

HOP OILS

(Maximizing Hop Flavor)

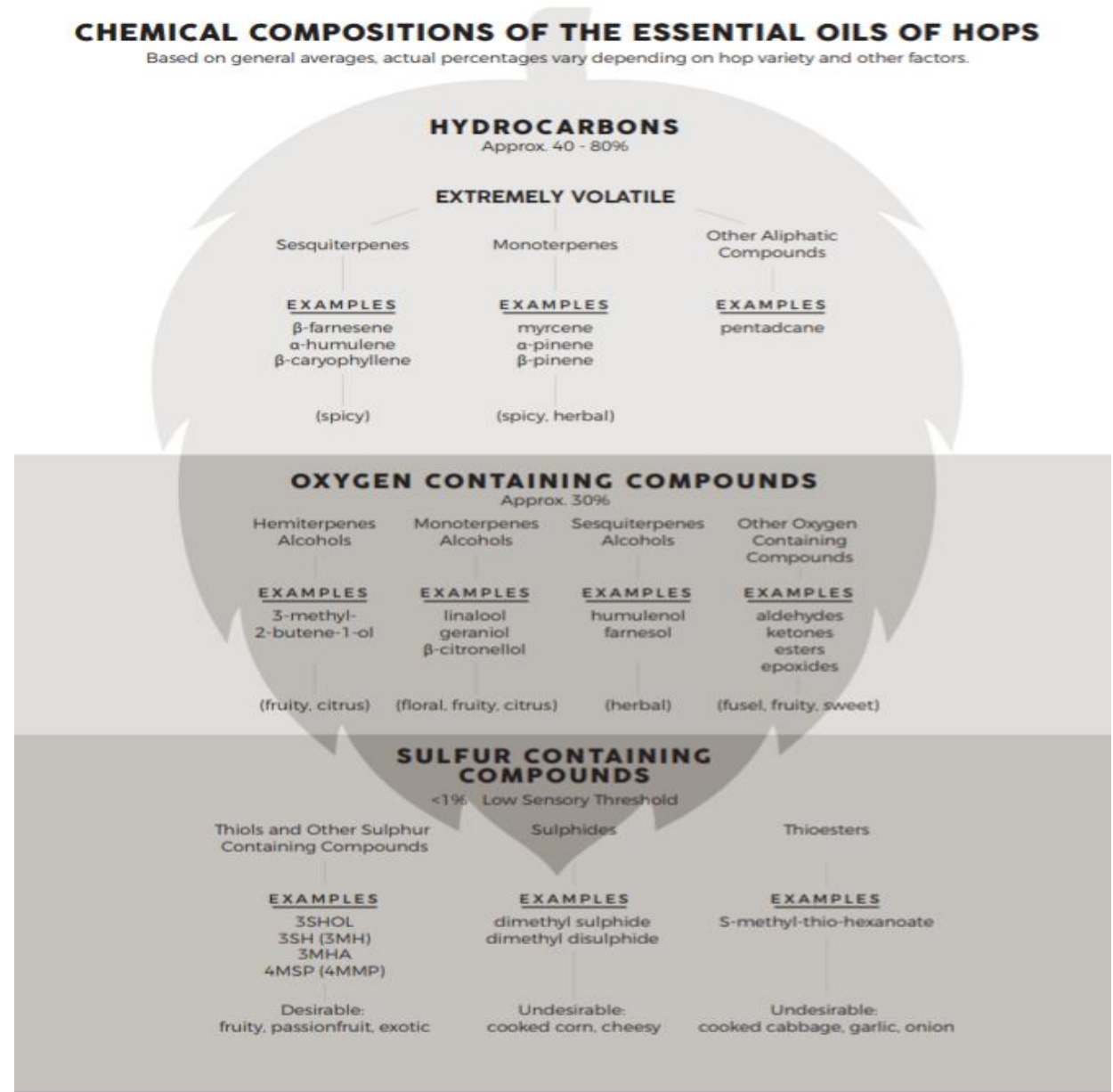
Over **1000** Different Oil Compounds are Contained Within the **Lupulin Gland** of Hops

We Will **Concentrate on Fruit-Forward Oils** in Hops

- **Essential Oils of Hops**
 - Breakdown of different Hop Oils
- **Hop Oil Usage for Maximum Survivability**
 - Maximize Oils in different Stages of Brewing (i.e. Whirlpool)
- **Flavor Impact in Hop Varieties**
 - Favor/Aroma Extraction of Oils in Different Hop Varieties (i.e. Mosaic, etc..)
- **Tables on Hop Oils and Summary Table**
 - Popular Hops & Oils in the Brewing Process

Essential Oils of Hops Chart

- **40-80%: Hydrocarbons (Terpenes – volatile unsaturated hydrocarbons found in essential oils of plants)**
 - Most are woody, herbal, pine, spicy.
 - **Myrcene** (herbal/woody) most prevalent – up to 75% of hop's Total Oil. (i.e. **Citra**)
- **30%: Oxygenated Hydrocarbons (Terpene Alcohols or Oxygen Containing Compounds)**
 - Most are citrus, tropical, berry, floral, ethereal.
 - **Linalool, Geraniol, Citronellol** - byproduct of Geraniol. (i.e. **Centennial**)
 - Minor amounts (15% of total hop oils) are **Ketones** and **Esters** (i.e. **Mosaic**)
- **<1%: Sulfur Containing Compounds (Hydrocarbons with Chemically Bound Sulfur)**
 - (Polyfunctional) **Thiols** – free and locked, VERY potent (i.e. **Idaho 7-free**)



Notes on Essential Hop Oils

*Hop Oils are **volatile** – vaporize easily and at high temps.*

- **Hydrocarbons (Terpenes)**

- Hydrocarbons 50% lost in 10min boil, **100% 60 min.**
- More viscous protein rich base encourages myrcene to stay in solution, hence more **hop bite** in high concentrations.
- Flaked oats limited to **10% due** to protein, can add malted wheat (not flaked).

- **Oxygen Containing Compounds**

- **Linalool** - booster for fruity flavors. (80% loss in 5min boil). **Geraniol** survives much better
- Geraniol to **Citronellel** mostly in whirlpool & fermentation.
- **Keytones and Esters** – Hops high in **Alpha Acids** generally contain more fatty acids that can turn into Keytones/Esters during fermentation.

- **<1%: Sulfur Containing Compounds**

- Most Thiols are **bound** (i.e., Sulphur/ Carbon needs to be broken)
- Needs beta-glucosidase (in yeast) to free bound thiols - most do a **poor job**.
- New bio-engineered yeast does a much better job freeing thiols.
- For every **one** microgram (μg) of free 3MH in **Cascade** hops, there are **35** μg of the Cyst-3MH precursors and **1,574** μg of the Glut-3MH precursors.

Survivability

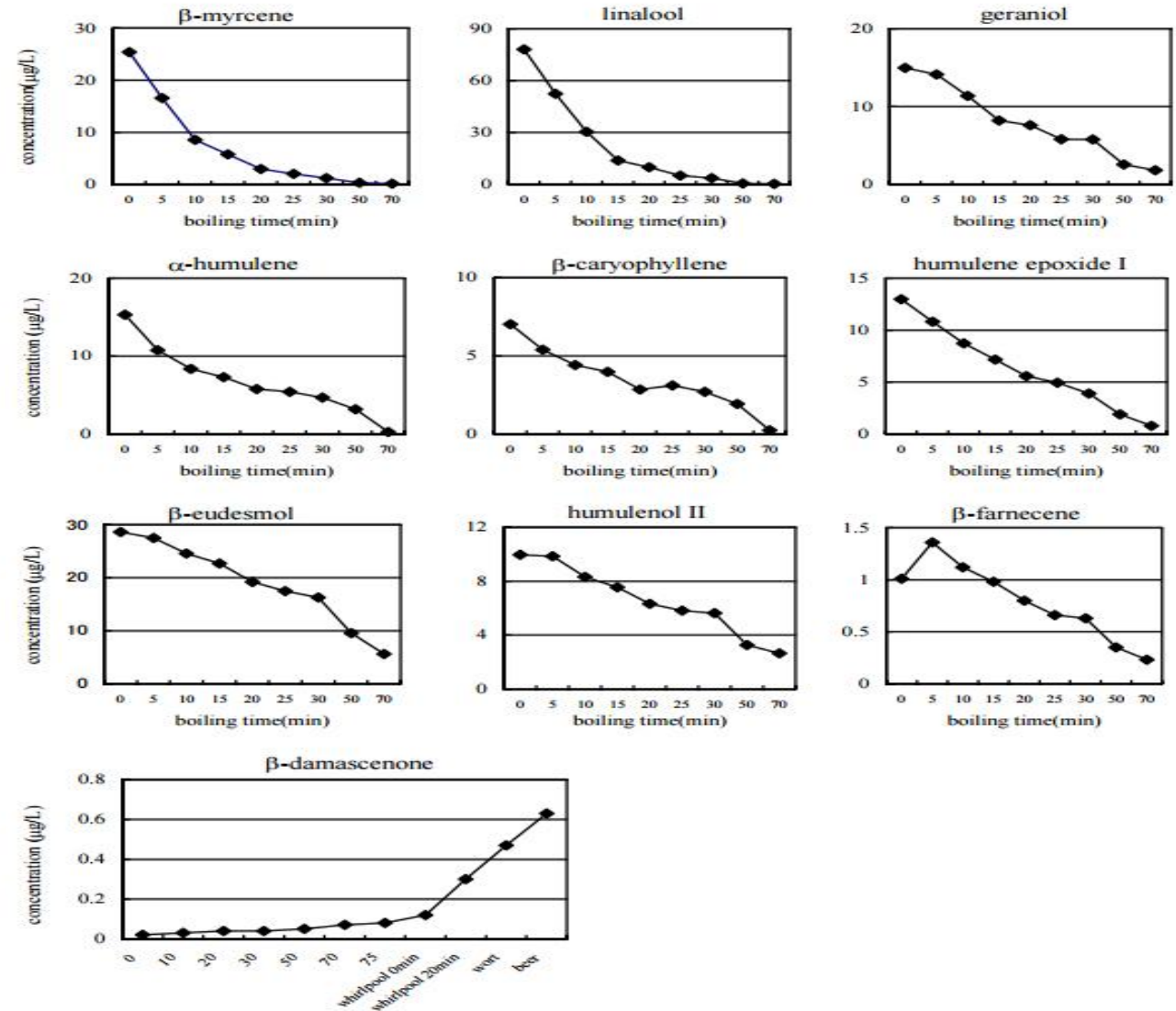
- Usage Timing

- Boil

- Both myrcene and linalool drop off quickly during boil (both have high extraction rate during dry hop tho)

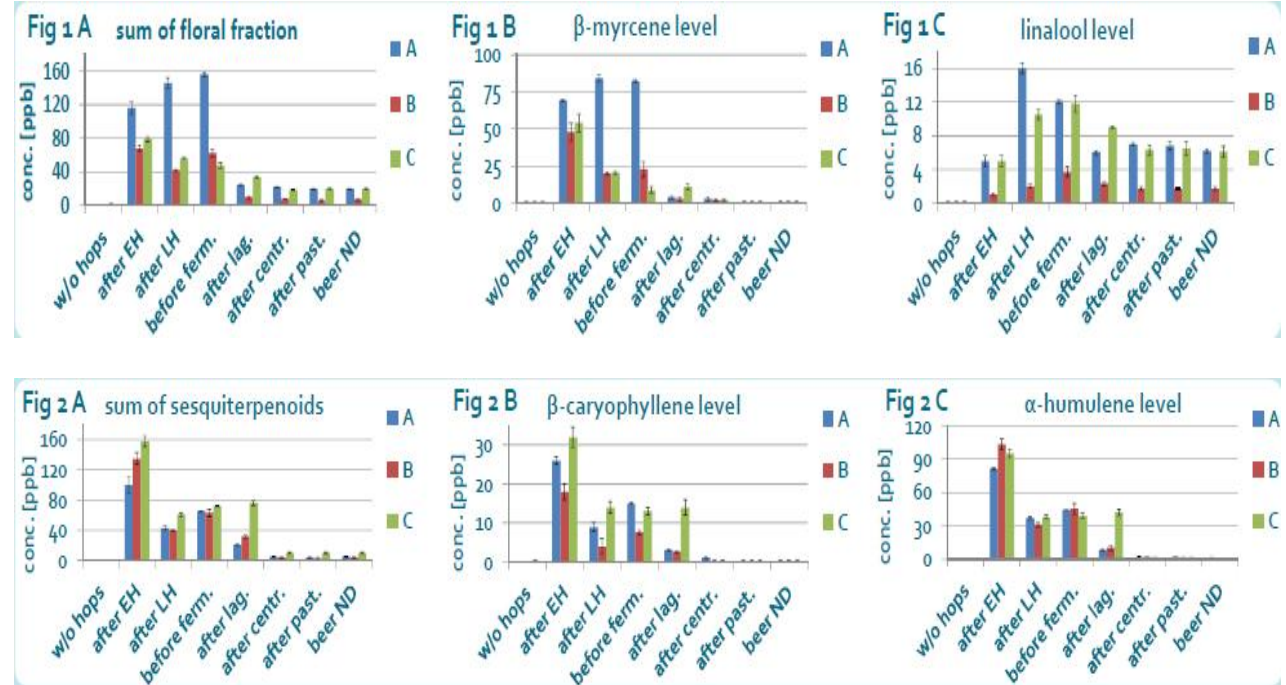
- Whirlpool

- Whirlpool 203deg more citrus, spicy, ester; Whirlpool 185deg more linalool measured; floral and herbal; Whirlpool 167deg woody.
- 170-180deg F probably best to maximize terpene alcohols into solution/beer.
- Free thiols – 3MH can increase and 4MMP can increase during whirlpool.
- Can increase geraniol rich hops for more beta-citronellol production (in Fermentation).
- About 5oz whirlpool hop rate.



Fermentation Dry Hop (DH)

- Early DH additions (before completed fermentation) could lessen **aromas**
- Early DH additions will strip more resinous compounds (**hydrocarbons**).
- **Linalool** drops off during fermentation.
- Early fermentation DH can lead to increase **haze** (particle light reflection).
- Hops high in **geraniol** are best early in fermentation and can increase beta-citronellol. (i.e. **Motueka**)
- Up to 80% **Esters/Keytones** survive late DH (After Fermentation) – original state can change during fermentation.



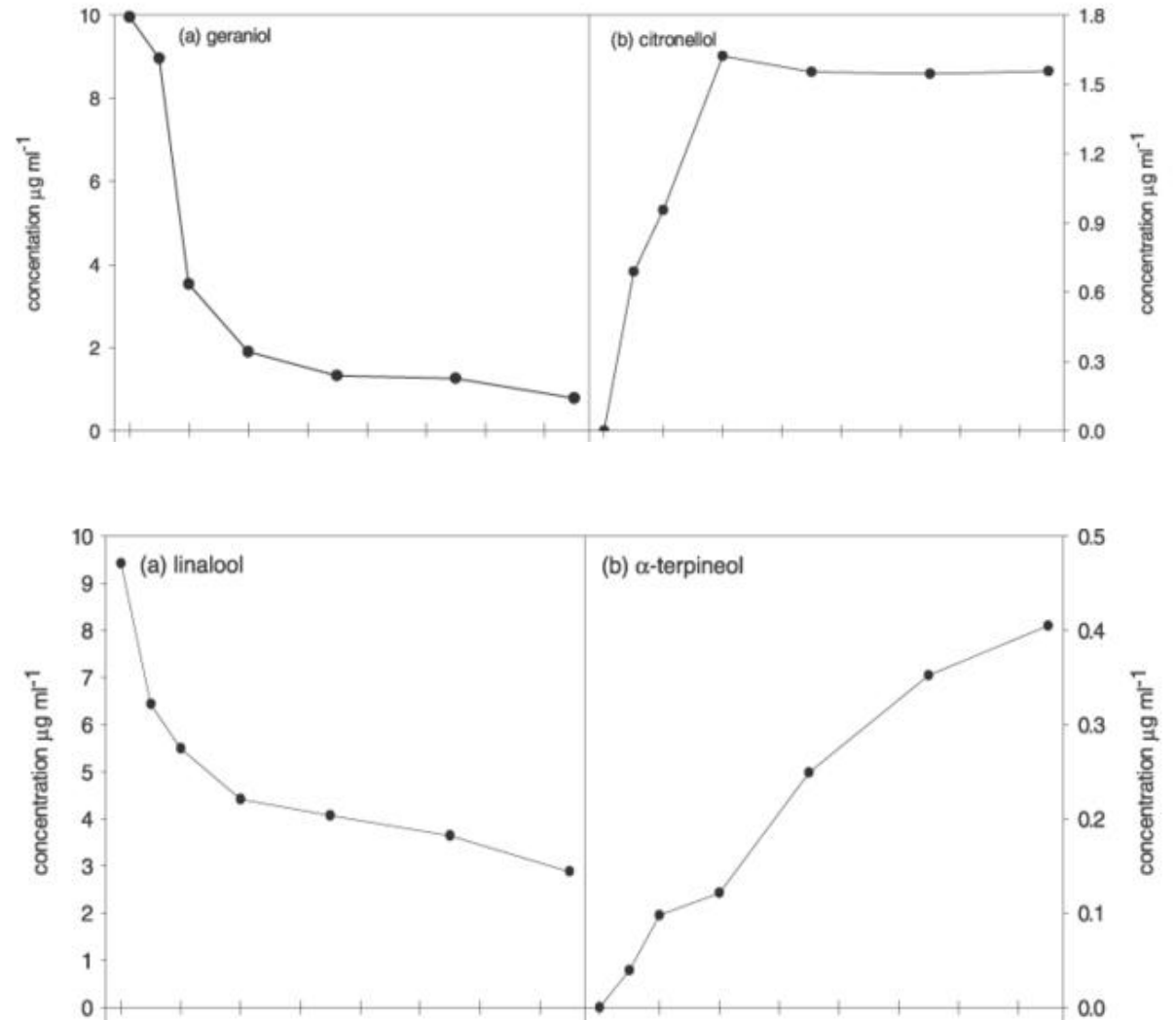
(from Dresel, Praet, Opastaele, Van Holle, Van Nieuwenhove, Naudts, Keukeleire, Aerts, and Cooman)

Abbreviations

- w/o hops: after 15' boiling – just before early hopping
- after EH: after 75' boiling – just before late hopping
- after LH: after 5' cooling
- before ferm: after 10' cooling – just before fermentation
- after lag: after lagging – just before centrifugation
- after past: after pasteurization
- beer ND: bottled beer without dry hopping

Post Fermentation (Late) DH

- Post Fermentation DH increases polyphenols (perceived bitterness); decrease during fermentation.
- 5°F below low yeast range to minimize scrubbing of oils (hop creep); esp. for Thiols.
- Cooler DH doesn't extract as much woody, spicy, and resinous compounds (hydrocarbons).
- Dry hopping 3oz (per 5 gal) per charge maintain citrus qualities of hop (up to 6oz total).
- Green/Oniony flavor when heavily dry hopped after fermentation - high in myrcene.
- Between 48 to 72 hours per DH stage (maximize hop surface contact).
- Longer DH, myrcene and linalool levels didn't increase, increases risk resinous vegetative.



Flavor Impact in Hop Varieties

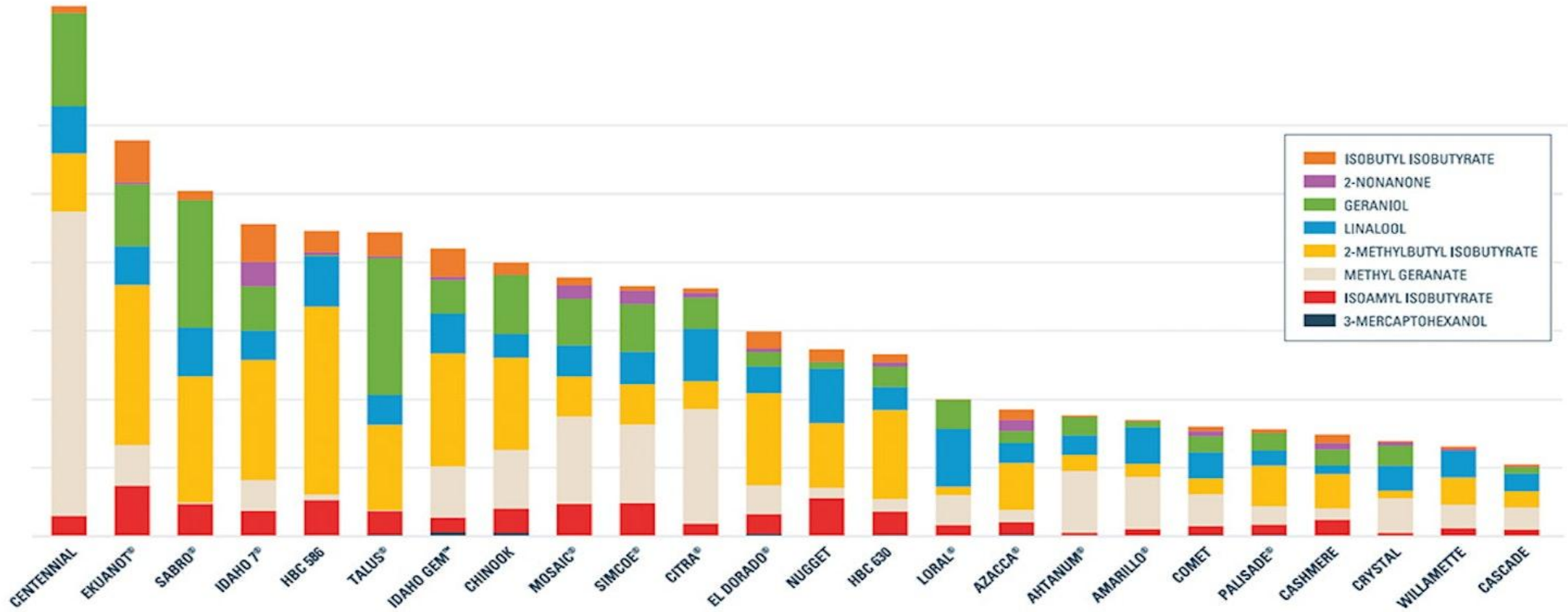
- **Hydrocarbons (Terpenes)**
 - Popular Myrcene-rich hops: **Citra, Mosaic, Sabro, Centennial**
 - **Nelson** – high alpha hop that could contribute to spicy/earthy kettle aroma
 - Popular Linalool/Geraniol rich hops: **Citra, Loral, Centennial, Sabro, Motueka, Chinook**
 - Popular Ester/Keytone rich hops: **Nelson, Ekuanot, Mosaic, Simcoe, Idaho7, Sabro, Centennial, Citra, Chinook, El Dorado**
- **Oxygen Containing Compounds**
 - Good Hot side hops - **Citra, Mosaic, Simcoe, Centennial, Ekuanot**
 - Good IBU hops to neutralize (Hydrocarbon) aroma - **Citra, Mosaic, Galaxy, Loral, Wiamea**
 - Great Whirlpool hops for oil survivability – **Idaho7, Mosaic, Citra, Ekuanot, Simcoe**
 - Most free geraniol - **Motueka, Cascade, Chinook, Citra, Mosaic** (best early in fermentation)
 - **Simcoe** - hop free thiols great - 83% linalool extraction rate during dry hopping
 - **Centennial** huge on all survivable oils.
- **<1%: Sulfur Containing Compounds**
 - **Amarillo and Mosaic** - most bound geraniol - needs beta-glucosidase (B-lyase) enzyme to free geraniol.
 - Dry hopping at the end of fermentation, with hops high in free thiols (**Sabro and Mosaic**)
 - **Citra** is such a popular hop when brewers are trying to target 4MMP.
 - **Citra** also has linalool and geraniol. So that makes Citra synergistic for Whirlpool and DH.
 - Top Hops with 4MMP: **Citra, Cascade, Chinook, Sabro, Galaxy**

Hop Acid and Oil Chart

* - ml/100g ** - % of Total Oils # - Total Geraniol/Linalool Oils and Top 10 Source = Yakima Chief Hops @ yakimachief.com

Hop Pellet	Aroma Profile	Alpha Acid	Beta Acid	Total Oil*	Myrcene**	Linalool**	Geraniol**	#
Cascade	Floral, Grapefruit, Herbal, pine	4-9	5-9	0.5-2.0	40-60	0.1-0.6	0.1-0.5	1.1
Centennial	Floral, Lemon, Orange, Tropical, Wdy	8-12	3-6	1.0-3.5	60-75	0.4-0.8	0.7-1.7	2.5
Citra	Citrus, Stone, Tropical, Woody	10-16	3-5	1.0-3.0	50-70	0.5-1.0	0.2-0.7	1.7
Ekuanot	Bubblegum, Cit, Stone, Tropical, Wdy	14-16	4-6	2.5-4.5	30-40	0.2-0.5	0.5-1.3	1.8
El Dorado	Citrus, Stone, Tropical, Woody	13-16	5-8	1.5-3.0	45-60	0.3-0.6	0.1-0.3	0.9
Galaxy	Citrus, Stone, Tropical	13-19	6-12	1.9-2.9	32-56	0.5-1.0	0.1-0.3	1.3
Idaho7	Berry, Bubblegum, Cit, Stone, Tropical	12-15	3-6	1.0-3.0	40-55	0.2-0.6	0.5-1.0	1.6
Krush	Berry, Mango, Cit, Stone, Tropical, Wdy	10-14	7-9	0.5-3.0	40-60	0.5-1.0	0.1-1.0	2.0
Loral	Citrus, Floral, Herbal, Lemon, Tropical	10-13	4-7	1.0-3.0	45-55	0.6-1.2	0.2-0.7	1.9
Mosaic	Berry, Citrus, Stone, Tropical	10-15	3-5	0.5-3.0	45-65	0.4-0.8	0.4-1.0	1.8
Motueka	Fruity, Lemon, Lime, Tropical	6-8	5-6	0.8-1.5	45-60	0.6-0.9	0.8-1.5	2.4
Nelson-NZ	Citrus, Tropical, White Wine	10-13	5-8	0.8-1.5	35-45	0.2-0.6	0.1-0.4	1.0
Riwaka	Apricot, Cit, Resinous, Stone	9-13	4-6	0.8-2.0	45-55	0.4-0.8	0.1-0.3	1.1
Saaz	Earthy, Floral, Spicy, Woody	2-4	4-6	0.4-1.0	25-35	0.1-0.4	0.1-0.4	0.8
Sabro	Cit, Coconut, Herbal, Stone, Tropical	12-17	5-8	1.0-1.04	55-70	0.3-0.6	0.8-1.6	2.4
Simcoe	Cit, Grapefruit, Stone, Tropical, Wdy	10-16	3-6	0.5-3	40-60	0.3-0.8	0.5-1.2	2.0
Wiamea	Citrus, Stone, Sweet, Tropical	14-17	7-9	1.5-2.5	50-60	0.6-0.8	0.8-1.2	2.0
HBC638	Cit, Herbal, Stone, Sweet, Tropical	13-16	4-6	2-4	30-40	0.2-0.4	0.4-1.0	1.4
HBC682	Cit, Earthy, Herbal, Stone, Wdy	16-21	5-8	2-4	60-70	0.3-0.6	0.1-0.6	1.2
Superdelic	Berry, Citrus, Sweet, Tropical	9-12	3-5	1.5-2.2	30-38	0.4-0.7	1.2-1.8	2.5

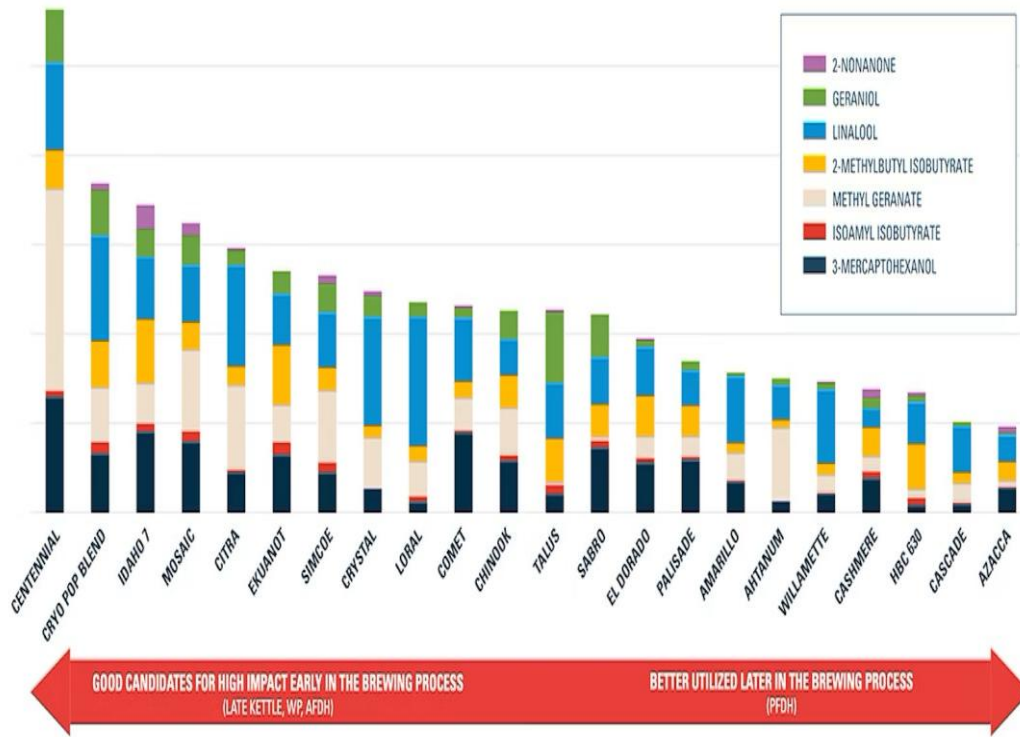
2023 Yakima Chief Hop Oil Survivability Graph



GOOD CANDIDATES FOR HIGH IMPACT EARLY IN THE BREWING PROCESS
(LATE KETTLE, WP, AFDH)

BETTER UTILIZED LATER IN THE BREWING PROCESS
(PFDH)

2020 Takima Chief Hop Oil Survivability Graph



- Butanoic acid, 3-methyl butyl ester is an ester with fruity apricot, pear and banana aroma.
- Methyl geranate is a monoterpene ester with floral, green and fruit aroma.
- 2-Methylbutyl isobutyrate (2MIB) is an ester that has a green apple and apricot aroma.
- Linalool is a monoterpene alcohol with floral and citrus aroma.
- Geraniol is a monoterpene alcohol with rose-like aroma.
- 2-Nonanone is a ketone with fruit, floral and herbaceous aroma.
- 3-Mercaptohexanol (3MH) is a thiol with grapefruit and gooseberry aroma. It can be converted by certain yeasts into 3MHA (passionfruit/guava).
- Note – Units – Part per million (PPM)

Hop Variety	Butanoic acid, 3-methylbutyl	Methyl Geranate	2MIB	Linalool	Geraniol	2-Nonanone	3MH	Total
Idaho 7	19	92	153	148	64	64	189	729
Mosaic	25	192	64	134	67	31	167	679
Citra	6	195	45	239	33	11	92	621
Ekuantot	28	86	145	120	50	3	136	568
Simcoe	19	164	56	128	67	25	95	554
Loral	11	81	33	306	36	0	22	490
Chinook	11	109	78	83	67	6	120	473
Sabro	17	6	81	111	100	0	156	470
El Dorado	8	47	97	111	11	8	120	404
Amarillo	3	61	25	156	11	0	70	326

	Ester	Ester	Ester	Ester	Keytone	Thiol (Bound)	OVERALL
	2MIB	Isoamyl Isobutyrate	Isobutyl Isobtyrate	Methyl Geranate	2-Nonanone	3MH	RANK
	Fruity, Apricot	Fruity, Tropical	Fruity, Pineapple	Fruity, Floral	Sweet, Fruity	MANY!	
1	Ekuanot (145)	Krush	El Dorado	Centennial	Idaho7 (64)	Chi (120)	EKUANOT
2	Krush	Ekuanot	Ekuanot	Citra (195)	Mosaic (31)	Krush	EL DORADO
3	El Dorado (97)	Sabro	Idaho7	Mosaic (192)	Simcoe (25)	Sabro (156)	MOSAIC
4	Sabro (81)	Mosaic	Citra	Simcoe (164)	Citra (11)	El Dorado (120)	KRUSH
5	Idaho7 (153)	Simcoe	Sabro	Chinook (109)	El Dorado (8)	Idaho7 (189)	IDAHO7
6	Chinook (78)	El Dorado	Mosaic	Amarillo (61)	Cascade	Ekuanot (136)	CITRA
7	Centennial	Citra	Krush	Ekuanot (86)	Krush	Mosaic (167)	SABRO
8	Citra (45)	Chinook	Centennial	Loral (81)	Ekuanot (3)	Simcoe (95)	SIMCOE
9	Mosaic (64)	Idaho7	Chinook	Idaho7 (92)	Sabro (0)	Citra (92)	CHINOOK
10	Simcoe (56)	Centennial	Simcoe	Cascade	Loral (0)	Amarillo (70)	CENTENNIAL
11	Cascade	Loral	Cascade	El Dorado (47)	Amarillo (0)	Loral (22)	CASCADE
12	Loral (33)	Cascade	Amarillo	Krush	Chinook (6)	Centennial	LORAL
13	Amarillo (25)	Amarillo	Loral	Sabro (6)	Centennial	Cascade	AMARILLO

Source = Yakima Chief Hops @ yakimachief.com (rankings only)
(78) = 2020 Yakima Hops Table Value in PPM

Compound	Sensory characteristics	Detection threshold (ng/l)
1-Sulfanylpentan-3-ol	Green odor	n/a
2SEA	Onion	n/a
3MH	Rhubarb, grapefruit flavor	60
3MHA	Passion fruit, grapefruit flavor	4.2
3SH	Grapefruit like flavor, rhubarb	0.8
4MMP	Black currant, passion-fruit-like flavor	0.8
4MSP	Tree-like flavor	1.5

SENSORY CHARACTERISTICS OF DESCRIBED SULFUR COMPOUNDS AND THEIR DETECTION THRESHOLD (determined in beer, wine or model solutions) (Copper et al., 2021; Mafata et al., 2018; Michel et al., 2019; Nizet et al., 2013, 2014; Peltz & Shellhammer, 2017; Zott et al., 2011). From Biotransformation of Hops-Derived Compounds – 2022. **1 Million PPM = 1 PPT = 1 ng/L**

SUMMARY

Description	BOIL	WHIRLPOOL	FERM DH	POST FERM DH
Myrcene	Best to use hi %	Ok to use	Ok to use	Want Low %
Hi Myrcene Hops	Citra, Mosaic, Sabro, Centennial ⁽¹⁾ , Simcoe ⁽²⁾ , Galaxy, Loral, Wiamea ⁽¹²⁾			Ekuanot, Nelson ⁽¹¹⁾ , Saaz
Geraniol	Most will be lost	Can use	Can use	Want to use
Hi Geraniol Hops			Motueka, Chinook, Mosaic, Cascade, Citra ⁽⁶⁾	Motueka, Chinook, Mosaic, Cascade, Citra ⁽⁶⁾ , Centennial, Sabro
Geraniol to Citronellol	Most will be lost	Can use	Want to use early	Won't work
Hi Geraniol Hops	Mosaic, Amarillo ⁽³⁾	Motueka, Chinook, Mosaic, Cascade, Citra ⁽⁶⁾ , Centennial, Sabro ⁽⁹⁾	Mosaic, Amarillo ⁽³⁾	
Linalool	Will be lost	Can use	Can use	Want to use
Hi Linalool Hops				Simcoe ⁽⁵⁾ Citra, Krush, Loral, Galaxy, Amarillo
Esters/Keytones	Most will be lost	Most will be lost	Can change	Want to use
Hi Ester / Keytone Hops				Ekuanot, Mosaic, Simcoe, Idaho7, Sabro, Citra, El Dorado, Krush, Amarillo, Nelson ⁽⁴⁾
Total Oxygenated Compounds	Most will be lost	Can use	Can use	Want to use
Hi Total Oil Hops	Centennial	Idaho7, Citra, Simcoe, Mosaic, Ekuanot ⁽⁸⁾ , Centennial, Krush, Sabro, Motueka, Wiamea ⁽¹³⁾		Citra, Ekuanot, Mosaic, Centennial ⁽⁷⁾ , Idaho7, Loral, Sabro, Motueka, Chinook ⁽¹⁴⁾
Free Thiols	Possible Increase	Can use (&4MMH)	Can use	Want to Use
Hi Free Thiol Hops		Chinook, Krush, Sabro, El Dorado ⁽¹⁰⁾ , Idaho7, Mosaic, Simcoe ⁽¹⁵⁾		Citra, Cascade, Chinook, Sabro, Galaxy ⁽¹⁶⁾

- (1) - Sabro, Centennial - also High Geraniol - some could survive
- (2) - Citra, Mosaic, Sabro, Centennial, Simcoe - Janish Top 5
- (3) - Mosaic/Amarillo - Most Bound Geraniol - some yeasts free them better than others
- (4) - Also, Amarillo and Nelson - Janish
- (5) - Simcoe has 83% linalool survival rate during DH BUT less than 5% Late kettle or Whirlpool - Janish
- (6) - Motueka, Chinook, Mosaic, Cascade, Citra - Janish
- (7) - Total Oil and High Oxygenated Compound hops: Citra, Ekuanot, Mosaic, Centennial - Janish
- (8) - Oil Survivability Hops - Janish
- (9) - Can be used in Whirlpool or Early Fermentation
- (10) - Chinook, Krush, Sabro, El Dorado (Best used in early Fermentation or Mash) - Shanleigh Thomson
- (11) - Nelson could contribute to spicy/earthy kettle aroma - Janish
- (12) - Kettle hops help to neutralize hydrocarbon (spicy/earthy) aroma - Janish
- (13) - Hi total oil hops in whirlpool can impart higher flavor profile than during DH
- (14) - Additional Geraniol/Linalool rich hops: Loral, Sabro, Motueka, Chinook - Janish
- (15) - For 4MMP, want 90 deg (F) or less in Whirlpool or DH - Yakima Valley Hops
- (16) - Top Hops with free 4MMP: [Citra](#), [Cascade](#), [Chinook](#), [Sabro](#), [Galaxy](#) - Yakima Valley Hops

Note - if no Hop reference, then from one of the above referenced Tables.

Hop Variety	<u>Cascade</u>	<u>Centennial</u>	<u>Citra® Brand</u>	<u>Ekuanot® Brand</u>	<u>El Dorado® Brand</u>	<u>Galaxy™ - AU</u>
Brand	N/A	N/A	HBC 394	HBC 366	N/A	N/A
Aroma Profile	Floral	Lemon	Citrus	Bubblegum	Citrus	Citrus
	Grapefruit	Orange	Stone Fruit	Citrus	Stone Fruit	Stone Fruit
	Grassy	Tropical	Tropical	Stone Fruit	Tropical	Tropical
	Herbal	Woody	Woody	Tropical	Woody	
	Pine	Floral		Woody		
Alpha Acid Range Low	4	8.5	10	14	13	13
Alpha Acid Range Hi	9	12	16	16	16	18.5
Beta Acid Range Low	5.5	3.5	3	4	5.5	6.1
Beta Acid Range Hi	9	5.5	4.5	5.5	7.5	11.6
Total Oil Range Low	0.5	1	1	2.5	1.5	1.9
Total Oil Range Hi	2	3.5	3	4.5	3	2.9
Co-Humulone Low	29	23	20	30	30	32
B-Pinene Low	0.5	0.8	0.6	0.4	0.6	0.3
B-Pinene Hi	1	1.2	1	0.7	0.9	0.6
Myrcene Low	40	60	50	30	45	32
Myrcene Hi	60	75	70	40	60	56
Linalool Low	0.1	0.4	0.5	0.2	0.3	0.5
Linalool Hi	0.6	0.8	1	0.5	0.6	1
Caryophyllene Low	4	3	4	9	6	7
Caryophyllene Hi	10	7	8	12	10	14.7
Farnesene Low	4.5	0.1	0.1	0.1	0.1	2.8
Farnesene Hi	8.5	0.5	1	1	1	5.1
Humulene Low	10	7	7	17	8	0.8
Humulene Hi	20	12	12.5	22	15	2.2
Geraniol Low	0.1	0.7	0.2	0.5	0.1	0.1
Geraniol High	0.5	1.7	0.8	1.3	0.3	0.3