New insights into bitterness perception of beer

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• Bitterness is a key sensory property of beers. Largely, but not wholly, derived from the bitterness of iso-α-acids (hops).

• Bitterness is a diverse taste percept encompassing a range of qualitative sensations and mediated by a large family of taste receptors (25 x TAS2R receptors identified; Intelmann et al., 2009).

• Beer bitterness has both temporal (Hughes & Bolshaw, 1995; Fritsch & Shellhammer, 2009) and qualitative aspects (McLaughlin et al., 2008).

• Traditionally bitterness of beer has been indicated in terms of IBU’s (1 IBU nominally = 1 mg/L isohumulones)

• Prior studies and our sensory experience of different beers suggest that perceived bitterness is more complex than a number derived from absorbance of an extract of beer at 275 nm.
Research Approach

• Develop a **sensory lexicon** to describe the full array of sensations associated with bitterness perception of lager beers
  – Diverse sample set of lager beers
  – Attribute generation
  – Rationalisation of terms
  – Defined lexicon
  – Train panel to rate terms and anchor scales

• **Apply the new sensory lexicon to better understand beer bitterness perception and how it is influenced by beer composition and hop products usage**
**Bitterness lexicon: consensus terms**

**Harsh**: Tingly, painful, warning signal, irritating, raspy.

**Acidic**: Vinegary, fruit-associated acidity.

**Sharp**: Instant, bitterness taste at the tip of tongue.

**Tart**: Acidic with sour notes.

**Vegetative**: Cabbage, Sprout-like bitterness, Hop tea flavour.

**Artificial**: Chemically, unnatural beer flavour.

**Metallic**: Taste of tin/metal, silver coin taste.

**Astringent**: Dry, causing drying of the mouth.

**Smooth**: Velvety.

**Rounded**: Pleasant, not spiky, not harsh.

**Progressive**: Bitterness perception increases gradually.

**Instant**: Instantaneous bitterness perception.

**Diminishing**: Bitterness perception decreases quickly after ingestion.
The impact of hop bitter acid and polyphenol profiles on the perceived bitterness of beer

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Epicatechin (PubChem CID:72776)
Caffeic acid (PubChem CID:88043)

ABSTRACT

Thirty-four commercial lager beers were analysed for their hop bitter acid, phenolic acid and polyphenol contents. Based on analytical data, it was evident that the beers had been produced using a range of different raw materials and hopping practices. Principal Components Analysis was used to select a sub-set of 10 beers that contained diverse concentrations of the analysed bitter compounds. These beers were appraised sensorially to determine the impacts of varying hop acid and polyphenolic profiles on perceived bitterness character. Beers high in polyphenol and hop acid contents were perceived as having ‘harsh’ and ‘progressive’ bitterness, whilst beers that had evidently been conventionally hopped were ‘sharp’ and ‘instant’ in their bitterness. Beers containing light-stable hop products (tetrahydro-isocoumarins) were perceived as ‘diminishing’, ‘rounded’ and ‘acidic’ in bitterness. The hopping strategy adopted by brewers impacts on the nature, temporal profile and intensity of bitterness perception in beer.
Global lager study

• Survey of analytical bitterness composition versus perceived quality of bitterness for 33 fresh, globally/regionally significant lager brands (Right).

• Bitterness Units (ASBC-23) in range 8-36 BU.

• HPLC bitterness (sum iso-α-acids/ reduced side-chain iso-α-acids in range 8.7-43 mg/L. α-acids and humulinones also analysed (Oladokun et al. 2016a).

• Total polyphenols (ASBC-35), phenolic acids & flavanol monomers(HPLC) and amino acids (GC-MS) all analysed.

• Sensory bitterness characteristics using the novel lexicon.
PCA separation of the 33 beers according to their analytical profiles

The ten circled beers were selected as representative of the diversity present in the analytical data set and were used in sensory studies of the quality of perceived bitterness.
Sensory evaluation of the 10 beers selected on the basis of their analytical diversity

• Panel used ‘Check All That Apply’ (CATA) methodology to evaluate the beers.

• 9 of the 13 lexicon terms were scored significantly differently amongst the beers ($P<0.05$; Cochran’s Q test).
  – i.e. these terms were useful in distinguishing the bitterness characteristics present in the sample set.

• Correspondence analysis was then used to separate the beers according to their sensory bitterness qualities........
Correspondence analysis of bitterness attributes and beers

In GG & CC bitterness is sharp, artificial and instant.

S had diminishing bitterness & beer V had rounded bitterness.

E and AA had Progressive & Harsh bitterness.

BB had Vegetative & Smooth bitterness.
Correlation analysis then allowed the sensory bitterness data to be mapped against the analytical data.


Bitterness of conventionally hopped beers was ‘sharp’ & ‘instant’.

Beers bittered with pre-isomerised & tetra were ‘smooth’, ‘vegetative’ & ‘diminishing’.

Dry-hopped beers (high concentration of hop acids and polyphenols) were ‘harsh’ and ‘progressive’.
Predictive PLSR modeling of sensory bitterness qualities against analytical composition data.

Table shows the coefficients of the terms for selected compounds/group of compounds in the models for each bitterness quality

<table>
<thead>
<tr>
<th>Bitterness Attribute</th>
<th>TPC</th>
<th>Iso-α-acids</th>
<th>Humulinones</th>
<th>Tryptophan</th>
<th>Tetrahydroiso-α-acids</th>
<th>α-acids</th>
<th>Model $R^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intensity</td>
<td>+0.013</td>
<td>+0.048</td>
<td>+0.26</td>
<td>-0.020</td>
<td>-0.096</td>
<td>+0.21</td>
<td>0.90</td>
</tr>
<tr>
<td>Harsh</td>
<td>+0.017</td>
<td>+0.079</td>
<td>+0.073</td>
<td>-0.041</td>
<td>-0.078</td>
<td>+0.26</td>
<td>0.93</td>
</tr>
<tr>
<td>Smooth</td>
<td>-0.0064</td>
<td>+0.0060</td>
<td>-0.68</td>
<td>-0.017</td>
<td>+0.14</td>
<td>-0.12</td>
<td>0.95</td>
</tr>
<tr>
<td>Round</td>
<td>-0.0088</td>
<td>-0.053</td>
<td>+0.15</td>
<td>+0.014</td>
<td>+0.014</td>
<td>-0.13</td>
<td>0.95</td>
</tr>
<tr>
<td>Metallic</td>
<td>+0.0058</td>
<td>+0.10</td>
<td>-1.29</td>
<td>-0.01</td>
<td>+0.17</td>
<td>+0.061</td>
<td>0.96</td>
</tr>
<tr>
<td>Progressive</td>
<td>+0.010</td>
<td>+0.069</td>
<td>-0.24</td>
<td>-0.017</td>
<td>-0.0081</td>
<td>+0.16</td>
<td>0.97</td>
</tr>
</tbody>
</table>
Conclusions

- Hop products selection and hopping practice give distinct hop bitter acid & polyphenol profiles, which in turn impact on the perceived bitterness quality of beers.

- Beers low in hop bitter acids and polyphenols rated as having artificial, rounded & diminishing bitterness.

- Conventionally hopped beers high in hop acids, α-acids were rated as having a sharp and instant bitterness.

- Beers bittered with a blend of tetra and pre-isomerised iso-α-acid products rated as having a smooth and diminishing bitterness.

- Bitterness of dry-hopped beers high in hop bitter acids and polyphenols was perceived as harsh and progressive.
Modification of perceived beer bitterness intensity, character and temporal profile by hop aroma extract

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ABSTRACT

The effect of hop aroma on perceived bitterness intensity, character and temporal profile of beer was investigated. A hop aroma extract was added at 3 levels (0, 245, 490 mg/l) to beers at low, medium and high bitterness. Beers were evaluated for perceived bitterness intensity, harshness,oundedness and lingering by a trained panel using a rank-rating technique at each bitterness level, with and without nose clips. The use of nose clips enabled the olfactory aspect to be decoupled from taste and mouthfeel aspects of bitterness perception. Results showed significant modification of perceived bitterness in beer by hop aroma depending on the inherent level of bitterness. These modifications were mainly driven by olfaction – an example of hop-aroma interactions as well as certain tactile sensations elicited by the hop aroma extract in the oral cavity. At low bitterness, beers with hop aroma added were perceived as more bitter, and of “rounded” bitterness character relative to those without hop aroma. When judges used nose clips, this effect was completely eliminated but the sample was perceived to have a “harsh” bitterness character. Conversely, at high bitterness, even when nose clips were used, judges still perceived beers containing hop aroma to be more bitter. These increases in bitterness perception with nose clips indicates the stimulating of bitter receptors, e.g. trigeminal receptors by hop aroma extract, which in tandem with the high bitterness, cause perceptual interactions enhancing bitterness intensity and also affecting bitterness character. Bitterness character attributes such as “round” and “harsh” were found to significantly depend on bitterness and aroma levels, with the second level of aroma addition (245 mg/l) giving a “rounded” bitterness in low bitterness beers but harsh bitterness in high bitterness beers. The impact of aroma on temporal bitterness was also confirmed with time-intensity measurements, and found to be mostly significant at the highest level of hop aroma addition (490 mg/l) in low bitterness beers. These findings represent a significant step forward in terms of understanding bitterness flavour perception and the wider impact of hop components on sensory perception.
This study examined the effects of varied addition rates of hop aroma oils to beers at different BU levels on perceived bitterness quality and intensity.

An un-hopped base beer was prepared (70% pilsner malt/30% dextrose adjunct) which had an ABV of 5.0%, pH 4.23 and total polyphenol content (ASBC Beer-35) of 133 mg/L.

Isohop and pure hop aroma (PHA) products were then added to the same base beer to produce the following sample matrix:

<table>
<thead>
<tr>
<th>Bitterness</th>
<th>Hersbrucker PHA (mg/L)</th>
<th>East Kent Goldings PHA (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low (13 mg/L)</td>
<td>L0  0  245  490</td>
<td>L0  0  245  490</td>
</tr>
<tr>
<td>Medium (25 mg/L)</td>
<td>L0  0  245  490</td>
<td>L0  0  245  490</td>
</tr>
<tr>
<td>High (42 mg/L)</td>
<td>L0  0  245  490</td>
<td>L0  0  245  490</td>
</tr>
</tbody>
</table>
Experimental

• After addition of isohop and pure hop aroma, beers recapped, mixed and stored for 2 days at 3°C.

• Beers evaluated by trained sensorial panel at 4±2°C.

• Preliminary studies on the sensory bitterness of the beers was used to select 3 qualitative bitterness terms which best differentiated the samples:
  – Harsh (tingly, painful); Round (pleasant, smooth, non-spiky bitterness); Lingering (perceived bitterness intensity 10 seconds after beer consumption).
Impact of EKG aroma at low bitterness level (13 mg/L isohop)

Significance at 5%*, 1%** based on ANOVA of intensity ratings and Rank analysis by Friedman’s test (p<0.05); n= 7 trained panelists.

At low bitterness levels, added hop aroma significantly increased perceived bitterness intensity and (with EKG aroma) made the bitterness harsher and more lingering.

Significance at 5%*, 1%** based on ANOVA of intensity ratings and Rank analysis by Friedman’s test (p<0.05); n= 7 trained panelists.
Impact of EKG aroma at medium bitterness level (25 mg/L isohop)

At medium bitterness levels, similar effects of hop oil addition were noted but the bitterness also became less rounded as it became progressively harsher and lingering.

Significance at 5%*, 1%** based on ANOVA analysis of intensity ratings and Rank analysis by Friedman’s test (p<0.05); n=7 trained panelists.
Impact of EKG aroma at high bitterness level (42 mg/L isohop)

Whereas at high bitterness levels the impacts of added hop aroma on perceived bitterness was minimal.

Significance at 5%, 1%** based on ANOVA of intensity ratings and Rank analysis by Friedman’s test (p<0.05); n= 7 trained panelists.
Impact of Hersbrucker aroma at low bitterness level (13 mg/L isohop)

Assessment without wearing nose-clips

Same evaluation, panel wearing nose-clips to eliminate sense of smell

Significance at 5%*, 1%** based on ANOVA of intensity ratings and Rank analysis by Friedman’s test (p<0.05); n=7 trained panelists.
Impact of Hersbrucker aroma at high bitterness level (42 mg/L isohop)

Assessment without wearing nose-clips

Same evaluation, panel wearing nose-clips to eliminate sense of smell

Significance at 5%*, 1%** based on ANOVA of intensity ratings and Rank analysis by Friedman’s test (p<0.05); n=7 trained panelists.
Conclusions

• Addition of hop aroma oils changed the perceived intensity and quality of bitterness.

• The magnitude of such effects was found to depend on the BU of the base beer and was greatest in beers of low to medium BU’s.
  - Clear implications for beer design/NPD to achieve desirable bitterness

• At low bitterness the with/without nose-clip experiments indicated that perceived aroma was influencing bitterness via cross modal (taste-aroma) interactions.
• Even with nose clips, at high BU the panel could consistently differentiate the samples according to rate of aroma oil addition
  – Components of the Hersbrucker oil mediated trigeminal sensations in the mouth which can moderate perceived bitterness quality and intensity
  – Hop oils do indeed add more to beer than purely aroma!
Perceived bitterness character of beer in relation to hop variety and the impact of hop aroma

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Abstract

The impact of hop variety and hop aroma on perceived beer bitterness intensity and character was investigated using analytical and sensory methods. Beers made from malt extract were hopped with 3 distinctive hop varieties (Hersbrucker, East Kent Goldings, Zeus) to achieve equi-bitter levels. A trained sensory panel determined the bitterness character profile of each singly-hopped beer using a novel lexicon. Results showed different bitterness character profiles for each beer, with hop aroma also found to change the hop variety-derived bitterness character profiles of the beer. Rank-rating evaluations further showed the significant effect of hop aroma on selected key bitterness character attributes, by increasing perceived harsh and lingering bitterness, astringency, and bitterness intensity via cross-modal flavour interactions. This study advances understanding of the complexity of beer bitterness perception by demonstrating that hop variety selection and hop aroma both impact significantly on the perceived intensity and character of this key sensory attribute.
Perceived bitterness character in relation to hop variety and the impact of hop aroma

- In this study 3 base beers were brewed similarly but bittered with 3 different hop varieties (Hallertau Hersbrucker, East Kent Goldings, Zeus) no aroma hop addition.
- Varietal hop aroma oils extracted from Hallertau Hersbrucker, East Kent Goldings were added to each base beer.
- Sensory bitterness characteristics were evaluated using the novel lexicon.
- **Learnings:**
  - Further evidence of the strong influence of hop aroma on perceived bitterness quality.
  - The sensory bitterness character of each base beer depended significantly on the particular varietal hop oil added to it.
  - Some limited support for the concept of congruency – i.e. adding each of the hop aroma oils to its’ respective base beer gave a higher perceived bitterness intensity than when paired with bitterness of other varieties.
• Beer bitterness is a multi-faceted sensory property with qualitative and temporal dimensions.

• Beer bitterness is the result of a combination of congeners:
  – Iso alpha acids, their oxidised or degradation products and light-stable counterparts
  – Polyphenols and simple phenolics
  – Bitter tasting amino acids

• The mixture of congeners, and thus the quality of beer bitterness is entirely dependent on brewing raw materials and their points of addition to the process.
Bringing it all together.....

• Human flavour perception is multisensory.

• Our work shows that interactions between the senses are dependent on bitterness level of the beer, and on the nature of the hop oil used to modulate the bitterness.

• Hop aroma oils such as Hersbrucker can contribute trigeminal sensations which influence bitterness perception.

• Use of different varietal hop aroma oils imparted different bitterness characteristics to the same base beer.

• Perceived bitterness is much more complex than a number derived from absorbance of an extract of beer at 275 nm!!
References


Thank you for your attention......Questions?

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