

# Hop

Subjects: Agronomy

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Hops is considered a short-day, temperate species, so the major challenge for the development of hop cultivation in Brazil, with high-yield capacity and with local typicity of bitterness and aroma, is the adaptation of cultivars to the photoperiod conditions in subtropical regions.

Keywords: *Humulus lupulus* ; cultivars ; climatic requirements ; photoperiod

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## 1. Hop Production and Economic Importance

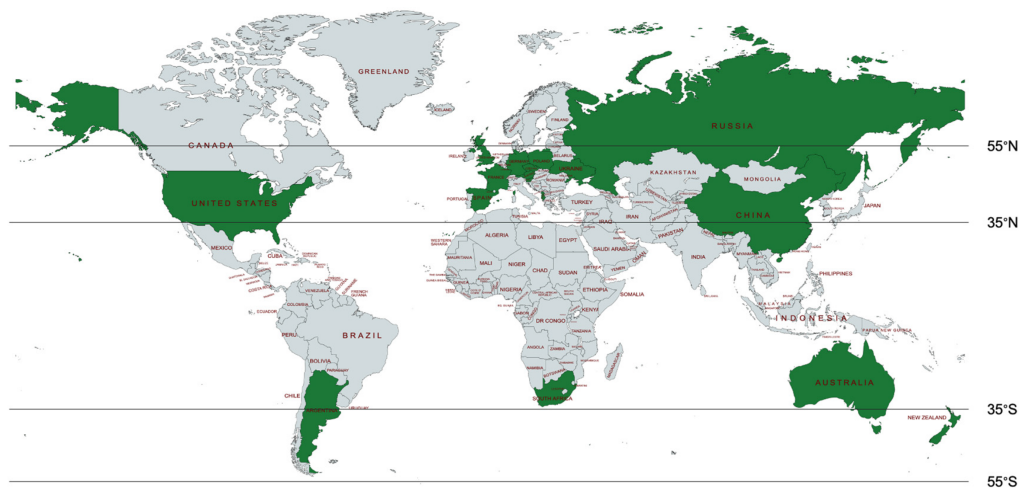
Hop (*Humulus lupulus* L.) is a dioecious twining herb of ancient domestication and use, found in the wild throughout almost all temperate climate ranges <sup>[1]</sup>. It is a perennial species that annually produces inflorescences, over an approximately four-month season <sup>[2]</sup>. The female flowers develop in cones, also known as strobiles, which are responsible for adding bitterness, aroma, and microbiological stability to beer. Hop is one of the essential raw materials for beer production worldwide <sup>[3]</sup> and, to a lesser extent, is used in the pharmaceutical industry <sup>[4]</sup>.

Each hop cultivar has different levels of aroma and essence in its composition, and the compounds of interest to the brewing industry are the levels of alpha and beta acids and the essential oils present in the cones of the hops <sup>[5]</sup>. Hops can be marketed in various forms: fresh, dehydrated, powdered, and extracts. In the brewing industry, the most commonly used form is pellets. In addition, hop is an essential raw material for the characterization of brewing products in the modern brewing industry. In addition to giving beer the typical bitter and aromatic flavor, hop is an important cofactor in several processes of stabilization of the finished product. Due to the reaction between bitter acids and wort proteins, hop allows for the clarification of beer, stabilizes foam, and is also a natural preservative <sup>[6]</sup>.

Hops are one of the most important components the brewing industry and, although they are used in relatively small amounts, they account for a large percentage of the cost of production <sup>[7]</sup>. Based on the type and amount of hops, it is possible to produce a variety of beer with different aromas and degrees of bitterness <sup>[8]</sup>.

The world's largest beer producers are China, the United States, and Brazil <sup>[9]</sup>, and the demand for a diversified range of quality hops has been growing in industries around the world. In Brazil, beer production is approximately 15.3 billion L year<sup>-1</sup> and represents 1.7% of the national GDP, with annual revenue of BRL 160 billion, and is one of the most important sectors in the Brazilian economy <sup>[9][10]</sup>. However, Brazil imports almost all of the hops used in the production of beer, and in 2020, 3243 tons were imported, mainly from the United States and Germany, for a total of USD 57 million <sup>[11]</sup>.

Hops are commercially produced in more than 20 countries, mainly in temperate regions between latitudes 35° and 55° N or S of the Equator (**Figure 1**), with the regions of Hallertau in Germany and Yakima in the United States being the most important, together representing 77% of world production. In 2020, global hop production was 122 thousand tons in an area of 62,366 ha <sup>[8][12]</sup>. The United States stands out as the world's largest producer, with approximately 47,540 tons on 24,738 thousand ha, which corresponds to 40% of the total produced, generating USD 637 million. Germany is the second largest producer, with 46,878 tons in an area of 20,706 ha, which corresponds to 33% of the volume produced. In the last 10 years, the increase in the volume of hop production and the planted area in the world was approximately 45% <sup>[12][13]</sup>.



**Figure 1.** Main producing countries and hop production areas in the world (in green), with emphasis on those located between latitudes 35° and 55° N and S.

In some production databases, Ethiopia has been considered an important hop-producing country; however, Ethiopia produces *Rhamnus prinoides* (not *H. lupulus*), an African shrub or small tree in the family Rhamnaceae, commonly referred to as *gesho*. It is used in a manner similar to hops in the brewing of *tella*, an Ethiopian beer prepared from honey, water, and the leaves of *gesho* [14].

More recently, the dynamics of global trade have greatly encouraged the expansion of hop-growing areas, now spanning between 35° and 55° parallel to both hemispheres [15], especially in Australia, New Zealand, South Africa, Argentina, and Brazil [16].

Hop cultivation in Brazil has been driven mainly by the increase in a large number of new craft breweries, which have demanded diversified raw material for the production of various types of beer. In 2020, 1383 new breweries were registered in the Ministry of Agriculture, Livestock, and Food Supply, which corresponds to a growth of 14.4% compared to 2019, and 80% are located in the South and Southeast regions of the country, between latitudes 20° and 30° S [9].

Although there are reports of attempts to grow hops in Brazil in the 19th century when the country was still a colony of Portugal, its commercial production only started to be important in 2016, when several cultivars were imported and registered by commercial nurseries with authorization from the Ministry of Agriculture, Livestock, and Food Supply, which later began to multiply and provide healthy nursery plants of high genetic quality [17].

Interest in cultivation in Brazil has increased with the influence of adapted technologies, the manipulation of the species by crossbreeding for genetic improvement, and the possibility of adaptation to local conditions [18]. This escalation of interest, both in the cultivation and commercial exploitation of hops, has attracted important investments for its establishment on the national level. Although still in the development phase, hop production has interested several entrepreneurs, mainly in the south and southeast regions of the country [16][19].

The major challenge for the development of hop production in Brazil is the adaptation of cultivars to the local geographic and climatic conditions. High yield capacity and local typicity of bitterness and aromatic flavor are two desirable features to meet the growing demand for raw material by the brewing industry in Brazil. Researchers address the main characteristics of hop cultivation in Brazil, such as the history, introduction, plant use, adaptation of cultivars, and cultivation techniques, as well as analyze and discuss the main climatic elements that influence its cultivation in emerging subtropical regions of different latitudes.

## 2. Hop Growing in Brazil

The first reports of hop cultivation in Brazil date back to 1885, when Emperor Dom Pedro II brought seedlings to cultivate in the state of Rio de Janeiro. There are also reports from 1869 of the introduction of seedlings brought by Polish immigrants to the state of Paraná. Decades later, in approximately 1953, the Austrian immigrant Roland Hoblik planned to cultivate hops in Nova Petrópolis in the state of Rio Grande do Sul, but cultivation of the species failed to prosper when the local breweries that supported its production were acquired by a larger brewery that imported this raw material from other countries [17], and the activity was discontinued. Other isolated attempts at cultivation were also carried out later in the early 1980s at the Instituto Agrônômico do Paraná, but without success.

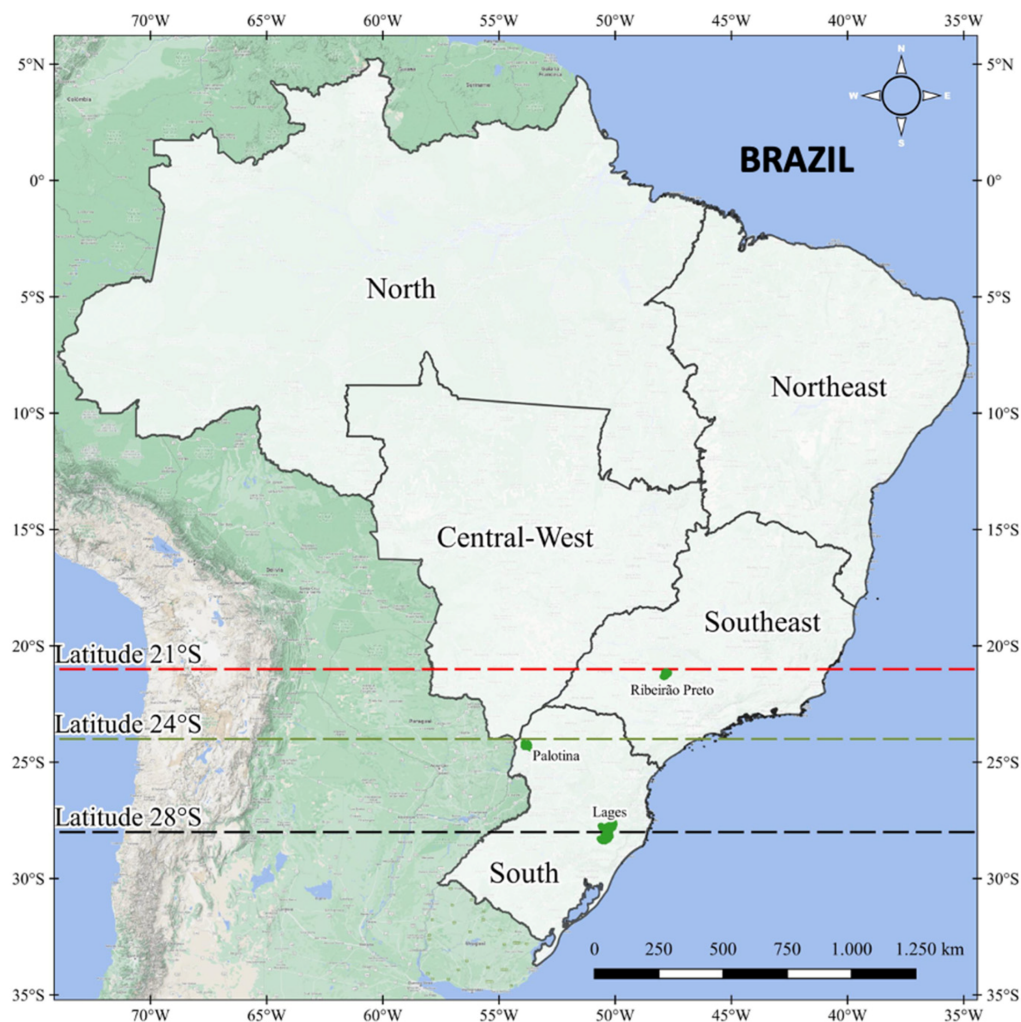
In the mid-2000s, attempts to cultivate hops resumed in Brazil. A grower in the state of São Paulo started to grow hops plants from seeds imported from Canada, but he had no success and decided to remove the plants. In 2005, one of the plants that had been removed naturally regrew and developed in the field, completing its full life cycle. Subsequently, this plant multiplied and the cultivar was given the name Mantiqueira. This sparked interest in imminent production in several locations in the country [20].

By 2010, the cultivation of national hops became more important, driven by the growing number of craft breweries in the country which demanded diverse raw material for the production of different types of beer. This resurgence motivated several entrepreneurs to invest in new cultivation areas due to the availability of new technologies developed by some research institutions [19][21][22]. Among these technologies, the use of supplemental lighting from LED lamps to control the flowering of plants in the field stands out. No regions of Brazil otherwise meet the minimum requirements for the hop photoperiod, specifically that of regions between latitudes 35° and 55° North or South of the Equator (**Figure 1**), and this was one of the main causes of the failure of hop cultivation in the country previously.

It is noteworthy that the national hop demand was also influenced by the search for freshly harvested and dehydrated raw material, requiring shorter storage time, as the hops lose quality in the pelleting process due to oxidation and degradation of their chemical compounds over time [5].

Given the growing interest in hop cultivation in Brazil, in 2018, the Brazilian Association of Hop Producers—APROLÚPULO—was founded in association with the University of State of Santa Catarina, UDESC, Lages, in the state of Santa Catarina, with the objective of gathering information and promoting hop cultivation in the country [18]. Additionally, in 2018, a network was formed for the promotion of hop cultivation in the Região da Serra Fluminense, in the state of Rio de Janeiro, bringing together several public research institutions and private companies to share knowledge and resources so that hop cultivation could become a viable activity.

The main Brazilian hop production initiatives are spread over 50 ha in regions of different latitudes and climates, especially in the southern region of the country [16]. For this reason, this region has the highest concentration of hop producers and craft breweries in the country, and the state of Santa Catarina has the largest number of producers, specifically in the Lajes region (latitude 28° S). Other hop production initiatives have also been carried out in other regions in the south of the country, such as in Palotina, in the state of Paraná (latitude 24° S), and in the southeast region, including Ribeirão Preto (latitude 21° S (**Figure 2**), whose main climatic characteristics will be summarized later.



**Figure 2.** Map of Brazil including some emerging hop-growing areas located at different latitudes: Lages, Santa Catarina state (28° S, 50° W, elevation 916 m a.s.l., Cfb climate, humid subtropical with temperate summer); Palotina, Parana state (24° S, 54° W, elevation 320 m a.s.l., Cfa climate, humid subtropical with hot summer); and Ribeirão Preto, São Paulo state (21° S, 48° W, elevation 516 m a.s.l., Aw climate, tropical with dry winter).

Thus, the hop production chain in Brazil represents the integration of different sectors, and several studies have been carried out, among which the following topics stand out: adaptability of cultivars; breeding; training systems; supplemental lighting; irrigation and fertilization management; disease and pest control; economic and feasibility studies; and methods of chemical evaluation of cones and quality for the brewing industry <sup>[4][17]</sup>.

In addition, due to the climatic conditions in Brazil, the possibility of more than one production cycle per year was explored in some regions, while in regions following traditional cultivation practices, only one cycle is obtained per year <sup>[19]</sup>. This is a differential that can further enhance hop cultivation in the country, similar to the state of Florida, US <sup>[23]</sup>, whose climate is also subtropical and situated at latitude 31° N.

These hop cultivation initiatives in Brazil have generated great enthusiasm for the production of this important raw material for the brewing industry. In addition, Brazilian hops have shown distinct characteristics in terms of bitterness and aroma when compared to imported products, which have led to the production of beer with typicity <sup>[5][24]</sup>, which has been the focus of several initiatives in the country.

Brazil has great potential for the development of hop cultivation, and the interest in expanding the production chain has led to the union between public research institutions and private companies, such as AMBEV (Americas' Beverage Company), with the aim of generating, expanding, and disseminating knowledge about the production of high-quality and sustainable raw materials in the country <sup>[25]</sup>.

### 3. Botanic Characteristics and Hop Cultivars

The genus *Humulus* consists of three species, *Humulus lupulus*, *Humulus japonicus*, and *Humulus yunnanensis*, with *H. lupulus* being the main commercially cultivated species used by the brewing industry because of its high levels of lupulin <sup>[16][26]</sup>.

Hops are climbing, herbaceous, and perennial plants belonging to the Cannabaceae family. They are a dioecious plant, developing male and female flowers on separate plants [27][28]. However, only female plants are cultivated on a commercial scale, since female flowers, called cones or strobiles, have a higher yield of resins. The flowers of the male plant have only 10–15 lupulin-secreting glands, while the female flowers have 10,000 or more glands [16]. Thus, male plants, which are easily distinguished from females, are only important for breeding and are used to develop new cultivars in controlled crosses [29] but should not be used for commercial production in the field.

The resins produced in cones originating from female flowers are characteristic of hops and are not found in any other plant species. The resins are produced in lupulin glands present in the trichomes of the bracts of the inflorescences [20].

Lupulin-secreting glands have the ability to synthesize and store resins and essential oils due to the presence of more than 300 aromatic compounds. Essential oils are formed mostly by hydrocarbons [4], phenolic terpenes, and polyphenols [30]. Terpenoid compounds, including alpha acids, also known as humulones, serve as a source of flavors and aromas, while beta acids, or lupulones, produce wort biostasis [31]. In resins, the percentage of alpha acids, beta acids, and essential oils varies between 3 and 17%, 3 and 7%, and 0.5 and 2%, respectively [16].

Alpha acids contribute to beer bitterness and act as bacteriostatic agents, favoring the action of yeasts during the fermentation process and inhibiting the action of some bacteria. Alpha and beta acids start to accumulate in cones from the beginning of the flowering stage [27].

Essential oils are chemical compounds related to the aromatic components of different cultivars and provide aroma to beer. The groups to which these compounds belong are the monoterpenes (myrcene, limonene, and alpha-pinene), sesquiterpenes (farnesene, humulene, and beta-caryophyllene), and terpene alcohols (linalol) [5].

The chemical composition of hop cones depends on the genetic factors of the different cultivars, harvest points, and climatic and geographical conditions [32]. The concentrations of these compounds are largely dependent on the age of the plant, the cultivar, and the soil and climate conditions associated with the cultivation location [33]. The yield increases until the third year of the plant's life, when they tend to stabilize, and in the first two years, their quality is lower [34].

The cultivation of hops for use in beer production originated in the Northern Hemisphere, starting in Eastern Europe around Bohemia, Slovenia and Bavaria before the XIII century, then spreading to other European countries [16]. In addition to the characteristic bitter and aromatic flavor, hops became known for their conservation properties in beer, as opposed to the combination of herbs, flowers, fruits, roots, bark, and even vegetables, known as *gruit*, which were added to the beverage for these purposes [4]. Thus, in 1516, in Bavaria, Germany, the Purity Law was created also known as *Reinheitsgebot*, in which only hops could be added to impart bitterness in beer [20]. In 1629, European hops began to be introduced in the United States, and soon cultivation of the plant spread to the south and west of the country; however, it was only in the 1800s that production on a larger scale was successful [29].

Starting in the 1800s, the British introduced the crop in their southern hemisphere colonies, such as in South Africa, Australia, and New Zealand. In approximately 1860, the Germans introduced hops to China and Korea, and in 1876, with the popularity of hop beer, the Japanese began to produce American and German cultivars. Finally, hops arrived in South America in 1851, brought by a Chilean diplomat who started their commercial cultivation in Chile in 1857. Later, German immigrants living in southern Chile introduced hops in Argentina in 1865 [20].

Hop cultivars differ according to their country of origin, morphological characteristics, maturation periods and chemical composition [35], especially in relation to the quantity of alpha and beta acids and essential oils [36]. Bitter cultivars are characterized by having higher levels of alpha acids in their chemical composition [5].

There are currently more than 260 cataloged hop cultivars, each with different characteristics appreciated by the brewing industry in terms of bitterness, aroma, and flavor [35]. However, the most abundantly cultivated cultivars worldwide include approximately 30 American and 40 European cultivars, with a smaller number of Asian cultivars.

The hop cultivars with the largest production area in the US today are Citra®, Mosaic®, Simcoe®, Cascade, Centennial, and CTZ (an acronym for Columbus, Tomahawk, and Zeus, three trade cultivars owned by various private corporations for the same cultivar of hop) [12], while in Germany, the most important cultivars are Perle, Hallertau Tradition, Hallertau Magnun, and Herkules [8].

In Brazil, there are 48 hop cultivars registered in the Ministry of Agriculture, Livestock, and Food Supply, the most abundantly cultivated currently being Cascade, Columbus, Chinook, Nugget, Saaz, Centennial, Comet, Hallertau,

Hallertau Mittelfrüher, Mapuche, Magnum, Zeus, Fuggle, and Northern Brewer<sup>[9]</sup>. An important impetus for the increase in new hop areas in Brazil was the establishment of commercial hop nurseries, such as Ninkasi, Hops Brasil, Van de Bergen, and Lúpulo Gaúcho, which have provided a supply of female nursery plants of different cultivars and of high genetic quality, multiplied via cuttings.

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