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Characterization of Brazilian Cascade and Chinook hops and their dry-hopped beer

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Abstract

The flowers (cones) of Hop (*Humulus lupulus L.*) have extensive applications in the brewery industry and in Brazil, 98% of which is imported. The Brazilian cultivated hops have multiple flowerings, and therefore the cone cultivation period could be shortened. Herein, Cascade and Chinook whole cones cultivated in Brazil were analyzed and compared with American pellets. Following the European Brewery Convention (EBC) methodology, the contents of alpha acids, polyphenols, and essential oils were quantified and used as comparison criteria. Amidst the Brazilian Cascade essential oils, isoamyl propanoate and 6-methyl heptanoate were identified, both of which were responsible for pineapple aromas and were absent in American pellets. The dry hopping (DH) process promoted higher alcohol beverage value, lower dissolved oxygen, and higher polyphenol values. In comparison with the commercial counterpart, the Brazilian Cascade hops presented similar characteristics, but with different organoleptic properties (*terroir*), inherent to their growing place. The resulting terroir adds value to the Brazilian Cascade usage, considering the DH overall process and the application in special beers.

Keywords: Brazilian hops; hop chemistry; brewing process; hop technology.

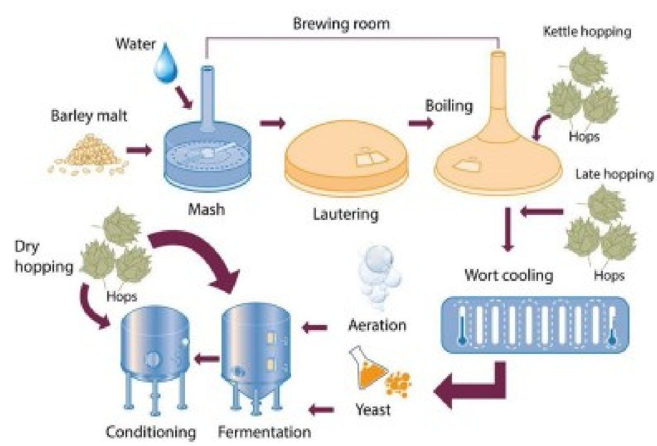
Practical application: The resulting terroir adds value to the Brazilian hops for application in special beers.

1 INTRODUCTION

Beer is made from four main ingredients, namely, water, barley malt, hops, and yeast. Hops are the inflorescence of Humulus lupulus L., also known as hop cones (Gomes et al., 2022). Although used in relatively small amounts, hop cones account for a large percentage of the cost of production (Kramer et al., 2015). Based on the type and amount of hops, it is possible to produce a variety of beers with different aromas and degrees of bitterness (Durello et al., 2019).

Hops are traditionally added during boiling, where alpha acids are turned into iso-alpha acids. However, as the temperature is high, most of the aroma compounds are lost in the process. Some of them may suffer chemical reactions (such as hydrolysis) and have modified aromas (Gomes et al., 2022). Essential oils are very volatile and lost during standard boiling. To avoid essential oil losses, the dry hopping (DH) process (addiction of hops at the cold steps) may be applied, resulting in a beer with an aroma similar to that of hop cones, as illustrated in Figure 1.

The hop production occurs mostly between the parallels 35 and 55 in either hemisphere (temperate regions), with Hallertau (Germany) and Yakima (USA) being the most important ones, accounting for 77% of the world production (Economic Commission, 2022). In Brazil, the growing number of craft breweries has driven the usage of local ingredients, which includes hops. Nevertheless, adapting plants for local edaphoclimatic conditions has been a major challenge for producers (Jastrombek et al., 2022). In addition, due to the Brazilian climatic conditions, the possibility of more than one production cycle per year was explored, while in other regions, only one cycle was obtained per year (Almeida et al., 2021).



Source: Gomes et al. (2022).

Figure 1. The brewing process highlighting common hop addition possibilities.

The hop cultivation initiatives in Brazil have generated great enthusiasm to produce this important raw material for the brewing industry. Brazilian hops have shown distinct characteristics in terms of bitterness and aroma when compared with imported

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products, which have led to the production of beer with local terroir and the focus of several initiatives in the country (Durello et al., 2019). To better understand the characteristics of Brazilian hops, in this study, Brazilian raw hops were chemically evaluated and compared with the American pelletized counterparts while evaluating their sensory and physicochemical impacts in the dry-hopping process.

2 MATERIALS AND METHODS

Pure Pilsen malt beer (100 L) was brewed, using 16.5 kg of Pilsen malt (Agrária Malte, Guarapuava, Brazil), 50 g of American Magnum hops (BarthHaas, Yakima, United States) added at the beginning of the boil, 88 g of Safbrew yeast S-23 (Fermentis, Lille, France), 66 L of primary water, and 64 L of washing water in a pilot plant (Serra Inox Company, Bento Gonçalves, Brazil). The mashing was made with stops carried out: protein enzymes at 52°C for 5 min; beta-amylase enzymes at 63°C for 20 min; and alpha-amylase enzymes at 72°C for 20 min. The mixture was boiled for 1 h and fermented at 12°C for 240 h, followed by 480 h of maturation at 0°C. The beer was then divided into smaller fermenters,and 4 g L^{-1} of sample hops was added at 12°C for 24 h. Then the beer was stored in bottles at 2°C, without pasteurization.

Hops used were American-grown Cascade and Chinook hop pellets T-90 (BarthHaas,Nürnberg, Germany) crop year 2018 and Brazilian-grown Cascade and Chinook dried whole-cones hops cultivated in the Federal District, Brazil, crop year 2019 obtained from a local farmer. Hops were stored cold until chemical analysis and DH. As harvesting and processing are carried out at different times, it is not possible to work with hops under the same conditions. However, the choice of hops was defined by the processing that maintained the best qualities of the hops harvested in the previous year (which was verified by the report on the flowers harvested and analyzed provided by BarthHaas, Nürnberg, Germany). The results for alpha and beta-acids, storage index, and essential oils were similar after 1 year of pelletization.

The alpha-acid (AA) quantification was done as stated in EBC 7.4, hop storage index (HSI) as in EBC 7.13, polyphenols as in EBC 7.14, and total essential oils as in EBC 7.10 with sample reduction to 75 g. The hop volatile analysis was performed by hydrodistillation to determine the total oil content of the homogenized hop grist using the American Society of Brewing Chemists (ASBC) Hops – 13 (17). Hop volatile analysis was conducted as in EBC 7.12, but using a gaseous chromatography-mass spectrometer (GC-MS). The equipment used was a GC-2010 chromatograph with a GCMS-QP2010 Plus detector and an AOC-5000 injector (Shimadzu, Kyoto, Japan). Hop essential oils were diluted in a 1:1,000 ratio prior to injection. GC-MS parameters were ionization energy 70 eV, 1 µL sample injection at 200°C with a split ratio of 1:10, Restek Rtx-5MS column (30 m × 250 µm × 0.25 µm), carried by He-carrying (White Martins, São Paulo, Brazil) flow of 1.4 mL min^{-1}, and scan from 30 to 450 m/z.

The experimental design was made by taking five beers (including control). Beer samples were prepared by statically dry-hopping a lager beer (6.3% – alcohol beverage value (ABV)) with either commercial pellets or ground Cascade/Chinook cones from a single harvest lot at 400 g hL^{-1}, for 24 h at 12°C, the same treatment realized in some Brazilian commercial breweries and reported by Gomes et al. (2022). The unpasteurized beers were stored in bottles at 2°C. Descriptive sensory analysis (description below) was used to scale the aroma intensity and quality of beers. Non-volatile and volatile chemical analyses were performed on hops used for dry-hopping and on the finished beers to determine the extraction efficiencies of hop-derived aroma and flavor compounds into beer.

The beer's non-volatiles were characterized by the density of original and final extracts (% m m^{-1}), alcohol content (% v v^{-1}), dissolved amount of CO2 (mg L^{-1}), remaining sugars (mg L^{-1}), fermentation degree rate (%), and caloric content (Beer Alcolyzer Plus, Anton Paar, Graz, Austria). Total polyphenols analysis was performed as in EBC 7.14 increasing boiling time to 60 min. The analysis of beer volatiles was performed by GC-MS. The equipment used was a GC-2010 chromatograph with a GCMS-QP2010 Plus detector and an AOC-5000 injector (Shimadzu, Kyoto, Japan). The analyzed samples were prepared as follows: 150 g of beer was centrifuged for 5 min at 2,000 rpm, and then, in a separator flask, it was added to 75 mL of dichloromethane, shaken, and left to stand for 2 h. The organic phase was removed and centrifuged for 4 min, at 2,000 rpm. The GC-MS parameters were: ionization energy (IE) of 70 eV, injection of 1 µL of sample at 200°C with 1:10 split, Restek Rtx-5MS column (30 m × 250 µm × 0.25 µm), He-carrying (White Martins, São Paulo, Brazil) flow of 1.4 mL min^{-1}, and scan from 30 to 450 m/z. The heating ramp used was 50°C for 1 min and 50–180°C at 2°C min^{-1}.

The beer sensory evaluation was made to identify and quantify the organoleptic characteristics of the beer. The sensorial analyses were conducted at the Universidade de Brasilia (UnB), with a trained panel of analysts that was evaluated through theoretical and practical classes using the off-flavors kit (FlavorActiv, Thame, United Kingdom) and trained by specific personnel, according to Brazilian Norm (NBR) ISO 5492:2017 (Associação Brasileira de Normas Técnicas, 2017).

The results of sensorial analyses were divided into two groups for each sample: aroma and flavor. The analysis file had a pre-determined list of aromas and flavors, which are characteristics of beverages. The file had a 1–5 grading system, where 1 was the least sensorial perception and 5 was the highest sensorial perception. The arithmetic average of the panel's grades for each characteristic was calculated to analyze the data and plotted as spider graphs for visual representation.

Seven panelists were served each one glass of each sample labeled with a random three-digit number. A nine-point scale was used to evaluate color, aroma, aroma intensity, flavor, and global overall, ranging from extremely disliked to extremely liked. A six-point scale was instead, where 0 is "not perceived" and 5 is "intense" for the aromas (sweet fruits, spicy, floral, woody, cream caramel, citrus, berry and currant, green-grassy, green fruits, vegetal, menthol, and herbal) and flavors (tropical fruits, sweet fruits, citrus, pear/apple, floral, spicy, herbal, grassy-green, hop, woody, malty, cereal, dimethylsulfate (DMS), alcohol, sulfurous, and bitter).

The experimental design was randomized, and the experiments were evaluated in triplicate and in three independent replicates, except for sensory analyses, CG-MS, HSI, and total essential oil. The results were submitted to analysis of variance ($p < 0.05$) and multiple comparative tests when pertinent. The software Statistica version 12.0 (StatSoft Inc., Tulsa, United States) was employed in the statistical analysis.

3 RESULTS AND DISCUSSION

The chemical composition of hops is dependent on genetic factors, harvest points, and climatic and geographical conditions of the variety (Almeida et al., 2021). The yield of such compounds increases in the first 2 years of the plant's life, plateauing in the third year. Hop compounds of major importance to brewers (Guimarães et al., 2021) were evaluated and compiled in Table 1. The concentrations of these compounds are largely dependent on the age of the plant, the cultivation method, and the soil and climate conditions associated with the location.

Cascade whole cone hops cultivated in Brazil (CasBR) had an AA content of 2.9 ± 0.67%, lower than the commercial pellet from the United States (CasUS), 4.04 ± 0.30%, and lower than another Brazilian Cascade analyzed by Arruda et al. (2021), 3.86 ± 0.08%. The AAs expected for Cascade are in the range of 4.5–7% (Woodske, 2012). The HSI indicates that flowers were better conserved than pellets up to the moment of analysis. This is expected as pellets have been milled, heated, pressed, and harvested before flowers. Regarding polyphenols, both Cascades obtained values close to 4% which is said to be common for most varieties (Woodske, 2012). Total essential oils for both Cascade varieties were close to 0.5 mL 100 g^{-1}, slightly lower than the reference values for it (0.7–1.4 mL 100 g^{-1}). The lower value may be because early harvest or oils were lost or volatilized during cultivation due to higher temperatures (Blendl et al., 2014). Quantitatively, essential oils and polyphenols seemed to have less impact by place of cultivation.

Whole cones of the Brazilian Chinook variety (ChiBR) reached 6.93 ± 0.41% for AAs, being significantly lower than the commercial pellet (ChiUS) which was 10.37 ± 1.72% ($p = 0.05$). Chinook variety is expected to present between 12% and 14% of AA (Arruda et al., 2021). ChiBR polyphenols were closer to that given as typical of the flower (4%), indicating that the production of this compound was not strongly influenced by the cultivation conditions (daily light hours, humidity, temperature, etc.). Still, ChiBR presented a lower value than the pellet (ChiUS), which presented the highest value among the samples, with polyphenols reaching 7.59% (Arruda et al., 2021). Chinook from the United States presented a higher number of polyphenols than Brazilian one, which may impart an astringent taste to beer and a higher antioxidant potential to it as well. ChiBR had almost half of the essential oils compared with ChiUS. The differences in both varieties regarding their places of cultivation do not make them invalid for use, but rather unique properties that may impact how much should a brewer use to obtain the same effect.

Brazilian Cascade raw hops showed a statistically equal value for AAs and polyphenols, with lower HSI and total essential oils compared with American pellets. Brazilian Chinook raw hops displayed lower values for all measured physicochemical properties. The lower value of AAs does not invalidate Brazilian hops but suggests that a higher amount of them should be used to achieve the same bitterness in the boiling step to achieve the IBU desired.

Both Brazilian varieties had a higher amount of beta-myrcene (Cascade, 83.59% and Chinook, 84.29%) than American ones (Cascade, 62.65% and Chinook, 70.29%), as shown in Table 2. CasUS had higher amounts of sesquiterpenes (trans-caryophyllene, alpha-humulene and beta-farnesene). Despite being the same variety, some aroma molecules were identified in only one of the samples. DL-limonene and several esters (isoamyl propanoate, amyl isobutyrate, methyl 6-methyl heptanoate) were only identified in CasBR, whereas linalool and beta-farnesene were exclusively identified in CasUS. Isoamyl isobutyrate was identified in ChiBR and delta-cadinene in ChiUS. Several molecules were present in all samples, i.e., alpha-humulene, trans-caryophyllene, and beta-myrcene. A though isoamyl propanoate, beta-pinene, and methyl decenoate were identified in both Brazilian varieties, no molecule was only present in both American samples. These compounds may be due to the place of growth, resulting in the distinct terroir. Their content depends on the harvest year, which is usually higher in years with unfavorable weather, as polyphenols have defensive functions for the plant. In addition to that, some compounds related were also found by Almeida et al. (2021), which shows that they are characteristic of the Brazilian climate and growing conditions.

The essential oil content in the Brazilian samples (CasBR and ChiBR) was lower (Table 1), but more compounds were identified by GC-MS (Table 2), which combined could aggregate

Table 1. Alpha-acids, hop storage index (HSI), polyphenols, and total essential oils from in natura hop cones Federal District of Cascade (CasBR) and Chinook (ChiBR) varieties and their commercial pellet counterparts of the United States, Cascade (CasUS), and Chinook (ChiUS). Major importance compounds identified by technological prospection.

Sample	Alpha-acids (%)	Hop Storage Index	Polyphenols (%)	Total essential oils (mL 100 g^{-1})
CasBR	2.90 ± 0.67	0.31	4.85 ± 0.82	0.48
CasUS	4.04 ± 0.30	0.44	3.84 ± 0.56	0.52
ChiBR	6.93 ± 0.43	0.31	4.38 ± 0.19	0.79
ChiUS	10.37 ± 1.72	0.55	7.04 ± 1.44	1.35

Source: Guimarães et al. (2021).

different aromas and flavors compared with commercial samples (CasUS and ChiUS). This fact was observed by the sensorial analysis of the samples that were submitted to the DH process (Figures 2 and 3). If Brazilian hops are used in the boil, it is expected that the essential oils will be evaporated by the time and intensity of the boiling process, as the focus is to isomerize AAs from the used hops.

The addition of hops during fermentation and maturation is known to cause further fermentation due to hop creep, and the lower temperatures increase the solubilization of volatile molecules, which is the case for all aroma molecules (Gomes et al., 2022). Table 3 shows the results for physicochemical attributes for dry-hopped beers and the control. The DH process or hop addition on the cold process (fermentation and maturation) adds flavor and aroma to the beer. However, as there are no conditions for AA isomerization to occur, it is known that the composition of essential oils is more important for the characteristics of the final product (Gomes et al., 2022). For its use in the boiling process, the AA content is essential, as it will be responsible for adding bitterness to the beer, but the essential oil could be evaporated.

As demonstrated by Kirkpatrick and Shellhammer (2018) for dry-hopped beers with Cascade variety, ABV increased with the addition of hops. Although our results with Cascade (0.25%) were not as high as the 1.3% they observed, lower contact time and temperature were used. This extra sugar fermentation may

Table 2. Volatile compounds identified (peak area %) in samples with Cascade whole cones from the Federal District, Brazil (CasBR), Cascade pellets from the United States (CasUS),Chinook whole cones from the Federal District, Brazil (ChiBR), and pellets from the United States (ChiUS) and their similarity (%).

Molecules	CasBR	CasUS	ChiBR	ChiUS
4-hydroxy-4-methyl-pentan-2-one	-	8.89	-	-
Diketone alcohol	3.92	-	-	-
Isoamyl propanoate	0.63	-	0.43	-
Beta-pinene	0.81	-	0.69	-
Beta-myrcene	83.59	62.65	84.29	70.29
Linalool	-	2.42	-	-
Alpha-pinene	-	-	-	0.28
DL-limonene	0.53	-	-	-
Isopentyl isobutanoate	-	-	-	3.3
Isobutyl isobutanoate	-	-	-	0.2
Isoamyl isobutanoate	-	-	1.38	-
Amyl isobutanoate	3.76	-	-	-
Methyl 6-methyl-heptanoate	1.3	-	-	-
Methyl decenoate	0.64	-	0.54	-
Trans-caryophyllene	0.9	5.65	1.38	6.58
Alpha-humulene	3.38	18.25	8.87	15.31
Beta-farnesene	-	1.06	-	-
Delta-cardinene	-	-	-	0.88

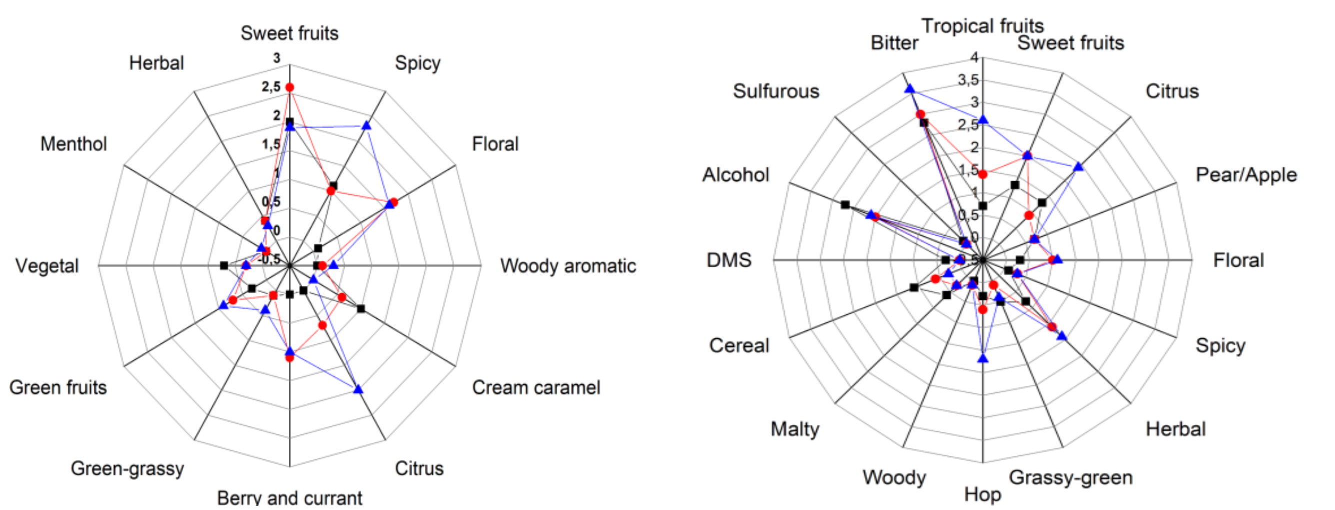
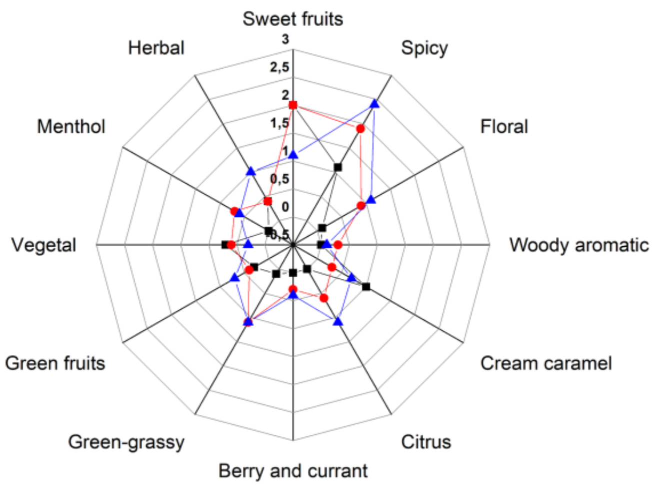


Figure 2. Sensory analysis of Cascade dry hopped beers. Brazilian Cascade (CasBR in red) and American Cascade (CasUS in blue), black is control beer. On the left, aromas of were represented and on the right, main flavors.



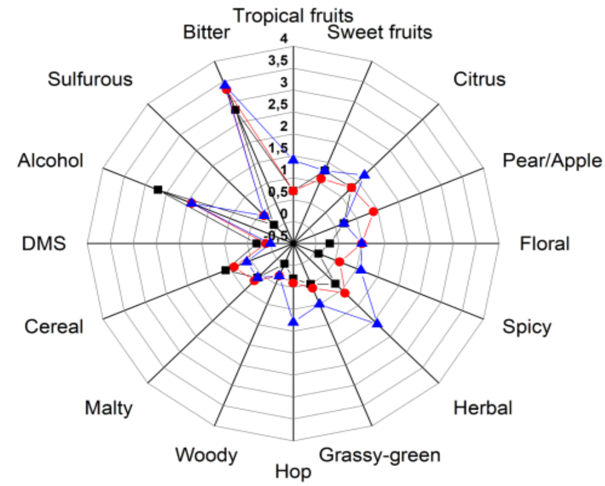


Figure 3. Sensory analysis of Chinook dry hopped beers. Brazilian Chinook (ChiBR in red) and American Chinook (ChiUS in blue), black is control beer. On the left, aromas of were represented and on the right, main flavors.

Table 3. ABV, original extract, RDF, O2 concentration ion, sugar concentration ion, and polyphenols in beer without dry hopping (control) and with dry hopping of CasBR, CasUS, ChiBR, and ChiUS.

Sample	ABV (%)	Original extract (ºP)	RDF (%)	O_2 concentration (mg L^{-1})	Sugar concentration (mg L^{-1})	Polyphenols (mg L^{-1})
Control	6.26 ± 0.03	15.27 ± 0.04	62.76 ± 0.23	0.883 ± 0.193	3.77 ± 0.04	167 ± 10
CasBR	6.52 ± 0.02	15.52 ± 0.05	64.22 ± 0.22	0.321 ± 0.061	3.56 ± 0.04	213 ± 1
CasUS	6.59 ± 0.03	15.40 ± 0.05	65.47 ± 0.25	0.391 ± 0.035	3.29 ± 0.03	232 ± 8
ChiBR	6.57 ± 0.04	15.51 ± 0.03	64.76 ± 0.27	0.334 ± 0.054	3.45 ± 0.01	187 ± 3
ChiUS	6.34 ± 0.03	15.35 ± 0.03	63.16 ± 0.24	0.342 ± 0.043	3.72 ± 0.02	209 ± 7

ABV: alcohol beverage value; RDF: real degree of fermentation.

be due to enzymes in hops that are capable of breaking down some dextrins into fermentable sugars. ChiBR decreased its sugar concentration and increased its ABV, whereas ChiUS obtained values similar to the control, indicating that either their enzymes were denatured during pelletization or their concentration might differ according to the place of cultivation. There was not much difference between using milled whole cones or pellets for DH, and the addition of hops decreased the O_2 concentration in the beverage. This reduction increases shelf life and reduces some oxidation reactions that produce unwanted odors, i.e., cardboard.

Regarding the concentration of polyphenols, pellet samples had an increase in relation to whole cones, which is due to the greater surface area that pellets have as they were crushed. It was also observed that the amount of polyphenols in the plant sample does not match the amount transferred to beer. ChiUS obtained 7% and other samples approximately 4%, and even so, the highest amount of dissolved polyphenols was in CasUS, with 232 mg L^{-1}, whereas ChiUS obtained only 209 mg L^{-1}. Almeida et al. (2021) and Arruda et al. (2021) also observed the same results, but they did not evaluate their use in the brewing process.

When the hops were used as pellets or as raw hops, some differences between values are observed in Table 3. An over-attenuation (commonly known as hop creep) was observed in both hop varieties and all samples had increased ABV, RDF, and lower O_2 and sugar concentration values compared with the control. The addition of hops increased the total polyphenol content for all samples, and the increase was not directly related to the amount of polyphenol in the hop sample.

The increase in alcohol content by DH was observed by Kirkpatrick and Shellhammer (2018) for the Cascade variety, and the effect observed in this study was smaller than that reported by the authors, up to 1.3%, as it was performed at lower temperatures and shorter contact time (Lafontaine et al., 2019). The authors in their study attributed the presence of several enzymes in hops capable of breaking the chain of oligosaccharides (dextrin) present in the beverage into fermentable sugars, which were then converted to ethanol by the action of yeasts (Lafontaine et al., 2019). These data were verified by the decrease in the concentration of residual sugar in the beverage for both Cascade and Chinook varieties (Table 2). ChiUS's sugar concentration and alcohol content are not different from the control, although ChiBR is. This indicates that the Brazilian variety may have different concentrations of enzymes than the American ones, or that the drying of the variety has been more intense, denaturing the enzymes.

The use of DH using flowers or pellets did not show a pronounced difference, but DH decreased the amount of dissolved oxygen by up to 63%. This reduction in dissolved oxygen increases the shelf life of the product by reducing oxidation reactions that can even cause unwanted odors, especially cardboard.

That is, when submerged, even though the flower had a greater amount of air in comparison with the pressed pellets, the air did not interfere, meaning that there was no greater incorporation of oxygen by the use of the flower.

For the analysis of volatiles in DH beer by GC-MS on samples using Cascade hops, the addition of hops to the beer promoted the alteration of several compounds. Some identified in the control were no longer identified in the samples, and others were specific to the addition of the cones. Some of the compounds identified in the control sample were germacrene D (sesquiterpene), 6-methyl-heptan-1-ol, cumene, and other various hydrocarbons. Hydrocarbons are easily carried out of solution by CO_2 bubbles because they have low solubility in aqueous solutions due to their less interaction with the solvent.

Beta-myrcene, present in all hop cones and pellets, was identified only in the CasUS DH sample. However, both CasBR and CasUS showed dihydro myrcenol — a reduced form of myrcenol — and all samples with DH showed dihydro citronellol — a reduced form of citronellol which is also the hydrated form of beta-myrcene. This indicates that some molecules underwent biotransformation, that is, some of the compounds originally found in hops were modified by the yeast present in beer, in this case, hydrated and reduced.

The beta-farnesene molecule was found in the CasUS hop pellet, but not in the sample with its DH. However, farnesane, a reduced form of beta-farnesene, was found in the CasBR DH sample. The iso-AA molecule identified in CasUS can be either from the volatilization of an Index of AAs (IAA) or from the volatilization of an AA that was isomerized during analysis due to the high injection temperature.

For Chinook samples, ChiBR cones showed dihydro myrcenol and farnesane, which were also found in beers with CasBR, indicating a possible terroir tendency. The ChiUS DH sample obtained hexahydro farnesol and hexahydro nerolidol; these molecules are isomeric and derived from farnesol, an open-chain sesquiterpene. Farnesol is used by the pharmaceutical industry to emphasize sweet and floral odors (Blendl et al., 2014). Adding ChiUS to the beer added the methyl nonanoate ester, which has a fruity aroma of pear and tropical fruits (Kirkpatrick & Shellhammer, 2018). All samples with DH showed dihydro citronellol, which is the hydrated form of beta-myrcene. This indicates that the samples underwent biotransformation, that is, some of the compounds originally found in hops were modified by the yeasts present in the beer, in this case, hydrated and reduced.

The sensory analysis for the DH beer did not change the color of the beer but increased its aroma, aroma intensity, flavor, and overall impression, as shown in Table 4. The aroma of samples was strongly influenced by DH, especially with the Cascade variety, which obtained averages one or two points higher. On the contrary, Chinook did not have an aroma more appreciated by the panelists. The intensity of aromas of the evaluated samples also observed an increase in their averages when compared with the control, only except for the ChiBR that obtained a similar value. This trend has continued for flavor and overall impression.

This difference between the samples suggests that the Cascade cultivar is less sensitive to the tropical climate of the Brazilian savannah than the Chinook. This difference can be explained by the fact that its results were closer to those of the American commercial product. To better assess the differences, aromas and flavors of each variety were individually evaluated, according to Figures 2 and 3.

DH caused a reduction of alcohol sensation and increased bitterness of the beverage. DH with CasBR was not as citrus, herbal, or spicy as CasUS samples, but it had more aromas of sweet fruits. As with Cascade, using Chinook also brought out more sweet fruit aromas, the dry-hopped beer had a stronger green fruit flavor (apple and pear), and not as strong tropical fruits, according to Figures 2 and 3.

The Cascade and Chinook varieties are known for contributing citrusy aromas to beer (Woodske, 2012). Figure 2 shows that domestic hops contributed less with citrus, herbal, or spice (cloves, fennel, anise, marjoram) aromas but brought more intense aromas of sweet fruits (cherries, passion fruit, apricots). The addition of hops increased the aromas and flavors of most of the criteria evaluated, with a reduction in the alcoholic, cereal, and malty flavors. Because of the recent hop cultivation in the country, it is not known yet if there are any distinct differences in beer styles that predominate in each region (Jastrombek et al., 2022). The overall characteristics of both Brazilian hops indicated that they are good substitutes for their imported pellet counterparts.

4 CONCLUSIONS

The obtained new findings support the emerging initiatives of feasible hop production in subtropical areas, which may encourage the expansion of hop-growing areas in a wider latitude range around the world. The Brazilian Cascade whole cone hops were more closely related to their American pellets than the Chinook variety. Dry-hopped beer samples had higher alcohol content and lower values of final extract, residual sugars,

Table 4. Average values of color, aroma, aroma intensity, flavor, and global overall for the samples CasBR, CasUS, ChiBR, and ChiUS.

Samples	Color	Aroma	Aroma intensity	Flavor	Global Overall
Control	7.0 ± 1.0	5.4 ± 1.8	4.6 ± 1.0	5.9 ± 1.2	5.4 ± 1.4
CasBR	7.0 ± 1.5	6.4 ± 1.5	6.0 ± 1.5	6.6 ± 1.8	6.7 ± 1.4
CasUS	7.3 ± 0.9	7.3 ± 1.2	6.9 ± 1.5	7.1 ± 1.1	7.7 ± 0.9
ChiBR	7.4 ± 0.9	4.9 ± 1.1	4.9 ± 1.8	5.4 ± 1.4	5.7 ± 1.4
ChiUS	6.9 ± 1.0	5.9 ± 1.9	5.9 ± 1.5	6.6 ± 0.9	6.9 ± 0.6

and dissolved oxygen than the control sample, which in short provide a longer shelf life by hindering bacterial contamination and oxidation of the beverage.

The addition of hops also caused an increase in the number of polyphenols. However, this increase was not proportional to the number of polyphenols present in the added hops. The CasUS and ChiUS varieties exhibited higher values for organoleptic properties in relation to the CasBR and ChiBR. The sensory profiles of aromas and flavors between the varieties were similar, with CasBR presenting stronger sweet fruits and weaker citrus and herbal aromas in relation to CasUS. The resulting similarity indicates that both CasBR and ChiBR may be readily able to replace commercial (imported) hops.

Based on the results, it was observed that Brazilian hops have the potential to replace imported hops in terms of AA content, which is important for the usage of boiling hops while increasing the hop mass by 10%. Regarding the DH process, the aromas identified in Brazilian hops showed great potential for their use in higher market value special beers, where complex aromas are expected.

In Brazil, hop cones are mostly imported, which results in high costs and, consequently, higher costs for final products. Despite attempts to adapt the species in Brazil, especially aiming for large-scale production, the correct use and characteristics of this raw material can be explored to produce a final product with higher added value. Adding to that, there is the cost reduction and the stimulus for the Brazilian technological development expertise on the production of hop for exportation or internal use.

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REFERENCES

Almeida, A. R., Marciela, M. V. O., Gandolpho, B. C. G., Machado, M. H., Teixeira, G. L., Bertoldic, F. C., Noronha, C. M., Vitali, L., Block, J. M., & Barreto, P. L. M. (2021). Brazilian Grown Cascade Hop (Humulus lupulus L.): LC-ESI-MS-MS and GC-MS Analysis of Chemical Composition and Antioxidant Activity of Extracts and Essential Oils. *Journal of the American Society of Brewing Chemistry*, *79*(2), 156-166. https://doi.org/10.1080/03610470.2020.1795586

Arruda, T. R., Pinheiro, P. F., Silva, P. I., & Bernardes, P. C. (2021). A new perspective of a well-recognized raw material: Phenolic content, antioxidant and antimicrobial activities and α- and β-acids profile of Brazilian hop (Humulus lupulus L.) extracts. *LWT – Food Science Technology*, *141*, 110905. https://doi.org/10.1016/j.lwt.2021.110905

Blendl, M., Engelhard, B., Forster, A., Gahr, A., Lutz, A., Mitter, W., Schmidt, R., & Schönberg, C. (2014). *Hops: Their Cultivation, Composition and Usage*. Fachverlag Hans Carl GmbH.

Associação Brasileira de Normas Técnicas (2017). *NBR ISO 5492:2017: Sensorial analysis - Vocabulary*. Associação Brasileira de Normas Técnicas.

Durello, R. S., Silva, L. M., & Bogusz, S. J. (2019). Química do Lúpulo. *Química Nova*, *42*(8), 900-919. https://doi.org/10.21577/0100-4042.20170412

Economic Commission (2022). International Hop Growers' Convention. *Summary reports*. Economic Commission. Available at: Http://www.hmelj-giz.si/ihgc/doc/2022_APR_IHGC_EC_Report_Summary.pdf. Accessed on: October 7, 2023.

Gomes, F. O., Guimarães, B. P., Ceola, D., & Ghesti, G. F. (2022). Advances in dry hopping for industrial brewing: a review. *Food and Science Technology*, *42*, 1. https://doi.org/10.1590/fst.60620

Guimarães, B. P., Evaristo, R. B. W., & Ghesti, G. F. (2021). Prospecção Tecnológica do Lúpulo (Humulus lupulus L.) e suas Aplicações com Ênfase no Mercado Cervejeiro Brasileiro. *Cadernos de Prospecção*, *14*(3), 858. https://doi.org/10.9771/cp.v14i3.33059

Jastrombek, J. M., Faguerazzi, M. M., de Cássio Pierezan, H., Rufato, L., Sato, A. J., da Silva Ricce, W., Marques, V. V., Leles, N. R., & Roberto, S. R. (2022). Hop: An Emerging Crop in Subtropical Areas in Brazil. *Horticulturae*, *8*(5), 393. https://doi.org/10.3390/horticulturae8050393

Kirkpatrick, K. R., & Shellhammer, T. H. (2018). Evidence of Dextrin Hydrolyzing Enzymes in Cascade Hops (Humulus lupulus). *Journal of Agricultural and Food Chemistry*, *66*(34), 9121-9126. https://doi.org/10.1021/acs.jafc.8b03563

Kramer, B., Thielmann, J., Hickisch, A., Muranyi, P., Wunderlich, J., & Hauser, C. (2015). Antimicrobial activity of hop extracts against foodborne pathogens for meat applications. *Journal of Applied Microbiology*, *118*(3), 648-657. https://doi.org/10.1111/jam.12717

Lafontaine, S., Varnum, S., Roland, A., Delpech, S., Dagan, L., Vollmer, D., Kishimoto, T., & Shellhammer, T. (2019). Impact of harvest maturity on the aroma characteristics and chemistry of Cascade hops used for dry-hopping. *Food Chemistry*, *278*, 228-239. https://doi.org/10.1016/j.foodchem.2018.10.148

Woodske, D. (2012). *Hop Variety Handbook: Learn More about Hop... Create Better Beer*. Createspace.