Dry Hop Aroma in Beer – a review

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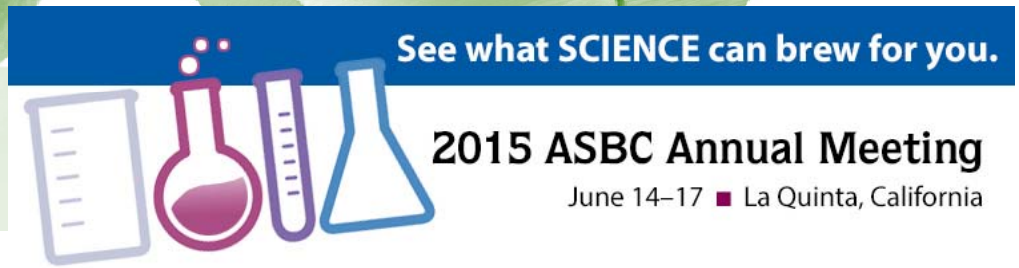
Barth Haas Group



Agenda

1. A look into the past of dry hopping
2. Basics of hop aroma and dry hopping
3. A background on flavour perception and odor activity
4. Why do dry hopped beers smell and taste the way they do ?

Since when do we dry hop ?

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1768

- (english) brewers knew enough to say that “if the beer is to be sent into a warmer climate in the cask, **one third more hopping** is absolutely necessary.”

1796

- “Put some hops in your ale and small beer casks a few days before you want to tap them for use; **even those hops that have already been used in brewing will be found serviceable** in fining your beer and will not cause it to be too bitter, but will **prevent your small beer from becoming sour.** Notwithstanding their being used in brewing, they will be found by experience to be very serviceable for the purpose mentioned.”E. Hughes

1821

- It is well known that other things being equal, **the liquor keeps in proportion to the quantity of hops**. Fresh beer may have from a pound to a pound and a half to a barrel of 32 gallons, June beer two pounds and a half, beer for the month of August three pounds and for a second summer three and an half. **For India voyages, four pounds.**
- The first American edition of Andrew Ure’s *Dictionary of Chemistry*

1835

- William Chadwick suggested reserving a portion of hops for use in the cask. “They will be found to contribute the **delightful smell and fine flavour** of the hop, much more perfectly than those hops which have undergone a long boiling, and they will equally contribute to the preservation of the beer and prevent any **after-fretting that might arise**,”
- *A Practical Treatise on Brewing*

https://zythophile.wordpress.com/2010/03/29/the-first-ever-reference-to-ipa/

Since when do we dry hop ?

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1890

- It is calculated that since 1880 the decrease in the use of hops for brewing and " *dry hopping* " amounts to at least **one pound** of hops per barrel of beer. **Light beer and quick draught** are the order of the present day

1893

- .. are now in position to ascertain **how far the sugars of the hop** are accountable for the after-fermentation induced of *dry hopping*. If we consider that the brewer uses from a **half to three-quarters of a pound of dry hops** per barrel,

1894

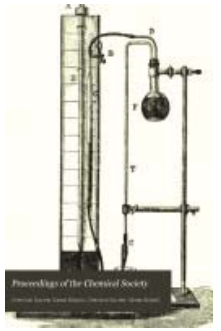
- , to discover the explanation of the conditioning effect of "*dry-hopping*," i.e., the addition to finished beer of a small amount of dry hops. This was ultimately traced to the presence in the **hop-strobiles of a small but appreciable amount of diastase** ...

1898

- **It is a simple matter for brewers to waste large amounts of money in the purchaseof unsuitable hops, and I would suggest that more mistakes are made over purchasing this material for *dry hopping* than for use in the copper.** Frank Thatcher


THEORY AND PRACTICE
MODERN BREWING.
APPENDIX,
FRANK FAULKNER.
THEORY AND PRACTICE
MODERN BREWING.
APPENDIX,
FRANK FAULKNER.


BREWING & MALTING
PRACTICALLY CONSIDERED.
FRANK THATCHER.


Proceedings of the Chemical Society

The Germans and Dry hopping

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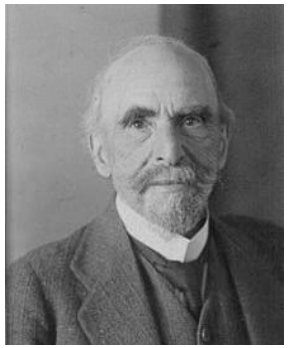

- In China the way of adding the hops is rather close to what is done in Middle Europe, especially in the United Kingdom and what is called „Hopfenstopfen“ (dry hopping)“ 1901, Dry hopped beers of the „Tarasuns“ in Manchuria 2000 years ago, 1914
- Higher amounts of essiential oils added in the lager tank can cause irritation of the nerves and the digestive system. This might be in context with some headache or restlessness experienced after extensive beer consumption, 1901
- „Hopfenstopfen“ is time consuming end expensive and needs a strict control to avoid overdosing, therefore the use of hop oil should be the preferred option, 1901

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Hop Oil Components

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➢ Substance groups and their concentrations in hop oil

(Hopfen- vom Anbau bis zum Einsatz in Bier, Hans Carl Verlag)

Substance Group	Concentration
Monoterpenes	approx. 40 %
Sesquiterpenes	approx. 40 %
Carbonacid-esters	approx. 15 %
Carbonacids	approx. 1 %
Monoterpenoxides	approx. 1 %
Sesquiterpenoxides	approx. 1 %
Aldehydes, Ketones	approx.1 %
Aliphatic hydrocarbons	< 1 %
Sulfur containing compounds	< 0,1 %
Glycosidically bound aroma compounds	?

Sensory relevant hop aroma compounds

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Compound	Aroma description	Threshold µg/l
4-Mercapto-4-methyl-pentane-2-one	muscat grape, blackcurrant	0.002
b-Damascenone	apple, peach, fruity	0.02
3-Mercapto-4-methylpentan-2-ol	rhubarb, grapefruit	0.07
(E,Z)-2,6-Nonadienal	cucumber, green	0.5
b-Ionone	floral, violet, berries	0.6
Ethyl-4-methylpentanoate	citrus, pineapple	1 – 18
Ethyl-2-methylbutanoate	citrus, apple	1.1 – 45
Linalool	lavender, floral	2 – 80
Ethyl-3-methylbutanoate	citrus, apple	2
Geraniol	floral, rose	4 – 300
Ethyl-2-methylpropanoate	citrus, pineapple	6.3 – 164
b-Citronellol	lime, lychee	9 – 40
Myrcene	herbal, resinous, green	9 – 1000
Humulene epoxide I	hay	10*
(Z)-3-Hexenal	green, leaves	20
4-(4-Hydroxyphenyl)-2-butanone	citrus, raspberry	21.2
Nerol	floral, lime, citrus	80 – 500
Humulenol II	pineapple, mugwort	150 – 2500
b-Caryophyllene	cedar, spicy, cloves	160 – 420
a-Terpineol	lilac, resinous, rose	330
1-Hexanal	green, leaves	350
Limonene	citrus, green	1493
Humulene epoxide II	cedar, lime	450
Humulene	floral, grassy	747
Humuladienone	-	100
Geranyl isobutyrate	-	450
Farnesene	-	550
Eudesmol	-	10000

Threshold Interaction

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µg/l	Linalool	Geraniol	Humulen	Caryo.	Nerol	Terp.	Myr.	Far.
Linalool	27	104[a]; 133[b]						493[c]
Geraniol	104[a]; 133[b]	90						2304 [d]
Humulene			3483	4346[e]	1843[f]	5668 [g]		
Beta-Caryophyllene			4346[e]	239	147[h]	1297[i]		
Nerol			1843[f]	147[h]	1206	2699[j]		
Alpha-Terpineol			5668[g]	1297[i]	2699[j]	1076		
Myrcene							119	
Farnesene	493[c]	2304[d]						2020

Single components
Synergism
additive
masking

Hanke 2009

Hop oil composition of different hops

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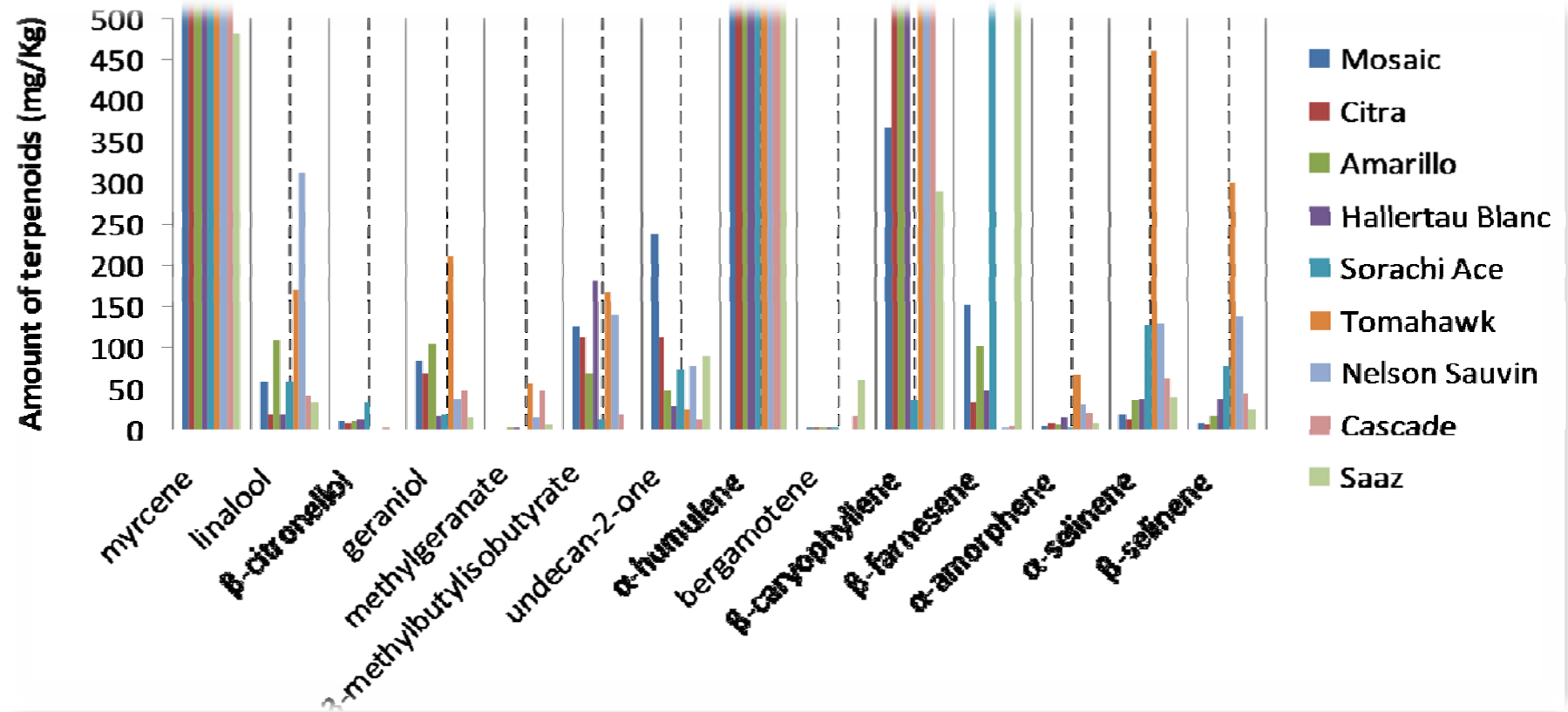

floral, lemon, sweet, citrus, resin, tea | spicy, woody, herbs

500-4000 ppm

- *Gros J., Nizet S., Collin S.; J. Agric. Food Chem. 2011, 59, 8853–8865.*
- *Kankolongo C. M-L., Gros J., Nizet S., Collin S., J. Agric. Food Chem. 2015, 63, 3022−3030.*

Kankolongo Cibaka, EBC 2015

Monoterpene composition of hops

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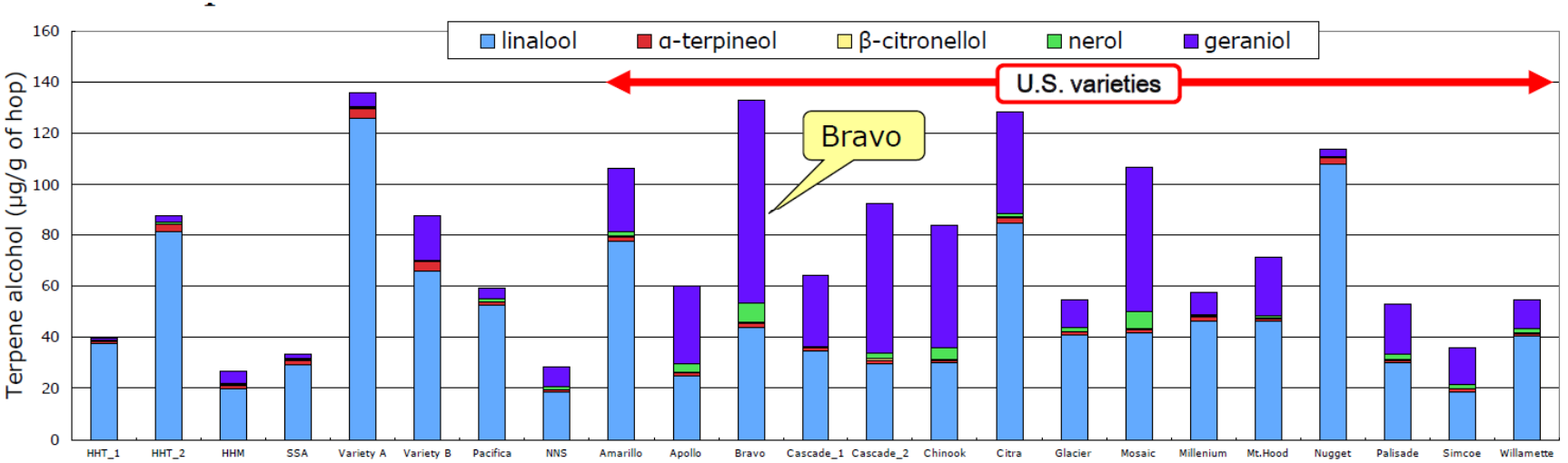

Figure 3. Comparison of monoterpene alcohol compositions in various hops: 2007 crop (HHT_1, HHM, Variety A, Variety B, Pacifica, NNS, Cascade_1, Citra, Millennium and Nugget); 2008 crop (Amarillo, Apollo, Bravo, Cascade_2, Chinook, HBC369, Glacier, Mt. Hood, Palisade, Simcoe and Willamette); 2009 crop (HHT_2 and SSA).

Takoi, 2012 WBC

Our Hop Aroma Vocabulary

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Descriptors	More detailled attributes
Menthol	Peppermint, melissa, sage, metallic, camphor
Tea	Green tea, camomile, black tea
Green Fruits	Pear, quince, apple, gooseberry, enteric, cognac oil
Citrus	Grapefruit, orange, lime, lemon, bergamot, lemongrass, ginger
Green	Green grass, tomato leaf, bell pepper
Vegetable	Selerie, leek, onion, artichoke, garlic
Cream/Caramel	Butter, chocolate, yoghurt, gingerbread, honey, cream, caramel, toffee, coffee
Woody/ Aromatic	Tobacco, cognac, woody barique, leather, tonka bean, sweet woodruff, resinous, incense, myrrh, resinous
Spicy/Herbal	Maggie, black pepper, chillies, curry, juniper berry, marjoram, estragon, dill, lavender, anis, liquorice, fennel
Red Berries	Cassis, blueberry, raspberry, blackberry, strawberry
Sweet Fruits	Banana, water melon, honeydew melon, peach, apricot, passion fruit, leeches, dried fruits, plum, pineapple, white jelly baby
Floral	Elder, camomile flower, muguet, jasmine, apple blossom, rose, geranium

Parameters important for dry hopping

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- Variety (s); crop year; growing region, post harvest handling, processing (pellet type)

- Presence of yeast, yeast strain, contact time
- Movement in tank, tank geometry

- Cones or pellets (or extracts)
- Composition and temp. of medium (beer; water etc.)

- Removing the hops (centrifuge; filtration; sedimentation)
- Pasteurization
- Bottling (oxygen pick up, crown compound material)
- Temperature of storage

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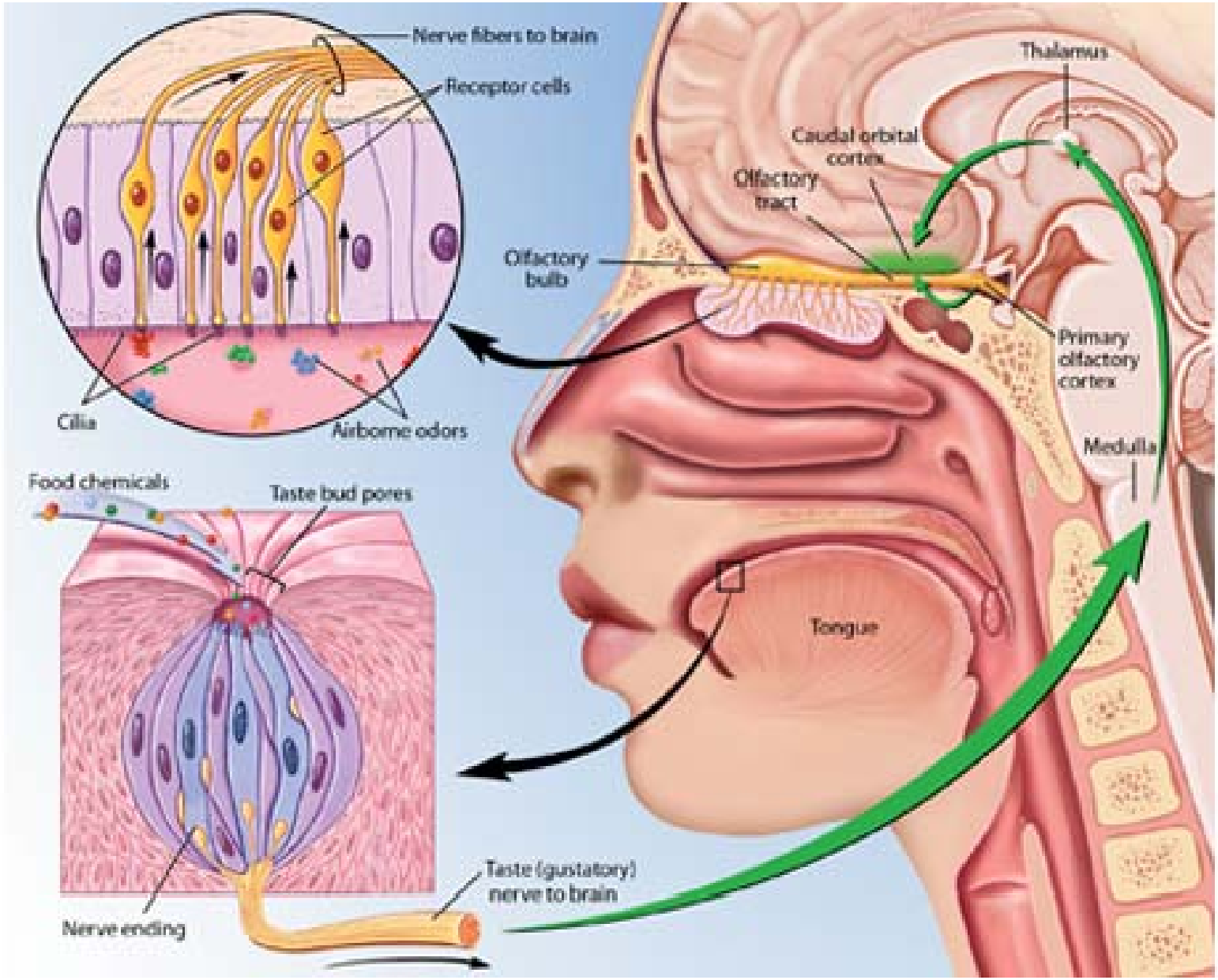

How do we smell and taste ?

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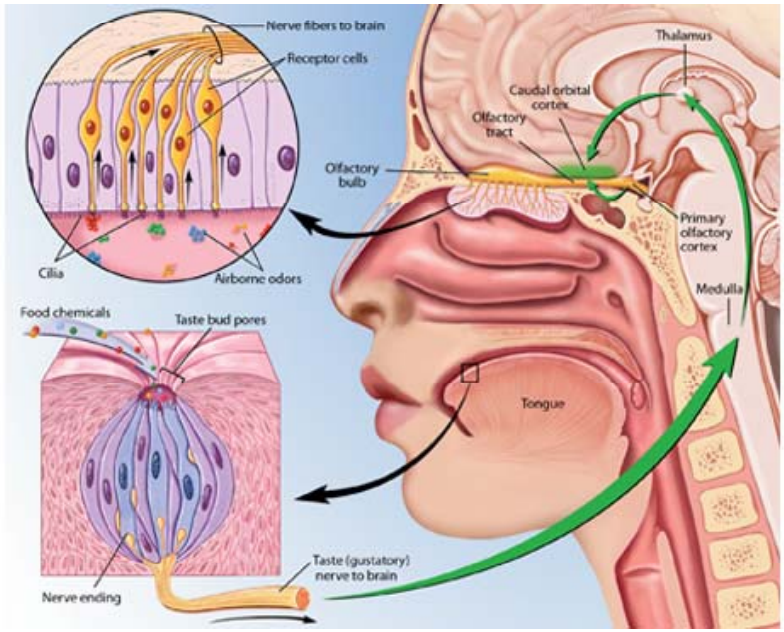
- Mol. Weight
- Lipid solubility
- Polarity
- Osmophore groups
- Mucosa solubility



Olfactory System :

- 400 types of odorant receptors (OR)
- translate external chemical stimuli into internal information that can be processed by neural circuits
- relationship between the number of odorants that we can discriminate and the number of receptors that we have is unclear
- Smell and emotion are just one synapse apart
- We breath (and smell) 15-30 000 times a day
- Olfaction is in context with objects (tough verbalisation) and emotions

Retronasal System plus Trigeminale System

How do we smell and taste

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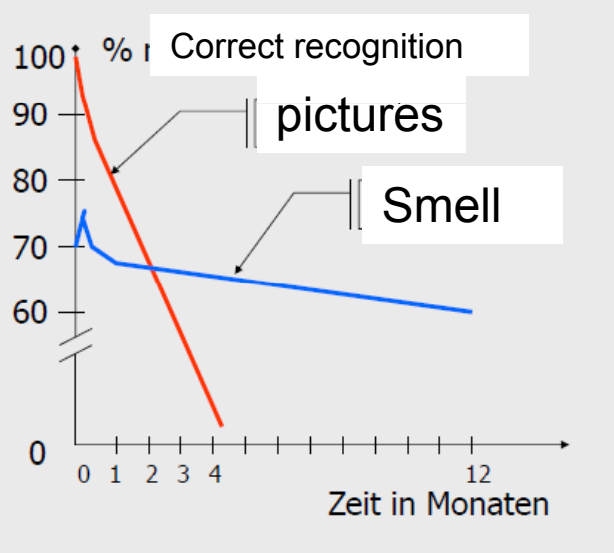
- Olfactation and Memory
- Odors can relax, decrease/increase concentration etc.
- Est. 1 trillion of odors that can be discriminated (Nature 2014)
- A mixture of 2 components is only correctly identified by 12 % of tasters
- A mixture of 5 components is only correctly identified by 0,5 % of tasters (80% can identify prevailing component)



Is there something like aroma activity?

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Aroma activity value = $\frac{\text{concentration of compound}}{\text{threshold value}}$

- Threshold values of volatiles have a high standard deviation
- There is no linear context for aroma activity
- Every threshold is influenced by another –don‘t believe in thresholds
- Additive, masking, synergistic, adaption, saturation effects change perception
- Quality of aroma changes according to configuration, concentration, individual perception, and matrix of the food…and emotions
- In mixtures with more than four components, odorants lose individuality and produce a new odor percept conveying a unique odor quality not elicited by the single components.
- Only few labs are in the position to measure relevant hop oil compenents in beer

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Questions about dry hopping

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Aroma

- Key flavour compounds ?
- Correlation sensory categories and compounds ?
- What do we know about thiols ?
- Harvest date and flavour
- Hops processing

Brewing

- What does the yeast ?
- Move the beer
- Oxygen and temperature
- Other things ?

- Take home message ?

Possible Key Odorants in dry hopped beers

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Key odorants in dh beers ?
Myrcene
Linalool
Geraniol
Citronellol
alpha-Terpineol
Limonene
Linalool oxide
Geranyl acetate
Methylgeranate
ß-Damascenone, beta-Ionone 2- Undecanone
3 Methylbutyl-2-methylproanoate
2-Methylbutyl-2-Methylproanoate
2-Methylbutyl-2-Methylbutanoate
2-Methylbutyl-3-Methylbutanoate
Ethylbutanoate, -hexanoate etc.
3MH
3MHA
3M4MP
4MMP
3MOal

Key odorants from other beverages	
Phenylethyl Acetat	spirits
Methylbutyl Acetat	spirits
Delta-nonalactone	spirits
cis-rose oxide (from geranyl-diol)	wine
4MMP	wine
Limonene	orange/grapefruit juice
Linalool	orange/grapefruit juice
Myrcene	orange/grapefruit juice
Pinene	orange/grapefruit juice/apple
3-Hexenal	orange/grapefruit juice
1-p-mentene-8-thiol	orange/grapefruit juice
ethyl 2- and 3 methylbuatonate	apple
ß-damascenone	apple
2,5-dimethy-4-hydroxy-3(2H)furanone	strawberry
1,3,5-undecatriene	pineapple
2-methyl-3-mercaptopropanoate	pineapple

And how they fit into sensory description

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Descriptors	Possible key compounds of dry hopped beers
Menthol	
Tea	Linalool
Green Fruits	Beta-damascenone, esters
Citrus	Limonene, linalool, myrcene, ethyl-2-methylbutanoate, α-pinene 3M4MP, 3MHA
Green	Cystein conjugates
Vegetable	Polyfunctional thios
Cream/Caramel	Lactones, vanillin
Woody/ Aromatic	Oxygenated sesquiterpenoids
Spicy/Herbal	Oxygenated sesquiterpenoids – aldehydes, ketones
Red Berries	4MMP
Sweet Fruits	3MH, 3MOal, esters..
Floral	Geraniol, Citronellol

24

Geraniol – the underestimated aroma compound?

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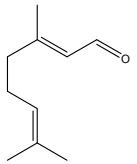
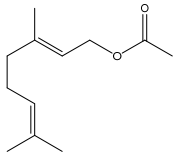
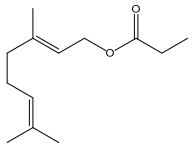
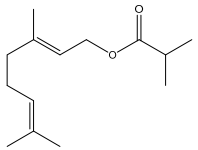
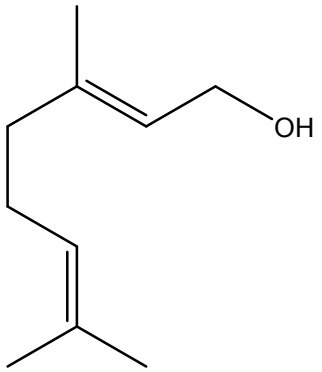
µg/g		A	B	C	D
geranial		10	4	6	4
geranyl acetate		22	< 1	102	17
geranyl propionate		4	< 1	29	25
geranyl isobutyrate		1	3	8	7
"geraniol potential"		38	7	145	53
geraniol		108	14	68	49
linalool		32	80	57	44



data Rettberg 2014, further reading: Takoi et al, J. Inst. Brew. 116(3), 251–260, 2010

Linalool

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- Is a good marker compound in kettle/late hopped beer
- contributes to the aroma of late hopped beers
- Linalool conc. are rather stable in final beer
- R/S linalool
- Not a key aroma compound in dry hopped beer
- Importance overrated (Peacock, MBAA 2010)

Results of organoleptic evaluation and preference of beer samples (Takoi 2011)

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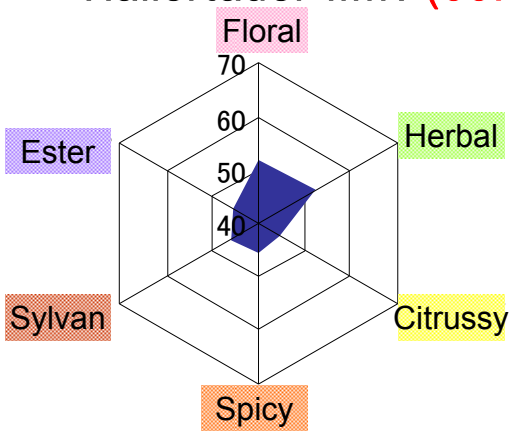
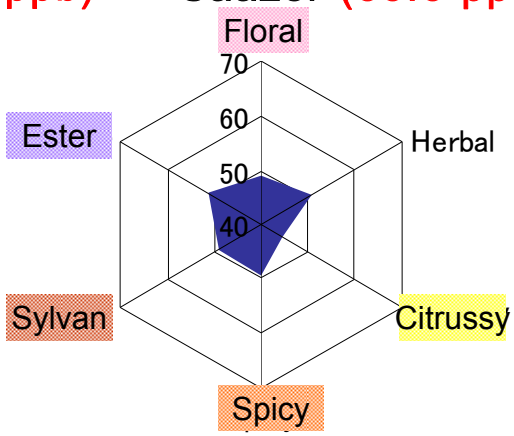
***The concentration of Linalool in beer**

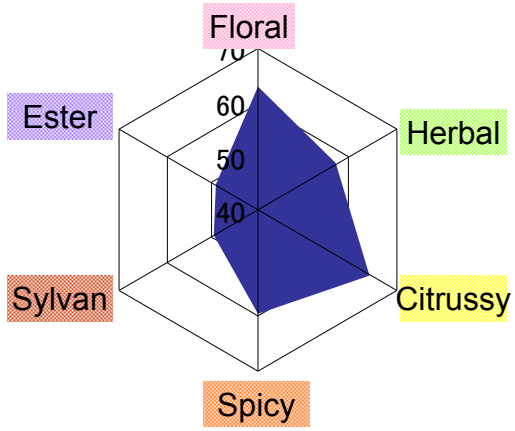
Hallertauer Mfr. (33.6 ppb)*



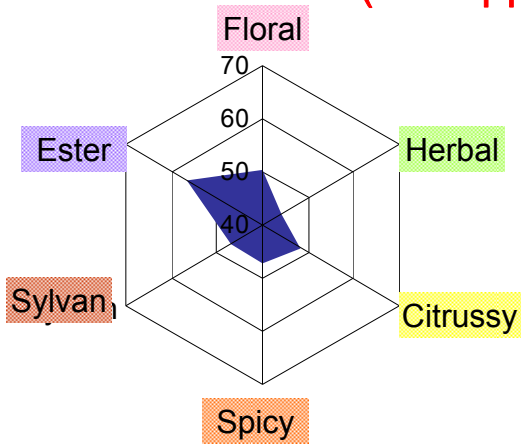
Saazer (33.3 ppb)*



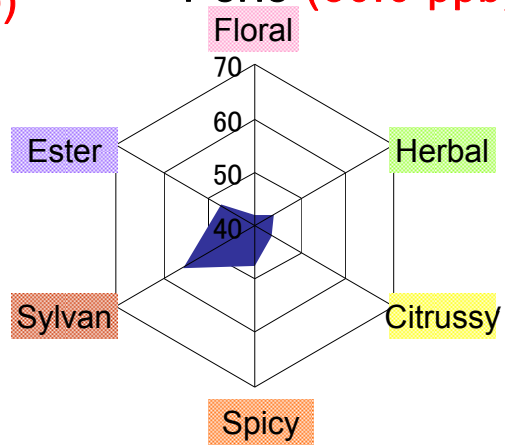
Cascade (32.5 ppb)*



Tradition (33.7 ppb)*



Perle (30.0 ppb)*



Thiols -the good, the bad and the ugly…

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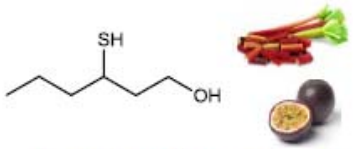
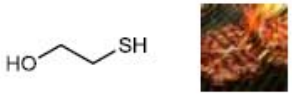
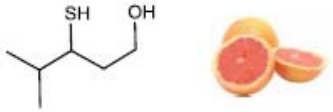


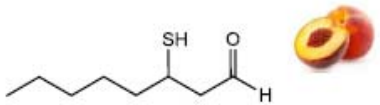
3-sulfanylhexan-1-ol
3SHol



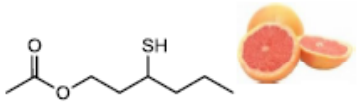
2-sulfanylethan-1-ol
2SEol



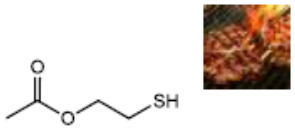
3-sulfanyl-4-methylpentan-1-ol
3S4MPol



3-sulfanyloctanal
3SOal

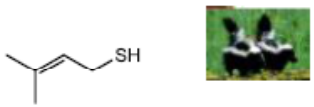


3-sulfanylhexyl acetate
3SHA



2-sulfanylethyl acetate
2SEA

4-sulfanyl-4-methylpentan-2-one
4S4M2Pone



3-methyl-2-buten-1-thiol
MBT

- **Pleasant bound thiols**

  → **late kettle hopping**: e.g.
  - Amarillo (Cys-3SPol, Cys-3SHol)
  - Citra (Cys-3SHol)
  - Hallertau Blanc (Cys-3S4MPol)
  - Sorachi Ace (Cys-3SHol)
  - Nelson Sauvin (Cys-3SPol, Cys-4S4M2Pone)

- **Free terpenoids and free thiols (+ bound thiols)**

  → **dry hopping**: e.g.
  - Citra (3SHA, 3SHol)
  - Mosaic (4S4M2Pone, 3S4MPol)
  - Hallertau Blanc (3S4MPol)

Threshold : 0.1 – 60 ng/L

1 drop in 200x
Olympic-size pools

Team of Prof. Collin, EBC 2015 and EBC 2013

Thiols-the good, the bad and the ugly…

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substance		
Name	Acronym	Odor (GC-O)
2-sulfanylethan-1-ol	2SEol	grilled
3-methyl-2-buten-1-thiol	MBT	coffee, skunky
3-sulfanylpropan-1-ol	3SProl	pop corn
2-sulfanylethyl acetate	2SEA	toasted, grilled
4-sulfanyl-4-methylpentan-2-one	4S4M2Pone	catty, blackcurrant
3-sulfanyl-3-methylbutan-1-ol	3S3MBol	sulfur, soup
1-sulfanyl-3-pentan-1-ol*	1S3Pol	nettle
3-sulfanylhexyl acetate	3SHA	Passion, grapefruit
3-sulfanylpropyl acetate	3SPrA	grilled
3-sulfanylhexan-1-ol	3SHol	grapefruit/rhubarb
3-sulfanylheptanal*	3SHptal	lemon, candy
3-sulfanyl-2-ethylpropyl acetate*	3S2EPrA	floral, vinegar
3-sulfanyl-4-methylpentan-1-ol*	3S4MPol	grapefruit
3-sulfanylheptan-1-ol*	3SHptol	lemon, hoppy
3-sulfanyloctanal*	3SOal	citrus, peach
3-sulfanyloctan-1-ol*	3SOol	catty, grapefruit
Total		

Onion, burnt, rubber, cat urine ⟷ **grapefruit, rhubarb, black currant, muscat, ribes, grapes**

depending on configuration, concentration, interaction and perception

bad ⟷ good

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Influence of harvest time and location on sensory profile; cones vs. pellets

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- Increases in oil quantity correlate with a-pinene, b-pinene, myrcene, limonene, methyl-heptonoate, and linalool (Shellhammer et al 2013).
- Beers brewed with typical harvested Cascade hops were significantly distinguishable in sensory analysis and preferred by consumers over late harvested hops (Shellhammer et al, 2013)
- Beers dry hopped with Mittelfrüh harvested late were preferred over beers with normal Mittelfrüh (Bailey et al, 2009)
- Beers hopped with same variety from different hop garden were significantly different (Bailey et al, 2009)
- Dry hopping with pelletized more rapid extraction higher concentration of hop aroma compounds compared to dry hopping with cones (higher polyphenol content) (Wolfe, 2011, Mitter 2012)

Sensory impact of pelletization..

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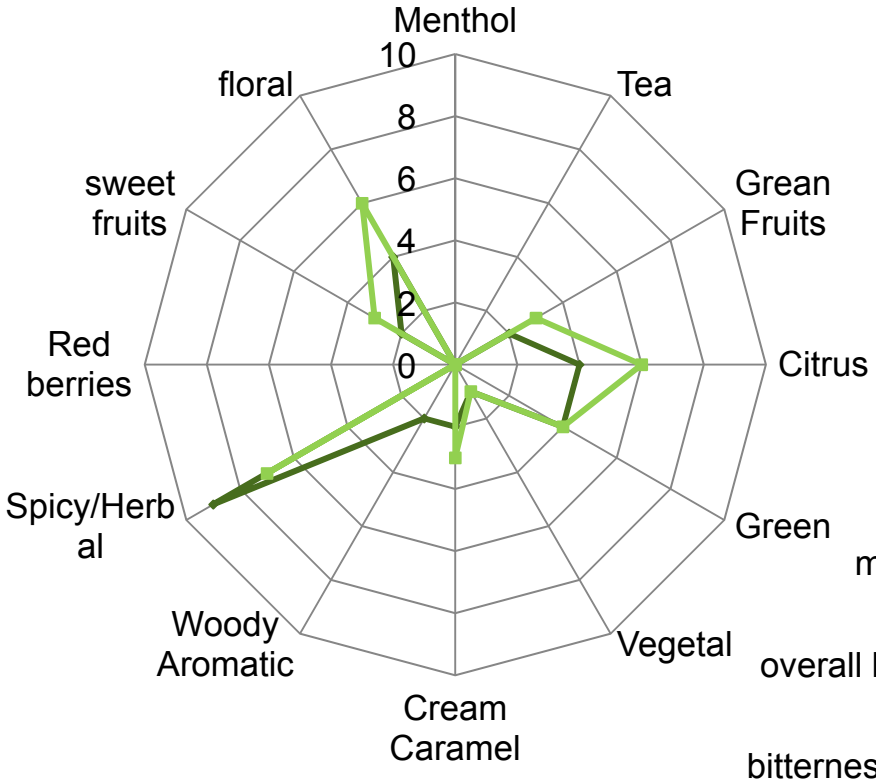
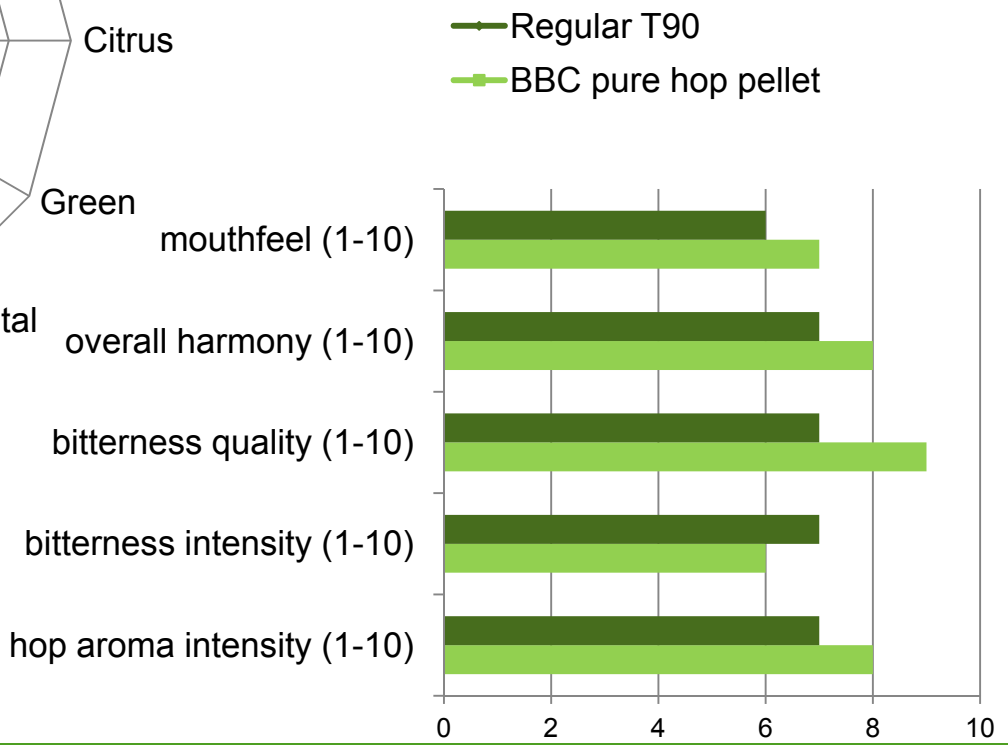


Lager Beer late and dry hopped
with different pellets of Hallertau Mittelfrüh
according to the same hop oil content



Extraction time

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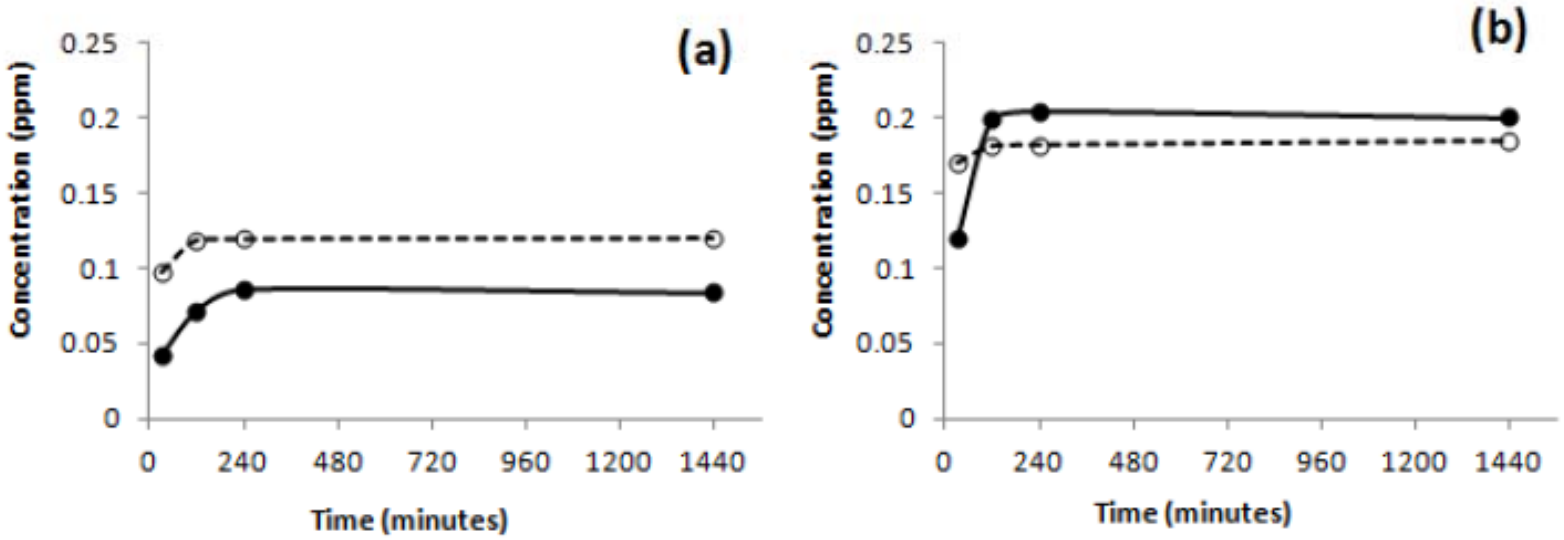

Figure 7. Myrcene (a) and humulene (b) concentrations during a 24 hour dry hop treatment with pellets (--o--) or whole cone hops (—●—).

Wolfe, Shellhammer 2011

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Extraction time

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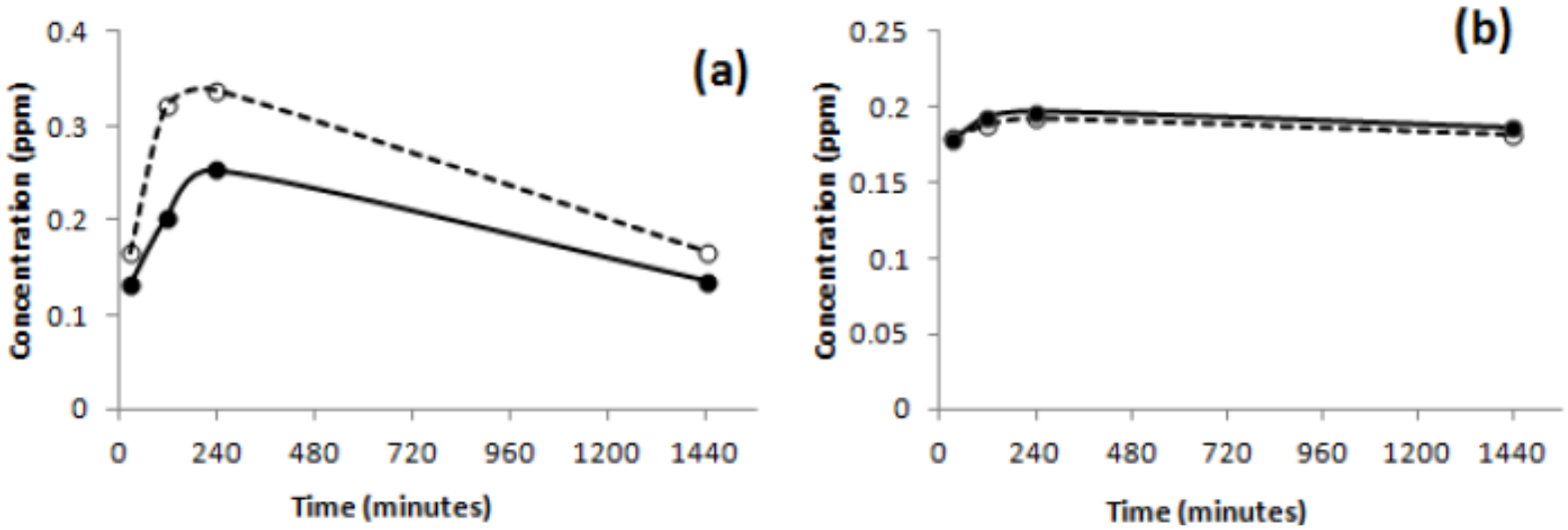

Figure 8. Linalool (a) and geraniol (b) concentrations during a 24 hour dry hop treatment with pellets (--o--) or whole cone hops (—●—).

Wolfe, Shellhammer 2011

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Questions about dry hopping

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Aroma

- Key flavour compounds ?
- Correlation sensory categories and compounds ?
- What do we know about thiols ?
- Harvest date and flavour
- Hops processing

Brewing

- What does the yeast ?
- Move the beer
- Oxygen and temperature
- Other things ?

- Take home message ?

What do we know about the yeast ?

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biotransformation by yeast or reactions triggered by beer pH

- glycosidically bound aroma precursors are released
- acids are converted into (ethyl) esters
- esters are trans-esterified or hydrolysed
- monoterpene alcohols isomerize
- carbonyl compounds, epoxides, and ethers are reduced to alcohols / diols

some odorants are efficiently removed (during fermentation)

- binding / adsorption of on biomass (hydrocarbons > terpenoids)
- stripping of volatiles

(Rettberg, personal conversation)

What do we know about the yeast ?

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- The presence of yeast decreased the aroma and flavour intensities of floral, citrus and fruity characters, also decrease in concentration of measured aroma components (Schönberger)
- Decrease of myrcene, geraniol and citronellol with yeast (Ruehle, YSS 2014)
- Influence of yeast strains (same hops) from minor (Sharp 2013) to very destinct (Schönberger, EBC 2015)
- Yeast influences the ester concentration, hop variety dependency (Dresel 2015)
- Except if spicy notes are the target, dry hopping in presence of yeast is damagable for the delicate and noble hoppy touches (peach, apricot, pineapple) (Derdelinckx 2013, ASBC)
- Temperature profile of fermentation effects intensities of hop fruity flavours
- Negative correlation between 1-heptanol and fruity hop flavours (masking effect) (Takemura 2012, WBC)

What is the role of the yeast?

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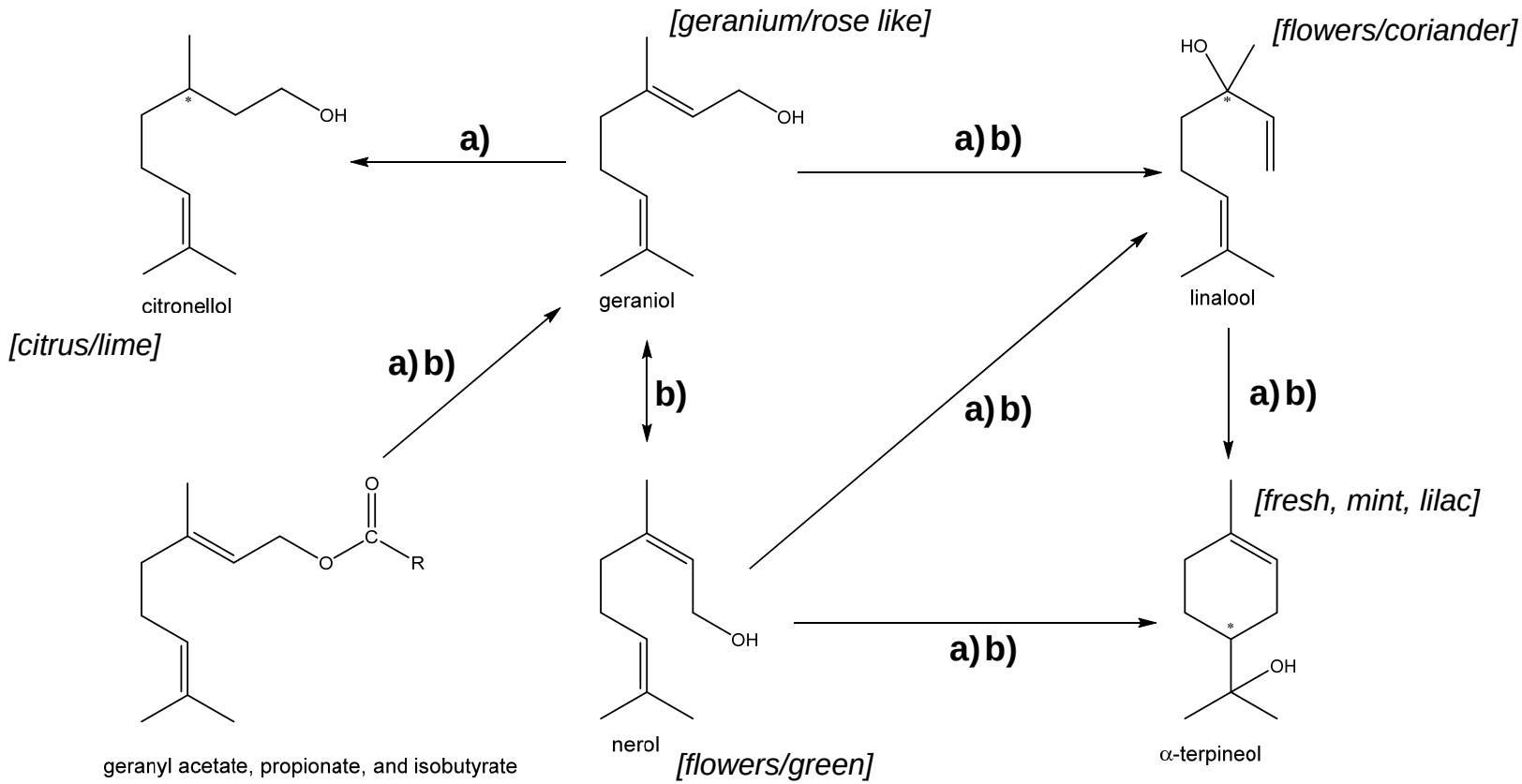
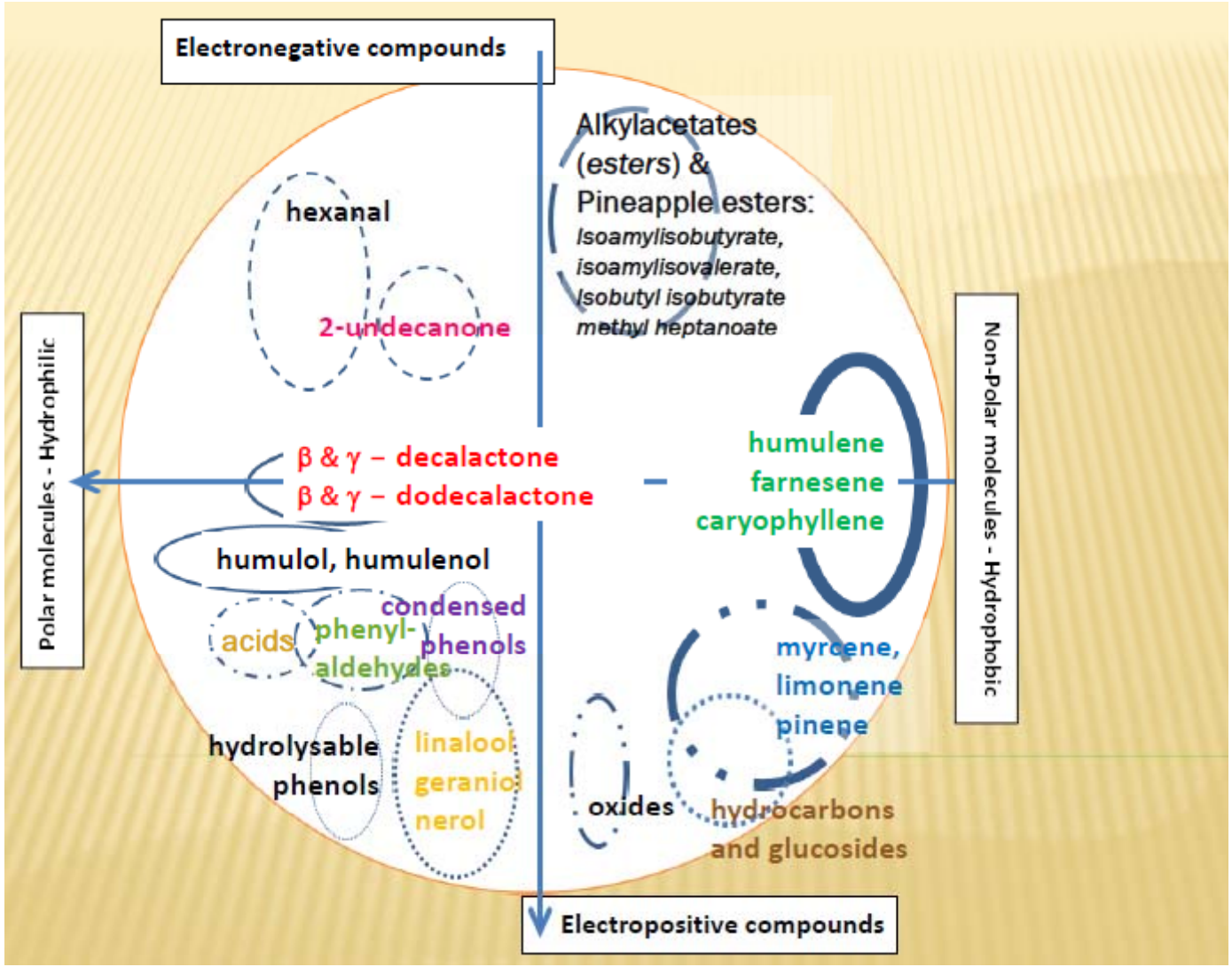


(isomeric) alcohols differ in aroma impression and flavor thresholds

a) enzymatic

b) acid catalysis

King and Dickinson 2002



Derdelinckx, 2013

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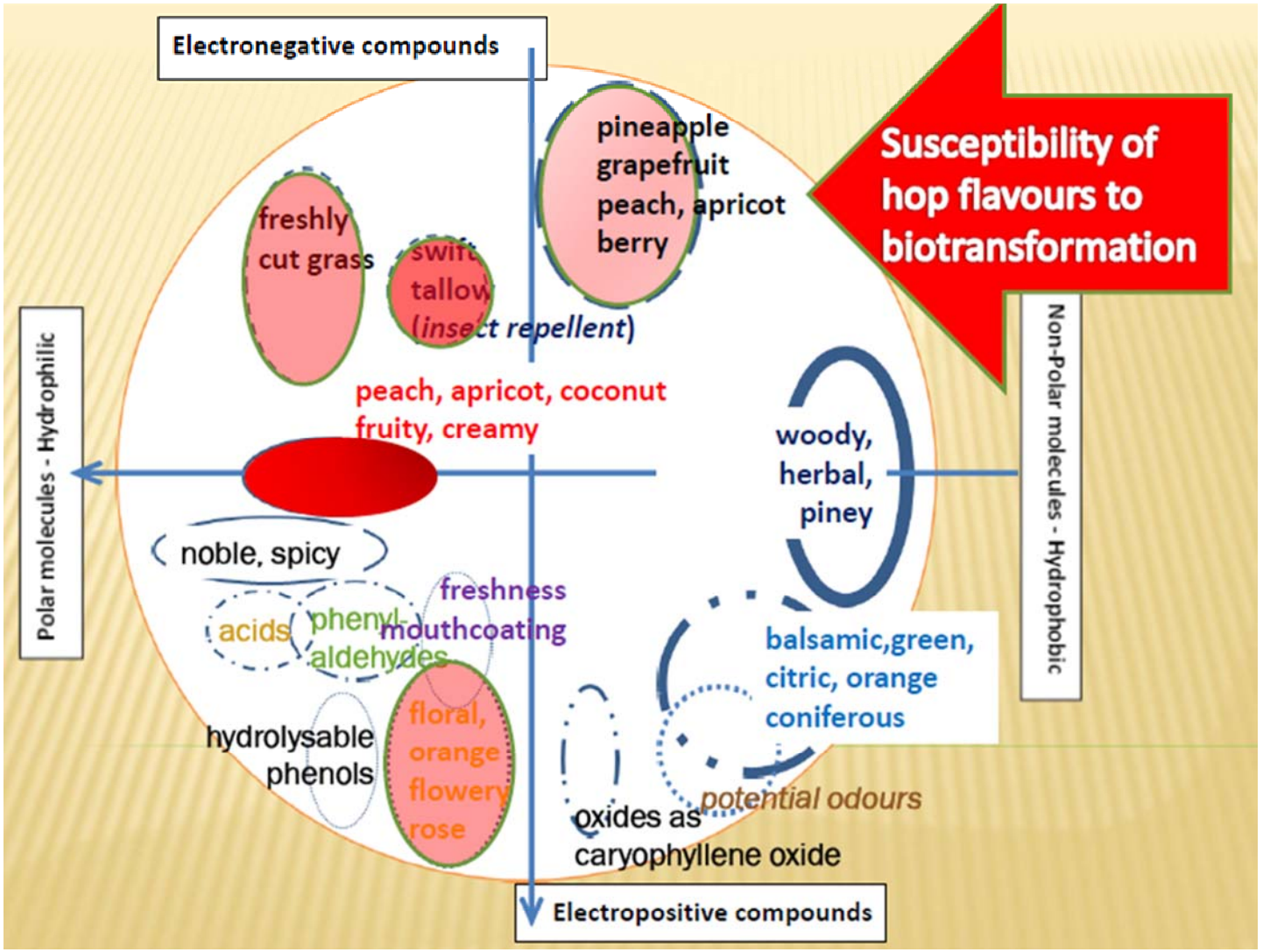

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Esterification

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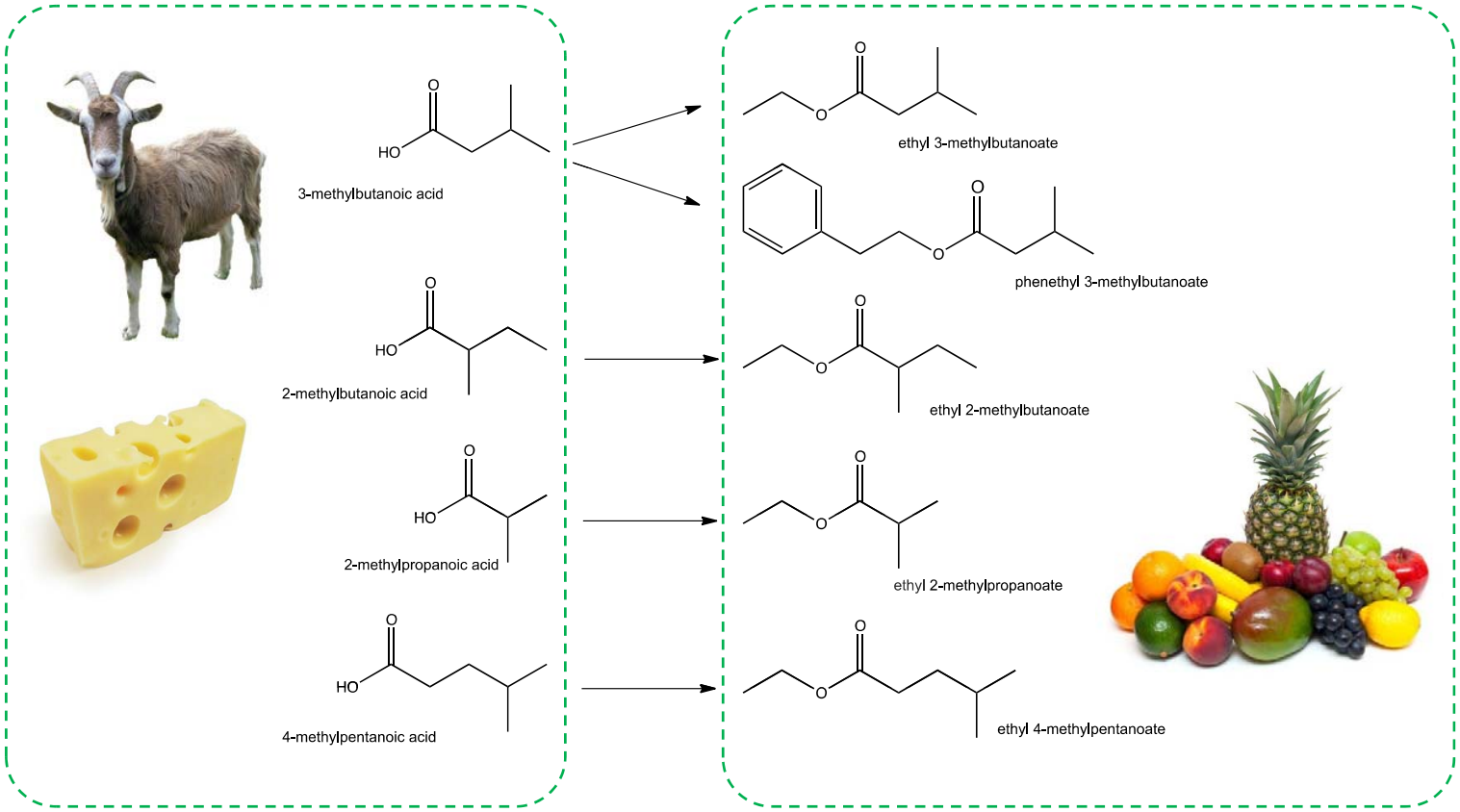

- flavor threshold of acids by factor 100 higher than those of corresponding ester
- Increase in ester concentration with yeast “stress”
- Increase of acids in old hops
- chemical esterification is slow (beer staling)

Kishimoto 2009
Rettberg et al. , BrewingScience 2014

Hydrolysis of bound aroma compounds with enzymes

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	Linalool					Geraniol	
Variety	linalool	(-) terpinene-4-ol	citronellol	nerol	beta-damascenone	geraniol	eugenol
Nelson Sauvin	4.6	1.0	0.3	2.1	0.0	8.7	1.7
Cascade	27.0	0.8	0.3	5.5	0.0	15.3	0.1
Centennial	11.9	4.3	5.3	12.7	0.3	88.7	8.3
Cluster	1.6	0.1	0.0	2.7	-0.1	21.7	2.6
Columbus	82.8	6.6	0.9	16.8	0.2	178.3	5.1
German Spalt	20.4	0.8	1.1	3.6	0.3	18.9	4.0
Hersbrucker	11.1	0.3	0.1	4.5	0.2	36.0	4.2
HHA	15.4	1.1	-0.5	4.7	0.2	39.4	2.6
Horizon	28.1	2.8	0.5	5.2	0.1	21.5	2.8
Magnum	30.2	3.1	2.5	4.1	0.3	17.8	4.5
Northern Brewer	29.5	2.2	-0.1	2.7	-0.1	9.3	0.5
Nugget	45.0	3.3	1.3	3.6	0.2	13.1	2.3
Perle	7.9	-2.2	0.7	4.4	-0.2	46.6	-0.1
Simcoe	27.6	1.4	0.9	8.0	0.2	44.5	2.9
Styrian Aurora	61.4	1.7	0.9	3.0	0.2	22.5	3.9
Summit	39.4	1.4	0.9	5.8	0.1	21.5	-0.1
Tettnang	9.5	0.6	0.0	2.7	0.0	17.8	3.3
Willamette	5.8	0.2	0.1	3.2	0.0	43.8	1.5

Instrumental Results

Δ *delta* = *Treatment - Control*

- Averages of duplicate injections using SBSE
- Centennial & Columbus
- Geraniol & linalool driving instrumental changes

Greater than 30 ppb

Between 10 – 30 ppb

Less than 10 ppb

Shellhammer, 2014, ASBC

Hop derived glycosides found in Cascade and Mt. Hood (Shellhammer)

- 3-methyl butanol glucose (fruity, banana, ethereal)
- Benzyl alcohol glucose
- 2-phenyl ethanol glucose (floral, rose)
- 1-octanol glucose (waxy, green, citrus, orange)
- Vanillin glucose (vanilla)
- Linalool glucose (citrus, orange, floral)
- alpha-terpineol glucose (pine, lilac, citrus, woody, floral)

Murakami et al, 2006, Use of hop glycosides extracted from hop plant parts to flavor malt beverages. US Patent 7,001,638 B2

If yeast is the only difference…

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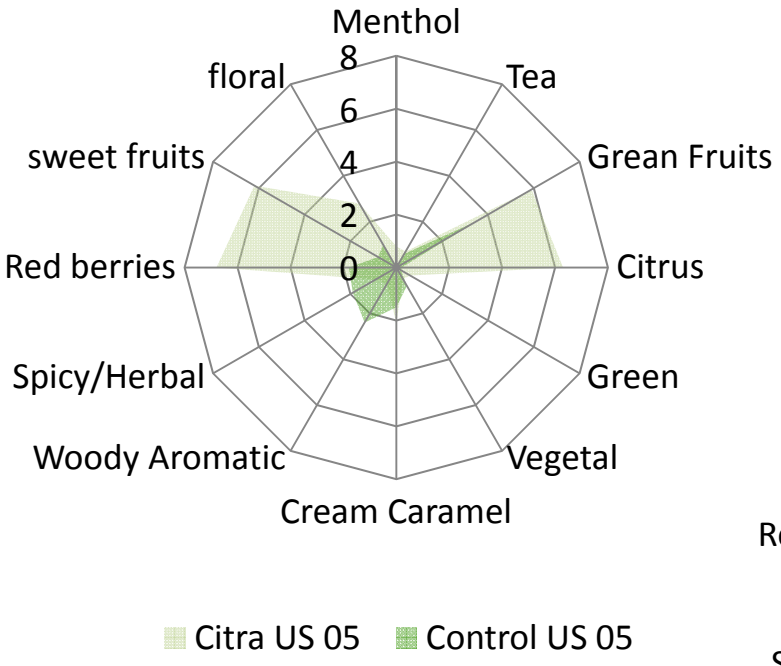

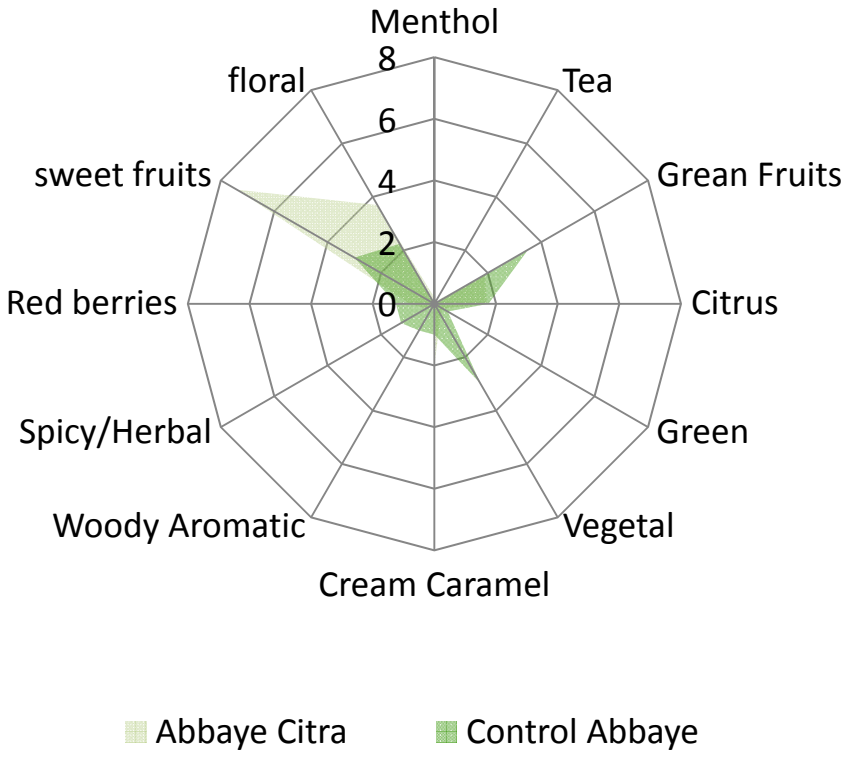

Barth and Fermentis EBC 2015

Dynamic vs. Static Dry Hopping

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- Dynamic dry hopping better aroma extraction (even in comparison to very long static contact time) (Wolfe, 2012)
- Dynamic dry hopping positively correlates with medium size polyphenols (procyanidines, polydatine,polyphenolglycosides)
- A negative correlation for dynamic dry hopping was shown for foam values, decanoic acid (indicates yeast quality) and low molecular carbonic acids (Schönberger, 2015)
- All systems with circular extraction show good efficiency (e.g. Hopgun)

Temperature

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- Higher temperature (8°C vs 0°C) higher concentration of hop aroma components (10-30%) (Schüll, Tech. Seminar 2014)
- Higher temperature (20°C vs 4°C) no influence on linalool extraction efficiency (Mitter et al 2012)
- Not much scientific material
- Higher temperatures, faster extraction, consequences for aroma and flavour stability?

Oxygen; thermal treatment and flavour stability

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- Moderate oxidation possibly benifitial for dry hop aroma (more intense)
- Oxidation produces fruity flavours in hops (Kishimoto, Vollmer 2014)

- Oxygen pick up with cone hops can be x 20 compared with pellets !
- Oxygen impact on polyfunctional thiols – ageing flavours (Tran, EBC 2013)
- Pasteurization decreased the aroma and flavour intensities of floral, citrus and fruity characters (more aroma than flavour)
- Typically hop aroma decreases strongly within 3 months, after that stable
- Decrease of floral and fruit flavour correlates with decrease of geraniol
- Decrease of esters; mono- and sesquiterpenes rel. stable (Forster, EBC)
- Linalool content is very stable

Other facts…

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- Increase of amino acid spectrum by dry hopping (especially L-Asparagine and L-Arginine, (turbidity and bitterness) (Foehr, 2014)
- Increase of polyphenols with dry hopping (turbidity and bitterness) (Foehr, 2014)
- Epicatechin and oligomers B2 and C1 improve shelf-life of beers versus Maillard reactions (ale beers), (Derdelinckx, 2013)
- Any kind of filtration reduces hop aroma
- Influence of crown material
- The more hops you use, the less efficient is the aroma extraction

Stripping

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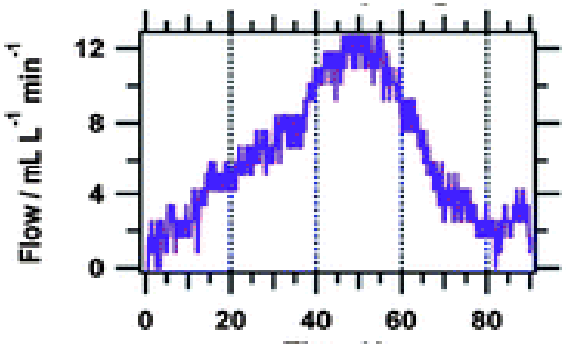
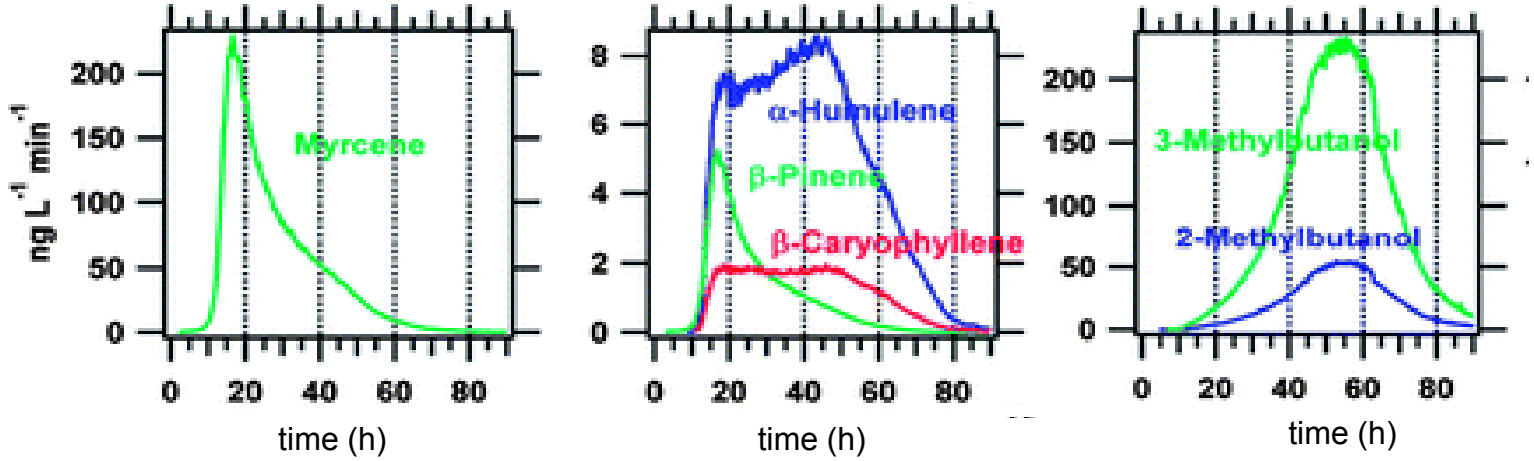
➢volatile + hydrophobic compounds are lost by stripping

carbon dioxide evolution rate



release curves of aroma compounds



Haefliger and Jeckelmann, Anal. Methods, 2013, **5**, 4409-4418

Questions about dry hopping

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Aroma

- Key flavour compounds ?
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- Take home message ?

Summary and take home messages

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- High hopping rates and the need for more efficient dry hopping was a topic already more than 100 years ago
- Also German beers were dry hopped
- Our olfactory/gustatory system is made to discriminate aromas but not to identify them, Dry hop aroma is emotional
- Looking into aroma research it is likely that the aroma of varieties and in dry hopped beers is determined by the individual combination of key hop aroma compounds (most of them we already know)
- The contribution of thiols is being discovered (powerful thresholds!)
- Calculating the sensory importance using thresholds is not helping
- Need for marker components in dry hop aroma that correlate with sensory descriptors

Summary and take home messages

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- **Everything outside of the brewery** has sensory influence, harvest time, location, drying, storage, pellet processing, product form and can be tasted in a dry hopped beer
- **Everything inside of the brewery** has sensory influence, time of dry hopping, number of dry hopping, method of dry hopping, presence of yeast, possibilities for oxygen pick up, centrifugation, filtration, bottling, crown material
- Why calculating transfer rates from hops to beer ?
- Myrcene is up in the air, linalool is the base, geraniol is underestimated
- Dry hopping does only good things for your flavour stability – but characteristic aroma is fragile
- Stable dry hop aroma is an illusion

Thank you for our attention

Thanks to

The teams of Guy Derdelinckx, Filip v. Opstaele (KU Leuven), Tom Shellhammer (OSU), Nils Rettberg (VLB) and Martina Gastl (TUM)

Andreas Gahr (Research brewery St. Johann)

All passionate brewers

www.HopsAcademy.com

www.BarthHaasGroup.com