Use of the Hop Aroma Component Profile to Calculate Hop Rates for Standardizing Aroma Units and Bitterness Units in Brewing

Earl L. Van Engel, *Blitz-Weinhard Brewing Company, Portland, OR 97209,* **and Gail B. Nickerson,** *Department of Agricultural Chemistry, Oregon State University, Corvallis 97331-6502*

ABSTRACT

Hop bittering resins and hop aroma essential oil components are separate hop fractions that vary individually with variety, crop year and climate, source, age, and processing conditions. Our taste panel, confirming the reports of others, found that the use of hop bittering values and preset varietal ratios to determine hopping rates can lead to unexpected and unwanted variations in the intensity of a beer's hop character when brewing a late moderately hopped or dry-hopped product that requires the use of a large quantity of aroma hops. Based on historical ratios, taste panel reports, α-acids averages, and the hop aroma component profiles of 22 hop aroma compounds, calculations were developed that first determine kettle aroma hopping rates and then bittering hopping rates. Some examples of production wort and beer aroma units and arbitrary bitterness units are presented, along with taste panel findings.

Keywords: α-Acids, Beer, Essential oil components, Flavor, Hop character, Wort

Many factors can affect the hop character of a specific beer or ale. Bittering resins and essential oils of hop cultivars vary with the year of harvest, source, plant maturity, conditions at the time of picking, processing procedures, storage conditions, and time of storage (2–9,14,19,21,26,27). Production variables include the variety and amount of hops used, time and place of addition, kettle boil and evaporation, losses during fermentation and filtration, tank blowdowns to reduce air content, taste panel perceptions, laboratory analysis, and packaging materials, specifically crown liners (2,6,8,14,17–19,23,27).

Many of the factors that can lead to variation in a beer's hop character, defined by Haley and Peppard (6) as ". . . the flavor imparted to beer by the essential oil of hops and traditionally introduced by dry hopping or late hopping," can be controlled with uniform brewing practices and the help of laboratory analytical methods (1,10,15,19,28). A complete hop analysis is needed to determine correct addition times and rates because, except for some hop extracts, breweries do not receive hops with a uniform bittering and/or aroma potential. Because hopping rates are traditionally based on bittering value (α-acids analysis) (27), such rate changes will provide uniformity only in final product bitterness. Therefore, when using aroma hops to impart a specific hop character of uniform intensity, which comes from the hop oil components and quantitatively changes independently of bittering values (6,12,13,15,20,21,27), it seems reasonable that aroma hopping rates should also be quantitatively adjusted to produce a beer with a more uniform hop character.

So far, the only hopping procedure that addresses this quality problem is the postfermentation injection of hop resins and oils, most recently obtained with the use of liquid carbon dioxide (2,3,6,12–14,20,22,23,27).

This study began in 1985 after taste panel reports indicated a loss of hop character in one of our beers. Similar reports on the variability of hop character in beer, even when bitterness remains constant, have been made by others (2,6,13,14,22,23,27).

Subsequently, four in-house Cascade hop pellet samples, harvested in 1983 and 1984 from three different suppliers, were blindly evaluated by six members of our taste panel. The panelists were asked to rate all four samples for intensity and purity of aroma and to rate each sample from 1 to 4, best to worst. The scores then were reversed to give the best rated hop sample the highest score. The overall ratings for the four samples were 20, 16, 15, and 9. The sample rated 9 was from the hop shipment used in production when our panel noted the decrease in the hop character of the beer.

Production hop samples then were sent to the hop chemistry laboratory at Oregon State University (OSU) for analysis of hop oil content and composition. While these data were being collected, our taste panel again noted a decrease in hop character in one of our beers. At that time, we were using 1986 hops, and to compensate for high bittering values, we had reduced the product's hopping rate by 20%. The aroma hops (Cascades) used at that time had a 6.7% α-acids content (1), which normally averaged 5.0% (Table I), and the bittering hops (Clusters) had a 7.2% α-acids content, which normally averaged 6.0% (Table II).

The hop oil component analysis and evaluation of seven commercial hop samples from the same agronomic area, supplied by four different hop brokers (Table I), led to the development of our current hop use concept (26). Initially, we called the hop aroma component profile (HACP) "Sigma" after Foster and Nickerson (4), who compared microliters of aroma components to grams of α-acids. Foster and Nickerson's Sigma included 19 specific hop aroma components. Our modified profile contains 22 components (15). These 22 components make up the current HACP and hop aroma unit (AU), which equals one microliter of hop aroma components per kilogram of hops or per liter of wort or beer (1 ppm). Expressing AUs in microliters per kilogram (ppm) quantitatively relates them to bitterness units (BU), which also are expressed in the same units.

Foster and Nickerson's 19 original hop aroma components were selected from compounds identified by Tressl et al (24,25) and Peacock and Deinzer (16,17) that were identified as contributors to hop character. Our modification of this list includes deleting nerolidol (which is not an oxidative product of humulene or caryophyllene) and including humulol (a humulene oxidation product) and α-muurolene, β-selinene, Δ-cadinene, and γ-cadinene, which are the result of improved gas chromatography separation of cadinene. It is likely that this new list of hop oil aroma compounds will be modified by hop and flavor chemists in the future.

The data presented in Table I and in our companion report (15) help confirm the previously cited reports that the hop oil components of a given hop variety vary independently of the hop bittering fraction. Most recently, Kenny (9) reported that the ratios of hop essential oil components did not differ, among the samples of one cultivar, as much as the actual amount of the aroma components did.

Finally, the evaluation of these data provided the basic information needed to develop a procedure to standardize hop aroma component addition rates, which should help produce beers with a more uniform hop character.

EXPERIMENTAL

Hop Samples

All hop samples were a blend of hop pellets, taken at random, from three different 20-kg hermetically sealed containers, from all shipments received at the brewery.

Wort Samples

All wort samples were taken from the brewery's wort line, after cooling, in 3.78-L (1-gal) jugs with foil-lined caps. To prevent

TABLE I
Cascade Hop Analyses 1985-1987

Sample	Supplier	Crop Year	Percent α- Acids	Percent β-Acids	Total α- and β-Acids	Hop Aroma Components, μl/kg of hops (ppm) HSI[a]	Oxidation Components	Floral	Citrus	Total AUs[b]
1	A	1983	6.0	4.5	10.5	0.35	187	324	612	1,123
2	B	1983	5.8	4.7	10.5	0.43	129	282	347	758
3	C	1983	3.7	5.1	8.8	0.53	537	346	523	1,406
4	B	1984	4.9	4.9	9.8	0.47	217	480	528	1,225
5	D	1985	3.6	6.1	9.7	0.48	174	472	563	1,209
6	B	1985	4.4	6.1	10.5	0.41	198	134	658	990
7	D	1986	6.7	5.5	12.5	0.34	202	879	463	1,544
Average			5.0	5.3	10.3	0.43	235	417	528	1,180

[a] Hop storage index (1).
[b] Hop aroma units.

TABLE II
Cluster Hop Analyses 1985-1987

Sample	Crop Year	Percent Hop Resins α	β	Total	HSI[a]
1	1983	7.0	4.5	11.5	...
2	1983	6.0	5.1	11.1	...
3	1984	6.9	4.8	11.7	0.32
4	1984	5.8	4.6	10.4	0.31
5	1985	5.2	4.8	10.0	0.31
6	1985	4.7	4.4	9.1	0.32
7	1986	7.2	4.5	11.7	0.34
8	1986	5.6	4.7	10.3	0.35
Average		6.0	4.7	10.7	0.33

[a] Hop storage index (1).

spoilage before analysis, each gallon was stabilized with 5 ml of 40% formaldehyde.

Beer Samples

All beer samples were normal production blends, consisting of beers from several brews and storage beer tanks related in time and content to the production wort samples used for analysis.

Analysis

All analyses were made according to ASBC methods (1) or by the hop analysis procedures described by Nickerson and Van Engel (15).

Calculations

Considering the following facts, a simple sequence of calculations was developed to determine aroma and bittering hop addition rates to produce beers with more uniform hop character.

First, hops vary in bittering values depending on α-acids and oxidized α- and β-acids resin content. The oxidized resins are the product of processing and age (4,10,19). The bittering values of the hops listed in Tables I and II vary up to 20%.

Second, hops vary in aroma units both in their ratios of oil components and in quantity (9,15). The AUs of the hops listed in Table I vary by up to 50%.

And third, quantitatively, α- and β-acids and AUs vary independently of one another (Table I) (15).

Calculating Hop Addition Rates at Average Bittering and Aroma Unit Content

The first set of calculations determines product AU and hop bittering rates based on standard historical hopping ratios and average bittering and AU content. This was done to establish normal acceptable levels of product hop character and bitterness.

To make these calculations, one must know the product's final targeted BUs, the pounds of α-acids required, the hops' historical use ratios, the hops' historical average for α-acids, adjusted for oxidation (4,10,19), and average AUs.

For the following formulas, the hypothetical factors used included: final beer BU target = 12, pounds of α-acids required = 7.55, historical average adjusted α-acids content = 6.7% for aroma hops and 7.0% for bittering hops, historical use ratios = 50% each hop fraction, and historical average AU content = 1,180.

$$\text{Hopping usage factor} = \text{pounds of } \alpha\text{-acids needed}/[(\text{percent aroma hops} \times \text{percent aroma hops } \alpha\text{-acids}) + (\text{percent bittering hops} \times \text{percent bittering hops } \alpha\text{-acids})] \times 10 \quad (1)$$

$$\text{Hopping usage factor} \times \text{hop ratio} = \text{pounds of hops} \quad (2)$$

Using the hypothetical factors mentioned above, the first equation gives a hopping usage factor of:

$$7.55/[(0.50 \times 0.067) + (0.50 \times 0.070)] \times 10 = 110.22 \text{ hopping usage factor}$$

$$110.22 \times 0.50 = 55.11 \text{ or } 55 \text{ lb of aroma hops and } 55 \text{ lb of bittering hops at average bittering and AU (1,180) content}$$

Once average hop addition rates have been determined, it is only a matter of adjusting current addition rates for changes in AU and bittering content, values that may be used for both kettle and dry hopping.

Calculating Hop Addition Rates When There is a Change in Hop Aroma Units and/or Hop Bittering Values

When the number of AUs in a new hop shipment differs from the historical average, the aroma hop addition rate is changed first to accommodate the hop AU change. The bittering hop rate then is adjusted to achieve the final BU target.

To make these calculations, the historical data plus the new hops' AU and bittering values are used. For example, if the hop AU content is 1,000 and the hop adjusted α-acids content is 7.9% for aroma hops and 6.7% for bittering hops, the calculations are as follows:

$$1{,}180 \text{ AU}/1{,}000 \text{ AU} = 1.18 \text{ aroma hop addition ratio} \quad (3)$$

$$55 \text{ lb of aroma hops} \times 1.18 \text{ aroma hop addition rate} = 64.9 \text{ or } 65 \text{ lb of aroma hops} \quad (4)$$

$$65 \text{ lb of aroma hops} \times 0.079\% \text{ aroma hops } \alpha\text{-acids} = 5.14 \text{ lb of } \alpha\text{-acids from the aroma hops} \quad (5)$$

$$7.55 \text{ total lb of } \alpha\text{-acids} - 5.14 \text{ lb of aroma hops } \alpha\text{-acids} = 2.41 \text{ lb of } \alpha\text{-acids needed from the bittering hops} \quad (6)$$

2.41 lb of bittering hops α-acids/0.067% bittering hops α-acids = 35.97 or 36 lb of bittering hops, which may have to be adjusted to correct for a change in utilization (7)

The original 50:50 hop addition ratio is now 64:36. However, the percentages of aroma and bittering hop fractions added are essentially unchanged.

Unfortunately, we cannot comment on a significant increase or decrease in aroma hop use during the past two years because we have not experienced one. However, we did make a major shift in bittering hop use, which is reported in the Results and Discussion section of this article.

Calculating Hop Addition Rates When Only Hop Bittering Values or Final Product BUs Need Correction

If only hop bittering values change or if final product BUs need adjusting, the only adjustment made should be to the bittering hops added to the kettle. The aroma hop addition rate should remain unchanged. This point of view discounts any significant changes in hop character imparted by adjusting early kettle hopping rates.

Adjusting Hop Addition Rates When All of the Hops Being Used are Aroma Hops

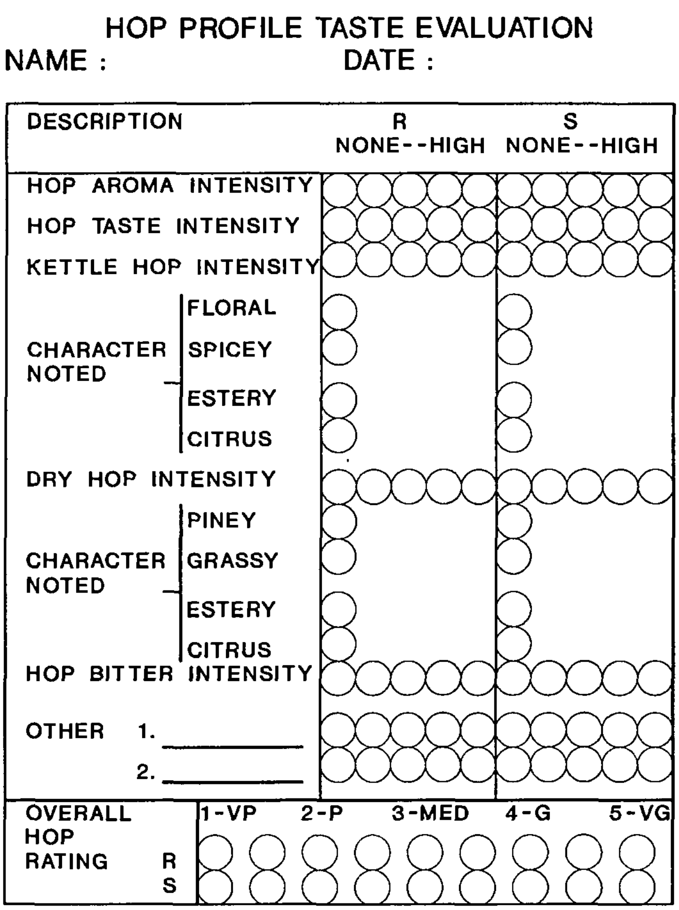
If the product being brewed requires the use of 100% aroma hops, an increase in the early kettle hop addition with extra hops or a shift of some of the late hop addition to an earlier addition time should increase BUs and/or reduce final product hop character—provided that is what is wanted.

Conversely, a shift in hopping from an early to a late kettle addition should result in reduced isomerization and an increase in hop character through a reduction in hop essential oil kettle distillation. Also, just increasing a late and/or a dry hop addition rate, while maintaining final BU specifications, could also be used to increase final product hop character.

Taste Panel

The taste panel was made up of brewing and quality control personnel who met at least once every morning at 11 a.m. for consecutive blind and production taste testing. Over the years, this daily regime has familiarized the panelists with the products' taste characteristics.

To aid the taste panel in evaluating the hop characteristics of the products, a hop profile taste form was developed (Fig. 1) that incorporates recommended hop flavor terminology (11). All of the taste results presented in this report use data from this form. All taste values in this study are from comparisons of fresh beer samples.


HOP PROFILE TASTE EVALUATION
NAME : DATE :

DESCRIPTION	R NONE--HIGH	S NONE--HIGH
HOP AROMA INTENSITY		
HOP TASTE INTENSITY		
KETTLE HOP INTENSITY		
CHARACTER NOTED: FLORAL		
SPICEY		
ESTERY		
CITRUS		
DRY HOP INTENSITY		
CHARACTER NOTED: PINEY		
GRASSY		
ESTERY		
CITRUS		
HOP BITTER INTENSITY		
OTHER 1. ________		
2. ________		

OVERALL HOP RATING	1-VP	2-P	3-MED	4-G	5-VG
R					
S					

Fig. 1. Hop profile taste evaluation form. R and S = sample codes, VP = very poor, P = poor, MED = medium, G = good, VG = very good.

RESULTS AND DISCUSSION

Once the HACP-based concept of adjusting aroma hop addition rates was put into practice, a series of taste tests were begun using a hop profile taste test evaluation form (Fig. 1), which contains six hop taste categories and six hop taste characteristics. The objective was to correlate taste test results to the hop, wort, and beer analyses of the samples we submitted to the OSU hop chemistry laboratory. Correlations have been made between taste and analysis by Seaton et al (20), who established a logarithmic relationship between linalool and floral flavor in beer. Also, Peppard et al (18) correlated a European hop flavor to linalool oxides and spiciness to hop oxidation products.

The result of these taste tests, which took place over one and a half years, are presented in Tables III and IV and Figure 2. These results represent taste comparisons between three production beers labeled A, B, and C. Beer A is an early bitter-hopped lager, beer B is an early bitter-hopped and a late aroma-hopped lager, and beer C is a late aroma- and dry-hopped mild ale.

The taste panel consistently perceived a greater level of hop character, including bitterness, in beers B (10 taste comparisons) and C (nine taste comparisons) when they were compared with beer A (19 taste comparisons), a product that has a poorly defined hop character except for bitterness. When beers B and C (eight

TABLE III
Taste Panel Ratings Comparing Beers A and B and A and C[a]

Taste Category	Beer	Low Rating	High Rating	Average Rating	SD	cv
Hop aroma	A	1.5	2.3	1.81	0.27	14.9
	B	2.2	3.3	2.79	0.36	12.9
	C	3.2	3.5	3.33	0.14	4.2
Hop taste	A	2.0	2.7	2.38	0.21	8.8
	B	3.0	3.8	3.37	0.28	8.3
	C	3.0	4.0	3.45	0.34	9.9
Kettle hop taste	A	1.8	2.8	2.15	0.27	12.6
	B	2.5	3.0	2.83	0.20	7.1
	C	2.0	2.7	2.53	0.27	10.7
Dry hop taste	A	1.0	1.5	1.12	0.14	12.5
	B	1.0	2.3	1.56	0.41	26.3
	C	2.5	2.8	2.60	0.13	5.0
	A	2.0	2.8	2.34	0.26	11.1
Bitterness	B	2.6	3.3	2.99	0.23	7.7
	C	2.5	3.0	2.70	0.24	8.9
Overall hop rating	A	2.6	3.5	3.08	0.25	8.1
	B	3.7	4.4	4.09	0.21	5.1
	C	4.0	4.4	4.23	0.16	3.8

[a] Based on 19 tests for beer A, 10 tests for beer B, and nine for beer C. Five to six panelists per test. Tests were conducted from 1988 to February 1990.

taste comparisons), which had a similar hop character, were compared with one another, the taste panelists were not able to detect the same degree of hop flavor intensity that they found when comparing them with product A. Subsequently, all taste and HACP analytical comparisons (Table V) were made between beers A and B and A and C, respectively.

Quantitatively, the total HACP values from Table V for beers B and C relate to reports by Chapman (2), who found that 0.050 μl/L of injected hop oil compounds give most beers a late hop flavor, and to Westwood (27), who reported that a late hop flavor is best at a 0.100 μl/L level of hop oil compounds in beer. Peacock and Deinzer (16) reported taste thresholds for linalool (0.027 μl/L) and geraniol (0.036 μl/L) that are slightly greater than the concentration of these components in beers B and C. However, they are comparable to the total floral-estery components found. Seaton et al (21) reported that total hoppy aroma and flavor are related to the total level of hop oil compounds in the beer. This concept accounts for any synergistic effects that the HACP compounds have on one another or on other beer components; to be more specific, total hoppy aroma and flavor may best be related to the total level of HACP compounds in the beer.

The correlation coefficients derived from the mean hop taste scores (Table III) and four HACP analytical values (total oxidation products, total floral-estery components, linalool, and total HACP components) (Table V) of these beers are presented in Table VI. All subsequent wort and beer HACP values have been adjusted to normal gravity for comparison purposes. There is a good degree of correlation between HACP analysis and the four taste categories of hop aroma, hop taste, dry hop taste, and overall hop rating. The best of these correlations are those between total floral-estery and linalool values and hop aroma ratings and between total oxidation components and dry hop taste. The strong floral-estery correlations with linalool and hop aroma are explained by the fact that Cascade hops are noted for their floral-estery taste characteristic. The reason for the strong correlation between oxidation products and a dry hop taste is not as clear. As previously mentioned, Peppard et al (18) related "spiciness" to hop oxidation products, whereas our taste panel noted "piney" as dry-hopped beer C's second most notable taste characteristic. Plots of the linearity of this data are presented in Figures 3–6.

Kettle hop taste, which the panel equates to bitterness, and bitterness taste values do not correlate with the HACP values but do correlate with the three beer's average BUs from this same time period. This correlation supports the taste panel's ability to relate AUs to hop character. The bitterness and BU correlation coefficients show approximately the same degree of error between analysis and taste (± 10%) that has been reported by others (12,19,20). The values used to correlate BUs for beers A, B, and C (1.83, 2.44, and 2.30, respectively) are arbitrary but in the same

TABLE IV
Taste Panel Ratings Comparing Beers B and C[a]

Taste Category	Beer	Low Rating	High Rating	Average Rating	SD	cv
Hop aroma	B	2.0	2.8	2.20	0.28	12.7
	C	2.3	3.0	2.60	0.24	9.2
Hop taste	B	2.3	3.2	2.79	0.30	10.8
	C	2.5	3.6	2.94	0.35	11.9
Kettle hop taste	B	2.3	3.0	2.69	0.24	8.9
	C	2.0	3.0	2.38	0.37	15.6
Dry hop taste	B	1.0	1.4	1.16	0.15	12.9
	C	1.3	2.8	2.09	0.44	21.1
Bitterness	B	2.3	2.8	2.71	0.21	7.8
	C	2.0	3.0	2.68	0.37	13.8
Overall hop rating	B	3.3	4.2	3.69	0.29	7.9
	C	3.5	3.9	3.76	0.17	4.5

[a] Based on eight tests with five to six panelists per test. Tests were conducted from 1988 to June 1989.

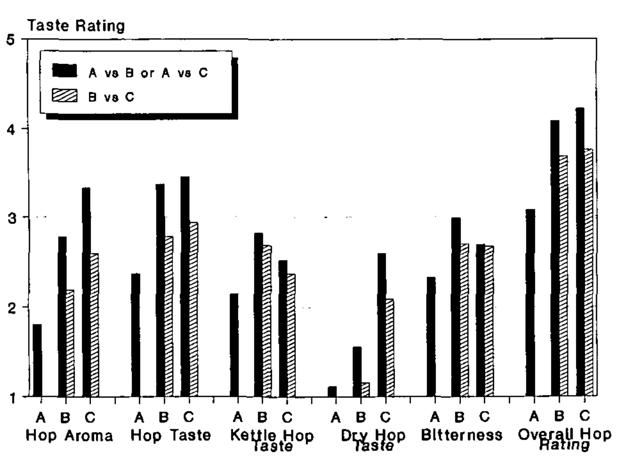


Fig. 2. Taste panel average ratings comparing beers A and B, A and C, and B and C.

TABLE V
Hop Aroma Component Profiles (HACP) of Three Differently Hopped Beers (A, B, and C)

Hop Oil Component	Concentration, μl/L (ppm) Beer A	Beer B	Beer C
Oxidation products			
Caryophyllene oxide	0.0035	0.0017	0.0020
Carolan-I-ol			
Humulene monoepoxide I	0.0039	0.0005	0.0032
Humulene monoepoxide II	0.0093	0.0308	0.0425
Humulene monoepoxide III		0.0063	0.0043
Humulene diepoxide A			
Humulene diepoxide B		0.0003	0.0009
Humulene diepoxide C			
Humulol	0.0080	0.0013	0.0042
Humulenol II	0.0103	0.0031	0.0034
Total oxidation products	0.0350	0.0440	0.0605
Floral-estery			
Geranyl acetate	0.0022	0.0029	0.0078
Geranyl isobutyrate	0.0011	0.0002	0.0008
Geraniol	0.0034	0.0083	0.0058
Linalool	0.0062	0.0170	0.0254
Total floral-estery	0.0129	0.0284	0.0398
Total citrus-piney[a]	0.0000	0.0000	0.0000
Total HACP components	0.0479	0.0724	0.1003

[a] Limonene, citral, nerol, limonen-10-ol, α-muurolene, β-selinene, Δ-cadinene, and γ-cadinene.

TABLE VI
Correlation Coefficients of Mean Sensory Ratings, Hop Aroma Component Profile (HACP) Values, and Bitter Units (BUs) for Beers A, B, and C

Taste Category	Oxidation Components	Floral-Estery Components	Linalool	Total HACP	BUs
Hop aroma	0.946**[a]	0.997***	0.996***	0.979**	...
Hop taste	0.811	0.933*	0.927*	0.881*	...
Kettle hop taste	0.411	0.628	0.616	0.526	0.973**
Dry hop taste	0.998***	0.950**	0.955**	0.982**	...
Bitterness	0.405	0.624	0.611	0.521	0.971**
Overall hop rating	0.836	0.948**	0.943**	0.901*	...

[a] * = Significant at 90% confidence level, ** = significant at 95% confidence level, and *** = significant at 99% confidence level.

ratio as the actual BU averages of these three products. The linear plots of this data are presented in Figure 7.

These results support the concept that the use of specific varieties and quantities of aroma hop cultivars is essential in producing the correct quality as well as quantity of hop character in a late- or dry-hopped beer. However, the source of the final product's bitterness, whether from aroma or bittering hop resins, should not make a quality difference in the final product as long as the quantity of bitterness is correct.

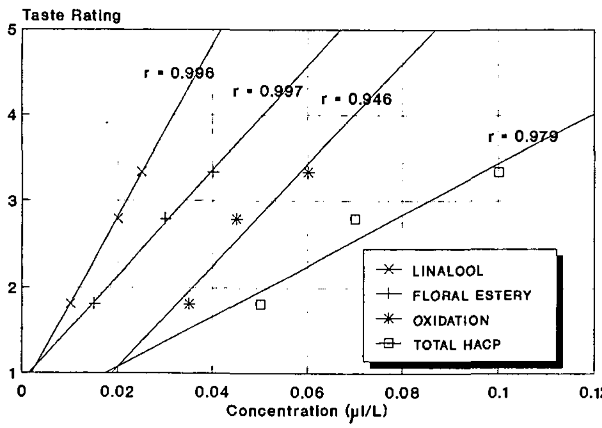


Fig. 3. Correlation between mean sensory hop aroma ratings and hop aroma components in beers A, B, and C. HACP = hop aroma component profile.

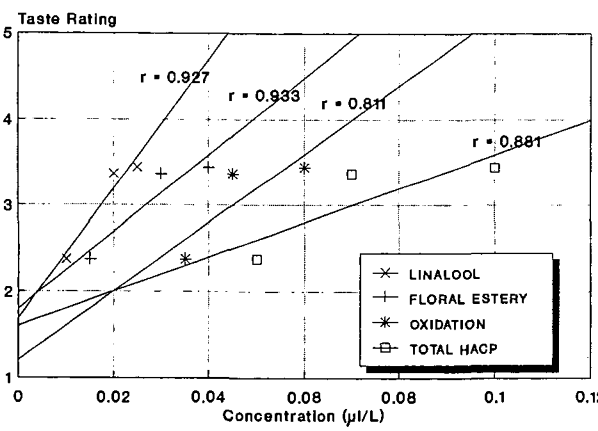


Fig. 4. Correlation between mean sensory hop taste ratings and hop aroma components in beers A, B, and C. HACP = hop aroma component profile.

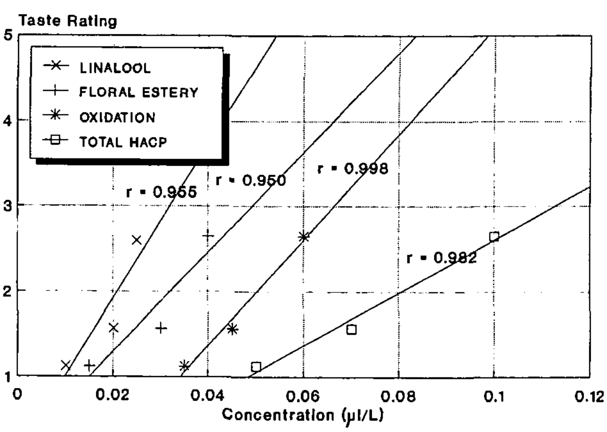


Fig. 5. Correlation between mean sensory dry hop ratings and hop aroma components in beers A, B, and C. HACP = hop aroma component profile.

The six specific hop taste characteristics on the taste form are floral, piney, spicy, grassy, estery, and citrus. Notation of these characteristics helps identify the specific kettle or dry hop taste. The results, from beer comparisons A and B and A and C (Fig. 8) were recorded only when 50% or more of the taste panelists were able to identify a particular taste characteristic.

The predominating kettle hop taste noted in beers B and C was floral, which is characteristic of Cascade hops. Spicy was noted 30% of the time by at least 50% of the tasters. The dry hop characteristic most often noted in beer C was piney. The taste panel found that beer A, a beer that is only bitter-hopped, does not have a well-defined hop character. In addition, taste corroboration between the lack of a citrus taste in beers A, B, and C and the HACP beer analytical results for citrus piney components (Table VI) was evident, even though these hop components make up 50% of the aroma hops total HACP value (Table I).

Figure 9 is similar to Figure 8 but shows taste comparisons only between beers B and C. These results confirm the taste panel's diminished taste acuity when comparing two beers with similar taste characteristics. Other than noting that a floral taste predominates in beers B and C, these taste results justify the decision to use only beer A and B and A and C taste test comparisons when profiling these beers.

As an example of the application of the concept of adjusting hopping rates based on HACP analysis as well as bittering values, during 1988 and 1989, we made four hopping rate changes to product B, one to the aroma and three to the bittering hops (points 1, 2 and 3 in Fig. 10). On August 23 and November 28, 1988, and May 8, 1989, the bittering hop rate was increased

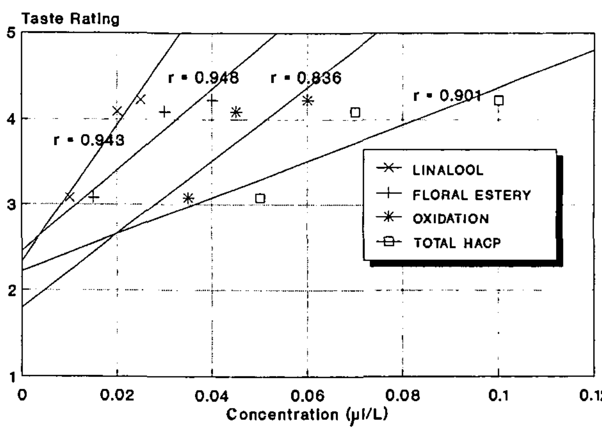


Fig. 6. Correlation between mean sensory overall hop ratings and hop aroma components in beers A, B, and C. HACP = hop aroma component profile.

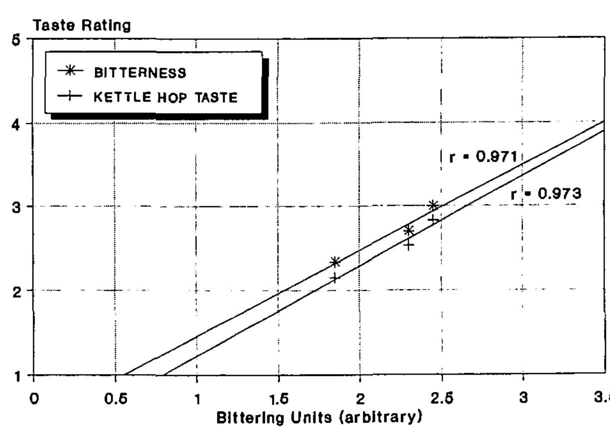


Fig. 7. Correlation between mean sensory kettle hop and bitterness ratings and arbitrary bitterness units in beers A, B, and C.

by 50, 21, and 10%, respectively, which doubled the initial bittering hop rate. On November 28, 1988, the aroma hopping rate was increased 3%. This amounted to a significant 15% shift in bittering-aroma hop ratios. Even so, product B's bittering units (Fig. 10) and taste profiles (Table VII) remained within acceptable limits. Only one rating, the 1989 overall hop taste rating, was not within one standard deviation of the average hop taste values shown in Table III. This 1988–1989 taste result comparison is the average of three A/B taste panel profiles made on beer brewed before August 23, 1988, and the average of three A/B taste panel profiles made on beer brewed between November 28, 1988, and May 8, 1989. During this time, beer B bittering hop rates were increased 82% and aroma hop rates were increased 3%. Beer A bittering hop rates increased by 24%.

Also of interest was the taste panel's hop aroma rating drop from 3.0 to 2.5 for beer B during this time period. This coincided with the 25% decrease in the beer's total floral-estery HACP values (Table VIII). Total HACP values, on which we based these hop addition rates, changed only 5%, which could be the result of any one of a number of previously mentioned production variables, including hop HACP content. These results also agree with our findings that hop aroma ratings correlate best with the floral-estery fraction of the hops and support the concept of basing aroma hop addition rates on total HACP and AU values.

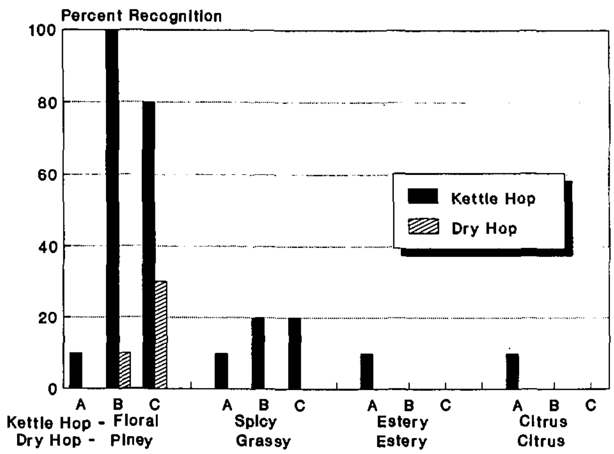


Fig. 8. Percent recognition of specific hop taste characteristics comparing beers A and B and A and C.

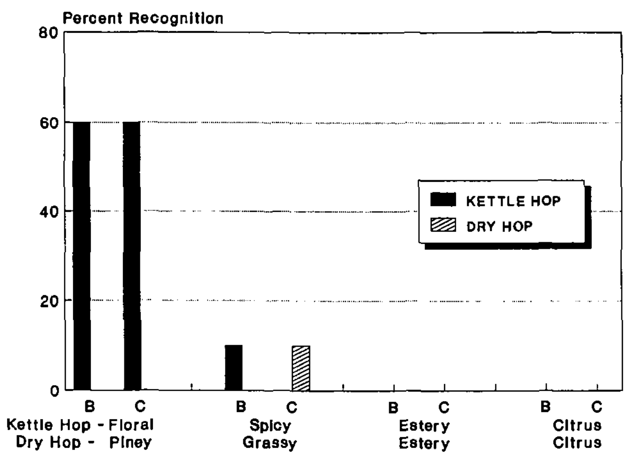


Fig. 9. Percent recognition of specific hop taste characteristics comparing beers B and C.

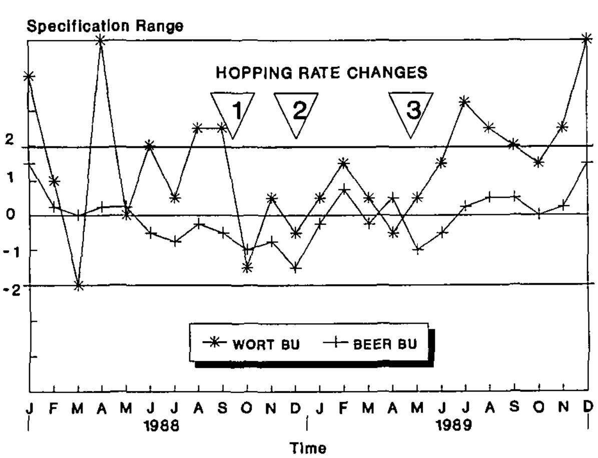


Fig. 10. 1988 and 1989 monthly wort and beer bitterness unit (BU) averages for product B.

CONCLUSIONS

Traditionally, hopping rate adjustments for late- and or dry-hopped beer or ale are based on hops bittering value without considering the variability of an aroma hop's essential oil composition and its effect on hop character. Now, with the use of

TABLE VII
Beer B Taste Panel Ratings in 1988, Before, and in 1989, After an 82% Kettle Increase in Pounds of Bittering Hops

	Taste Category					
Year[a]	Hop Aroma	Hop Taste	Kettle Hop Taste	Dry Hop Taste	Bitterness	Overall Hop Taste
1988	3.00	3.47	2.80	1.55	3.06	4.00
1989	2.50	3.55	2.90	1.40	3.15	4.35
Average overall	2.79	3.37	2.83	1.56	2.99	4.09

[a] There were three taste tests each in 1988 and 1989.

TABLE VIII
Product B Hop Aroma Component Profile (HACP) of Wort and Beer in 1988, Before, and in 1989, After an 82% Increase in Pounds of Bittering Hops

	Concentration, µl/L (ppm)			
	1988		1989	
Hop Oil Component	Wort	Beer	Wort	Beer
Oxidation products				
Caryophyllene oxide	0.0065	0.0017	0.0037	0.0013
Carolan-I-ol	0.0047	0.0005	0.0054	0.0020
Humulene monoepoxide I	0.0324	0.0308	0.0146	0.0303
Humulene monoepoxide II	0.0038	0.0063	0.0044	0.0043
Humulene monoepoxide III				
Humulene diepoxide A				
Humulene diepoxide B		0.0003		0.0008
Humulene diepoxide C				0.0005
Humulol	0.0059	0.0013	0.0043	0.0025
Humulenol II	0.0097	0.0031	0.0208	0.0058
Total oxidation products	0.0630	0.0440	0.0532	0.0475
Floral-estery				
Geranyl acetate	0.0032	0.0029	0.0035	0.0014
Geranyl isobutyrate	0.0029	0.0002	0.0022	0.0008
Geraniol	0.0307	0.0083	0.0316	0.0054
Linalool	0.0317	0.0170	0.0219	0.0138
Total floral-estery	0.0685	0.0284	0.0592	0.0214
Total citrus-piney[a]	0.0000	0.0000	0.0000	0.0000
Total HACP components	0.1315	0.0724	0.1124	0.0689

[a] Limonene, citral, nerol, limonen-10-ol, α-muurolene, β-selinene, Δ-cadinene, and γ-cadinene.

an HACP and a taste program specifically designed to rate hop character, a brewery laboratory can determine aroma hop, bittering hop, and dry hop addition rates to standardize AUs and BUs in the final product. Using these quality control tools in this manner should result in the production of a more uniform hop character in moderately hopped beer and ale. Fortunately, the low to moderate bittering values of aroma hops prevents too high an α-acids content from quantitatively restricting their use.

This report, which is primarily concerned with the control of AUs and hop character in beer, should increase interest in hops essential oil composition and content by the hop breeders, growers, processors, and chemists.

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