Because not every beer is Stone Enjoy by IPA

Preserving Hop Aroma
HOPS + MALT + YEAST + WATER = BEER

ODOR COMPOUNDS

AROMA & FLAVOR

EXPERIENCE MEMORY

NOSE (SMELL)

BRAIN PROCESSING ANALYZING

MOUTH (TASTE)

TASTE COMPOUNDS

MEMORY
The Plan

> Hop oils and odor compounds.
> How they end up in beer.
> Ear to the ground: ongoing research.
> Aroma survival guide.
In case there’s a vocabulary test
Landrace hops
New World hops
Aroma threshold
Anosmia
Synergy
Masking
Biotransformation
Hop oil

- **hydrocarbons**
  - monoterpenes (myrcene)
  - sesquiterpenes (beta-caryophyllene, farnesene)
  - aliphatic hydrocarbons

- **oxygenated compounds**
  - terpene alcohols (linalool, geraniol)
  - sesquiterpene alcohols (humulelenol I + II, humulol)
  - others (alcohols, epoxides, ketones, esters)

- **sulfur-containing compounds**
  - thioesters
  - sulfides (DMS)
  - other sulfur compounds

Source: “125th Anniversary Review: The Role of Hops in Brewing,” J I Brewing
Compounds, the short list

myrcene - green, resinous, piney

caryophyllene - woody

humulene - woody, piney

farnesene - floral

linalool - floral, orange

geraniol - floral, rose, geranium

citronellol - citrusy, fruity

nerol - rose, citrusy

pinene - spicy, piney

3-mercaptohexan-1-ol (3MH) - black currant, muscat

4-mercapto-4-methylpentan-2-one (4MMP) - black currant, tropical

<table>
<thead>
<tr>
<th><strong>Esters/Acetates</strong></th>
<th><strong>Monoterpenoids</strong></th>
<th><strong>Sesquiterpenoids</strong></th>
<th><strong>Ketones</strong></th>
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<tbody>
<tr>
<td>2-methylbutyl propanoate (1)</td>
<td><strong>Monoterpe hydrocarbons</strong></td>
<td><strong>Sesquiterpe hydrocarbons</strong></td>
<td>2-nonanone (31)</td>
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<tr>
<td>3-methylbutyl propanoate (2)</td>
<td>β-mycene (14)</td>
<td>β-caryophyllene (38)</td>
<td>5-undec-2-one (32)</td>
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<td>3-methylbutyl 2-methylpropanoate (3)</td>
<td>β-phaellandrene (15)</td>
<td>α-humulene (39)</td>
<td>2-undecanone (33)</td>
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<td>2-methylbutyl 2-methylpropanoate (4)</td>
<td>limonene (16)</td>
<td><strong>Oxygenated sesquiterpenoids</strong></td>
<td>Miscellaneous</td>
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<tr>
<td>cis-2-pentenyl butanoate (5)</td>
<td>cis-β-ocimene (17)</td>
<td>caryophyllenyl alcohol (40)</td>
<td>hexahydro-1,1-dimethyl-4-methylene-4H-cyclopentafuran (34)</td>
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<td>2-methylbutyl butanoate (6)</td>
<td>γ-terpinene (18)</td>
<td>humulene epoxide I (42)</td>
<td>3,4-dimethyl-2,4,6-octatriene (35)</td>
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<tr>
<td>2-methylbutyl 2-methylbutanoate (7)</td>
<td>terpinolene (19)</td>
<td>humulene epoxide II (43)</td>
<td>2,2-dimethyl-4,5-dipropenyl-1,3-dioxolane (36)</td>
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<td>cis-3-hexenyl isobutanoate (8)</td>
<td><strong>Oxygenated monoterpenoids</strong></td>
<td>humulene epoxide III (44)</td>
<td>β-damascenone (37)</td>
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<tr>
<td>2-methylbutyl 3-methylbutanoate (9)</td>
<td>linalool (20)</td>
<td>linalool (20)</td>
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<tr>
<td>methyl octanoate (10)</td>
<td>borneol (21)</td>
<td>borneol (21)</td>
<td></td>
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<tr>
<td>octyl acetate (11)</td>
<td>p-menth-1-en-4-ol (22)</td>
<td>p-menth-1-en-4-ol (22)</td>
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<tr>
<td>heptyl 2-methylpropanoate+isopentyl hexanoate (12)</td>
<td>citral (23)</td>
<td>citral (23)</td>
<td></td>
</tr>
<tr>
<td>methyl trans-4-decanoate (13)</td>
<td>α-terpineol (24)</td>
<td>α-terpineol (24)</td>
<td></td>
</tr>
</tbody>
</table>

**Hop oil-derived monoterpenoids**  
(not originally present in hop oil)  
myrcenol (28)  
citronellol (29)  
terpinyl ethyl ether (30)  

| (25) | (24) | (20) | (26) |

Table 1

4-methyl-4-mercapto-2-pentanone (4-MMP)

- Citra
- Cascade
- Chinook
- Simcoe
- Summit
- Apollo
- Topaz
- Cluster
- Mosaic
0810

Black currant
Ribes
Tom-cat urine
J.S. Ford of the Wm. Younger & Co.’s Brewery in Edinburgh, Scotland:

-Physical examination “pronounced, unpleasant nose.”
-In the dry hop tests at 4 ounces per barrel, “too bitter, rank and slightly unpleasant.”

Another opinion:

“It (the American hop) is rather a stronger bitter than the European hop, and with a stronger scented flavor in many cases.”
Fuggle

Source: Hop Aroma Compendium, Joh. Barth & Sohn
Hallertau Mittelfrüh

Source: Hop Aroma Compendium, Joh. Barth & Sohn
Mosaic

Source: Hop Aroma Compendium, Joh. Barth & Sohn

Diagram showing aroma profiles:
- Pear
- Gooseberry
- Mandarin
- Lime
- Peach
- Floral
- Sweet fruits
- Red berries
- Spicy/herbal
- Woody aromatic
- Cream caramel
- Green
- Vegetal
- Citrus
- Menthol
- Tea
- Green fruits

Legend:
- Mosaic® (cold infusion *)
- Mosaic® (raw hops)
### Crystal

<table>
<thead>
<tr>
<th>Descriptor</th>
<th>This includes the following aromas:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Menthol</td>
<td>Mint, melissa, sage, metallic, camphor</td>
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<tr>
<td>Tea</td>
<td>Green tea, camomile tea, black tea</td>
</tr>
<tr>
<td>Green fruits</td>
<td>Pear, quince, apple, gooseberry, wine yeast, ethereal</td>
</tr>
<tr>
<td>Citrus</td>
<td>Grapefruit, orange, lime, lemon, bergamot, lemon grass, ginger</td>
</tr>
<tr>
<td>Green</td>
<td>Green-grassy, tomato leaves, green peppers</td>
</tr>
<tr>
<td>Vegetal</td>
<td>Celeriac, leek, onion, artichoke, garlic, wild garlic</td>
</tr>
<tr>
<td>Cream caramel</td>
<td>Butter, chocolate, yoghurt, gingerbread, honey, cream, caramel, toffee, coffee</td>
</tr>
<tr>
<td>Woody aromatic</td>
<td>Tobacco, cognac, barrique, hay, leather, tonka, woodruff, incense, myrrh, resin</td>
</tr>
<tr>
<td>Spicy/herbal</td>
<td>Lovage, pepper, chilli, curry, juniper, marjoram, tarragon, dill, lavender, aniseed, liquorice, fennel</td>
</tr>
<tr>
<td>Red berries</td>
<td>Cassis, blueberries, raspberries, blackberries, strawberries</td>
</tr>
<tr>
<td>Sweet fruits</td>
<td>Banana, watermelon, honeydew melon, peach, apricot, passion fruit, lychee, dried fruit, plum, pineapple, white jelly bears</td>
</tr>
<tr>
<td>Floral</td>
<td>Elderflower, camomile blossom, lily of the valley, jasmine, apple blossom, rose, geranium</td>
</tr>
</tbody>
</table>

Source: Hop Aroma Compendium, Joh. Barth & Sohn
The Plan

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First wort hopping is not an aroma addition

<table>
<thead>
<tr>
<th></th>
<th>Brewery A</th>
<th>Brewery B</th>
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<tbody>
<tr>
<td></td>
<td>Moved last addition (Tettnager &amp; Saazer type) to first wort – 34% of total addition.</td>
<td>Moved last addition (Tettnager) to first wort – 53% of total addition.</td>
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<tr>
<td></td>
<td></td>
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<tr>
<td>OG</td>
<td>11.6</td>
<td>12</td>
</tr>
<tr>
<td>ABV</td>
<td>4.8%</td>
<td>4.8%</td>
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<tr>
<td>IBU</td>
<td>38</td>
<td>40</td>
</tr>
<tr>
<td>Linalool</td>
<td>29 ug/l</td>
<td>34.1</td>
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<tr>
<td>Geraniol</td>
<td>18.8</td>
<td>14.6</td>
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<tr>
<td>Humulene</td>
<td>32.7</td>
<td>10.8</td>
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<tr>
<td>Epoxides</td>
<td></td>
<td>10.8</td>
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</table>
Source: “Hop-Derived Odorants Contributing to Aroma Characteristics of Beer,” Toru Kishimoto
Source: “Contribution of Geraniol Metabolism to the Citrus Flavour of Beer,” J I Brewing
The influence of late-hopping temperature on the organoleptic profiles of beer

Hop adding temperature for the late-hopping

Source: “Study on the Attractive Aroma for Beer,” Takako Inui
**Fig 1 B**

**β-myrcene level**

<table>
<thead>
<tr>
<th>Condition</th>
<th>Conc. [ppb]</th>
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<td>w/o hops</td>
<td></td>
</tr>
<tr>
<td>after EH</td>
<td></td>
</tr>
<tr>
<td>after LH</td>
<td></td>
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<tr>
<td>before ferm.</td>
<td></td>
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<tr>
<td>after lag.</td>
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<tr>
<td>after centr.</td>
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<tr>
<td>after past.</td>
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<tr>
<td>beer ND</td>
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**Fig 1 C**

**Linalool level**

<table>
<thead>
<tr>
<th>Condition</th>
<th>Conc. [ppb]</th>
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<td>w/o hops</td>
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<td>after EH</td>
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<td>after past.</td>
<td></td>
</tr>
<tr>
<td>beer ND</td>
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Source: “From Wort to Beer: The Evolution of Hoppy Aroma,” KU Leuven @ KAHOSL
Source: “Contribution of Geraniol Metabolism to the Citrus Flavour of Beer,” J I Brewing
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Rock Bottom experiment

• Longer post-boil residence (80 minutes vs. 50) resulted in more hop flavor, aroma, and perceived bitterness than shorter. “This is in contrast to a commonly voiced opinion among craft brewers that volatile hop oils are quickly driven out of hot wort, and therefore, wort cooling should happen as quickly as possible after the addition of final hops at or near the end of the boil to preserve the hop flavor and aroma in the wort.”

• Longer post-boil residence resulted in more hop flavor than dry hopping, and that hop flavor is best developed in the kettle.

• A combination of late hopping and dry hopping resulted in greater hop aroma than longer late hopping. However, it appeared there was a diminishing return for additional quantities used in dry hopping.
Aldehydes were observed to increase with ageing time.

After 6 months, Strecker aldehydes and furfural levels were much higher for the DH beers, with the exception of hop variety C. Beer C-LH showed a significantly higher increase than beer C-DH.

The lipid oxidation aldehydes on the other hand, did not exhibit this trend, although C-LH did show a modest increase.

All the fresh beers showed negligible ageing effects. The sensory difference between the LH and DH beers became very clear after 6 months, with the DH beers receiving higher scores than the LH beers, at least for hop variety A and B. In contrast, C-DH was more stable than C-LH. For all three hop varieties, the panel’s personal preference between the 6 month old beers coincided with the lowest value of OAS.

Fresh beers - TPO (total package oxygen), HSO (headspace oxygen) and DO (dissolved oxygen)

Preliminary brewing: Cascade

- Typical harvest hops = apple, apricot/peach, and sweaty/onion/garlic notes.
- Late harvest hops = higher melon and floral notes.

Source: “Hop-related brewing research at Oregon State University, “Thomas Shellmammer and Daniel Sharp
More research: Thiols and refermentation

Still more research

At Kirin: Non dried, freshly frozen hops. Hops frozen soon after picking. “Frozen hops impart fresh and pure flowery aroma. Content of linalool along with other terpene alcohols was high, and terpene oxides were low, possibly due to non-heat treatment.”

At Kirin: Dip Hopping. Hops added to fermentation tank. Dip hopped beer high in linalool and low in myrcene compared to dry hopped beer. “We assume that high linalool was due to low temperature extraction, and low myrcene was due to elimination by yeast.”

In Germany: On variations between types of PET bottles. An IPA and a pilsner (both beers were dry hopped) were compared as they were aged in different PET bottles, A (Coated Monolayer) and B (Monolayer).
Source: “Flavour and hop aroma stability of craft beers packed in different PET bottles,” Roland Folz, et al.
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The Plan

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Chinook

Source: Sierra Nevada Brewing Company
Aroma survival guide

- Store your hops and your beer cold, your hops colder.
- Beware the skunk.
- Look beyond the hop variety.
- Remember the role of yeast in both fermentation and biotransformation. Ongoing research will reveal more about the importance of strains in the latter.
- Do not accept a Facebook friend request from oxygen.
- Use hydrophilic correctly in a sentence.
- Use the phrase “conflictual art” at least once at every homebrew meeting you attend.
- Drink it now. Those guys from Stone might be on to something.
- “Deliver” your own beer whenever possible.
Humulene

Source: Sierra Nevada Brewing Company