Climatological conditions of the southern Santa Catarina state highlands for hop production

Mariana Mendes Fagherazzi[1], Valéria Rodrigues Sarnighausen[2], Leo Rufato[1], Francine Regianini Nerbass[1], Marllon Fernando Soares dos Santos[1]*

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ABSTRACT

This study aimed to characterize solar brightness, photoperiod, phenology and productivity of Chinook, Columbus, Cascade and Yakima Gold hop cultivars grown in the municipalities of Lages and São Joaquim in Santa Catarina state, southern Brazil. The phenological stages evaluated were: beginning of sprouting, emission of lateral branches, beginning of flowering, formation of cones and beginning of harvest in the 2018/2019 production cycle. Photoperiod and solar brightness were calculated with data obtained from the Environmental Resources and Hydrometeorology Information Center of Santa Catarina State, in Lages and São Joaquim. The observed results demonstrate hops develops at latitude 27º South, there was a difference in behavior in the phenological cycle of the cultivars, characterizing Yakima Gold as early, with 143 days and Columbus with 191 days, late. Since the first agricultural harvest, there is the production of cones. With 5.87 hours per day solar brightness average, in Lages, 3,300 kg of fresh hops were produced per hectare. In São Joaquim, with a 5.53 hour per day solar brightness average, 6,000 kg of fresh hops were produced per hectare.

Keywords: photoperiod; solar brightness; phenology; *Humulus lupulus* L.

INTRODUCTION

As one of the five largest beer producers, Brazil stands out in the beer market internationally, producing and selling around 13 billion liters. As a necessary raw material for the preparation of beer, four basic ingredients are needed: water, malt, yeast and hops. This last ingredient is imported in full volume, to serve the national brewing industry. World hop production is concentrated between latitudes 35º and 45º, south and north, however the largest world hop producers are located in the northern hemisphere, with the United States and Germany being the largest producers of this culture (Fagherazzi & Rufato, 2018).

Hop farming got its place in Brazil more than 60 years ago, with the arrival of European immigrants (Pereira, 2021). However, the cultivation of hops has given way to other economic activities in the country. Less than 10 years ago, hop farming returned to the fields of cultivation, due to the growing number of microbreweries registered in recent years in Brazil (Spósito *et al.*, 2019).

For several plant species, flowering is dependent on the relative length of day and night, so the duration in hours of the day, in relation to the night, is called the photoperiod. This mechanism quantifies intervals of darkness with intervals of light to which plants are exposed (Baruzzi, 2005). According to Rybacek (1991), cultivated quality hops generally require 1,800 to 2,000 hours of solar radiation per year. Within this interval, 1,300-1,500 hours must occur in the vegetative period, where hop plant needs more energy to create biomass. Considering vegetative period of hops

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[1] Universidade do Estado de Santa Catarina, Lages, Santa Catarina, Brazil. marianaargentamendes@gmail.com; leo.rufato@udesc.br; fr.nerbass@udesc.br; marllon.soares@outlook.com
[2] Universidade Estadual Paulista 'Júlio de Mesquita Filho', Faculdade de Ciências Agronômicas, Departamento de Bioprocessos e Biotecnologia, Botucatu, São Paulo, Brazil. valeriacrs@fca.unesp.br
*Corresponding author: marllon.soares@outlook.com

lasts between 122 and 127 days (Rybacek, 1991), plants need an average of 11.2 hours of sunshine per day in the spring.In field, warmer temperatures and longer photoperiods bring the hop at transition from juvenile to adult phase. Warmer temperature is a condition to hop flower under shorter day length. However, to achieve a plenty of flowering and yield, the plants need more hours of light during early season (Jastrombek *et al.*, 2022). Recently the effect of photoperiod was disentangled of vernalization temperature. Increasing the photoperiod above the critical length for hop flower induction in both vernalized and non-vernalized plant material, hops do not require either low temperature chilling or dormancy to achieve typical flower initiation, formation, and cone yield (Bauerle, 2019).

This study aimed to characterize phenological development and quantify the photoperiod, solar brightness and productivity of four hop cultivars in the southern highlands region of Santa Catarina State, in order to identify new cultivation options for small producers.

MATERIAL AND METHODS

The experiment was developed in the 2018/19 harvest in two municipalities, Lages and São Joaquim, Santa Catarina State. In Lages, a study took place in an experimental area at the College of Agriculture and Veterinary of Santa Catarina State University, located at 27 ° 48'S South and 50 ° 19'West, and 922 meters above sea level, with Koeppen classification, with Cfb type climate (temperate climate with cool summer) and average annual temperature of 14.3 ºC, with average rainfall of 1479.4 mm per year (Cardoso *et al*., 2003). The soils in the experimental areas are classified as aluminum humic cambisol (Bertol, 1994). The evaluated hop cultivars were Cascade, Columbus, Chinook and Yakima Gold.

Another experimental area was conducted in the municipality of São Joaquim - SC, located in a commercial area of the Agricultural Cooperative of São Joaquim at 28º 17'S, 49º 56 'W, at an altitude of 1,280 meters above sea level, on classified soil in Neossolo Litólico. Region climate is characterized as humid subtropical, Cfb according to the Köeppen classification. Annual temperature average is 14.8 ºC, and annual precipitation average is 1,597 mm (INMET, 2022). The evaluated hop cultivars were Cascade, Columbus and Chinook.

Meteorological data were obtained from the Environmental Resources and Hydrometeorology Information Center of Santa Catarina State, in Lages and São Joaquim. Phenology analysis was performed only for the municipality of Lages.

Photoperiod was calculated for Lages and São Joaquim, for the period of one year, through the astronomical Earth-Sol relations (Silva, 2006). The mathematical relationship (Equation 1) for the calculation of the photoperiod (N) is given by:

$$N = \left(2 * \frac{hn}{15°}\right) \quad (1)$$

Hn considered as the hour angle for sunrise, in hours. The Hour angle, in turn, depends on a mathematical relationship (Equation 2) that considers the latitude of the location (Φ) and the solar declination (δ):

$$hn = arccosarccos\left[-tg\left(\Phi\right) * tb\left(\delta\right)\right] \quad (2)$$

Solar declination is calculated by the following mathematical relationship (Equation 3), considering the number of the day in the year (NDA), or Julian day:

$$\delta = 23.45 sen\left[360 * \frac{NDA - 80}{365}\right] \quad (3)$$

Data referring to the number of hours of sunlight, from the cultivation period, were obtained from the Epagri Automatic Meteorological Station, for the locations of São Joaquim and Lages

Determination of plant phenology was carried out by the same person and on the same plants. The beginning of sprouting, the emission of lateral branches, the beginning of flowering, the formation of cones and the beginning of harvest were evaluated weekly, following the phenological scale proposed by BBCH (Rossbauer, 1995).

Estimated productivity was determined from the production of fresh cones obtained by plant and estimated per hectare. The treatments consisted of cultivars in a four-block randomized design with six plants per treatment.

The data obtained were evaluated descriptively, according to Silvestre (2007), since through descriptive statistics it is possible to compare the same phenomena under different conditions.

RESULTS AND DISCUSSION

Figure 1 shows weeks and months of the main phenological stages of the cultivars evaluated, during the 2018/2019 harvest according to the methodology proposed by BBCH (Rossbauer, 1995). Results demonstrate different periods of development among the cultivars evaluated, corroborating with studies carried out in Italy, in the Mediterranean that point out that there is a significant difference between cultivars in relation to their phenology (Rossini *et al*., 2016).

Sprouting phase started in first week of September for Chinook and Columbus, in the second week for Cascade and in the fourth week of September for Yakima Gold, that takes longer to start sprouting, 15 days after the first early cultivar, Columbus.

Analyzing phenology of different grape varieties in Serra Gaúcha region, northern Rio Grande do Sul State, Mandelli (2003) explains the classification based on the growing season is important for wine growers, as it allows the use of early growing varieties in places with low risk of the occurrence of late frosts, and varieties of late sprouting in places prone to this phenomenon. If this same reasoning were used for hops cultivation, due to the fact that grapes are also grown in the studied regions and there is still no theoretical reference for the basis of discussions for hops varieties in Brazil, it could be indicating Yakima Gold as cultivar best option, of late sprouting, to try to avoid frost damage in the southern highlands of Santa Catarina.

Leaf development started in third and fourth weeks of September for Chinook and Cascade lasting three weeks. Columbus started leaf development in the fourth week of September and extended until the first week of October. However, Yakima Gold cultivar showed late leaf development if compared to other cultivars, from the second week of October, until the third week of November.

Formation of lateral branches started in the second week of October in Chinook and Columbus, extending until the second and third week of November. Cascade had the formation of the lateral branches from the third week of October to the first week of December. However, Yakima Gold presented the shortest period of formation of the lateral branches, the most recent was from the fourth week of November until the second week of December (Figure 1).

Main branch started growing in the third week of November in Chinook and lasted for six weeks, until the fourth week of December together with Columbus. Cascade also showed a period of growth of the main branch of five weeks like Columbus, but this was later, from the second week of December and extended until the second week of January. Yakima Gold had the shortest period, only in the third week of December (Figure 1).

Cascade and Yakima Gold shown a short reproductive period, between the emergence of the inflorescences and the harvest, when compared with the other cultivars. It was 37 days for Cascade, 38 days for Yakima Gold and approximately 60 days for Chinook and Columbus cultivars (Figure 1).

Yakima Gold is more precocious (143 cycle days), followed by Cascade (180 days), Chinook (189 days) and Columbus (191 days) (Figure 1). The lower cycle of cultivar Yakima Gold can be explained by its lower requirement in degrees days to enter the reproductive period, which can be confirmed by the results of 885.66 hours of accumulated sunlight throughout the period of vegetative and reproductive cycles (Table 1).

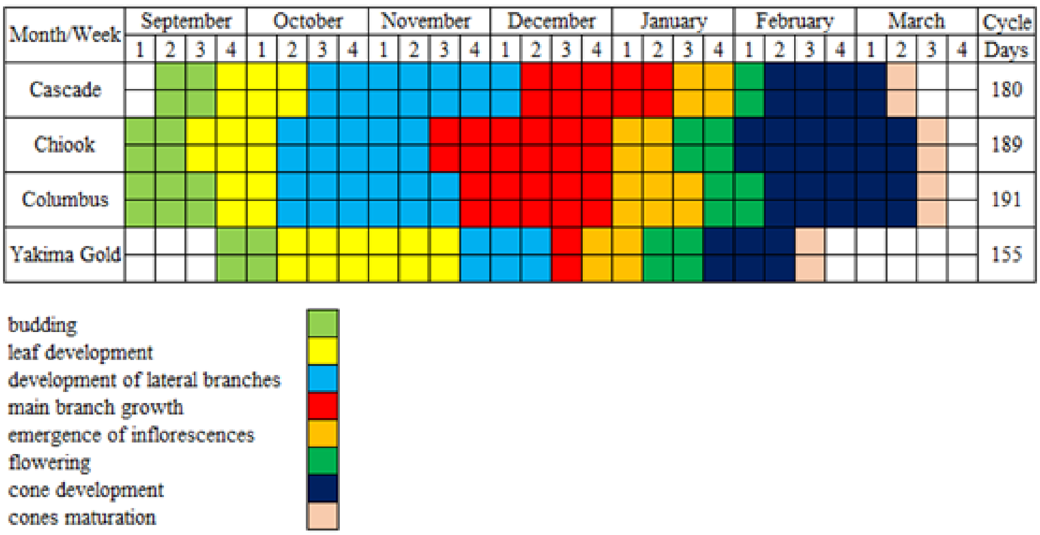

Figure 1: Hop cultivars phenology in the municipality of Lages, Santa Catarina State (SC), Brazil, during the 2018/2019 cultivation cycle. Lages, SC, 2019. Source: the authors, 2020.

Table 1: Characterization of accumulated daily sunlight amount for hop cultivars of the 2018/2019 production cycle, for Lages and São Joaquim. Source: the authors, 2020

Location/cultivar	Cultivation period	Days of cultivation cycle (day)	Total solar brightness in the period (h)	Average daily solar brightness (h/day)
		Lages		
Chinook	09/10/2018 - 03/19/2019	189	1107.97	5.86
Columbus	09/10/2018- 03/21/2019	191	1122.73	5.81
Yakima Gold	09/25/2018 - 02/17/2019	143	885.66	6.19
Cascade	09/15/2018 - 03/14/2020	181	1077.05	5.95
		São Joaquim		
Chinook	09/13/2018 - 03/28/2019	196	1156.93	5.87
Columbus	09/13/2018 - 03/28/2019	196	1156.93	5.87
Cascade	09/13/2018 - 03/28/2019	196	1156.93	5.87

Cultivars had different dates of occurrence for the main phenological stages in the present study. These differences occur due to variety, climate and geographical position (Jones, 1997).

Photoperiod, or effective length of day in hours, is defined as the time interval between sunrise to sunset, referring to a given location and date. This variation is related to the relative position between Sun and Earth and periods of illumination throughout the seasons. Insolation and photoperiod differ by the fact that insolation is defined as the total time of exposure, of a given location, to sunlight, or the same as the visible disposition of the solar disk to an observer on the surface of the analyzed place. Photoperiod is not related to the total time of exposure to the Sun, but to the period in which it will be possible to have situations of sunlight (Silva, 2006). In this way, the number of hours of sunlight will be less than or equal to the photoperiod, which will be the maximum possible value for heat stroke.

Due to the proximity between cities, the minimum and maximum values of the photoperiod throughout the year are similar (Figure 2).

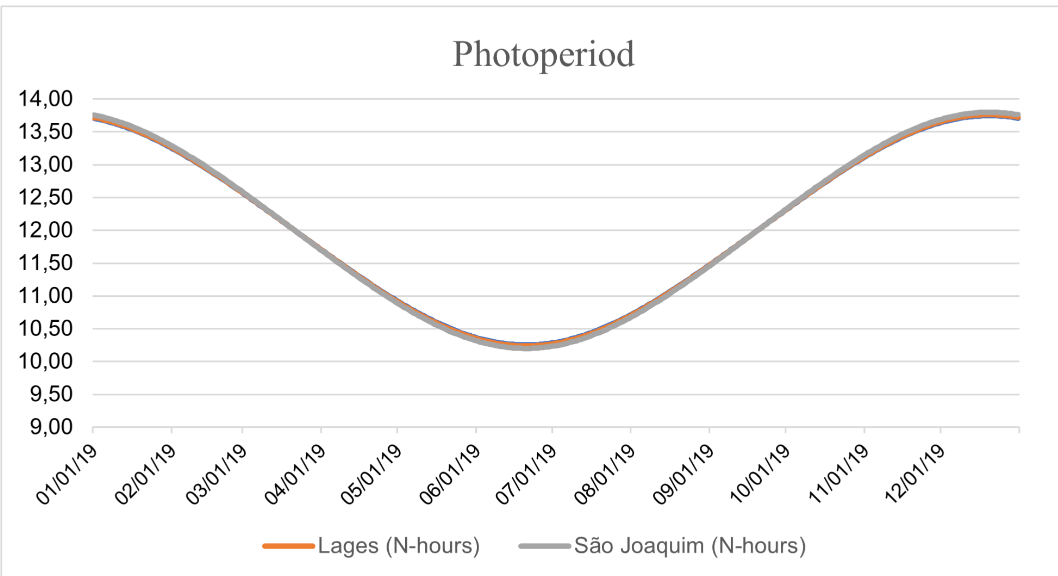

Figure 2: Photoperiod (in hours) for the municipalities of Lages and São Joaquim. Lages, SC, Brazil, 2020. Source: the authors, 2020.

Photoperiod values for the two cities analyzed vary from 10.2 to 13.8 hours, minimum and maximum, respectively throughout the year. Therefore, a maximum variation of 3.6 hours between the shortest day (winter solstice) and the longest day (summer solstice) for the southern hemisphere. However, it is worth mentioning that these values are actually possible values of solar brightness during certain times of the year. What is really important to know is the amount, in effective hours of sunlight, available in a given region.

According to data obtained by the Epagri Automatic Meteorological Station, for the locations of São Joaquim and Lages (Table 2), for the 2018/2019 harvest, annual profile of hours of sunlight (n) is shown below:

Table 2: Number of hours of medium, maximum and minimum solar brightness (BS) for the 2018/2019 harvest, in São Joaquim and Lages-SC. Lages, SC, 2020. Source: the authors, 2020

	Medium solar brightness (h day^{-1})	Maximum solar brightness (h day^{-1})	Minimum solar brightness (h day^{-1})
São Joaquim	5.87	13.10	0.0
Lages	5.53	13.33	0.0

Null values of solar brightness are presented throughout the year, due to cloudiness and the presence of rainy seasons. The maximum values obtained for the parameter coincide for the two localities, on the same date of the year (12/08/2018), as they are close regions, in summer season, with low or no cloudiness, a time when, according to analysis photoperiod, it is possible to obtain the highest values for solar brightness in the year.

In terms of annual average values, it is noticed that the two locations have daily average values that are below 6 hours of sunlight.

Considering the two locations studied, and their respective cultivation areas with four hop cultivars (Lages) and three hop cultivars (São Joaquim), and based on information of hours of sunlight (hours and tenths) provided by the Automatic Meteorological Station of Epagri, for the entire growing period, we have the following information (Table 1).

Reference information about hop cultivars in north hemisphere, on the amount of sunlight vary from 1,800 to 2,000 hours per year (Rybacek, 1991), from 1,330 to 1,500 in the growing season, so it has to be that, considering the duration of 122 to 127 days, 11.2 hours of sunshine per day in such a period. This is not observed in the present research, since the entire production cycle presented between 800 to approximately 1,200

Pavlovic *et al*., (2012) studied four meteorological parameters on the influence of alpha-acid in the cultivar Aurora during 16 harvests in Slovenia. Solar brightness total average for those years was 1,139.2 hours. Under the study conditions, Yakima Gold cultivar completed the production cycle with less than 1000 hours of sunlight (Table 02) and for São Joaquim the studied cultivars completed the cycle with more hours of sunlight when compared to the study conditions in Slovenia.

Smith (1974) studying four cultivars in four agricultural harvests in different European countries found that the average hours of sunlight varied from 4.4 hours and 8.8 hours in the period considered critical, July to August, for the northern hemisphere. In the study conditions, daily brightness average values varied between 5.81 to 6.19 hours per day (Table 03). There are no data in Brazilian literature that relate the number of sunlight hours and productivity of cones and/or stadiums of hops development.

Fresh cones estimated yields of studied cultivars ranged from 157.13 kg/ha to 3,365.54 kg/ha in Lages, and from 4,983.21 kg/ha to 6,192.44 kg/ha in São Joaquim. Considering cultivars, Columbus was the most productive in both evaluated regions, but there was similarity in estimated productivity between Chinook and Cascade in Lages. However, Yakima Gold showed the lowest estimated yield (Table 3).

Therefore, for choosing a cultivar it is necessary to know initially the maximum production potential in each region, to analyze at least the climatic conditions of the region and possible conditions of cloudiness, which results in different sum of sunlight hours from the photoperiod, and then verify the relationship between productivity and effective hours of sunlight.

Table 3: Cone productivity (mass) and average solar brightness in the 2018/2019 growing period. Source: the authors, 2020

Location / cultivar	Average daily solar brightness (h/day)	Estimated productivity of fresh cone mass (kg/hectare)
Lages		
Chinook	5.86	942.81
Yakima Gold	6.19	157.13
Columbus	5.81	3365.54
Cascade	5.95	932.81
São Joaquim		
Chinook	5.87	5613.02
Columbus	5.87	6192.44
Cascade	5.87	4983.21

Even with an average of hours of sunlight less than the estimated photoperiod values for the year, which generally varies from 10.2 to 13.8 hours per day, the observed yield of cultivars is consistent with that recommended by the literature, which indicates that the production may be related to the effective amount of hours of sunlight and that, even with values below the photoperiod, the diffuse radiation, present in cloudy days, common in the studied region, can be as important as the direct radiation, seen in several other cultures (Petter *et al*., 2016) diffuse radiation is photosynthetically more relevant than direct radiation.

In cloudy situations, there is an increase in the fraction of diffuse radiation, which can be useful for the better use of solar radiation by plants. Aikman (1989) and Radin *et al*. (2003) found that the increase in diffuse radiation promoted greater uniformity of radiation inside the canopy, causing the lower leaves to increase the interception of radiation and its use.

CONCLUSIONS

Cultivars cycles were different for the same region. The observed results, for the conditions of study, demonstrate hops develop at latitude 27º South, and there is production of cones since first agricultural harvest. With solar brightness average of 5.87 hours per day, there was a productivity of approximately six thousand kilos of fresh hops per hectare, consistent with literature found. Solar brightness parameter must be analyzed for the different hop cultivation regions in order to establish a reference in terms of hours of sunlight per period and productivity.

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