait	384491	1.14	84033	1.27	Slovenia	5524	0.02	1065	0.02
USA	347371	1.03	80261	1.22	Italy	3000	0.01	1215	0.02
Israel	333438	0.99	63141	0.96	Greece	1368	0.00	481	0.01
Colombia	297069	0.88	76707	1.16	Cyprus	0	0.00	2	0.00
Estonia	274381	0.81	45961	0.70	Malta	0	0.00	0	0.00
Slovakia	210888	0.63	35526	0.54	Other Countries	847725	2.51	202964	3.07
Belgium	188171	0.56	35104	0.53	***Total***	***2616303***	***7.76***	***557387***	***8.44***

Source: [7].

Table 3. Global barley trade: import in 2016.

On import side, in 2016, 17 Mt are traded, with a corresponding value equal to 3.7 M US$. A long period trend of barley imports is recorded in **Figure 6**. China and Saudi Arabia are the main barley importer with 8.1 Mt each, contributing to the total imported barley less than 50%. The demand of Saudi Arabia barley is almost totally satisfied by import due to the country's scarce water reserves. This policy is supported by government subsidizing barley and

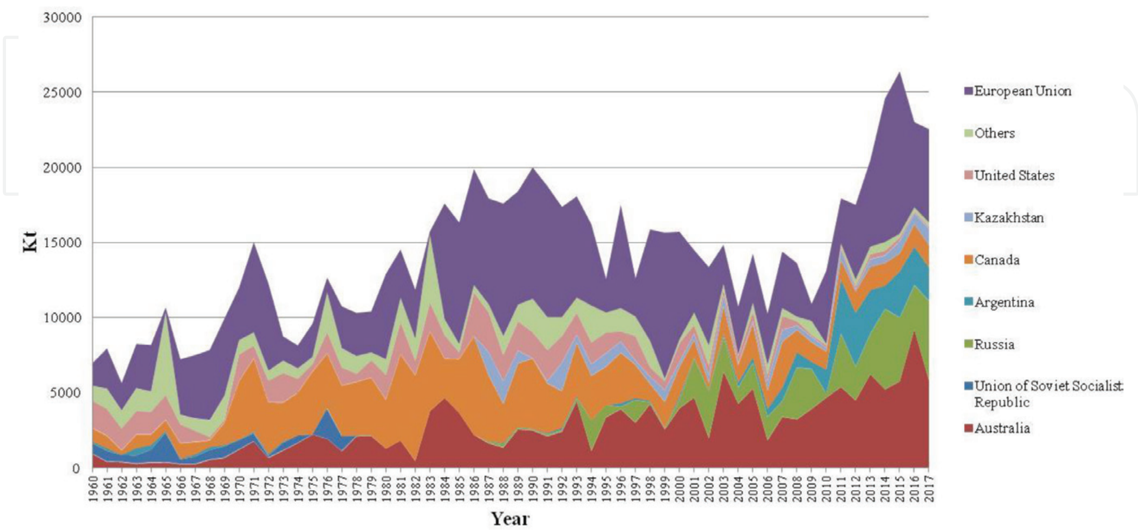

Figure 5. Trend of world barley exports (including the major country importer) (source: [12]).

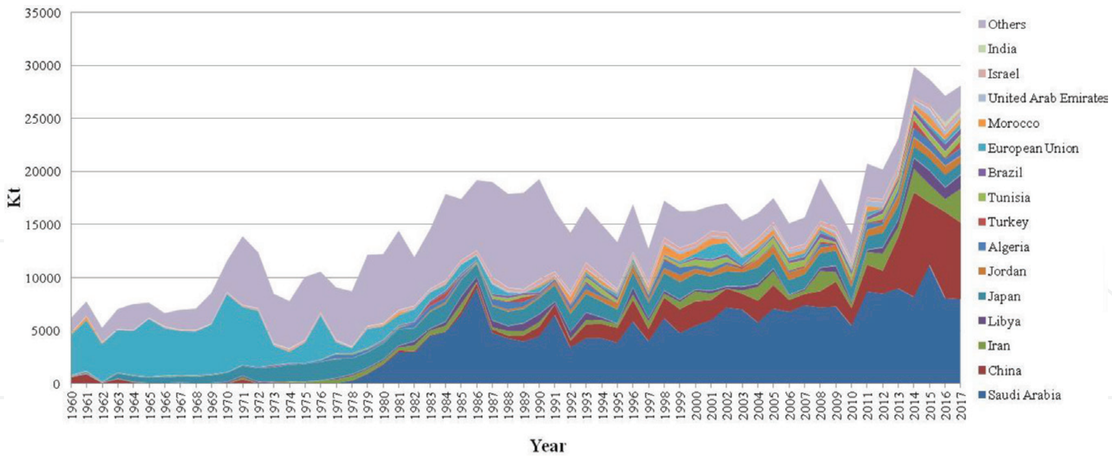

Figure 6. Trend of world barley imports (including the major country importer) (source: [12]).

based on the consideration that 100% of domestic barley (and wheat) cultivation is irrigated. The main quota of Saudi Arabia imported barley (more than 80%) is principally utilized as feed for livestock, mostly sheep, camels, and goats. Its use in the place of forage depends on its price and competitiveness [17]. Moreover, barley is also used to prepare specialty and traditional Saudi dishes during Ramadan fasting time and as feed ingredients.

The price of barley has always been lower than the other grains (**Figure 7**). Starting from 1980s to the middle of 1990s, it has been under 100 $/t, whereas later, it increased reaching a quotation more than 200 $/t in the year 2012. In the first 6 months of 2017, barley quotation was 146 $/t, which started to increase again. This is due to different reasons such as (1) China's and Saudi Arabia's rise demand, (2) the reduction of global barley production, and (3) the projections of barley stock down in all major exporting countries [18].

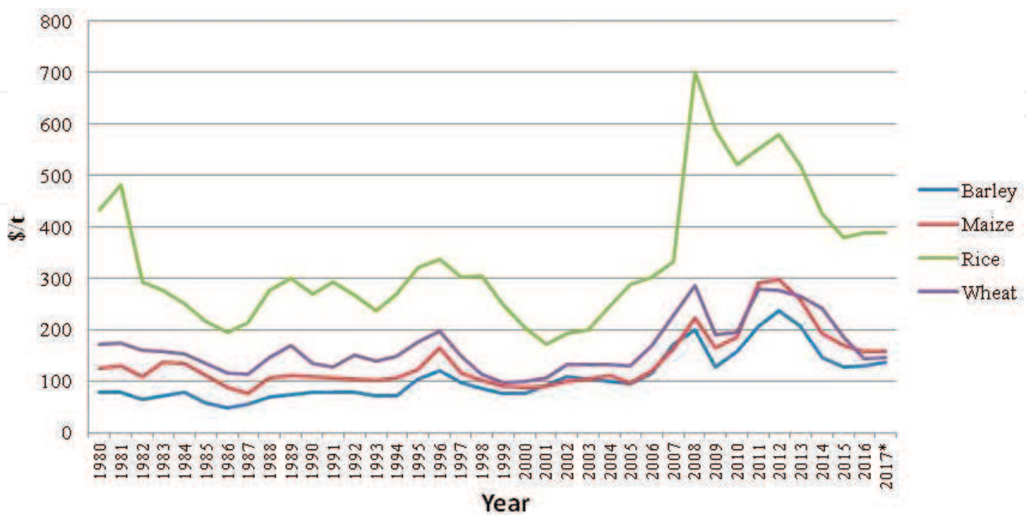

Figure 7. Trend of barley, maize, rice, and wheat price from 1980 to 2017 (source: [19]). *2017 is considered the first 6 months from January to June.

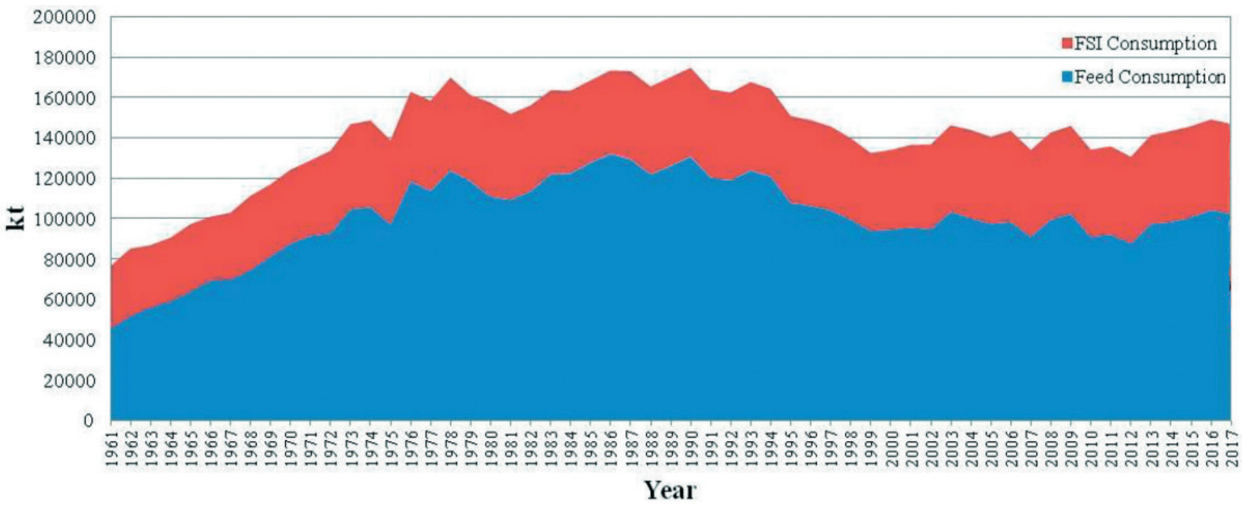

Figure 8. Trend of world barley feed and FSI consumption (source: [12]).

The trend of world barley consumption is similar to the production (**Figure 8**). However, in the last years, the robust global demand linked to a low world production has led to a decrease of stocks and consequently an increase of the barley price [18] in all major exporting countries. In 2017, the total barley consumption has been about 147 Mt of which 70% is used for animal feed and 30% for manufacturing of malt (primarily used in beer production) and other human food applications.

3. Barley uses

3.1. Barley grain main characteristics

Cultivated barley is one of 31 *Hordeum* species, belonging to the tribe *Triticeae*, of the grass family *Poaceae* also known *Gramineae*. It is an annual, self-pollinating, diploid species [10, 20].

Barley is differentiated into couplet and polistic. The former is characterized by larger, higher-quality seeds, used above all in the production of beer, while the latter are distinguished in tetrastic barriers (four rows) and exquisite bars (six rows).

Depending on the variety, it is also possible to distinguish hulled barley that preserve the glume adhering to the caryopsis, from hull-less barley (or naked barley) that lose the glumes after the threshing. Generally, hulled barley is intended for the production of malt while the hull-less one is used for feed, food, fermented, and unfermented beverages. For this type of barley, there is a particular interest also in new applications: as a whole-grain ingredient in value-added products, as bran and flour in several food applications [21].

All parts of the plant are generally used: fruit kernels, spike, whole plant for ensilage, and straw.

Barley grains are larger and more tapered than wheat, generally bright, light yellow, and the color can vary with purple, violet, blue, and black shades due to the different level of anthocyanins [21].

In the caryopsis, the main parts of the kernel are husk, pericarp, testa, aleurone layer, endosperm, and embryo. Husk and pericarp consist primarily of cellulose, hemicellulose, lignin, and lignan, the major constituents of insoluble fibers but also of minerals. The testa is composed of cellulose while the aleurone layer consists of protein-rich cells. The endosperm is a starchy mass in a protein matrix and the embryo is rich in proteins, lipids, and ash [22].

Grain barley chemical composition is strongly influenced by environmental and genetic factors. This last aspect mainly concerns the hulled and hull-less varieties which also have different uses.

In general, the composition of wholegrain barley consists of approximately 70% starch, 10–20% protein, 5–10% β-glucan (with values up to 20% for some cultivars), 2–3% free lipids, and approximately 2.5% minerals, with the total dietary fiber ranging from 11 to 34% and soluble dietary fiber being within 3–20% [1]. Barley kernels naturally contain many bioactive compounds localized in different parts of the kernel, including β-glucans, lignans, tocotrienols, folate, fructans, phytosterols, polyphenols, policosanol, phytates, pentosans, and arabinoxylans, which play numerous biological activities (prebiotic, probiotic, antioxidant, hypoglycemic, hypocholesterolemic, a reduction of cardiovascular disease, colon cancer, and neural tube defects), and with growing awareness of the need for healthy eating, they can be used as ingredients for the development of functional foods [23]. The last decade saw an increasing interest for this plant mainly due to its health and nutritional benefits [24]. In fact, consumers are even more conscious that food may contribute to also improve their psychophysical well-being [25, 26] Therefore, the food production and market have to be oriented to this type of products, contributing to the customer satisfaction. It is in this context that consumers increasingly appreciate functional food, a food intending to affect one or more functions of the body in a positive way, in a way that is relevant and to improve the health and well-being and/or reduce the risk of a disease [27, 28]. There are different types of functional foods and diverse approaches to obtain them. A functional food can be a natural food (e.g., food grains, cereals, wholemeal flours, etc.) or it can be obtained by processing a food utilizing different chemical or biological technologies [29]. Among these different possibilities, cereals are ideal to be used in transmitting compounds and substances with bioactive and dietary properties because, meeting consumer's favor, they are widely and frequently included in our dairy diet. In particular, barley (*H. vulgare L.*) is an excellent source of dietary fiber and a functional food ingredient such as beta-glucan [1, 2].

3.2. Barley for feed

As currently mentioned above, approximately 75–80% of global barley production is used as animal feed, 20–25% as malting, 2–5% for human food, and the remaining part in biofuel industry (bioethanol production) [1, 30].

In 2017, EU was the main utilizer of barley feed with 40.5 Mt followed by Russia (12.3 Mt), Canada (8.8 Mt), and Turkey (6.5 Mt) and Saudi Arabia (6.3 Mt, almost totally imported) [12] (**Table 4**).

The main reason of its large use in feed industry is essentially due to its great adaptability to a large variety of pedo-climatic conditions, making it available where other cereals are not and its nutritional value. The use of barley as feed depends on its chemical composition which is

Countries	Barley uses		Countries	Barley uses	
	Feed	Food		Feed	Food
EU-25	40509000	15636000	Marocco	1739000	870000
Russia	12343000	4944000	China	1656000	425000
Canada	8893000	1553000	Japan	1362000	300000
Turkey	6584000	809000	Algeria	943000	293000
Saudi Arabia	6326000	12000	Tunisia	883000	58000
Ukraine	4631000	1531000	South Africa	203000	153000
Iran	3737000	261000	Taiwan	68000	31000
Australia	2924000	961000	South Korea	30000	364000

Source: [31].

Table 4. Barley feed and food use in different countries (2016).

strongly influenced by cultivar and where and how it is harvested. Barley protein content, for instance, is very much dependent on the harvest practices and differs with growth conditions, particularly with the rate and timing of nitrogen fertilization [6, 32]. Furthermore, the good content of starch and protein in the grain (respectively, equal to 50–70% and 10–20% on dry matter base) makes barley a suitable energy source in ruminant and non-ruminant livestock, poultry, and fish [33].

Barley, compared with corn, shows an almost similar starch percentage but a higher content of total crude protein (respectively, equal to 10–20 and 8.8% on dry matter base), a higher value of essential amino acids such as lysine (respectively, equal to 0.43–0.21% on dry matter base), and almost double tryptophan amount. The average barley contents of neutral detergent fiber (NDF) and acid detergent fiber (ADF) are equal to 18 and 6–7%, respectively. The latter values are higher than corn (NDF 10.8%, ADF 3%), wheat (NDF 11.8%, ADF 4%), and sorghum (NDF 16.1%, ADF 7–9%) [30, 34]. The evaluation of NDF and ADF is important because it is related to the animal ability to digest them and to the feed efficiency use. Fiber main fraction is in hull (13%); dehulling practice is not suitable for feed utilization because the seeds are fused to the hulls by a cementing substance hard and expensive to remove. Barley is rich in potassium (0.57%) and vitamin A but poor or without vitamin C and B12. Barley contains a relatively high concentration of β-glucans, compared with other grains ranging from 3.9 to 4.9% (reaching a concentration equal to 8–10% [35, 36]. β-glucan content is an important parameter to evaluate, mostly in monogastric animals diet, because they act as anti-nutritional factors, reducing feed compound digestibility. In poultry nutrition, for instance, they have negative effects in both growth and feed efficiency but, adding exogenous enzymes such as β-glucanase, an improvement in bird performance is recorded [37]. The main products utilized in barley feed animal diet are (1) whole or minimal processed barley grain, (2) whole plant forage, (3) malt-based alcoholic beverage by-products, and (4) and milling ones. The first is largely used in cattle diet but, to improve the feed efficiency, minimal mechanical treatments are required. The fibrous hull of barley grain makes the kernels no totally "broken" during the mastication, and mechanical processes are needed. Dry rolled or grounded barley are the most diffused and the less expensive ones. During this treatment, the particle size is important to control because smaller they are, higher the fermentation is in rumen, higher the decrease in feed efficiency. Of course, variation in cattle barley wholegrain feedlot nutritional values depends on the animal's ability to masticate, digest, and adsorb them. There is no specific quality restriction to use barley grain in animal feed industry. Often, malting barley is destined to feed industry because there has been damage during agricultural phase or it has not met the quality level required by malting and brewing industries or due to market or price variations. Barley plants are used for forage, pasture, or hay, and their composition and quality mostly vary according to the harvested stage. Straw remaining after grain harvesting is a good fiber source for ruminant or can be used for animal bedding. On average, whole plant and straw ADF is equal to 345 g/kg on dry mass and 590 g/kg on dry mass, respectively, and NDF is 563–568 g/kg on dry mass and 725 g/kg on dry mass [30]. It has been a long time since byproducts of malting and brewing industries are used in animal feed. Their quantity and quality depend on technologies applied and barley varieties utilized. **Table 5** shows the chemical composition of main products (grain, whole plant, and straw) and by-products obtained from mainly brewer and milling industries useful and utilized in barley feed.

3.3. Barley for food

Barley's versatility as food is well known across the world, and it is historically acknowledged. Although barley has remained a major food source for some geographical areas [14, 32], it may be considered relatively underutilized with regard to its potential use as an ingredient in processed human foods. The quantity of barley used for food (excluding the beverage sector) is still very small considering its high nutritional value. The barley grain has a chemical composition extremely useful for the organism: low fat, complex carbohydrates, balanced protein level, a good presence of vitamins, minerals, antioxidants, insoluble, and soluble fiber [2]. The current appreciation of barley as a food source is due quite to its potential health benefits. As a matter of fact, in the past, barley foods had been considered as health-promoting and strength-enhancing. Subsequently, as already underlined, the diffusion of wheat for producing bread and other baked foods has taken over barley's use as food. However, recently, this grain has been reevaluated as having significant benefits in human health functions such as cholesterol-lowering, blood sugar control, and colon health [38, 39, 40, 1]. **Table 6** shows the major bioactive compounds, its localization in the kernel, and health benefits.

	Crude ash	Crude protein	Crude fat	Crude fiber
Grain	23	115	570	110-340
Whole plant	75-188	67-120	29-39	356-568
Straw	64-75	38-44	17-19	420-438
Hulls	71	85	44	276
Maltsters sprout and hulls	66	296	10	164
Milling process	43-71	138-111	34-37	81-209
Brewers grains	49	244	79	177
Brewers yeast	85	530	20	15

Sources: elaboration on [1, 30, 34].

Table 5. Chemical composition of main products and by-products utilized in barley feed (g/kg on dry mass).

Compound	Location	Activity
Beta-Glucans	endosperm/aleuronic layer	cholesterol-lowering/hypoglycemic
Tocopherols	embryo/aleuronic layer	antioxidant/cholesterol-lowering
Tocotrienols	embryo/aleuronic layer	antioxidant/cholesterol-lowering
Folate	aleuronic layer/embryo	reduction of neural tube's defects/reduction of cardiovascular risks
Phytosterols	embryo/aleuronic layer	cholesterol-lowering
Polyphenols	pericarp	antioxidant
Phytates	pericarp	reduction of colon cancer
Policosanol	pericarp	cholesterol-lowering
Pentosans	pericarp	cholesterol-lowering
Arabinoxylans	pericarp	cholesterol-lowering
Lignans	pericarp/aleuronic layer	reduction of cardiovascular risks/reduction of malignancies
Alkylresorcinols	pericarp	antioxidant

Source: elaboration on [23].

Table 6. Compounds with biological activity in barley caryopsis.

According to [14] the quite high content of β-glucan found almost exclusively in oats and barley contributes to heart disease prevention for people who regularly eat these cereals. In fact, numerous clinical trials show barley's equal or superior value as a hypocholesterolemic food compared to oats contributing to reducing the risk of coronary heart diseases. This compound has also a positive action to the bowel function. β-glucan with the resistance starch fermenting in the large intestine produces short-chain fatty acids especially butyrate and propionate. These fatty acids provide many benefits to the intestine such as energy for epithelial cells that contribute to produce a healthy colonic mucosa [41].

Moreover, the typology of carbohydrates present in the barley seed can contribute to reducing or stabilizing the progression of diabetes disease. This characteristic was already known by ancient Indian physicians some 2400 years ago which used barley to stabilize type 2 diabetes [42].

In the food industry, barley may be blended into many food products at various levels, adding texture, flavor, aroma, and nutritional value to products [43, 44].

Barley undergoes treatments/processes before it can be used in the food sector. The diverse operations modify the chemical composition of the kernel due to the significant differences in the anatomy and composition of the various parts of the same.

This determines a variation in the nutritional value of the kernel and a potential different product range [14]. **Figure 9** shows a simplified schematization of the main products and co-products derived from the treatments undergone by the barley.

Whole barley grain is mostly used for feeding animals, whereas for food purposes, it is mainly used as a dehulled grain or high fiber content products. Commercial products derived from wholegrain include barley flakes, grits, and flour.

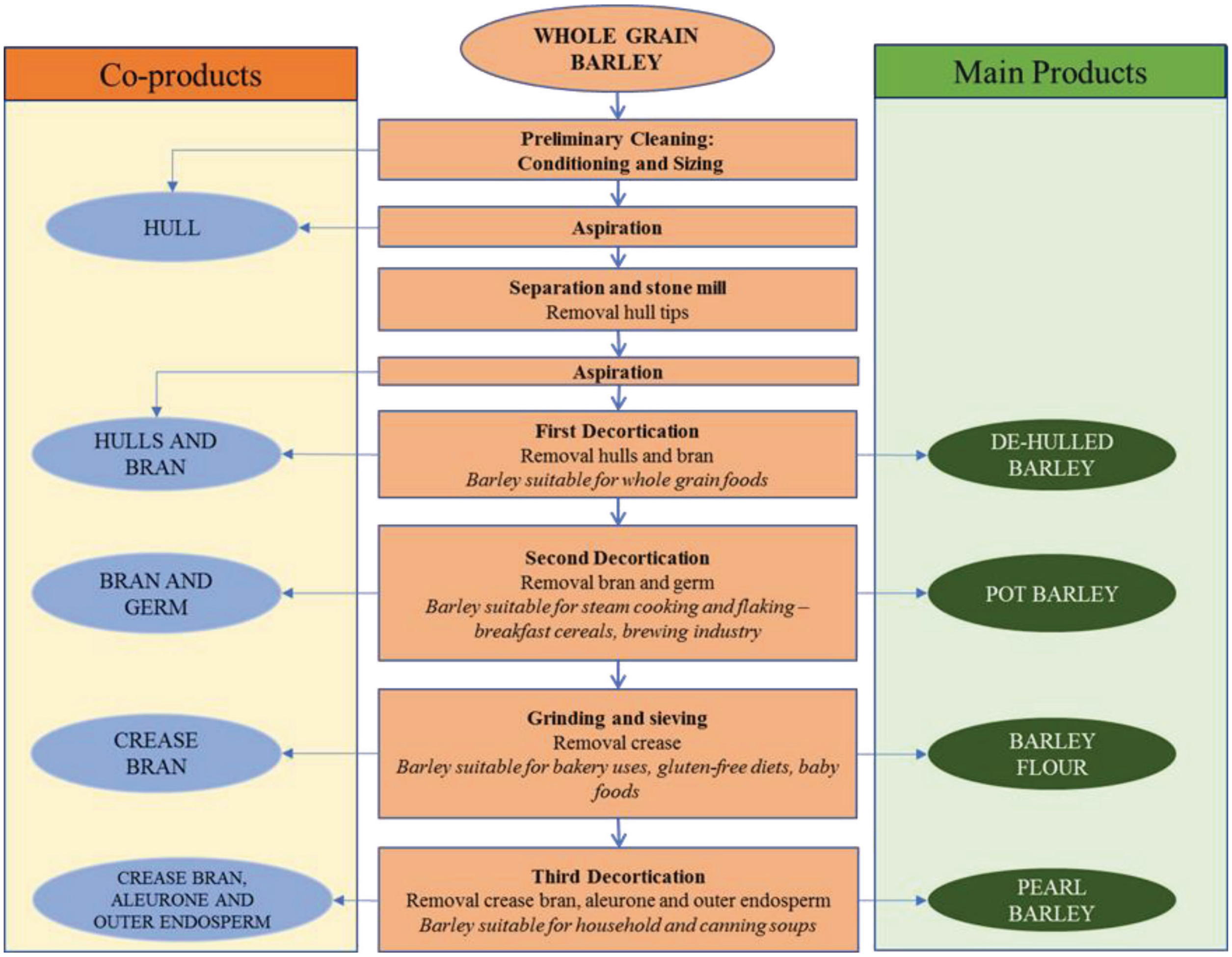

Figure 9. Main products and co-products derived from barley milling process (source: personal author's elaboration).

Food produced from barley is a good source for many nutrients such as protein, fiber, minerals, and B-vitamins [30].

For this purpose, barley grain is first abraded to produce pot or pearled barley and may be further processed into grits, flakes, and flour.

The most common method of processing hulled barley is pearling, which consists of the gradual removal of the outer tissues of the kernel by abrasion. As a result, pot and pearl barley are not considered wholegrains since they are high in β-glucan content. The hull represents about 10–13% of the dry weight of the kernel, but the commercial pearling method involves removing more than the hull in order to produce a white-colored, quick-cooking product. Pearling allows barley to have a longer shelf life since the lipid fraction, phenolic compounds, and enzymes contained in the germ are removed. These molecules cause rancidity and darkness barley. About 15% of the outer layers are eliminated in pot barley, whereas in pearl barley, more than 45%.

Pot and pearl barley are not considered wholegrain because the bran layer and germ are removed. They are also used to make porridge, pie fillings, as an alternative to rice, pasta, or potatoes. Barley flakes are used as an ingredient in muesli or breakfast cereals.

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Cooked pearled barley is used in the preparation of many traditional dishes and also used to produce miso, barley tea, and rice extender in the Japanese market.

Barley flour, prepared from pearled grain through hammer milling or roller milling, can easily be used to produce bread, flat breads (pitas, tortillas, and chapatis), cakes, muffins, cookies, noodles, and extruded snack foods [14, 43, 44]. Barley flour can replace all or part of the wheat flour in a wide assortment of bakery products such as, for instance, pasta and noodles.

The use of barley starch is also interesting for the food industry, where it is used as sweetener and binder. In the brewing industry, barley starch is used, together with barley malt, in the production of beer.

Barley for malt and beverages. The best known and most widespread use of barley for food purposes is related to the production of malt that is primarily used in the brewing industry, alcoholic and non-alcoholic beverages. Barley malt is mainly used for beer production while smaller amounts are used by the whisky distilling industry and by bakeries [25].

Barley malts, malt extracts, and syrups are used in small amounts in food products to improve some organoleptic characteristics such as flavor and color, for breakfast cereals, fermented and non-fermented bakery products (e.g., crackers, cookies, and muffins).

Malt extract is a source of soluble sugars, protein, and amylase in the dough and promotes the activity of yeast for better bakery products for texture, volume, etc.

The history of alcoholic drinks including beer goes back to at least 8000 years ago in the Middle East and in Egypt [14, 45]. Barley is used to make most beers because its carbohydrates are particularly well suited for malting. The malting process breaks down carbohydrates into sugars which provide unique flavors and fuel for fermentation. Barley can also be used to make whiskey, quite popular in Ireland and Scotland.

Starch fermentation products are also distilled to pure grain alcohol for vodka-type products as well as industrial ethanol that is sold mainly to the pharmaceutical industry.

Modest quantities of non-alcoholic drinks based on barley and malt are consumed in various parts of the world. A non-exhaustive list of non-alcoholic beverages based on barley is as follows:

1. *Barley infusion*: coffee substitute (contains no caffeine), obtained from toasted and ground grains, lyophilized or in pods prepared for espresso machines; barley coffee is very popular in Europe particularly in Italy.

2. *Barley water*: a drink that is made by boiling whole or pearled barley and then flavoring with various fruits. It is a flavorful drink that is enjoyed similar to soft drinks with healthy properties; barley water is used as a dairy substitute for drinks such as smoothies or hot chocolate, or to replace milk on breakfast cereals.

3. *Barley tea* is common in Asian countries (called *mugicha*) and is made by lightly roasting barley and then steeping in hot water.

4. *Malted beverage*: there are also various malted beverages available, often in the form of "malty milk" in which malt extract is blended with milk.

3.4. Other uses of barley

In this paragraph, both new technologies still under study or pre-commercial phase and niche uses of barley that could be developed in the near future are briefly presented. For instance, barley grain is currently utilized in United States of America and in European Union in bioethanol production when the cheapest starch sources such as corn or wheat are not available or a surplus of barley production is recorded [46, 47]. However, the possibility to utilize barley residues or leftover barley by-products (e.g. hulls and mostly dried distillers grain - DDGS) as sources in bio-energy industry is under study. So, hydrothermal liquefaction technology could be useful to obtain bio-oil for transport system or energy sector to produce heat and/or electricity [48]. Moreover, the potential exploitations of barley in non-feed and food fields are numerous and are strictly linked to barley composition, structure, and physicochemical properties of a single component of the plant. For example, the presently growing interest is focused on barley straw use as an alternative non-wood raw material in pulp and paper industry. Paper made from this agriculture residue presents great potential, in terms of paper sheet quality, compared with some wood species much commonly used such as *P. sylvestris* and *E. camaldulensis* [49, 50]. Moreover, the high concentration of biocompounds in barley grain and distillery and brewery byproducts (such as phenolics, vitamin E and β-glucan, sterols, fatty acids, and bioactive peptides) makes barley a potential source of row material in pharmaceutical and cosmetic industries. Also, lactic acid, xylitol, and microbial enzyme are products obtainable from barley and useful in different industrial sectors [51]. Barley collagen, for instance, is considered a good and profitable collagen vegetal source for cosmetic industry [52]. Furthermore, barley starch shows a suitable attitude to be modified, becoming an appropriate row material for numerous pharmaceutical applications or in the production of biodegradable materials useful in food packing industry [53, 54].

Finally, the interesting use is barley straw as an inhibitor for the growth of algae to preserve water resources from algae proliferation [55, 56]. This new technology could help substitute the chemical products contributing to reduce the environmental impact of water treatment process.

Barley, as already underlined, has developed during its millennial evolution some interesting characteristics, allowing its diffusion and adaptability in a wide range of geographical locations and climatic conditions. This aspect is particularly interesting in an era of climate change whose effects are also reflected in agricultural production. In the recent years, there have been a significant and increasing number of studies on the effect of climate change on agriculture [57] through the use of specific models and software [58]. Climate change is one of the major concerns related to food supply for the increasing population. It has already generated significant impacts on the availability of resources, water, and food production. It is one of the most significant factors influencing crop production [59]. In fact, it affects yield and yield quality due to impacts on crop physiology and in alterations in nutrient mineralization; barley for its characteristics, even in adverse climatic conditions, could represent the right answer to the greater demand for food, feeds, etc., in a strongly dynamic world context [60].

4. Conclusions

Barley represents one of the ancient grain crops cultivated and used worldwide. Thanks to its high adaptability, this plant grows in different global climates where other cereals (i.e., maize, wheat, and rice) do not live such as in arctic and subarctic zone to subtropical region. This work has presented some interesting aspects of this grain, regarding especially the international market trend and use. The principal results from this overview are the following:

1. in the last 70 years, the harvesting area is decreased especially in the major barley production countries such as Russia (including all the countries from former USSR), United States, India, and China, probably due to the low income deriving from this culture with respect to others such as maize. However, this situation has been balanced by the yield improving, changed from about 1.4 t/ha in the years 1960 to 3 t/ha in 2017, which has pushed the barley production from almost 79 (1960) to 141 Gt (2017);

2. currently, the leader, in terms of production and area dedicated, is EU followed by Russian Federation, Ukraine, Australia, and Canada. In particular, Germany and France are the first and second European barley producers followed by Spain and United Kingdom which contribute more than 35% of the total EU production;

3. regarding the barley consumption in 2017, it was about 147 Mt, of which 70% is used for animal feed and 30% principally for the production of beer ingredient (malt) and a little quantity for other human food applications;

4. in the recent years, the high barley demand on the global markets not balanced by the world production has led on one side to a decrease of stocks in many countries producer and on the other side an increase of the barley price. This situation could get worse in the future due to the increase of its request in the global markets (principally China);

5. finally, the principal uses of this grain is to produce feed and beer, although recently it has been revaluated as food in the human diet, thanks to its significant benefits on the human health such as cholesterol lowering, blood sugar control, and improving of the colon health.

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