Mid-fermentation Dry-hopping Parameters and Their Impact on the Evolution of Hop Volatiles and Biotransformation Potential

ASBC
THE SCIENCE OF BEER

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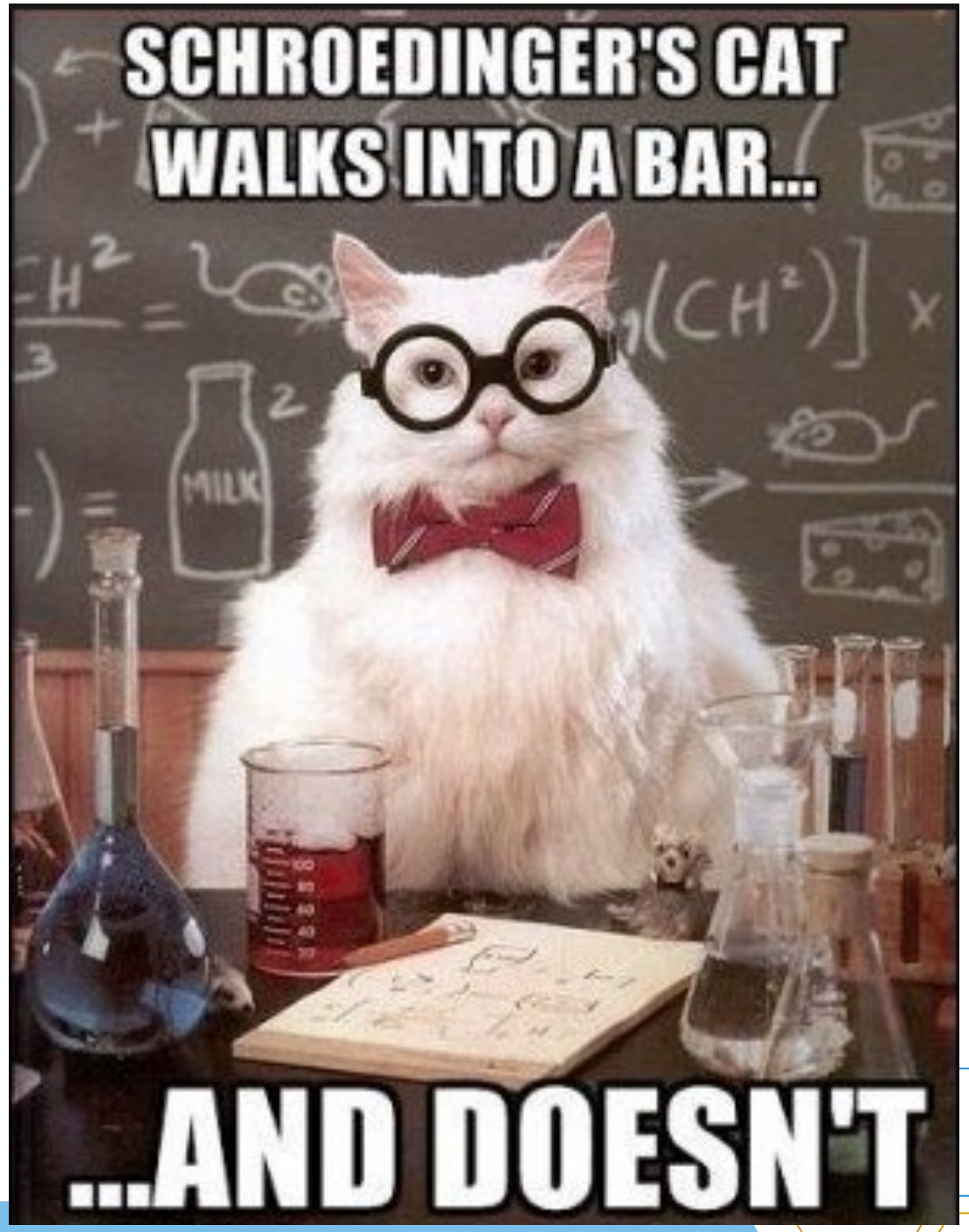
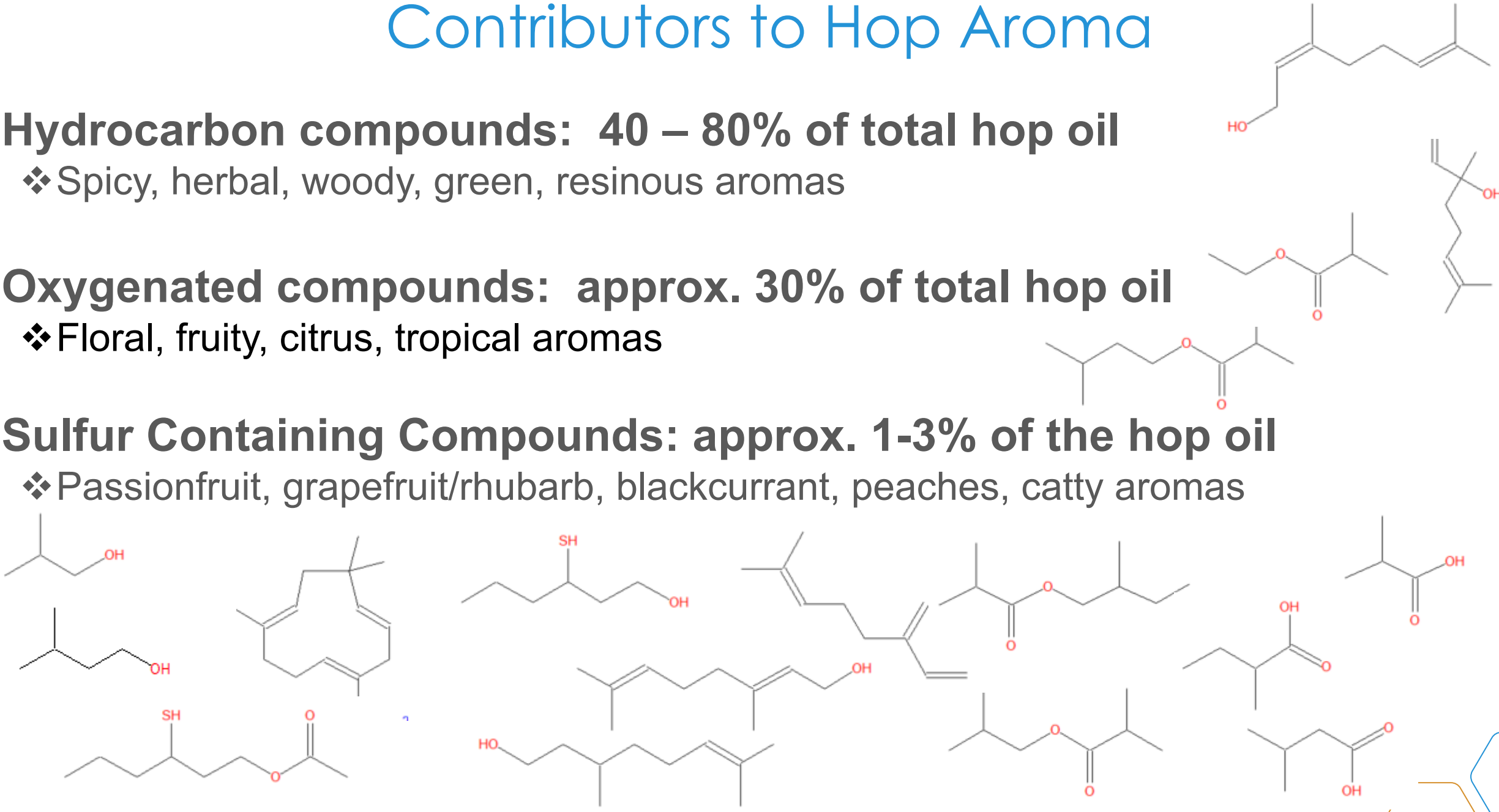
Agenda

- Contributors to hop aroma
- Advantages/Disadvantages of MFDH
- Experiments
  - Bench Scale (1L)
  - Pilot Scale (10hL)
  - Production Scale (>120hL)
- Whirlpool hopping
- Summary and Future Work
- Thanks



Contributors to Hop Aroma

- **Hydrocarbon compounds: 40 – 80% of total hop oil**
  - Spicy, herbal, woody, green, resinous aromas
- **Oxygenated compounds: approx. 30% of total hop oil**
  - Floral, fruity, citrus, tropical aromas
- **Sulfur Containing Compounds: approx. 1-3% of the hop oil**
  - Passionfruit, grapefruit/rhubarb, blackcurrant, peaches, catty aromas



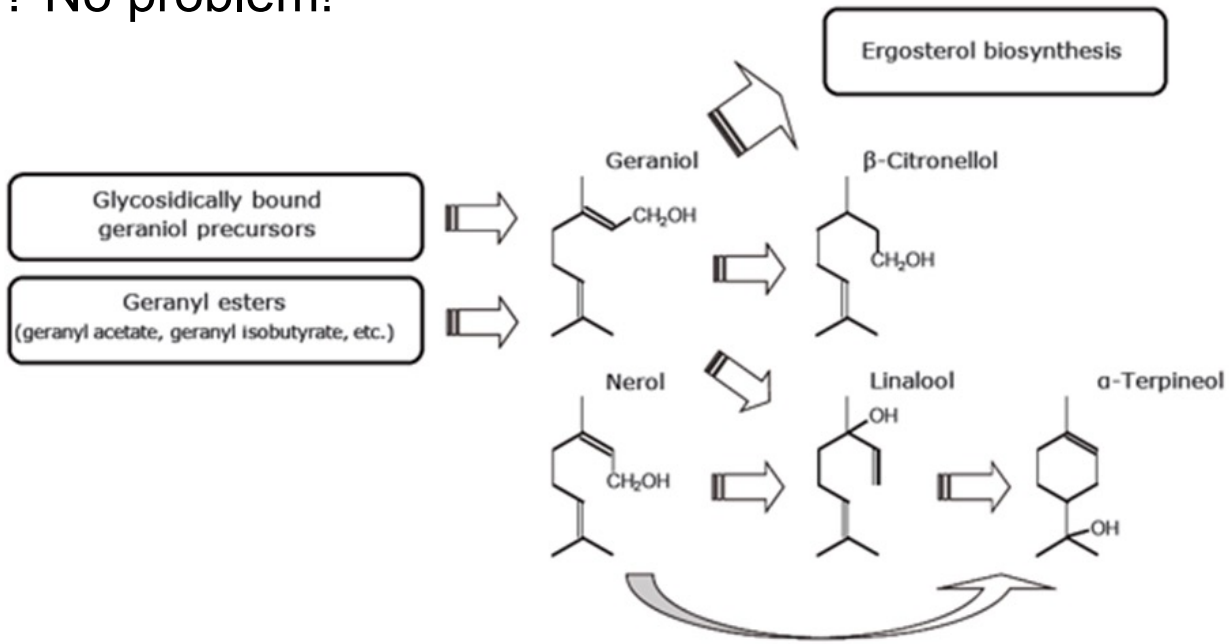
Advantages and Disadvantages of Mid-fermentation Dry Hopping (MFDH)

❖ Advantages of MFDH

- ❖ Oxygenated fractions and fruity profiles
- ❖ Hazy IPAs and Hydrocarbons
- ❖ Excess high alpha, old, or poorly stored hops? No problem!
- ❖ Liberation of bound polyfunctional thiols
- ❖ Hop creep
- ❖ Avoid oxidation

❖ Disadvantages of MFDH

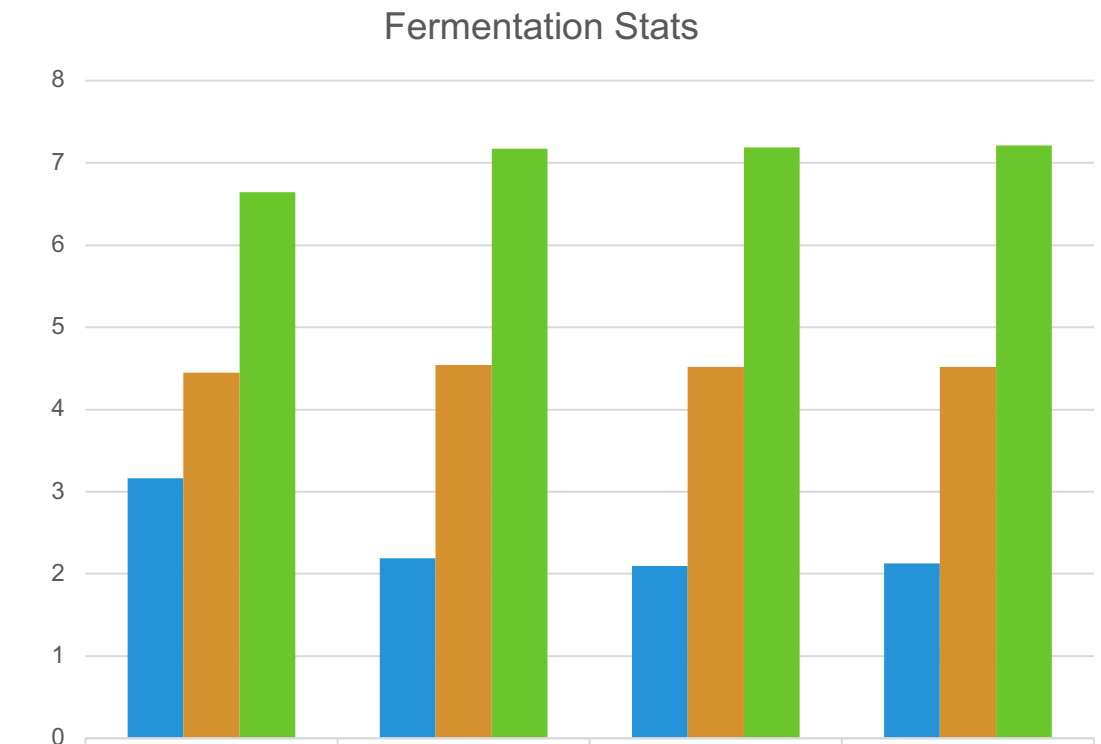
- ❖ Often a dead-end yeast source
- ❖ Adding hops at fermentation temperatures
- ❖ Iso-alpha Acid losses
- ❖ Hop creep
- ❖ Bitterness perception and pH
- ❖ Foam stability



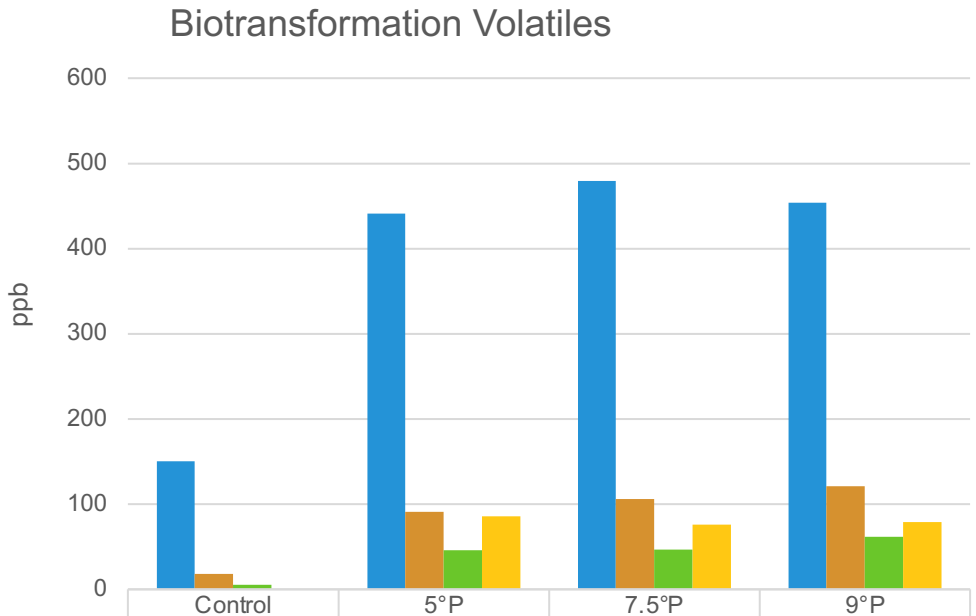
Bench Scale

MFDH – California Ale Yeast

Experimental design: To perform three different mid-fermentations using California ale yeast and T90 cascade hops at three different timings, 5°, 7.5°, and 9°P. Primary fermentation was conducted at 24°C.



	Control	5°P	7.5°P	9°P
Ea	3.16	2.19	2.1	2.13
pH	4.45	4.54	4.52	4.52
ABV	6.64	7.17	7.19	7.21

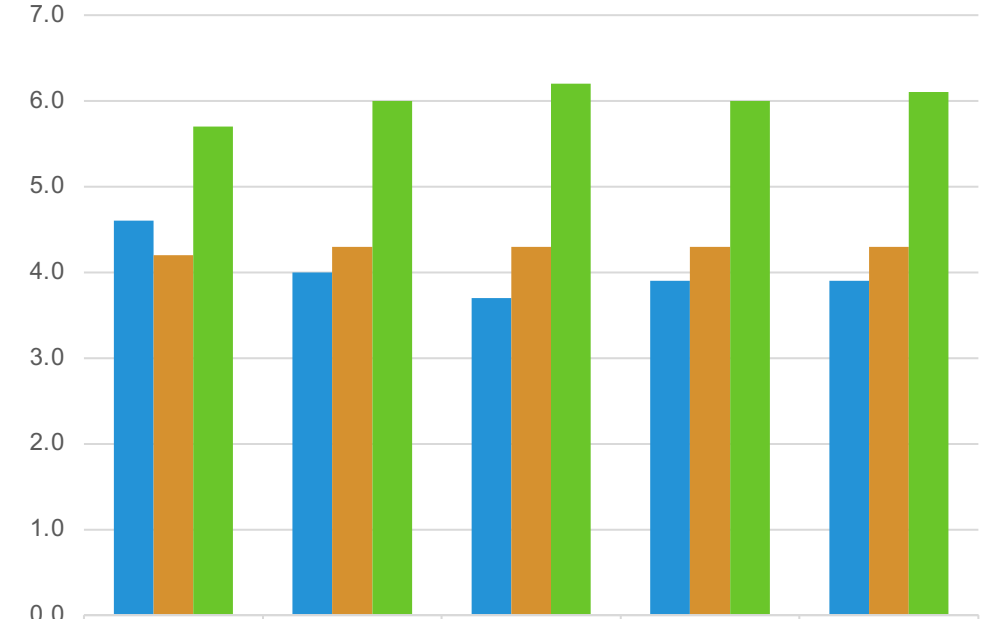


	Control	5°P	7.5°P	9°P
Geraniol	150	441	479	454
β-Citronellol	18	91	106	121
Ethyl Isobutyrate	5	46	47	62
2-Methylbutyl Isobutyrate	0	86	76	79

MFDH – L3 yeast

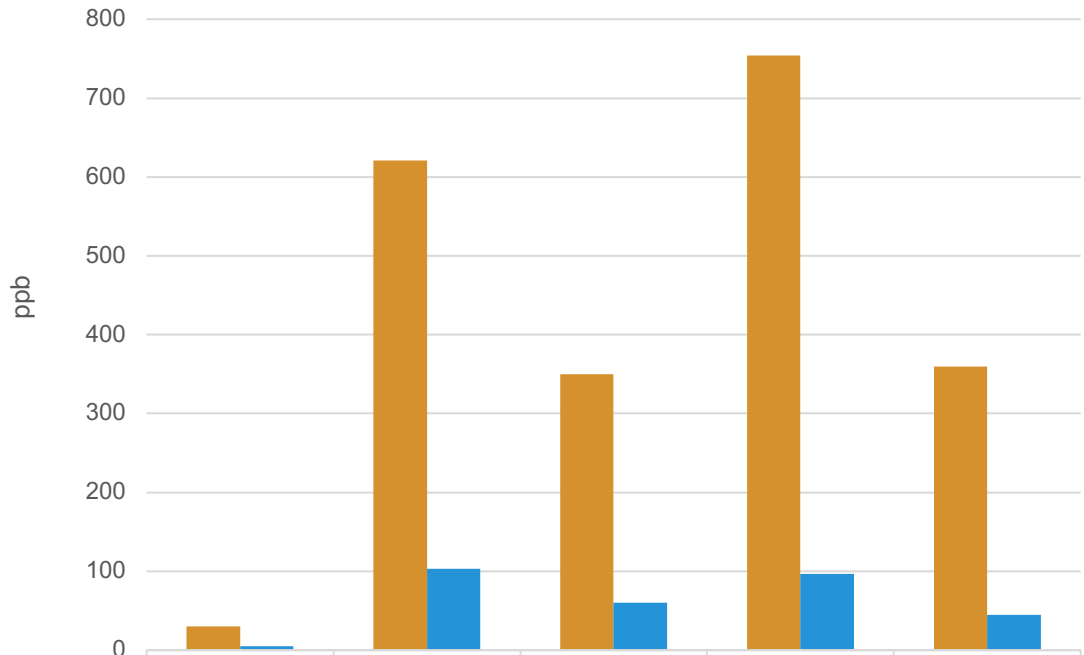
Experimental design: To perform four different mid-fermentations using London III yeast with T90 cascade hops and T90 Centennial hops at two different timings (5° and 10°P). Primary fermentation was conducted at 22°C.

Fermentation Stats



	Control	10°P - Centennial Hops	10°P - Cascade Hops	5°P - Centennial Hops	5°P - Cascade Hops
Ea	4.6	4.0	3.7	3.9	3.9
pH	4.2	4.3	4.3	4.3	4.3
ABV	5.7	6.0	6.2	6.0	6.1

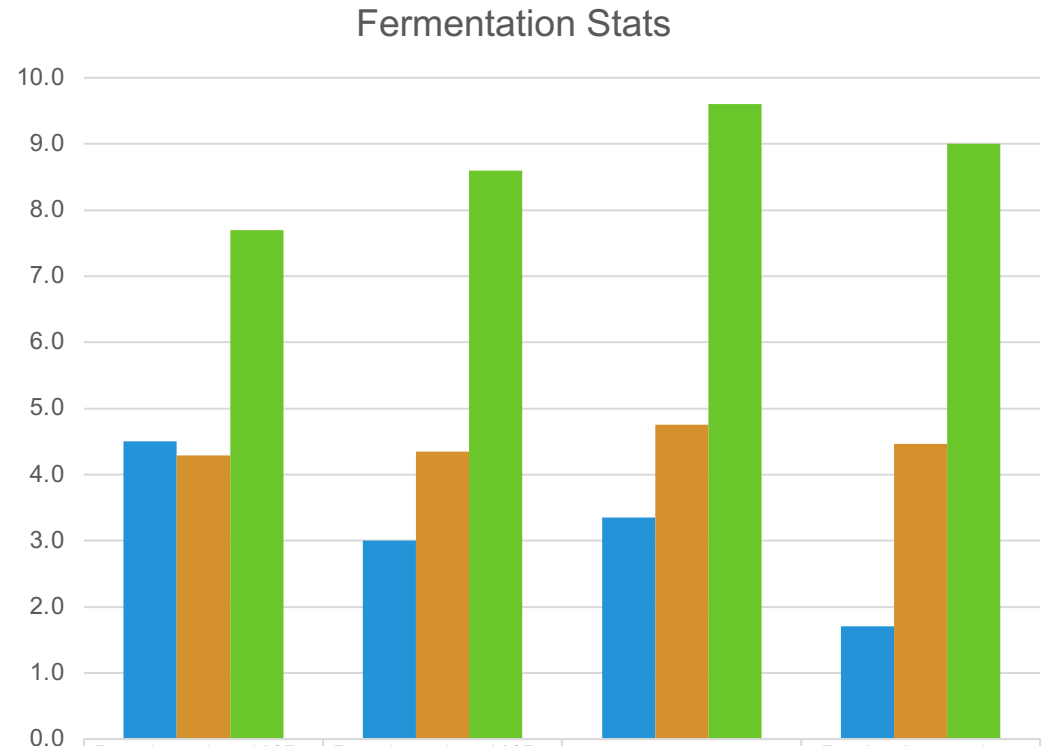
Biotransformation Volatiles



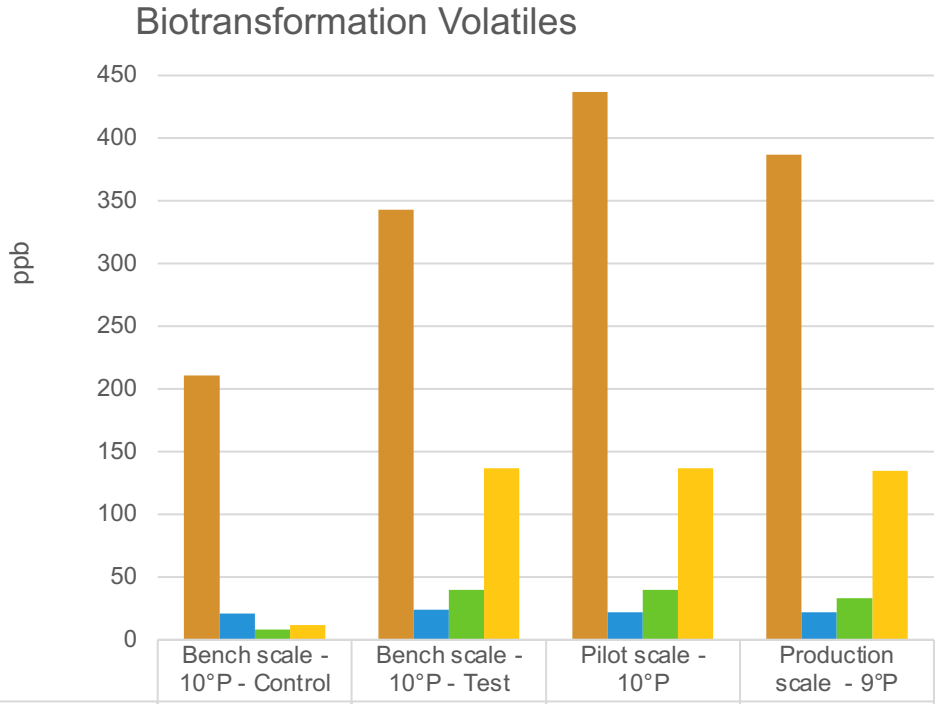
	Control	10°P - Centennial Hops	10°P - Cascade Hops	5°P - Centennial Hops	5°P - Cascade Hops
Geraniol (ppb)	30	621	350	754	360
β-Citronellol (ppb)	5	103	60	97	45

Production, Pilot and Bench Scale – L3 yeast

Experimental design: To perform four different mid-fermentations at three different scales (bench, pilot and production scale) using London III yeast and T90 hops at 10°P.



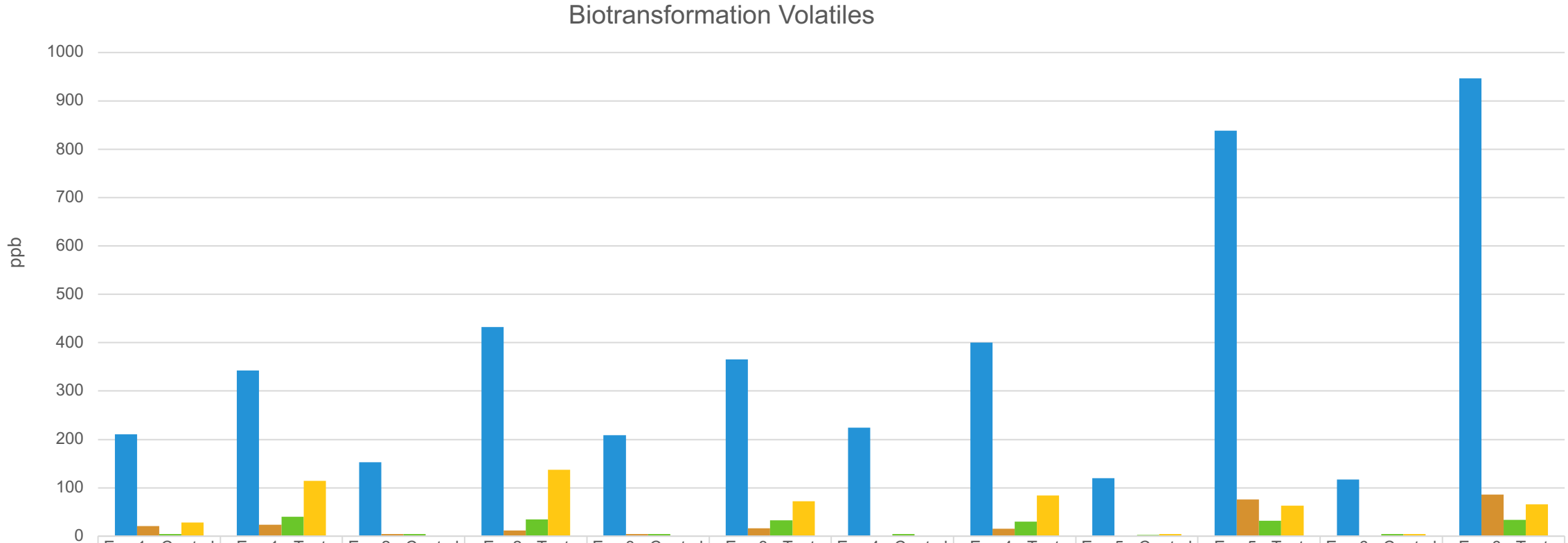
	Bench scale - 10°P - Control	Bench scale - 10°P - Test	Pilot scale - 10°P	Production scale - 9°P
Ea	4.5	3.0	3.4	1.7
pH	4.29	4.35	4.75	4.46
ABV	7.7	8.6	9.6	9.0



	Bench scale - 10°P - Control	Bench scale - 10°P - Test	Pilot scale - 10°P	Production scale - 9°P
Geraniol (ppb)	211	343	437	387
β-Citronellol (ppb)	21	24	22	22
Ethyl Isobutyrate (ppb)	8	40	40	33
2-Methylbutyl Isobutyrate (ppb)	12	137	137	135

MFDH – L3 yeast

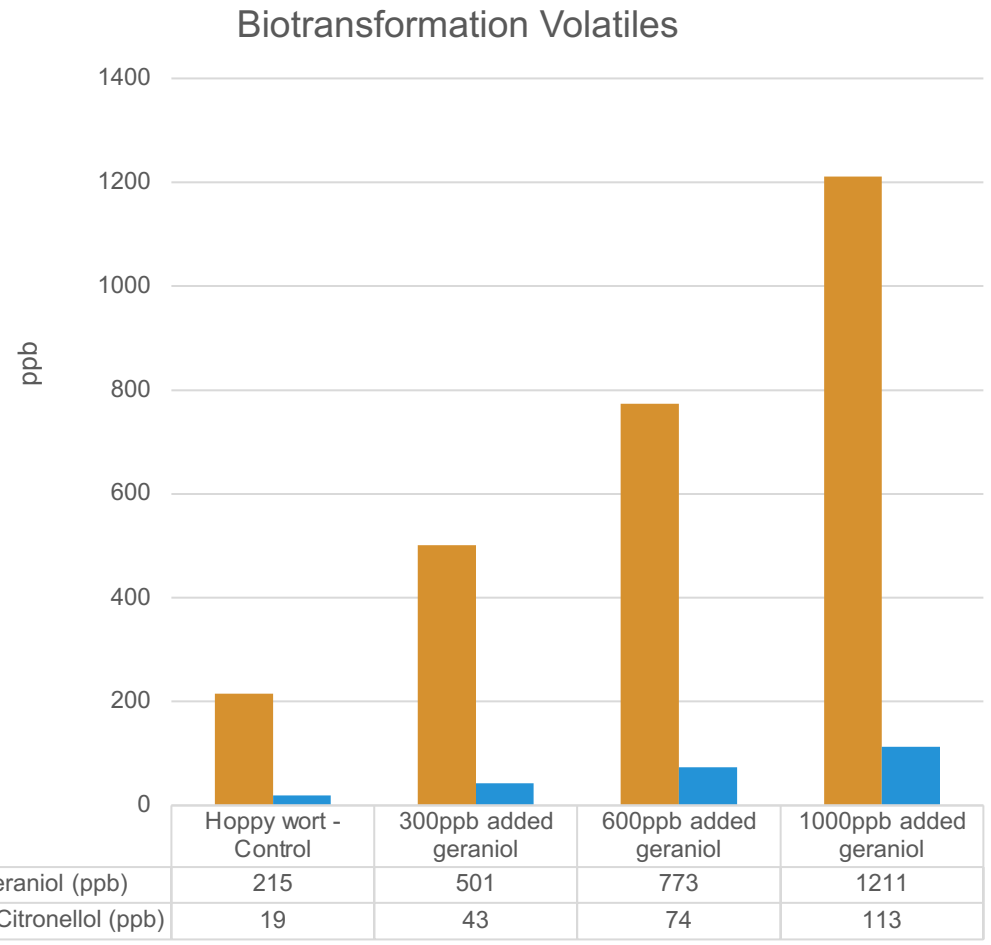
Experimental design: To investigate the lack of biotransformation of geraniol to β-citronellol by performing six different experiments with controls.



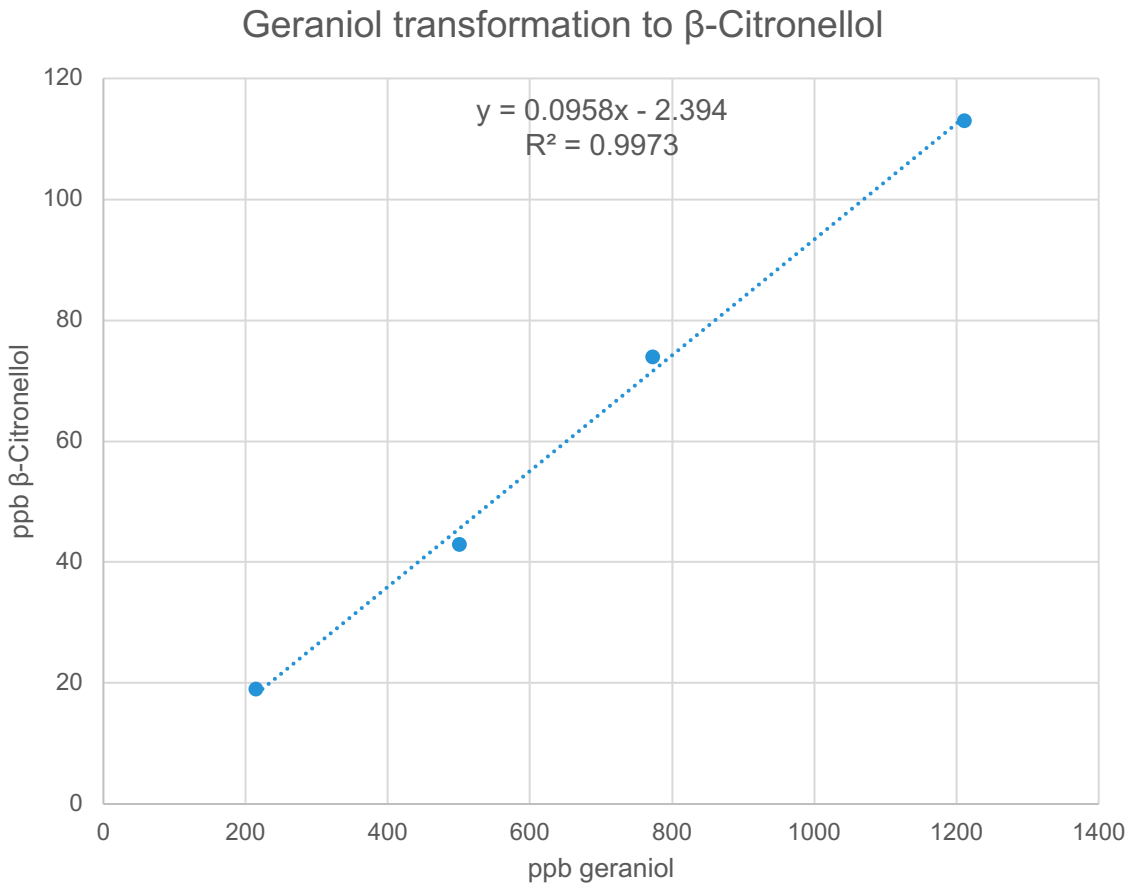
	Exp 1 - Control	Exp 1 - Test	Exp 2 - Control	Exp2 - Test	Exp 3 - Control	Exp 3 - Test	Exp 4 - Control	Exp 4 - Test	Exp 5 - Control	Exp 5 - Test	Exp 6 - Control	Exp 6 - Test
Geraniol	211	343	153	432	209	365	224	400	120	838	117	946
β-Citronellol	21	24	4	12	4	16	1	15	0	76	0	86
Ethyl Isobutyrate	4	40	4	35	4	33	4	30	3	32	4	33
2-Methylbutyl Isobutyrate	28	114	0	137	0	72	0	84	4	63	5	66

MFDH – L3 yeast

Experimental design: To determine if there is a geraniol concentration threshold for L3 yeast. A stock solution of geraniol was introduced into hoppy fermenting wort at different concentrations at 10°P



	Hoppy wort - Control	300ppb added geraniol	600ppb added geraniol	1000ppb added geraniol
Geraniol (ppb)	215	501	773	1211
β-Citronellol (ppb)	19	43	74	113

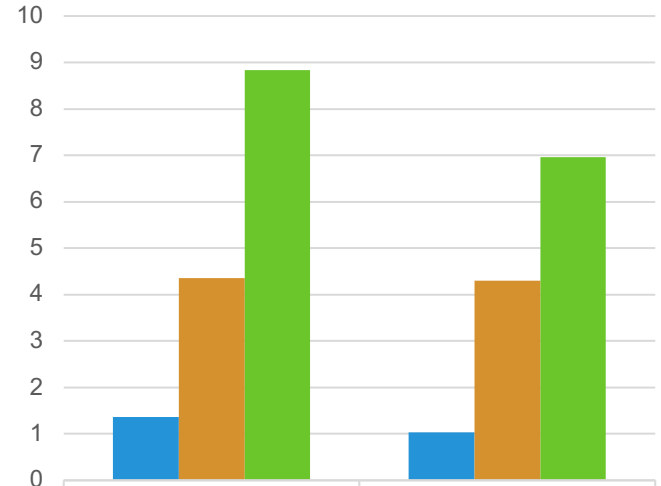


Pilot Brewery Scale

MFDH vs. Dry Hop on yeast – California Ale Yeast

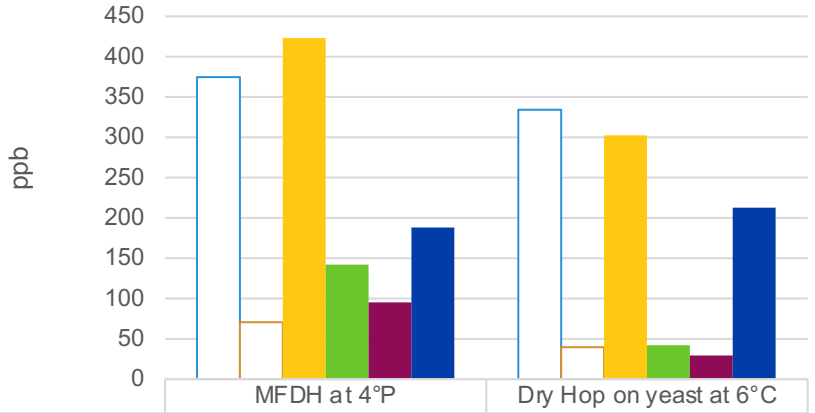
Experimental design: To compare the flavor profiles of two similar beers brewed at a 10hL scale with the same hops and usage rates. One beer MFDH at 4°P and one dry hopped on yeast at 6°C.

Fermentation Stats



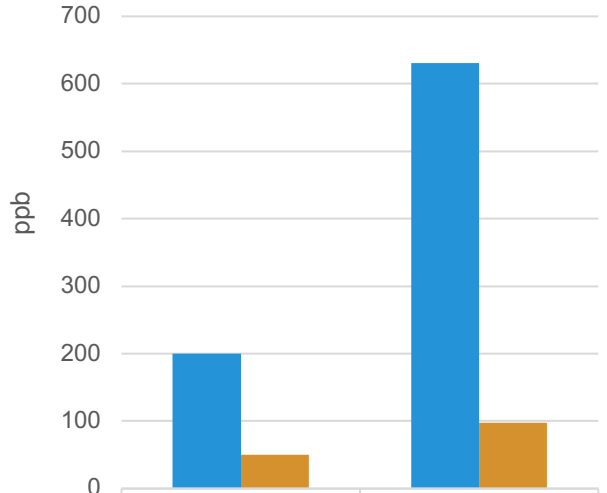
	MFDH at 4°P	Dry Hop on yeast at 6°C
Ea	1.37	1.03
pH	4.36	4.3
ABV	8.83	6.96

Oxygenated Terpenes



	MFDH at 4°P	Dry Hop on yeast at 6°C
Linalool	375	334
Nerol	71	40
Geraniol	423	302
β-Citronellol	142	42
Ethyl Isobutyrate	95	29
2-Methylbutyl Isobutyrate	188	213

Terpenes



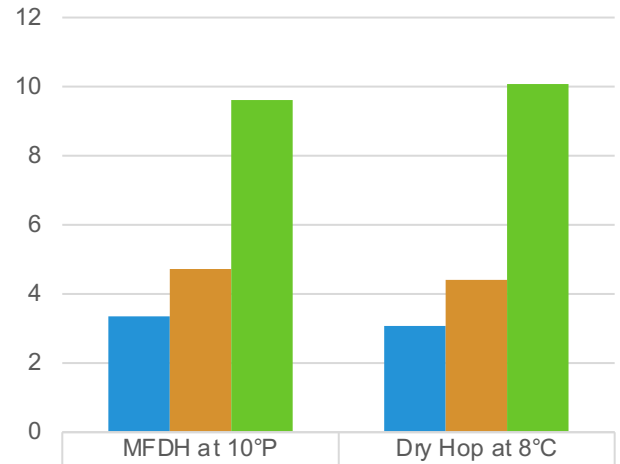
	MFDH at 4°P	Dry Hop on yeast at 6°C
Myrcene	200	631
Humulene	50	98

Beer	Aroma description
MFDH at 4°P	Moderate tropical (grapefruit, pineapple), citrus and myrcene. Slight-moderate catty. Slight herbal, bready, candy
Dry Hop on yeast at 6°C	Moderate tropical (mango, papaya) and myrcene. Slight-moderate stone fruit, orange juice, candy. Slight herbal and bready

MFDH vs Dry Hop – L3 yeast

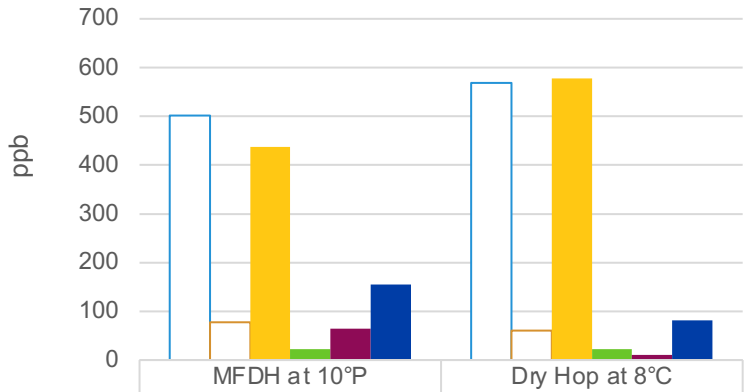
Experimental design: To compare the flavor profiles of two similar beers brewed at a 10hL scale. One beer MFDH at 10°P and one dry hopped at 8°C utilizing similar hops and dosage rates.

Fermentation Stats



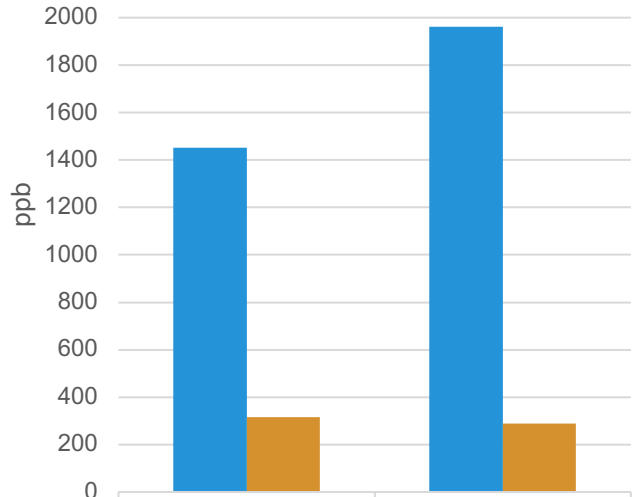
	MFDH at 10°P	Dry Hop at 8°C
Ea	3.35	3.08
pH	4.72	4.41
ABV	9.61	10.08

Oxygenated Terpenes



	MFDH at 10°P	Dry Hop at 8°C
Linalool	502	568
Nerol	78	60
Geraniol	437	578
β-Citronellol	22	22
Ethyl Isobutyrate	65	11
2-Methylbutyl Isobutyrate	155	81

Terpenes



	MFDH at 10°P	Dry Hop at 8°C
Myrcene	1452	1961
Humulene	315	288

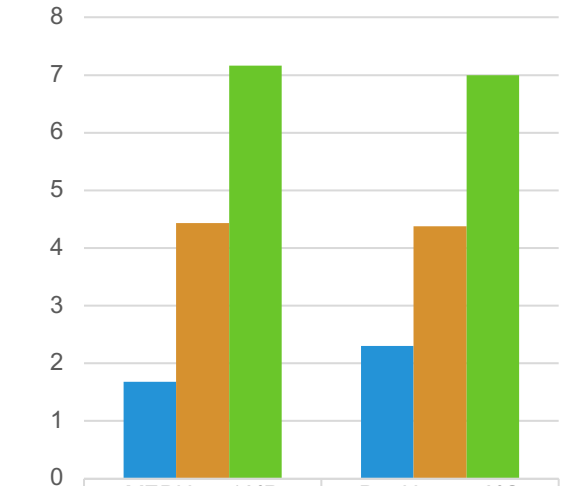
Beer	Aroma description
MFDH at 10°P	Moderate tropical (passionfruit, pineapple). Slight-moderate myrcene, catty, lemon. Slight herbal, bready, honey
Dry Hop at 8°C	Moderate tropical (mango, pineapple), citrus. Slight-moderate myrcene, catty. Slight herbal and bready

Production Scale

MFDH vs. Dry Hop – California Ale Yeast

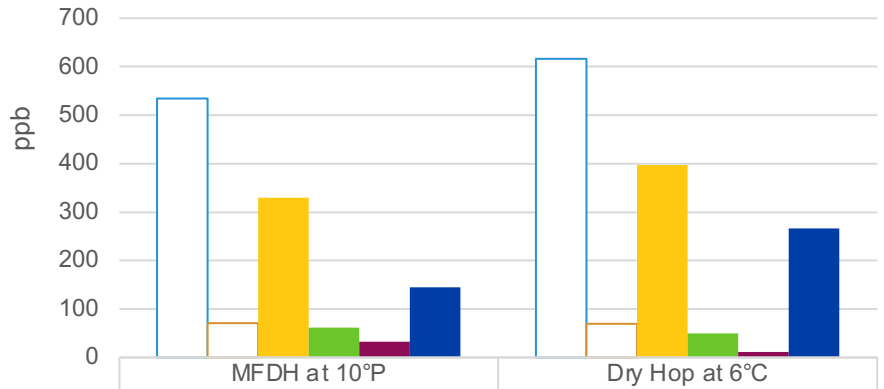
Experimental design: To compare the flavor profiles of two similar beers brewed at a 720hL scale. One beer MFDH at 10°P and one dry hopped on yeast at 6°C utilizing the same hops and dosing rates.

Fermentation Stats



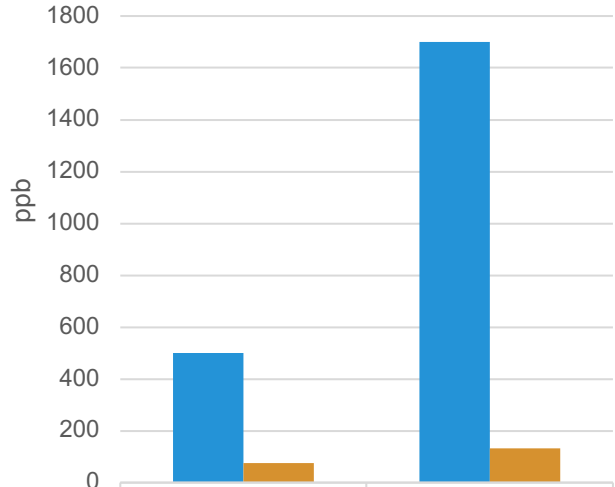
	MFDH at 10°P	Dry Hop at 6°C
Ea	1.68	2.3
pH	4.43	4.38
ABV	7.16	6.99

Oxygenated Terpenes



	MFDH at 10°P	Dry Hop at 6°C
Linalool	535	617
Nerol	71	70
Geraniol	330	397
β-Citronellol	61	50
Ethyl Isobutyrate	32	12
2-Methylbutyl Isobutyrate	145	267

Terpenes



	MFDH at 10°P	Dry Hop at 6°C
Myrcene	500	1700
Humulene	76	131

Control Beer Aroma description

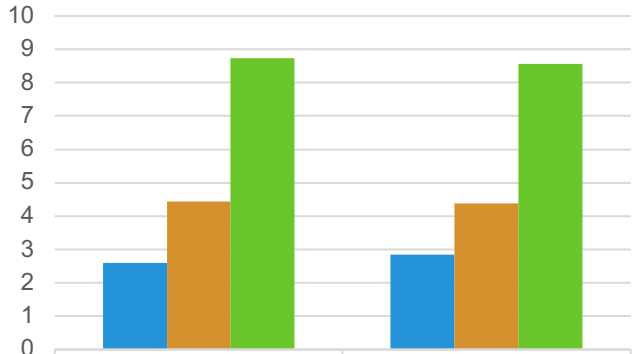
Moderate-strong myrcene. Slight-moderate catty, citrus (orange and lemon), tropical. Slight bready and watermelon rind.

- 2-AFC showed no significant differences between the MFDH and the dry hopped beer at fresh

MFDH vs Dry Hop – L3 yeast

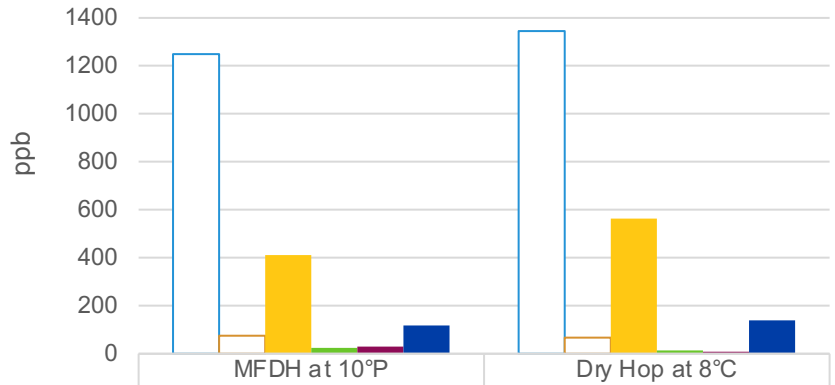
Experimental design: To compare the flavor profiles of two similar beers brewed at a 1000hL scale. One beer MFDH at 10°P and one dry hopped at 8°C utilizing the same hops and dosing rates

Fermentation Stats



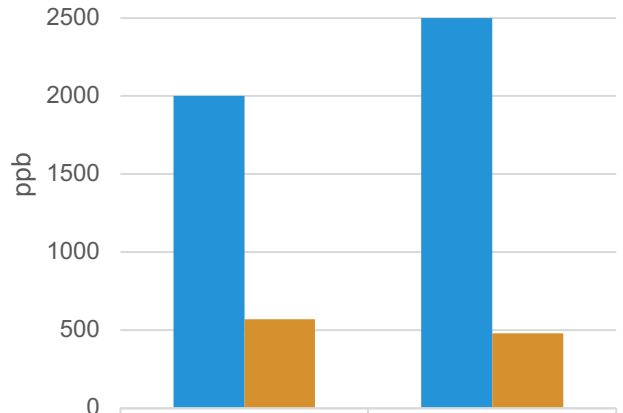
	MFDH at 10°P	Dry Hop at 8°C
Ea	2.59	2.84
pH	4.44	4.38
ABV	8.74	8.56

Oxygenated Terpenes



	MFDH at 10°P	Dry Hop at 8°C
Linalool	1250	1344
Nerol	75	68
Geraniol	412	563
β-Citronellol	24	15
Ethyl Isobutyrate	30	9
2-Methylbutyl Isobutyrate	119	139

Terpenes



	MFDH at 10°P	Dry Hop at 8°C
Myrcene	2000	2500
Humulene	572	480

Aroma description

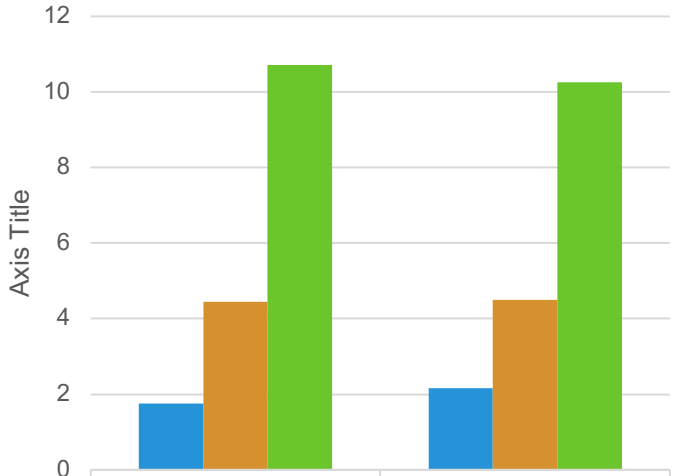
Moderate tropical fruit (mostly pineapple). Slight-moderate myrcene and citrus (mostly lemon). Slight catty, bready and sugar cookie

- 2-AFC showed no significant differences between the MFDH and the dry hopped beer at fresh

MFDH Yeast Harvestability – California Ale yeast

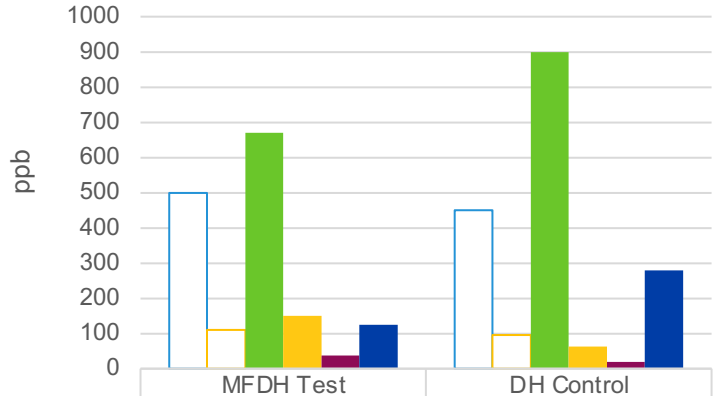
Experimental design: To assess yeast harvestability of two different beers that were MFDH at a production scale at 10°P. Hop Type considerations were made in this experiment

Fermentation Stats



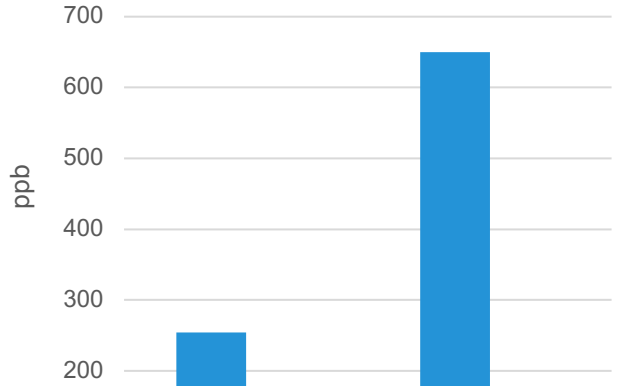
	MFDH Test	DH Control
ea	1.75	2.16
pH	4.44	4.5
abv	10.72	10.25

Oxygenated Terpenes



	MFDH Test	DH Control
Linalool	500	450
Nerol	110	95
Geraniol	670	900
β-Citronellol	150	62
Ethyl Isobutyrate	38	20
2-Methylbutyl Isobutyrate	125	280

Terpenes



	MFDH Test	DH Control
Myrcene	254	650
Humulene	101	80

Sample	Cell Count	Viability	Vitality
Lupomax MFDH Test	693MM cells/mL	81.4%	74.8%
Pitch Data for MFDH Test	30.5MM cells/mL	72.9%	58.8%
Post-harvest Data	795MM cells/mL	71.9%	56.0%

Whirlpool Hopping

Whirlpool Hopping

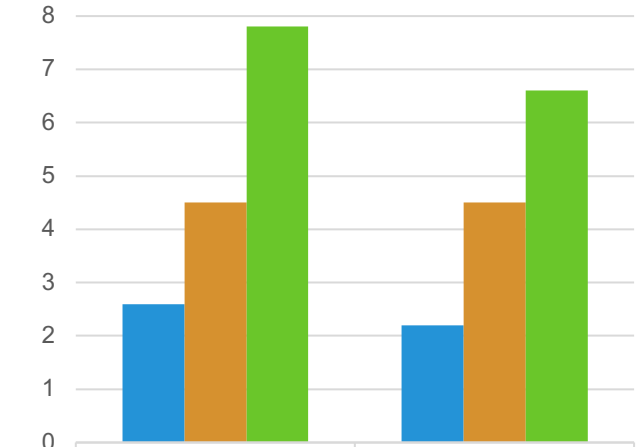
Benefits of Whirlpool Hopping

- Biotransformation potential
- Yeast harvestability
- Remove unpredictable hop creep
- Hop saturated flavor base

Whirlpool-only vs Whirlpool + Dry-hop – California Ale Yeast

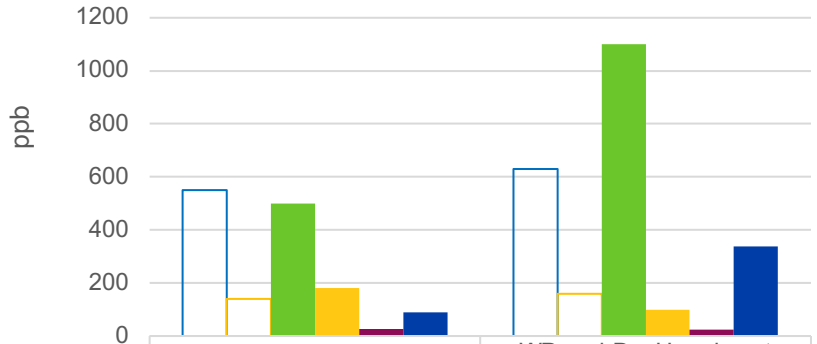
Experimental design: To compare the flavor profiles of the same base beer, one beer with no dry-hop additions, the second dry-hopped at 300g/hL.

Fermentation Stats



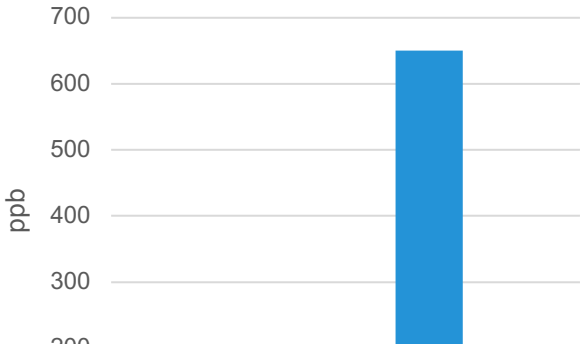
	WP Hopping only	WP and Dry Hopping at 6°C
ea	2.6	2.2
pH	4.5	4.5
abv	7.8	6.6

Oxygenated Terpenes



	WP Hopping only	WP and Dry Hopping at 6°C
Linalool	550	630
Nerol	140	160
Geraniol	500	1100
β-Citronellol	180	100
Ethyl Isobutyrate	26	23
2-Methylbutyl Isobutyrate	90	337

Terpenes



	WP Hopping only	WP and Dry Hopping at 6°C
Myrcene	50	650
Humulene	20	25

Beer	Aroma description
Whirlpool only	Moderate myrcene, tropical fruit, catty. Slight-moderate citrus (orange and grapefruit). Slight bready and stone fruit
Whirlpool and Dry Hop at 6°C	Moderate-strong Myrcene and pineapple. Slight-moderate coconut, citrus (orange and lime) and sugar cookie. Slight herbal, floral and bready

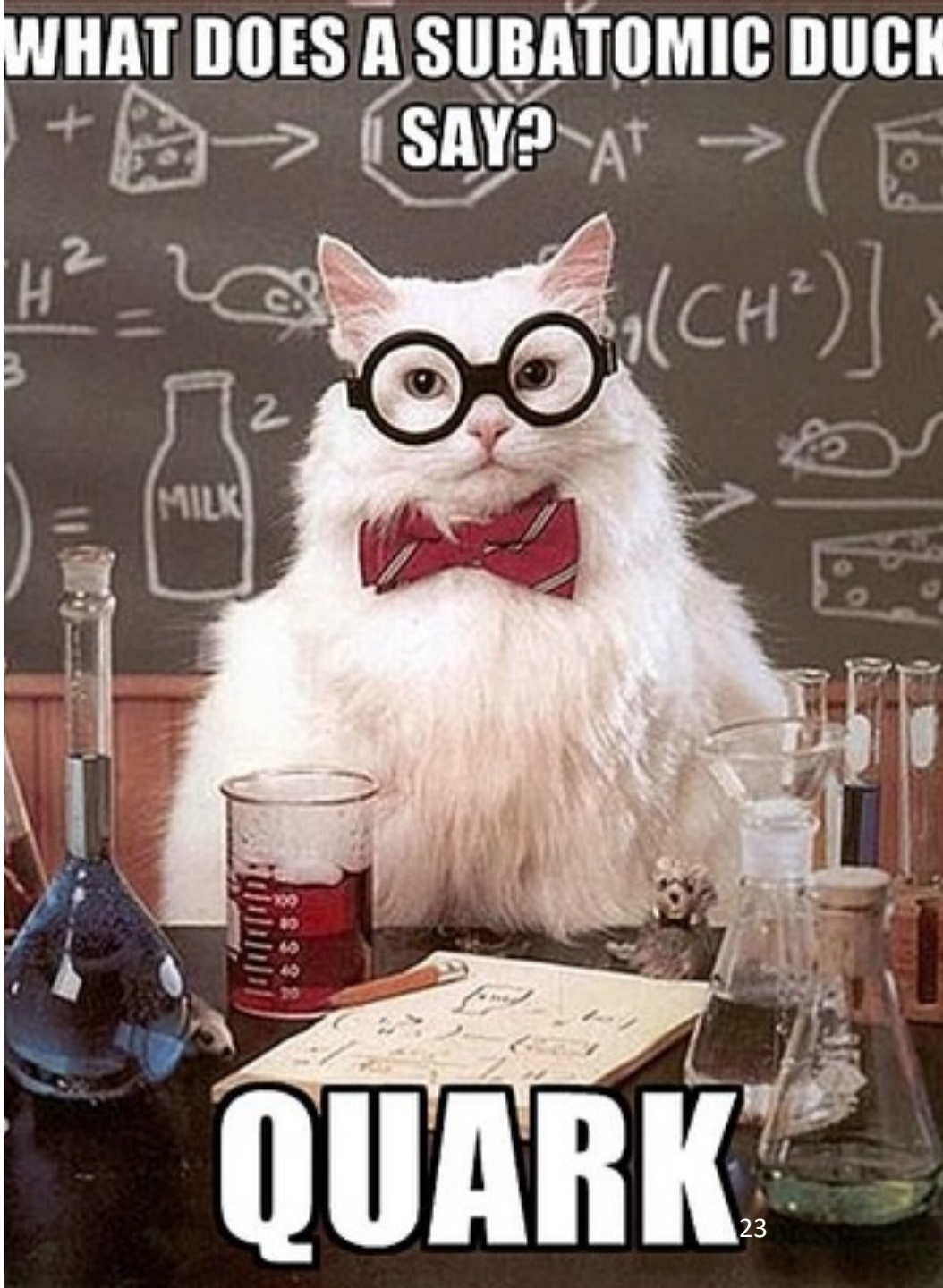
Summary and Future Work

Summary and Future Work

- Biotransformation Criteria
- Bench-scale work
  - Future work
- Pilot Scale
- Production Scale
  - Future work
- Whirlpool Hopping
  - Future work

Thanks!!

- Dr Dana Sedin
- Christian Holbrook
- Jeff Irby
- Your Mom
- The Analytical Team
- The Microbiology Team
- The Sensory Team
- The Pilot Brewing Team
- The Production Brewing Team



Resources

- Praet, T.; Van Opstaele, F.; Jaskula-Goiris, B.; Aerts, G.; De Cooman, L. Biotransformations of Hop-derived Aroma Compounds by Saccharomyces cerevisiae Upon Fermentation. Cerevisia. 2012, 36, 125–132. DOI:10.1016/j.cervis.2011.12.005
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