



The effect of different processing parameters on the transfer of hop aroma compounds to beer

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Challenges of Dry hopping

- Introduction and removal of hop material
- Low solubility of terpenes
 - Adsorb to trub, lipids, yeast
- Transformation by yeast
 - Positive and negative impact
- Expensive raw materials
- Can be inconsistent



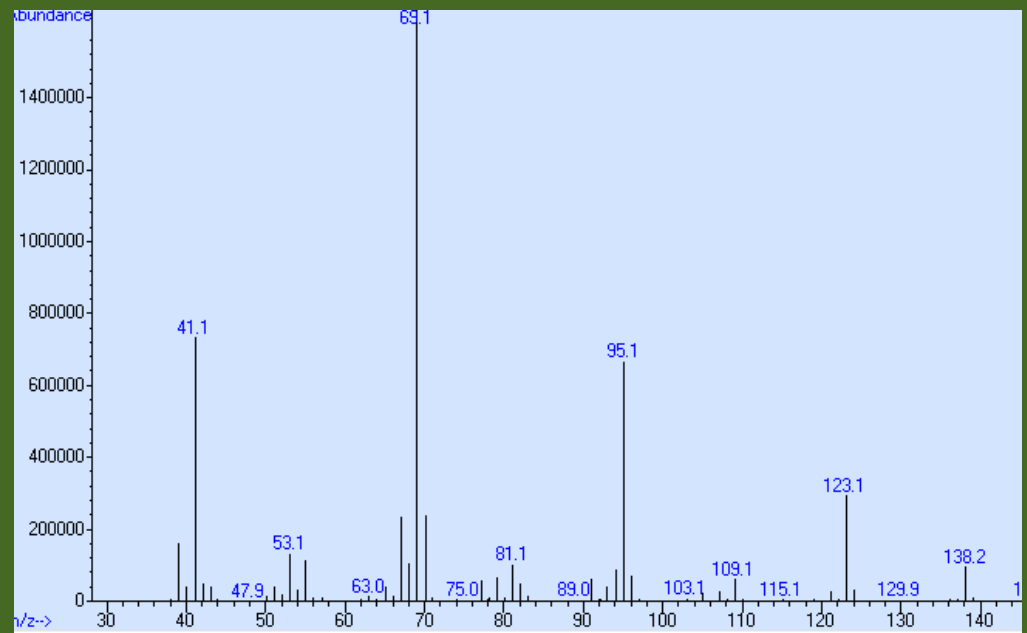
Process Control

- Routine measurement of Hop aroma compounds
 - Which compounds to monitor?
 - What process factors affect extraction?
 - Optimization of process to minimize raw material use, maximize aroma.



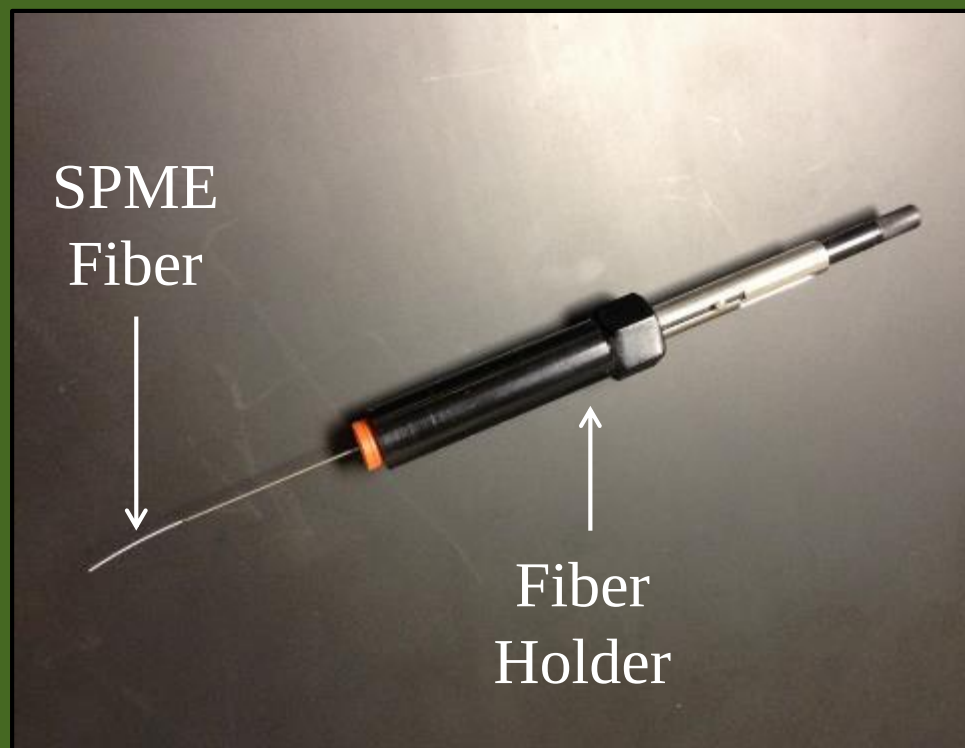
Analytical Challenges

- Difficult compounds to identify
 - Mass spectra of most terpenes are identical
- Low concentration
 - Sub mg/L for most compounds
- Complex matrix



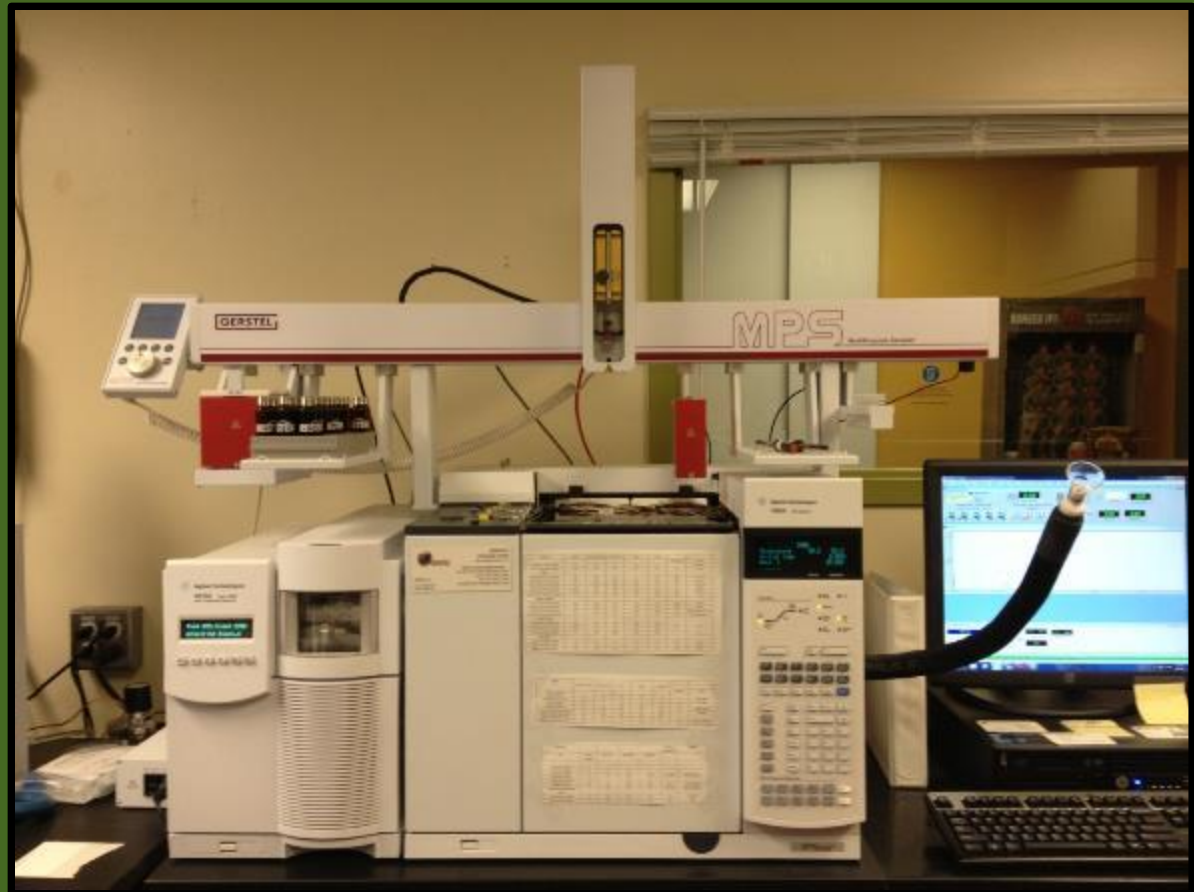
Solid Phase Microextraction

- Good sensitivity
 - Best for trace analytes
- Solventless
- Automatable



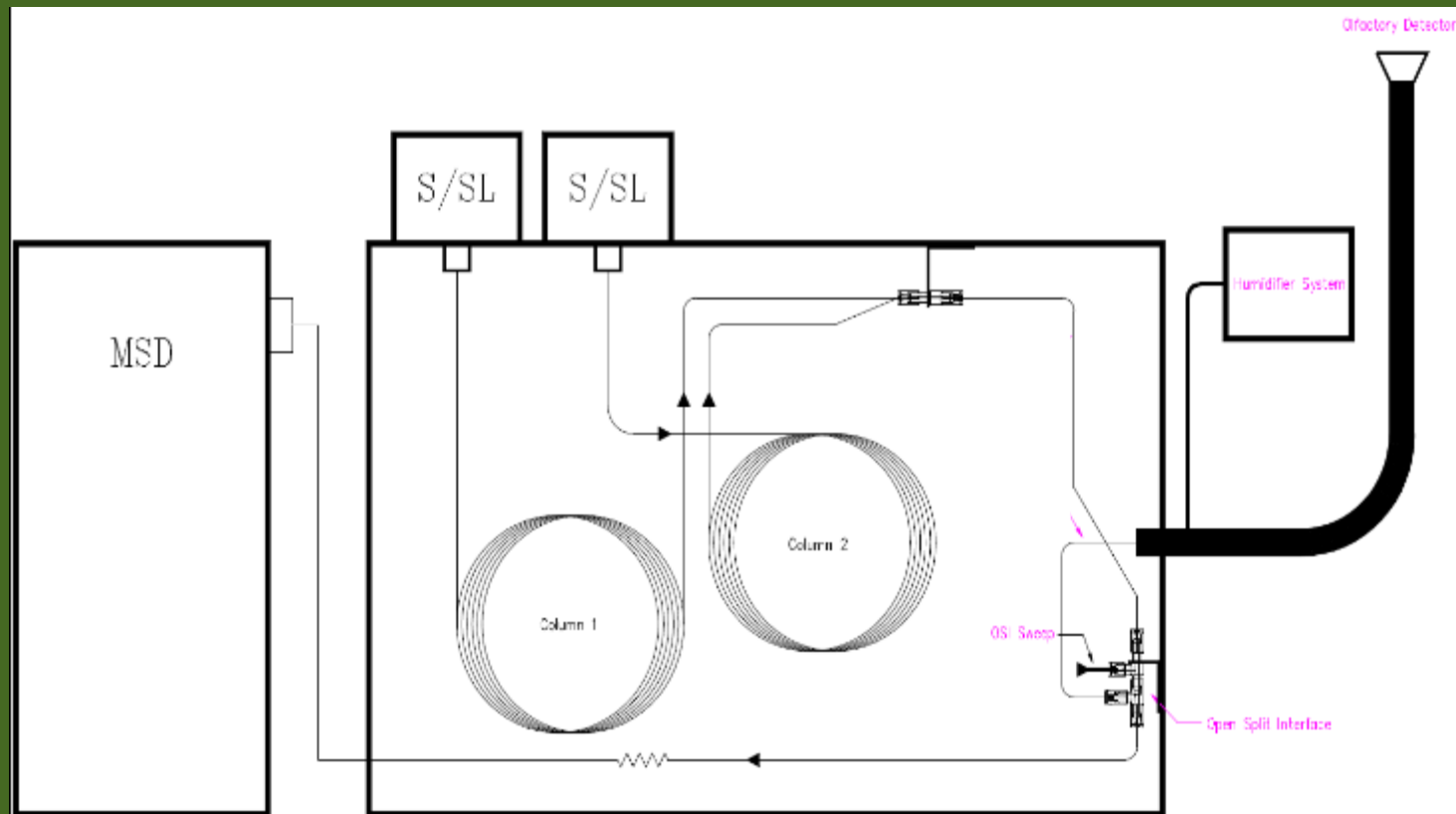
SPME Automation

- Gerstel MPS system



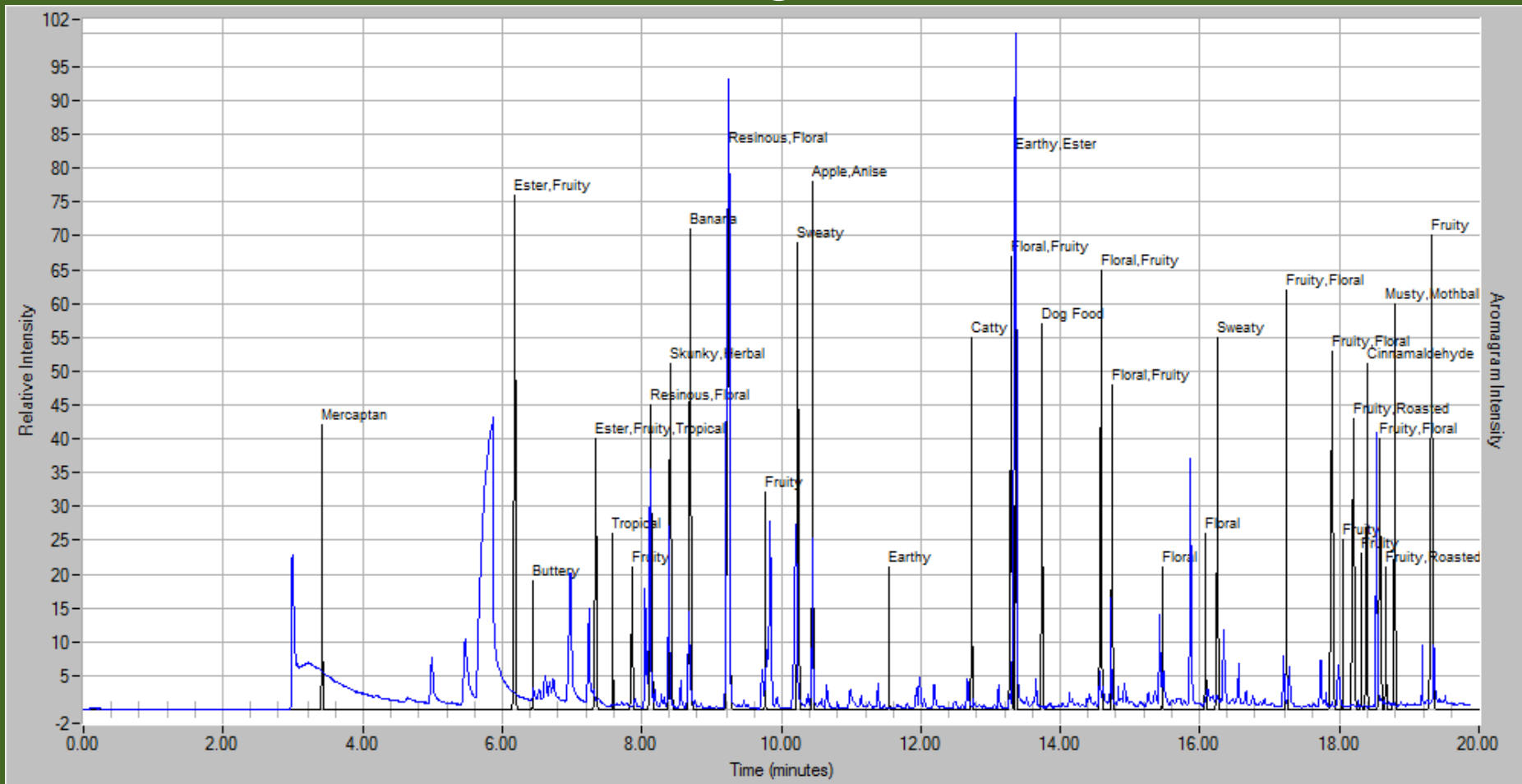
Compound Identification

- Mass Spectrum Detector (MSD)
- Retention Index
- Aroma Port



Gas Chromatography-Olfactometry

- Result is Aromagram
 - Overlaid on chromatogram



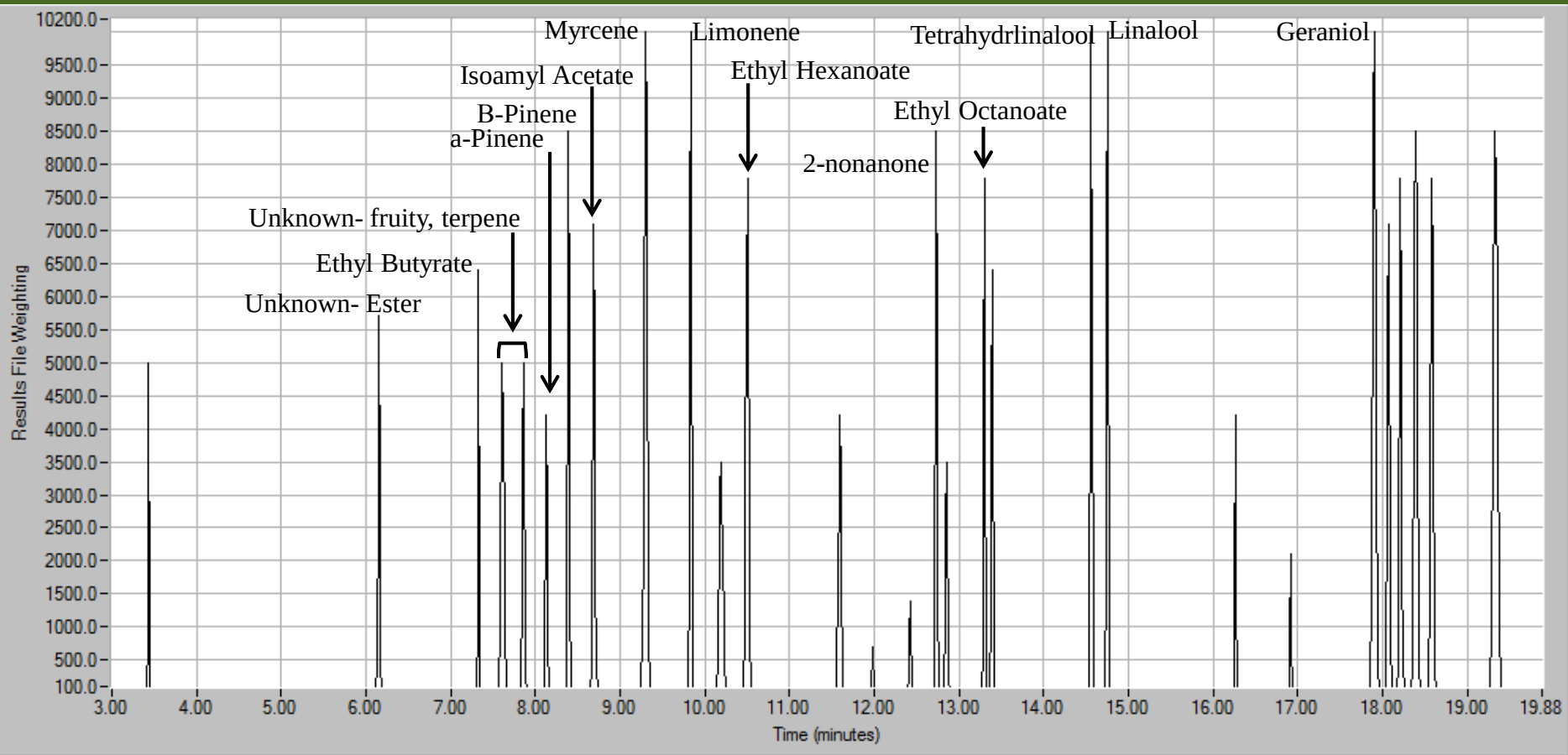
Aroma Extract Dilution Analysis (AEDA)

Sequential dilution of sample of interest

- Use split/splitless inlet
- Until no aromas appear



Aroma Dilution Results



Dry Hop Aroma

- From AEDA and PCA:
 - Terpenes
 - Myrcene- pine, resinous, vegetable
 - Humulene- sylvan, grassy
 - Limonene- citrus, orange
 - Oxygenated Terpenes
 - Linalool- floral, fruity
 - Geraniol- floral, rose, citrus
 - Nerol- floral, rose, citrus, carrot

Dry Hop Aroma

- From AEDA, and PCA:
 - Terpene Esters
 - Geranyl Acetate- lavender
 - Methyl Geranate- waxy, fruity, floral
 - Other Compounds
 - 2-Undecanone- creamy, fruity
 - Polyfunctional Thiols- various including tropical fruit, mellon, rubber, catty, skunky, grapefruit, grilled

Testing the Impact of Yeast on Aroma

- Several production size batches were processed and packaged exclusively
 - 6 with yeast, 7 without yeast
- Samples were quantified for hop aroma compounds
 - Focused on levels of Myrcene and Linalool
- Sensory evaluation performed
 - Triangle test with 19 validated panelists
 - Shelf life test

Dry Hop addition

- Pelletized Hops are slurried in beer
- The beer and hops are circulated in a large vessel to transfer hop aroma compounds



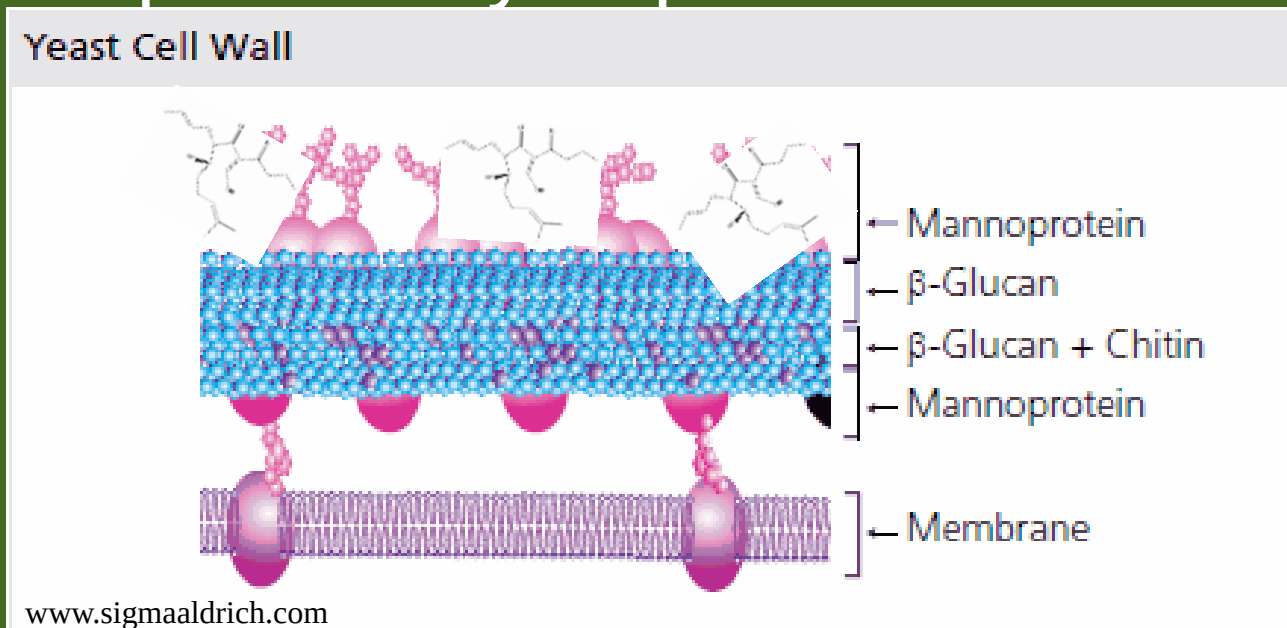
Dry hop removal

- Vegetative matter removed using a centrifuge
- Designed for yeast removal, yeast is less dense
- Solution was to leave the yeast in
- Removal of yeast, results in higher beer losses



Removal of hop compounds by yeast

- Bitter acids adsorbed by hydrogen bonding interactions (3)
- Transformation of aroma compounds(4)
- Adsorption to hydrophobic structures



(3) Dixon, I.; Leach, A.; The Adsorption of Hop Substances on the Yeast Cell Wall.

(4) King, A.; Dickinson, J.; Biotransformation of hop aroma terpenoids by ale and lager yeasts.

Analytical Results

	Myrcene (ppb)	Linalool (ppb)	IBU
Average with yeast	370.07	164.05	68.83
Standard Deviation	164.74	26.18	2.64
Average without yeast	578.84	156.40	70.06
Standard Deviation	132.42	24.34	1.90

- Marked decrease in Myrcene in tanks dry hopped with yeast present
- No appreciable difference in Linalool levels
- Variability in measurement from process variations

Sensory Results

- Two batches were compared in a triangle test
 - Of 19 validated panelists, 10 identified the difference between the beer dry hopped with and without yeast ($\alpha = 5\%$, $p = 0.002$).
- Discussion panel after 1 month shelf life
 - Notable difference in oxidation score (3.7 vs. 4.7)
 - More hop aroma remains

Significance: Terpenes

- Myrcene does not survive at an appreciable level through fermentation
- Sensory saturation occurs around 300-400ppb
- Levels of Myrcene reduced when dry hopped in the presence of yeast

Significance: Oxygenated Terpenes

- Levels of Linalool not impacted by presence of yeast
 - Higher water solubility of the compound
- Survive fermentation better than terpenes



Pasteurization

- 25PUs applied to a heavily dry hopped beer
- No significant analytical difference at fresh
- No significant sensory difference over shelflife

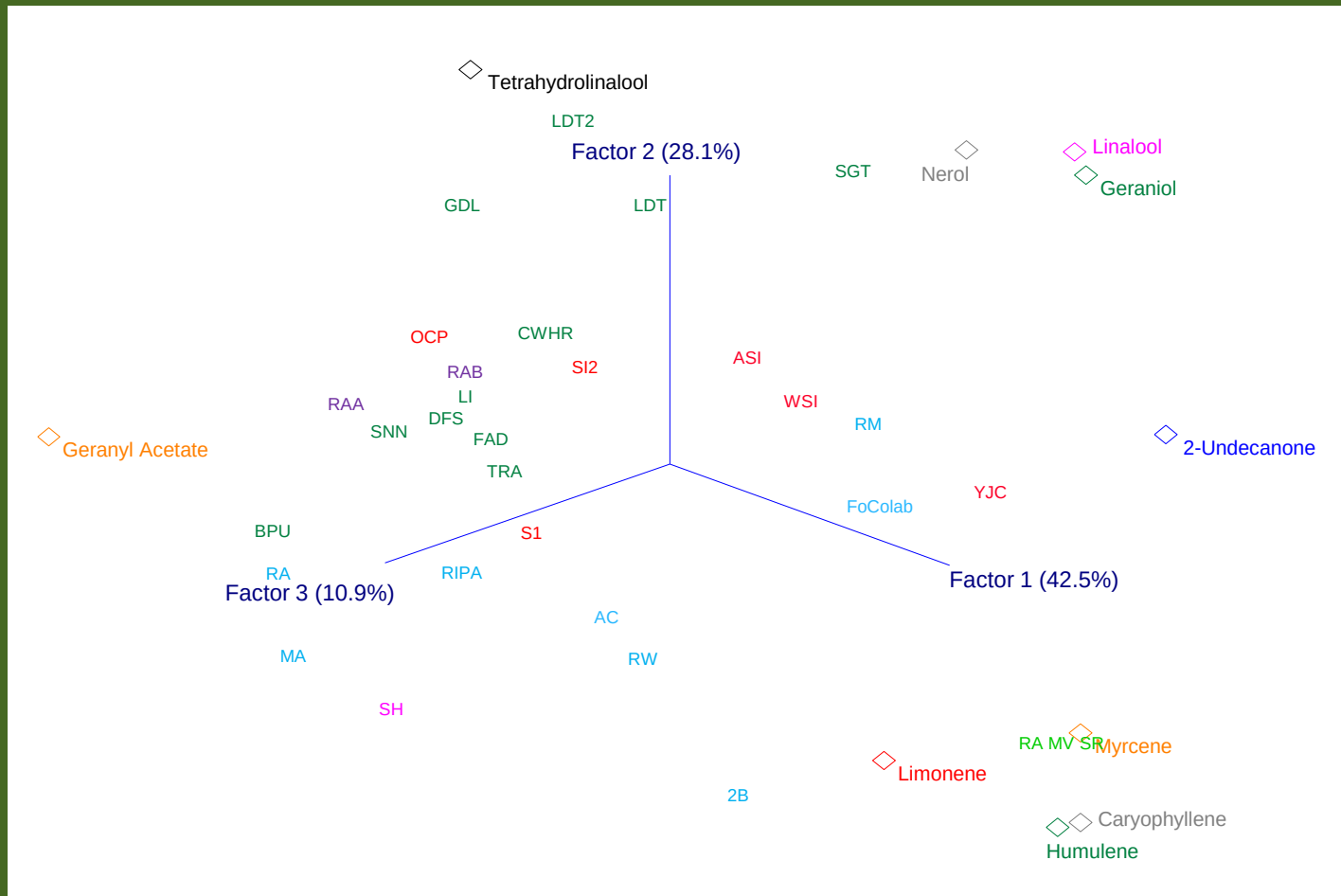
Conditioning with Yeast

- Known to scavenge oxygen
- Limit oxidative degradation of hop compounds
- Biotransformation in package?
- Preliminary data does not show large impact
- Potential to use of other yeast strains

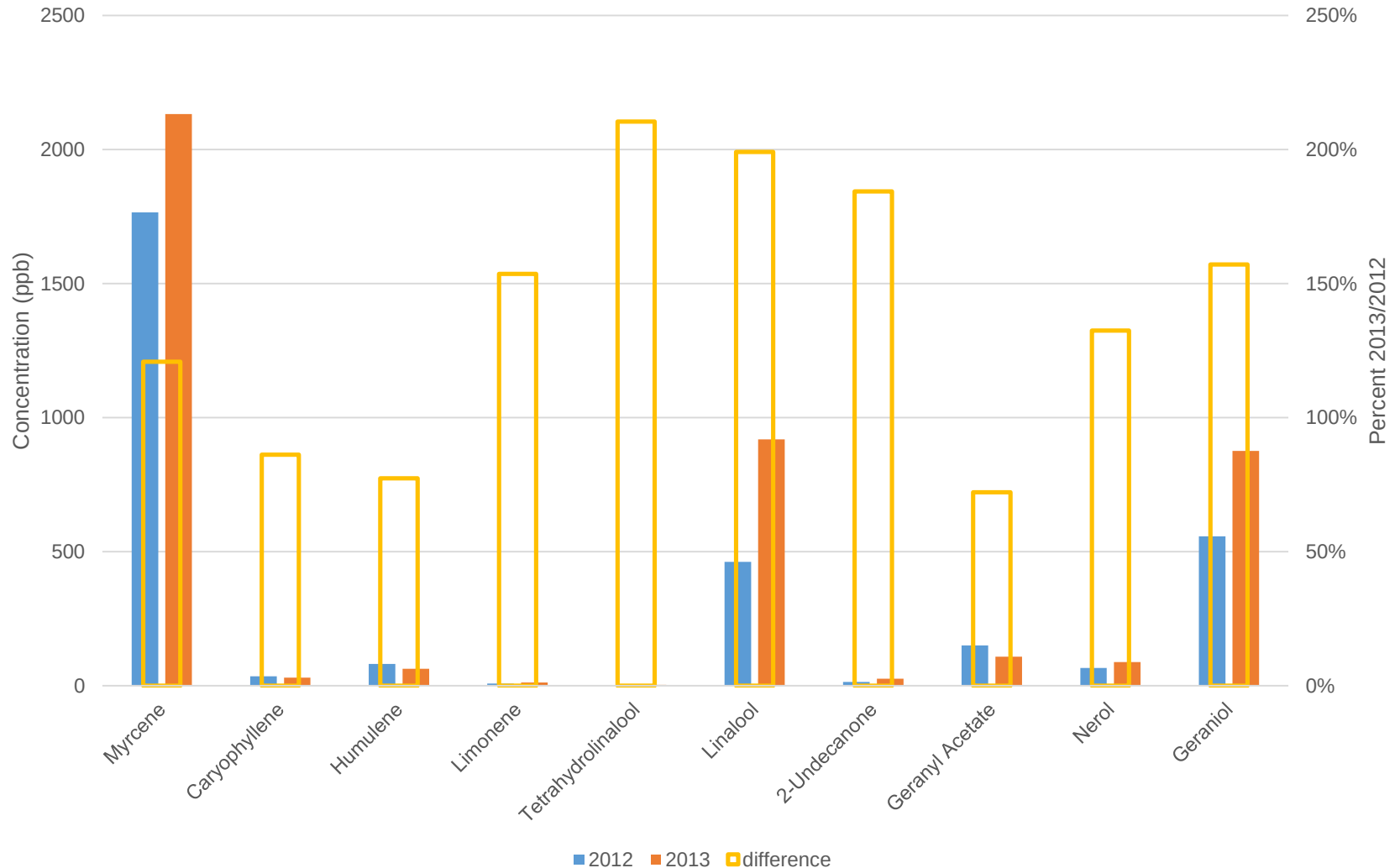
Yeast Metabolism Effects

- Adsorb hydrophobic compounds
- Esterify alcohols
- Reduce Aldehydes
- β -glucosidase activity
 - Reduce hop glycosides-release terpene alcohols
- Release conjugated Thiols

Principal Component Analysis of Hopped Beers



Crop Year variations



Other Processing Parameters

- Contact time with hop material
- Temperature
- Alcohol
- pH
- CO₂ scrubbing- pressure and headspace above beer
- Hop processing
 - Whole cone
 - Pellets
 - Extract

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