Considerations of hop quality for both the grower and brewer

Thomas H. Shellhammer
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Brewing Science (and beer-related) at OSU

- **Brewing Chemistry/Engineering** – Tom Shellhammer
- **Brewing Micro/Genetics** – Chris Curtin
- **Pilot Research Brewery** – Jeff Clawson
- **Distillation chemistry** – Paul Hughes
- **Instructor/Advisor** – Glen Li

- **Barley breeding & malting** – Pat Hayes
- **Hops breeding** – Shaun Townsend & John Henning
- **Hops pathology** – Dave Gent
- **Hops & health** – Fred Stevens
- **Beer Economics** – Vic Tremblay
- **Oregon Hops and Beer Archives** – Tia Edmunson-Morten

Exciting times for brewing research and teaching

Exciting times for brewing research and teaching

Trends in American IPA's

Brewers/consumers continually seek something new

- IPA
- Double IPA
- White IPA
- Belgian IPA
- Session IPA

- Brut IPA

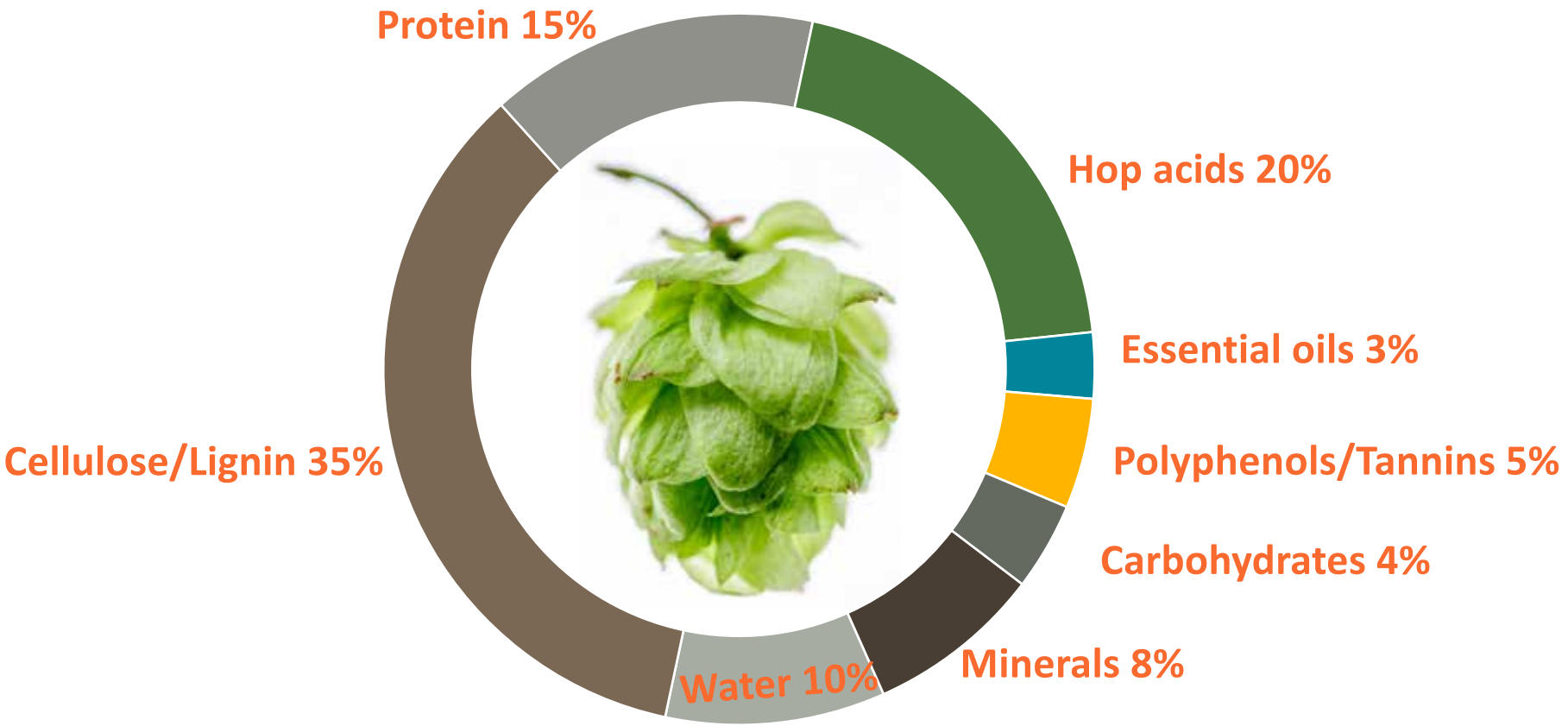
- Hazy/Juicy...NEIPA

Questions to be addressed today

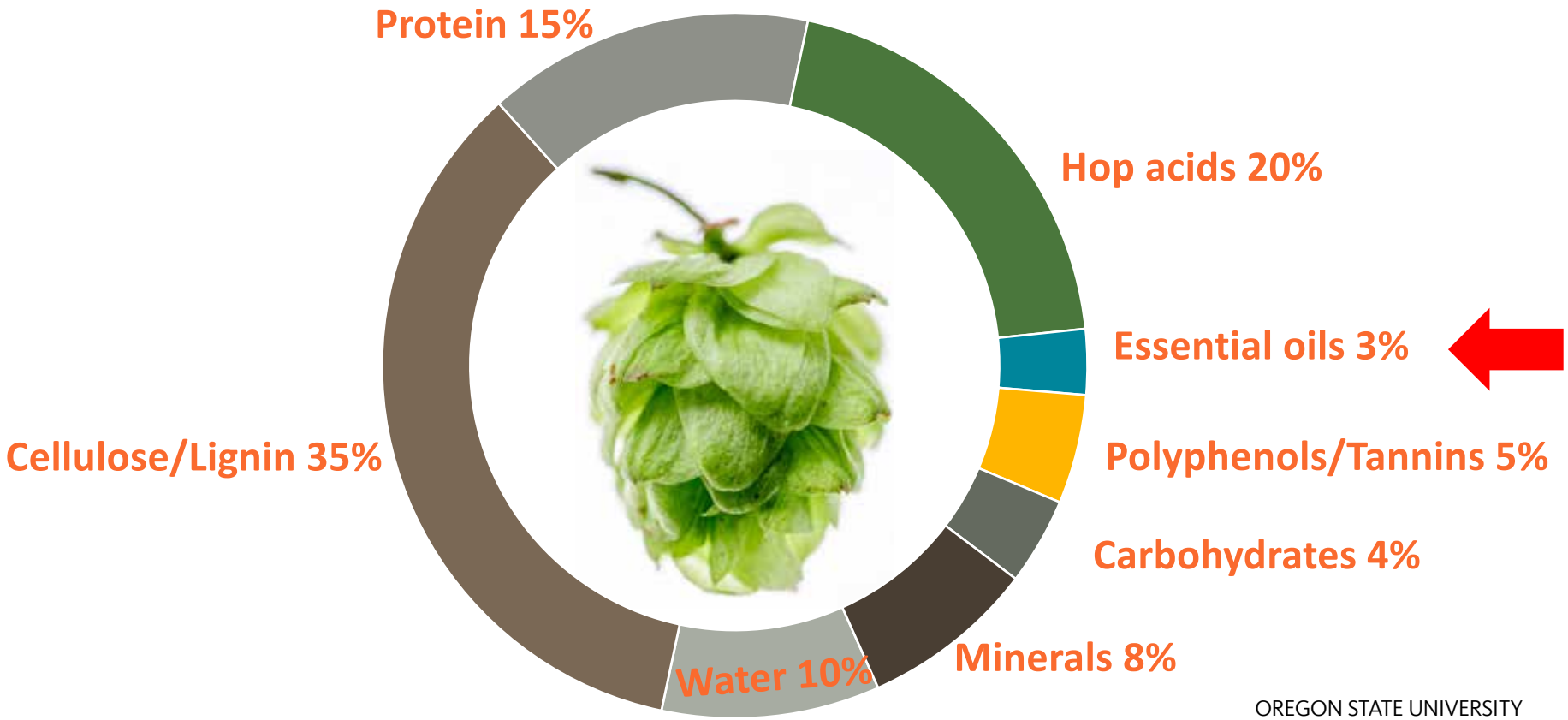
- Do more hops during dry-hopping = more hop aroma in beer?
- How (in)efficient is dry-hopping?
- Does total hop oil content matter when predicting hop aroma intensity?
- How does maturity influence hop chemistry and sensory?
- How does hop kilning temperature impact hop quality?
- Why does dry-hopping increase beer bitterness, in some cases?
- Does the BU work for hop-forward beers?
- What is hop creep and does hop variety matter?
- Does hop creep persist in packaged beers?

What's in hops?

What's in hops?



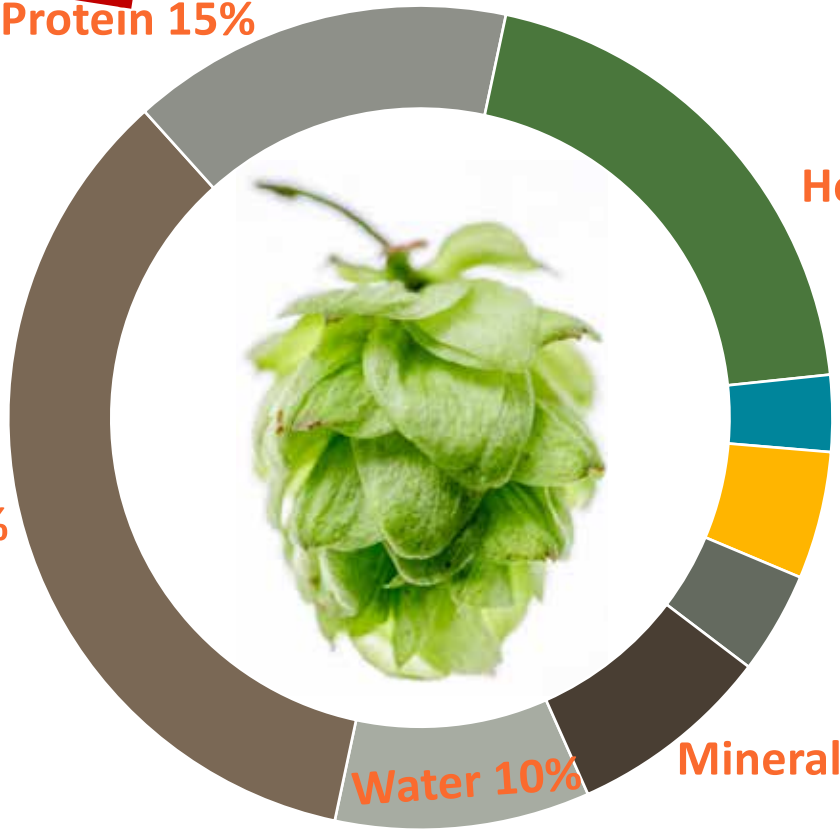
Hop composition – hop aroma



Hop Essential Oil

Major Grouping	Hydrocarbons	Oxygenated Compounds	Sulfur Compounds
Typical Proportion of Hop Essential Oil	~64%	~35%	~1%
Examples	Monoterpenes (Myrcene) Sesquiterpenes (Humulene, Caryophyllene) Aliphatic hydrocarbons	Terpene & (linalool, geraniol) Sesquiterpene alcohols, other alcohols Epoxides, Ketones, Esters	Thioesters Sulfides Thiols Other sulfur compounds
Log K_{ow}	High	Medium	Low
Flavor Threshold in Beer	mg/L to ug/L		ng/L

Hop composition – water extractables



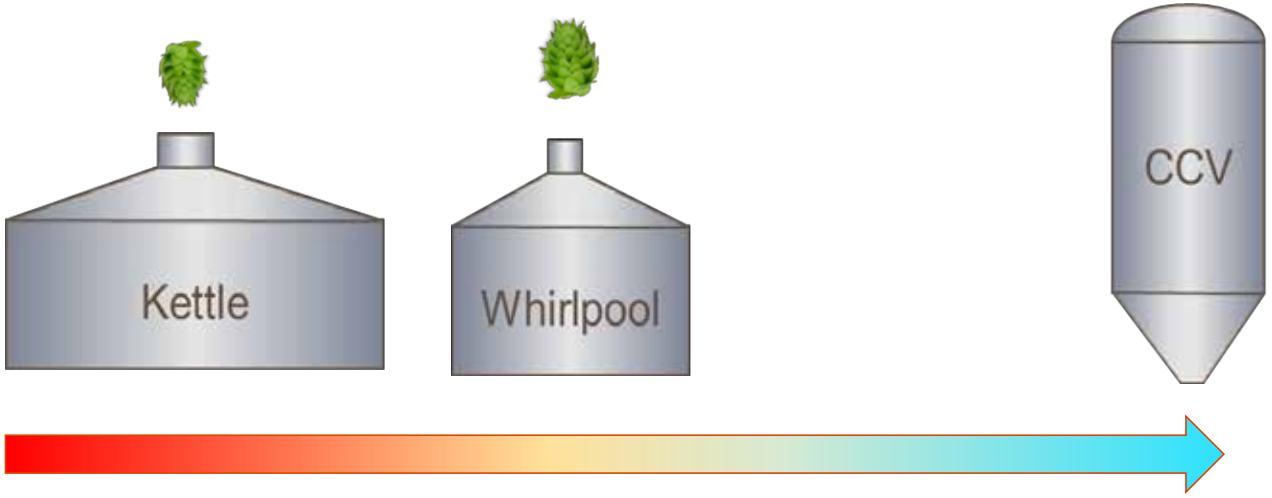
The brewing process: hop dosing time and temperature -A model lager brewery

Hot Side

- Increase: iso-alpha acid utilization
- Decrease volatile aroma compounds

Cold Side

- Decreased iso-alpha acid utilization
- Increase volatile aroma compounds
- Increase in hop aroma



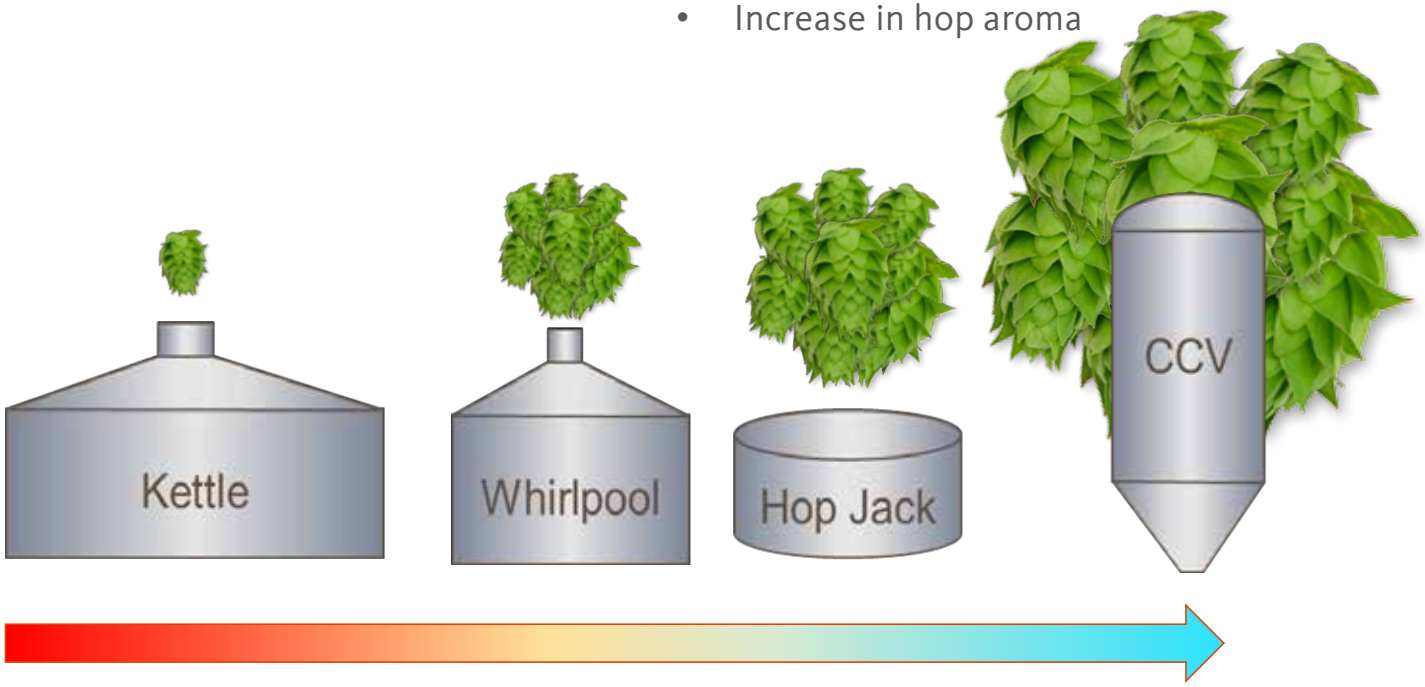
The brewing process: hop dosing time and temperature -A model craft brewery

Hot Side

- Increase: iso-alpha acid utilization
- Decrease volatile aroma compounds

Cold Side

- Decreased iso-alpha acid utilization
- Increase volatile aroma compounds
- Increase in hop aroma



Dr. Scott Lafontaine
Doctoral student (defended Dec 2018)
Oregon State University

GAUGING HOP AROMA INTENSITY IN HOPS

DOES TOTAL OIL CONTENT MATTER?

Oregon State University

Things to consider when dry-hopping on small scale..

- Sample inhomogeneity
- Dissolved oxygen uptake
- Package scalping

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PEER-REVIEWED PAPER

Dry Hopping on a Small Scale: Considerations for Achieving Reproducibility

Daniel M. Vollmer and Thomas H. Shellhammer
Department of Food Science and Technology, Oregon State University, Corvallis, OR 97331, U.S.A.

Hop Preparation and Dry-Hopping Parameters

- Blend brewer's cuts of whole cone hops by grinding

Brewing “unhopped” beer

Beer Specifications:

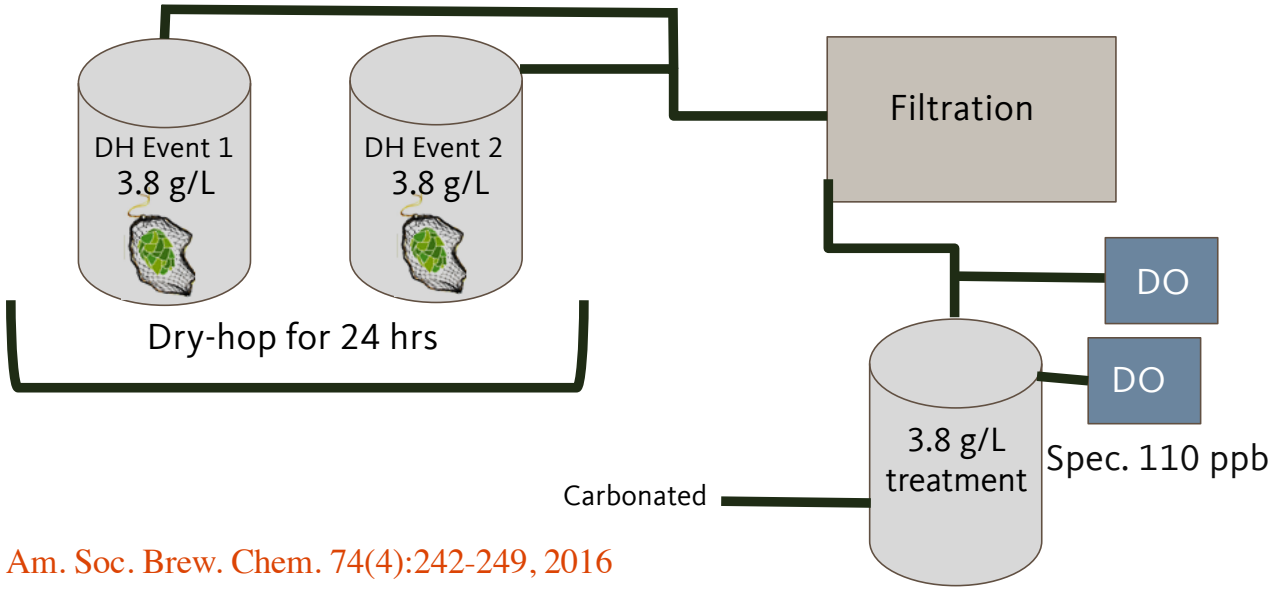
- Grist:
  - 85% Pale 2-row
  - 13.5% Carmel 10L
  - 0.5% Carmel 120L
- **Original Gravity:** 10.6 P
- **Real Extract:** 3.16 P
- **BU** = 20 mg/L (iso-extract)
- **ABV** = 4.8 % ABV

WIDMER BROTHERS BREWING

BRIDGEPORT BREW PUB
Portland OREGON

OSU's current small-scale dry-hopping process

- All dry-hop events occur in duplicate (40 L beer each)
- During filtration 2 kegs are blended during filtration into 1 keg
  - Oxygen monitoring



Vollmer, D. et. al. J. Am. Soc. Brew. Chem. 74(4):242-249, 2016

Evaluations using draft beer

- Minimized total package oxygen
- Great for sensory testing implementation

Sensory evaluation - descriptive analysis

Sensory evaluation – descriptive analysis external controls

	Attributes	Base (No dry hop)	3.8 g/L	16 g/L	Ballast Point Grapefruit Sculpin	Hop Valley Citrus Mistress
Assess Descriptors Based on Aroma Only	**Overall Hop Aroma Intensity**	0	8-9	14-15	14-15	7-8
	Citrus	0	7-8	5-6	13-14	6-7
	Herbal/Tea	0	5-6	12-13	1-2	6-7

- **Panelists came to consensus for attributes on commercial and internally made samples**
- **References were served to panelists at each DA session**

Cascade Hop Selection– 2014 Harvest vs 2015 Harvest

Cascade 2014 Harvest

	Region	Farm (coded)	OSU Hop Oil (ml/100g)
CAS_01_15	WA	3	0.6
CAS_18_15	WA	2	0.7
CAS_02_15	OR	4	0.7
CAS_11_15	WA	1	0.9
CAS_20_15	WA	2	1.0
CAS_06_15	WA	1	1.0
CAS_12_15	OR	4	1.0
CAS_05_15	OR	6	1.1
CAS_21_15	WA	2	1.2
CAS_14_15	WA	3	1.2
CAS_09_15	OR	6	1.3
CAS_03_15	OR	6	1.4
CAS_10_15	WA	1	1.5
CAS_04_15	OR	4	1.7
CAS_07_15	WA	1	1.7
CAS_13_15	WA	1	1.7
CAS_15_15	WA	1	1.7
CAS_16_15	WA	1	1.7
CAS_24_15	WA	2	1.8
CAS_08_15	OR	6	1.8
CAS_17_15	WA	1	1.9
CAS_22_15	WA	2	2.0

2014 Harvest

22 *Sample lots*

4 Farms

12 Unique oil values

2015 Harvest

29 *Sample lots*

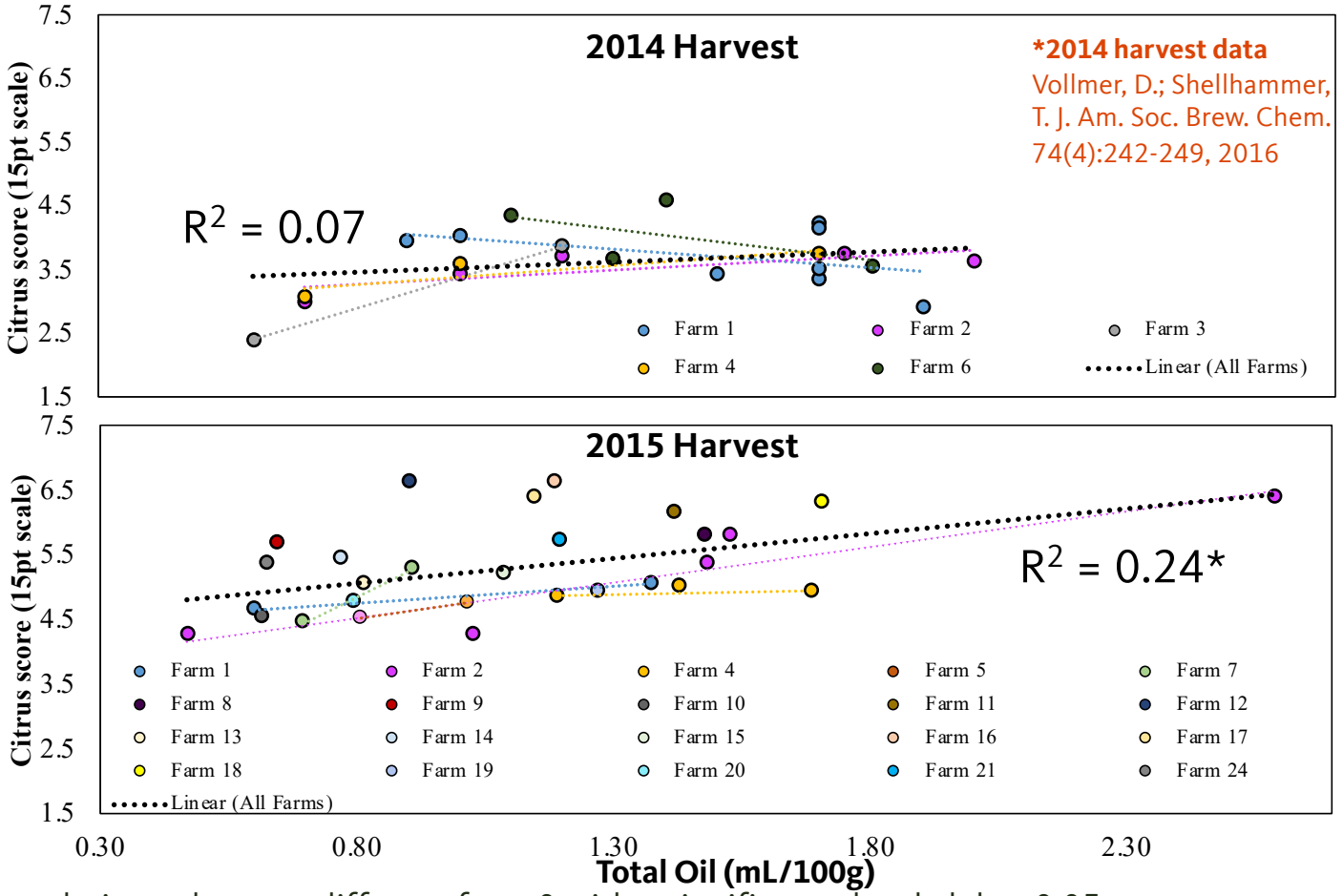
19 Farms

13 Unique oil values

Cascade 2015 Harvest

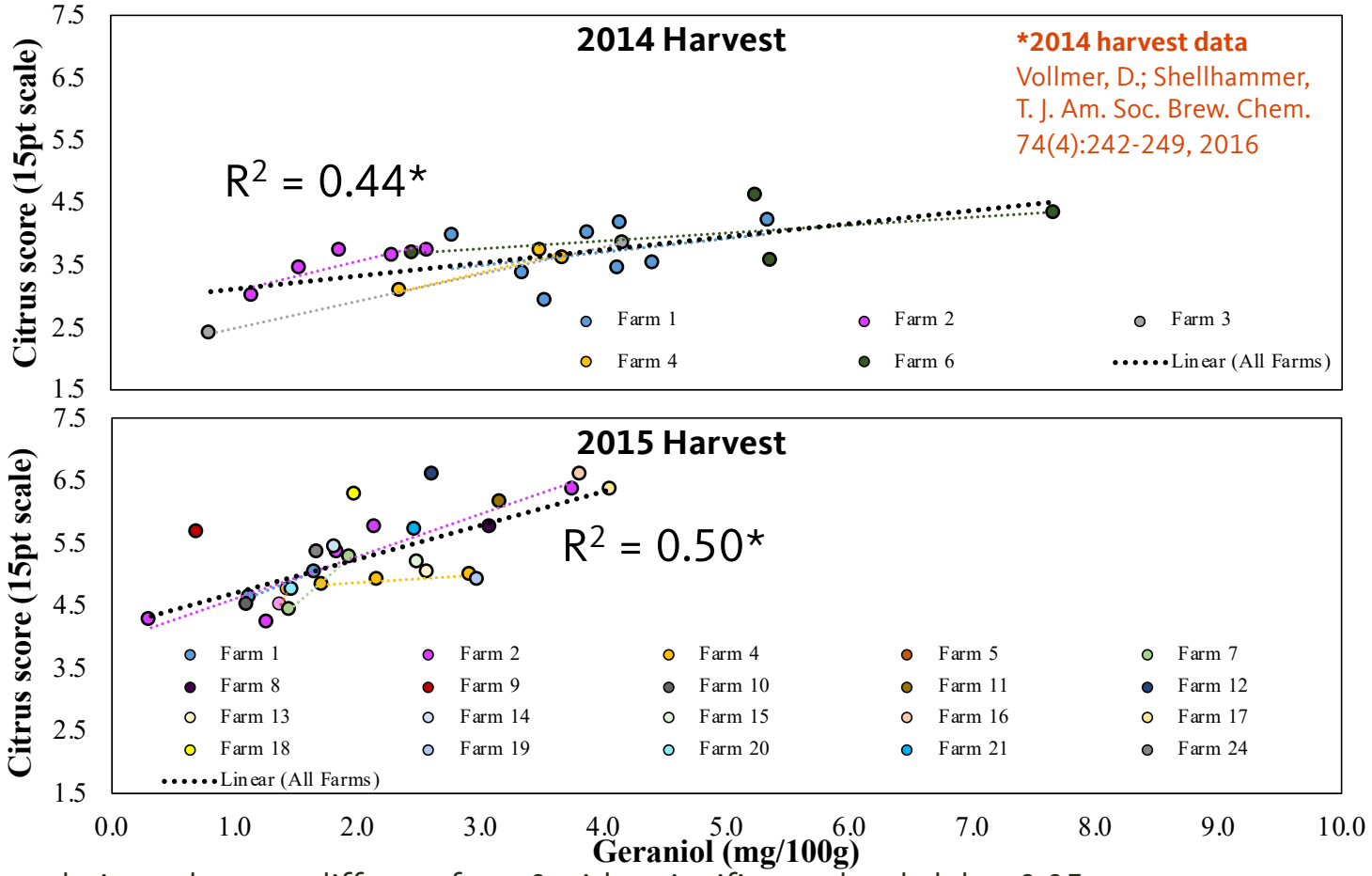
	Region	Farm (coded)	OSU Hop Oil (ml/100g)
CAS_12_16	WA	2	0.5
CAS_27_16	WA	1	0.6
CAS_21_16	ID	10	0.6
CAS_22_16	ID	10	0.6
CAS_24_16	WA	9	0.6
CAS_07_16	ID	7	0.7
CAS_09_16	ID	14	0.8
CAS_19_16	WA	20	0.8
CAS_04_16	WA	5	0.8
CAS_25_16	OR	13	0.8
CAS_26_16	WA	12	0.9
CAS_06_16	ID	7	0.9
CAS_05_16	WA	5	1.0
CAS_11_16	WA	2	1.0
CAS_16_16	WA	15	1.1
CAS_17_16	OR	17	1.1
CAS_15_16	WA	16	1.2
CAS_03_16	OR	4	1.2
CAS_23_16	WA	21	1.2
CAS_20_16	WA	19	1.3
CAS_28_16	WA	1	1.4
CAS_29_16	WA	11	1.4
CAS_02_16	OR	4	1.4
CAS_08_16	OR	8	1.5
CAS_13_16	WA	2	1.5
CAS_10_16	WA	2	1.5
CAS_01_16	OR	4	1.7
CAS_18_16	WA	18	1.7
CAS_14_16	WA	2	2.6

Cascade Samples: Citrus quality vs total oil content



**Pearson Correlation values are different from 0 with a significance level alpha=0.05

Cascade Samples: Citrus quality vs Geraniol concentrations



**Pearson Correlation values are different from 0 with a significance level alpha=0.05

Other interesting findings.....

- Impact of harvest maturity on dry-hop aroma

Impact of harvest maturity on dry-hop aroma quality- Farm 2

Cascade 2014 Harvest

	Region	Farm (coded)	OSU Hop Oil (ml/100g)
CAS_11_15	WA	1	0.9
CAS_06_15	WA	1	1
CAS_10_15	WA	1	1.5
CAS_07_15	WA	1	1.7
CAS_13_15	WA	1	1.7
CAS_15_15	WA	1	1.7
CAS_16_15	WA	1	1.7
CAS_17_15	WA	1	1.9
CAS_18_15	**WA**	**2**	**0.7**
CAS_20_15	**WA**	**2**	**1**
CAS_21_15	**WA**	**2**	**1.2**
CAS_24_15	**WA**	**2**	**1.8**
CAS_22_15	**WA**	**2**	**2**
CAS_01_15	WA	3	0.6
CAS_14_15	WA	3	1.2
CAS_02_15	OR	4	0.7
CAS_12_15	OR	4	1
CAS_04_15	OR	4	1.7
CAS_05_15	OR	6	1.1
CAS_09_15	OR	6	1.3
CAS_03_15	OR	6	1.4
CAS_08_15	OR	6	1.8

Cascade 2015 Harvest

	Region	Farm (coded)	OSU Hop Oil (ml/100g)
CAS_27_16	WA	1	0.6
CAS_28_16	WA	1	1.4
CAS_12_16	**WA**	**2**	**0.5**
CAS_11_16	**WA**	**2**	**1**
CAS_13_16	**WA**	**2**	**1.5**
CAS_10_16	**WA**	**2**	**1.5**
CAS_14_16	**WA**	**2**	**2.6**
CAS_03_16	OR	4	1.2
CAS_02_16	OR	4	1.4
CAS_01_16	OR	4	1.7
CAS_04_16	WA	5	0.8
CAS_05_16	WA	5	1
CAS_07_16	ID	7	0.7
CAS_06_16	ID	7	0.9
CAS_08_16	OR	8	1.5
CAS_24_16	WA	9	0.6
CAS_21_16	ID	10	0.6
CAS_22_16	ID	10	0.6
CAS_29_16	WA	11	1.4
CAS_26_16	WA	12	0.9
CAS_25_16	OR	13	0.8
CAS_09_16	ID	14	0.8
CAS_16_16	WA	15	1.1
CAS_15_16	WA	16	1.2
CAS_17_16	OR	17	1.1
CAS_18_16	WA	18	1.7
CAS_20_16	WA	19	1.3
CAS_19_16	WA	20	0.8
CAS_23_16	WA	21	1.2

Cascade 2016 Harvest

	Region	Farm (coded)	OSU Hop Oil (ml/100g)
CAS_1_17	**WA**	**2**	**0.76**
CAS_2_17	**WA**	**2**	**0.86**
CAS_3_17	**WA**	**2**	**1.07**
CAS_4_17	**WA**	**2**	**0.92**
CAS_5_17	**WA**	**2**	**1.29**
CAS_6_17	**WA**	**2**	**2.52**

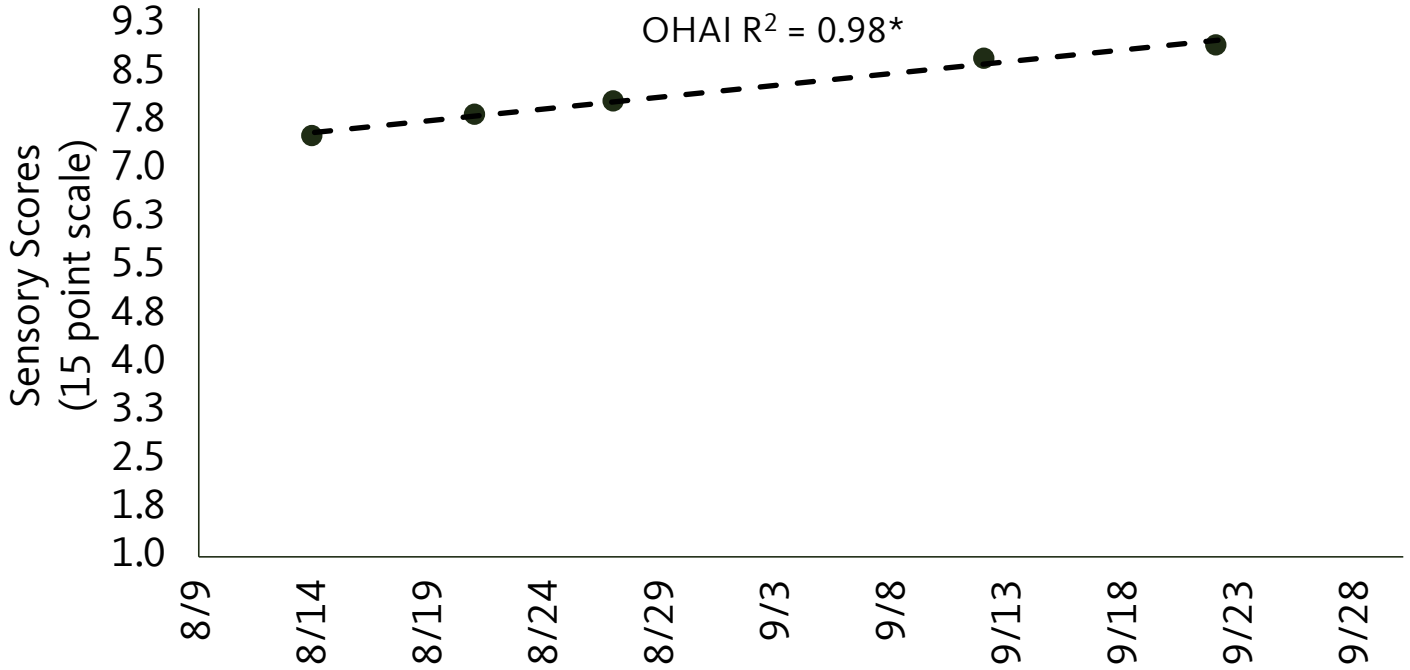
Uniqueness of Farm 2

- *5-6 sampling throughout harvest*
- *Small batch kilned*

Impact of harvest maturity on dry-hop aroma quality- Farm 2

2014 Harvest

- Later picked Cascades → higher dry hop aroma
  - Sensory analysis- evaluated amongst 22 samples



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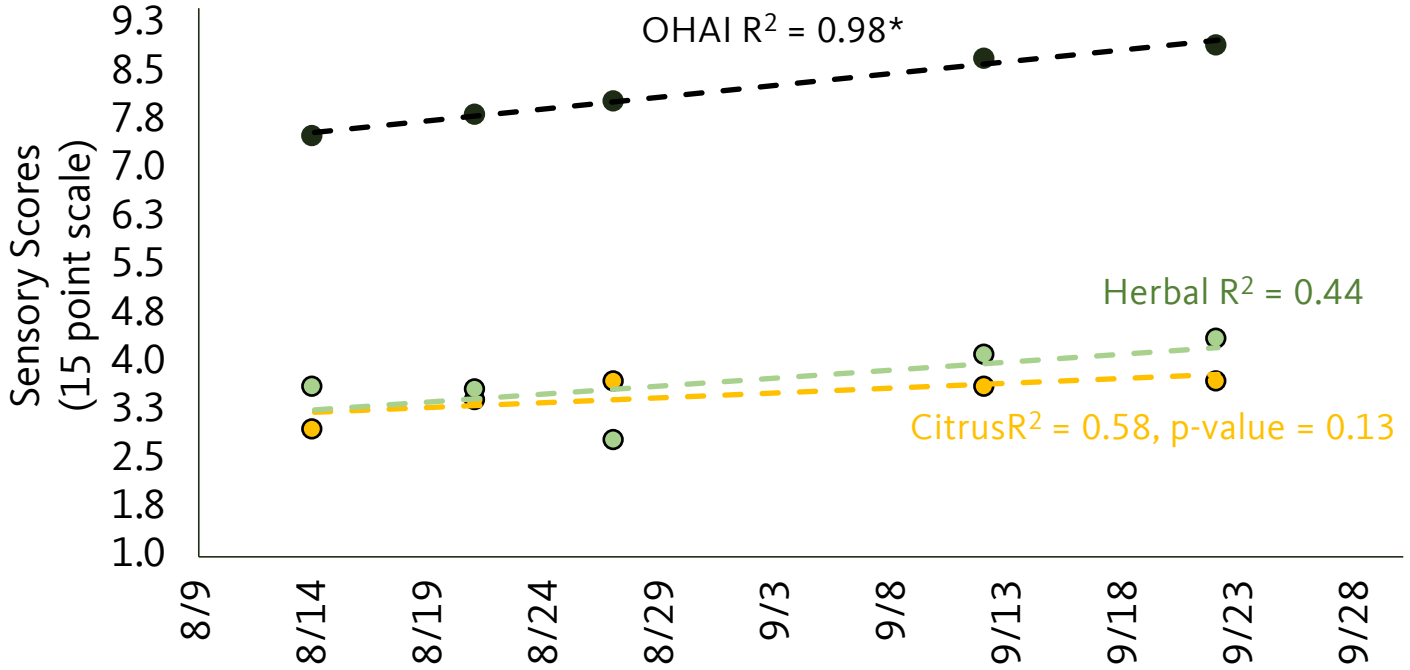
Impact of harvest maturity on dry-hop aroma quality- Farm 2

2014 Harvest

- Later picked Cascades → more citrusy in quality
  - Aroma quality develops with on bine ripening

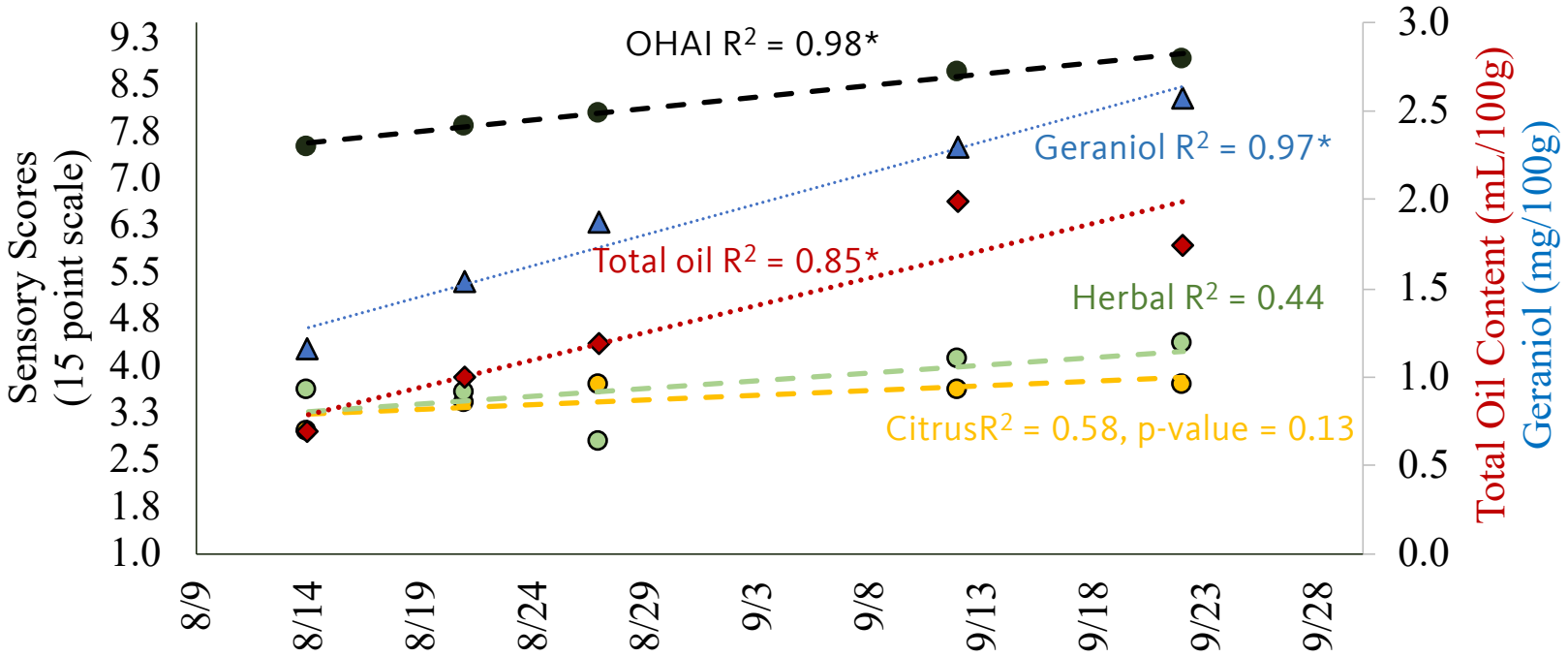


**Pearson Correlation values are different from 0 with a significance level alpha=0.05

Impact of harvest maturity on dry-hop aroma quality- Farm 2

2014 Harvest

- Later picked Cascades → more geraniol and higher total oil

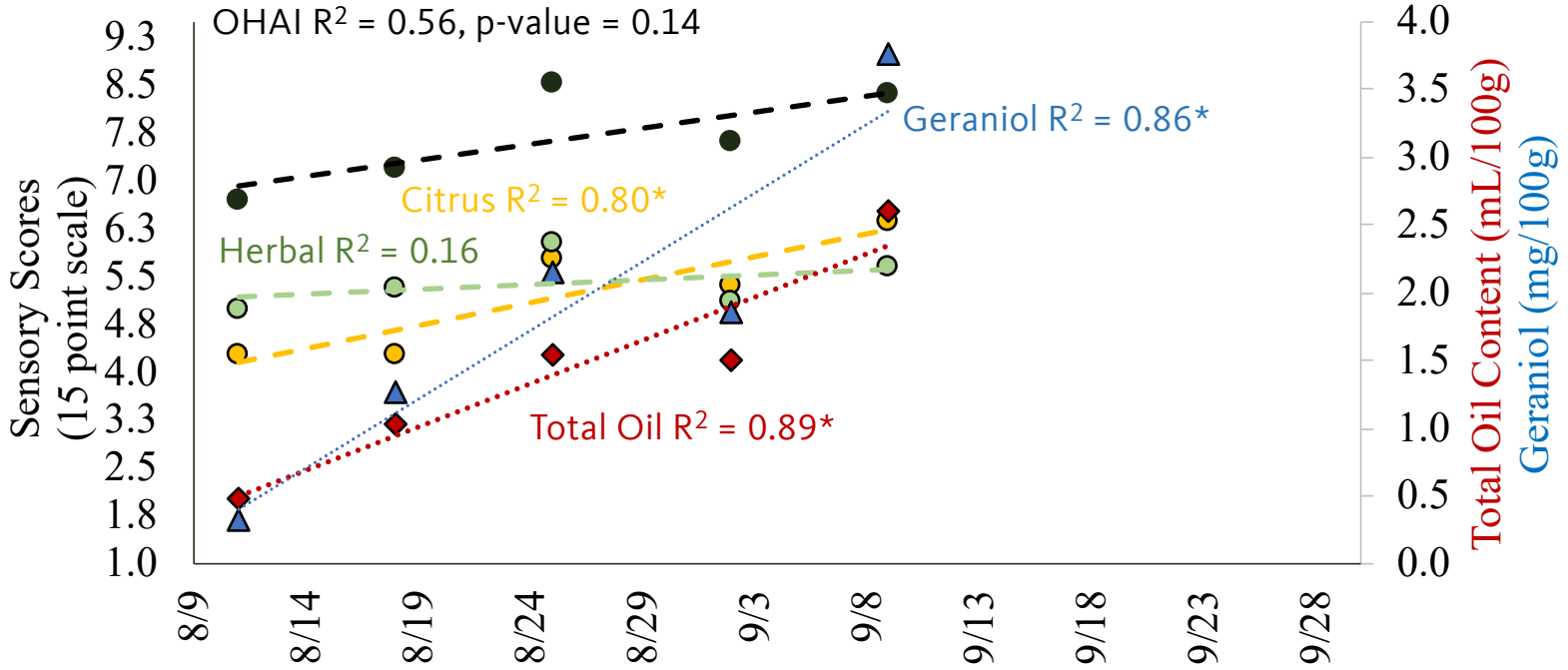


**Pearson Correlation values are different from 0 with a significance level alpha=0.05

Impact of harvest maturity on dry-hop aroma quality- Farm 2

2015 Harvest

- Similar trends in 2015
  - Sensory analysis- evaluated amongst 33 samples

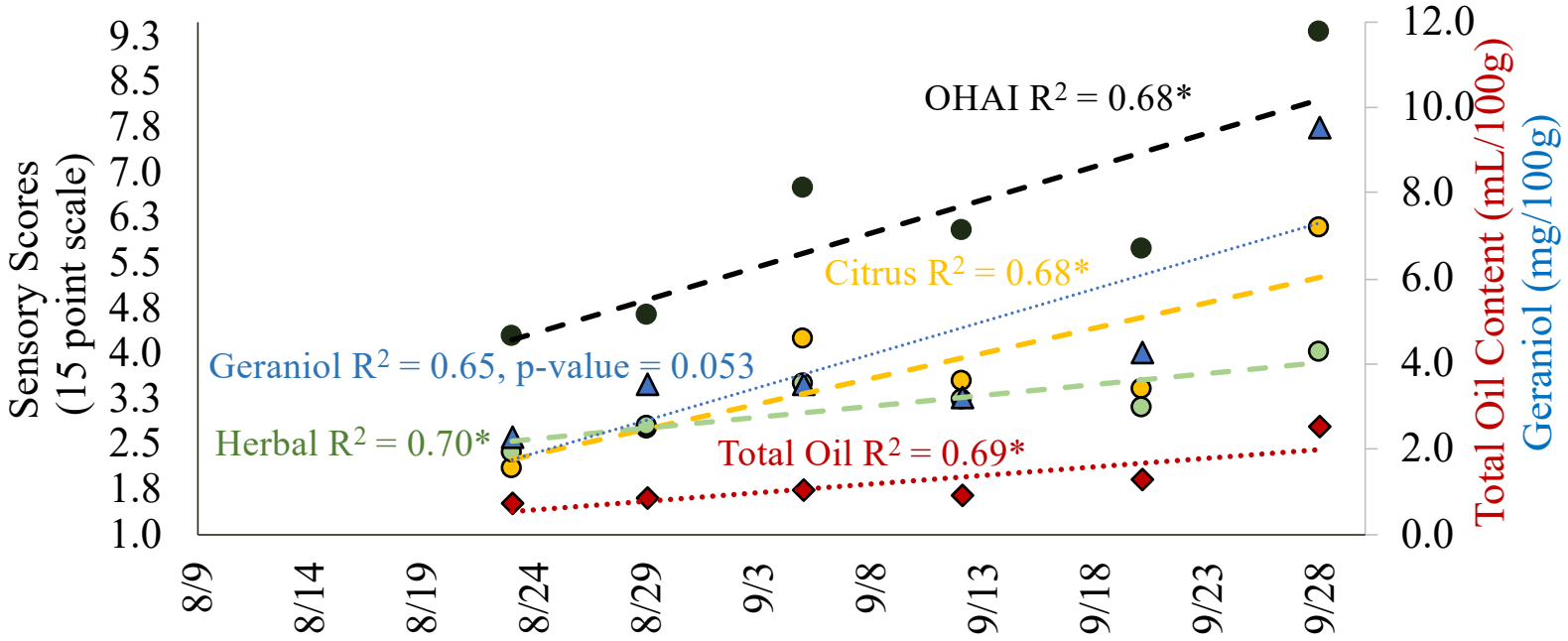


**Pearson Correlation values are different from 0 with a significance level alpha=0.05

Impact of harvest maturity on dry-hop aroma quality- Farm 2

2016 Harvest

- Similar trends in 2016



Conclusions

- Hop's total oil content may not be a good predictor of its aromatic intensity in dry-hopped beer
- A single hop oil component explains about 50% of variation
  - Cascade – geraniol
  - Centennial – β-pinene
- Harvest maturity impacts the levels of these compounds

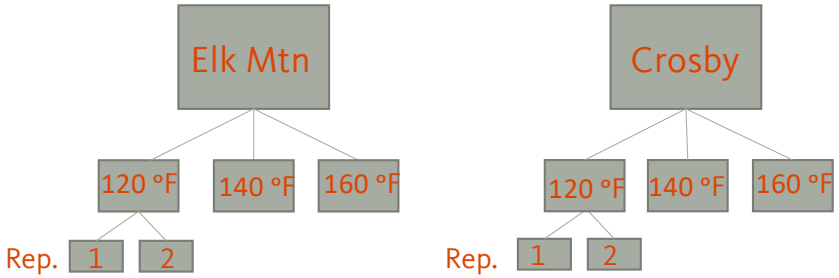
Lindsey Rubottom
Masters student (willdefend May 2020)
Oregon State University

IMPACT OF HOP KILNING TEMPERATURE ON HOP QUALITY

Oregon State University

Hop Kilning Temperature Research Plan

Variety: Amarillo ®
Commercial scale kilns



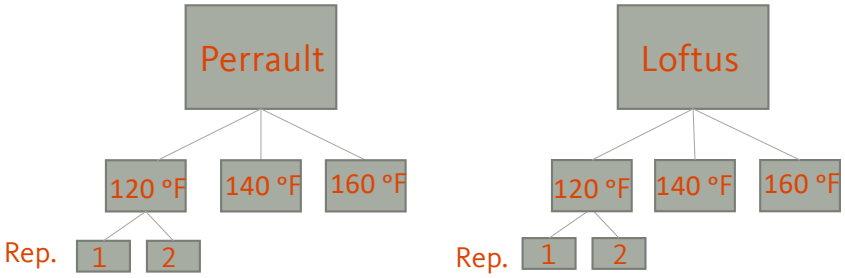
Farms: Crosby Hop Farm & Elk Mountain Farm

Kiln Temperatures: 120°F, 140°F, 160°F

Replications: Two for each temperature

Total # of Treatments: 12
Kiln Dimensions: 32 x 32 feet

Variety: Simcoe ®
Commercial scale kilns



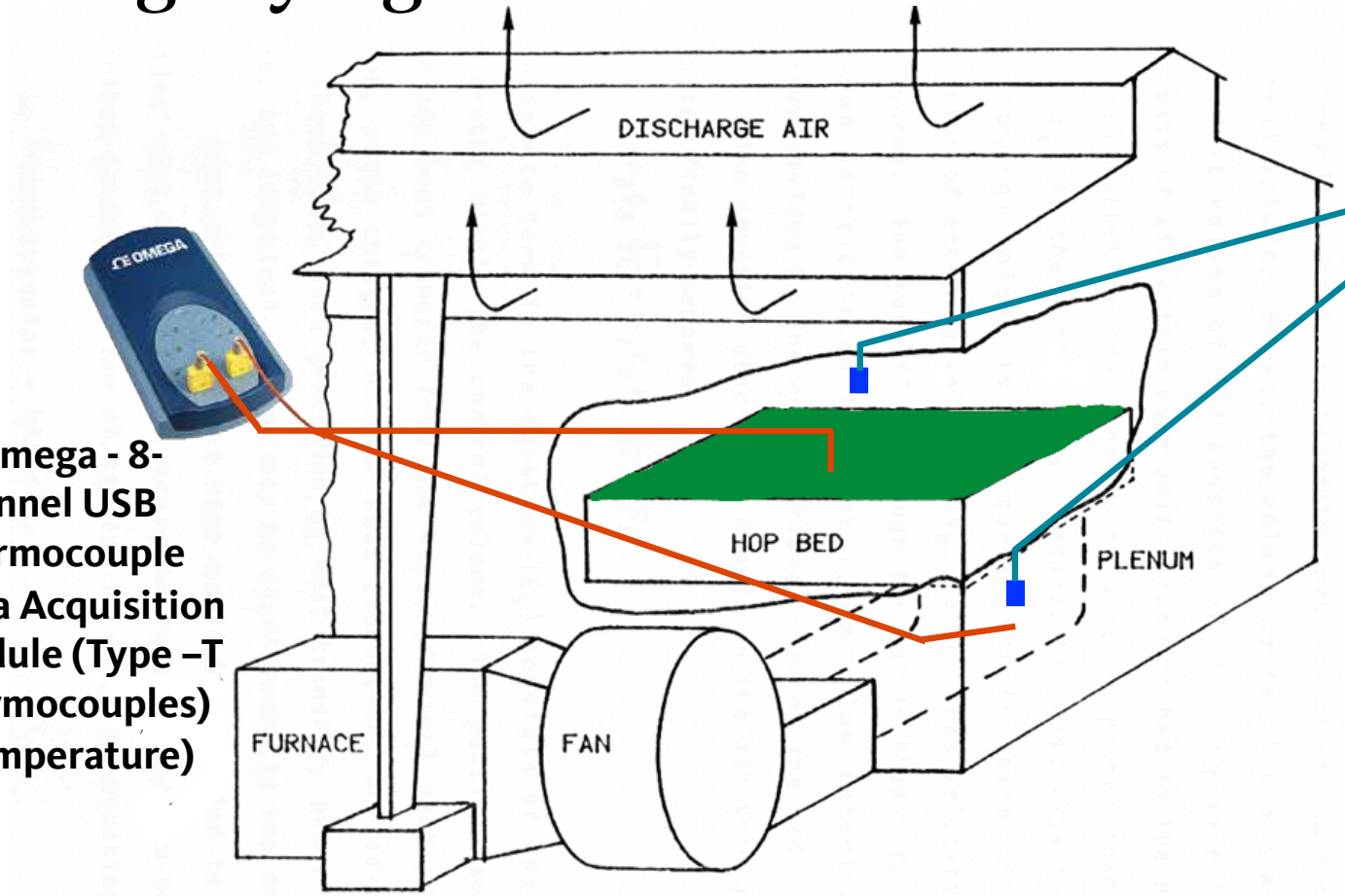
Farms: Loftus Ranches & Perrault Farms

Kiln Temperatures: 120°F, 140°F, 160°F

Replications: Two for each temperature

Total # of Treatments: 12
Kiln Dimensions: 16 X 32 feet

During drying measurements

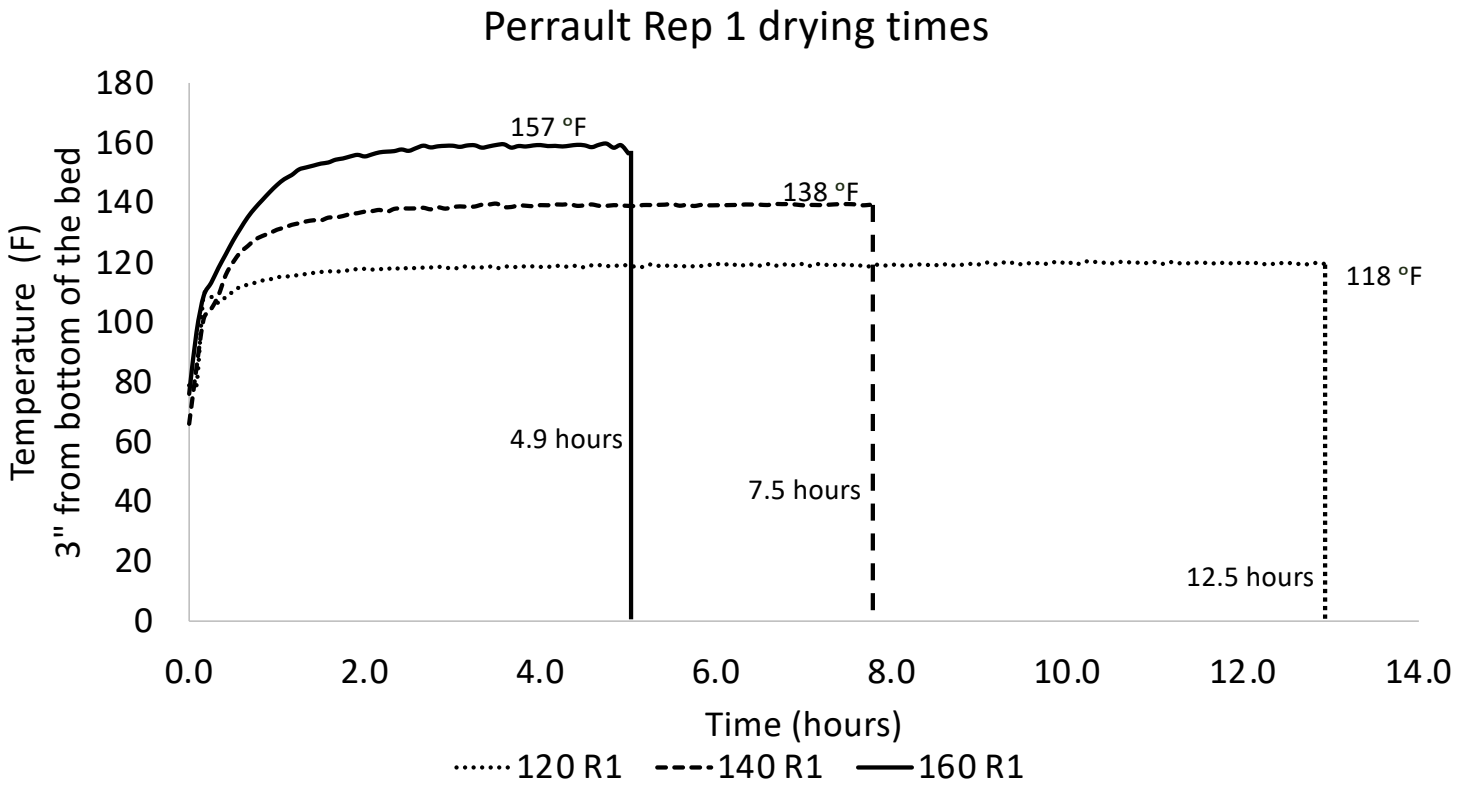


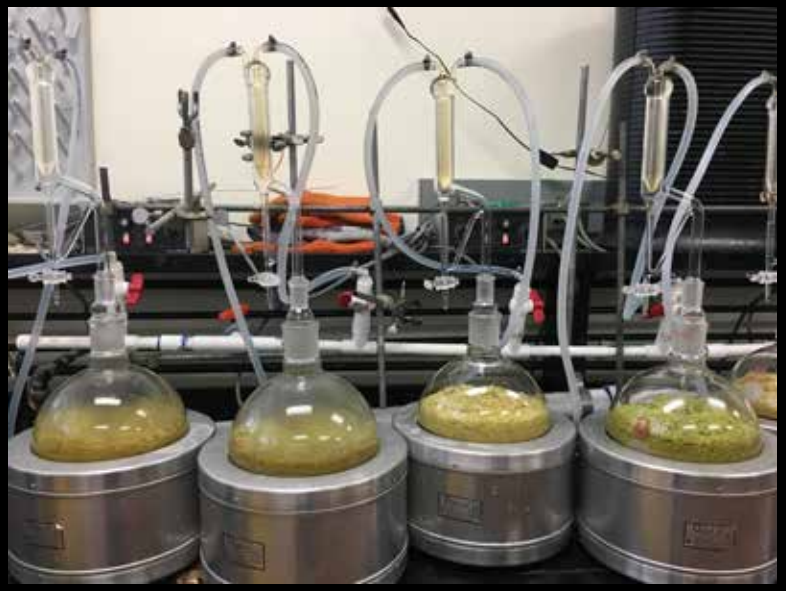
2: Omega - 8-Channel USB Thermocouple Data Acquisition Module (Type –T thermocouples) (Temperature)

1: LogTag HAXO-8 Humidity & Temperature Data Logger (Temperature and humidity)

*Hop kiln outline developed by Marvin A. Stone 1982

Air On in the plenum and drying time





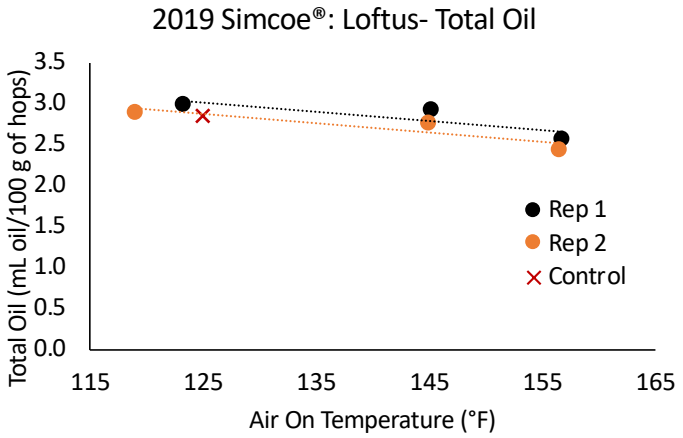
CHEMISTRY

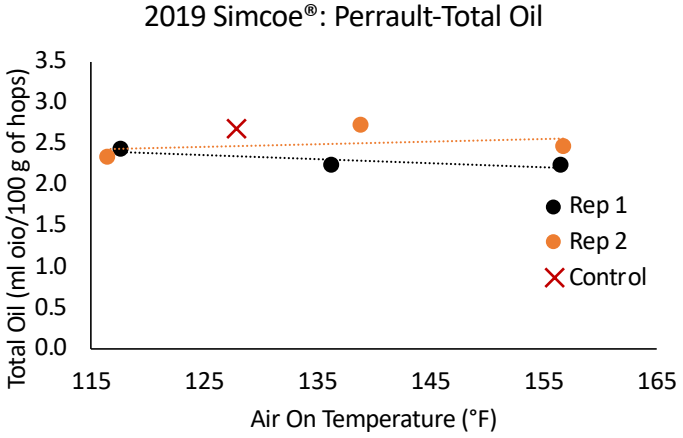
Oregon State University

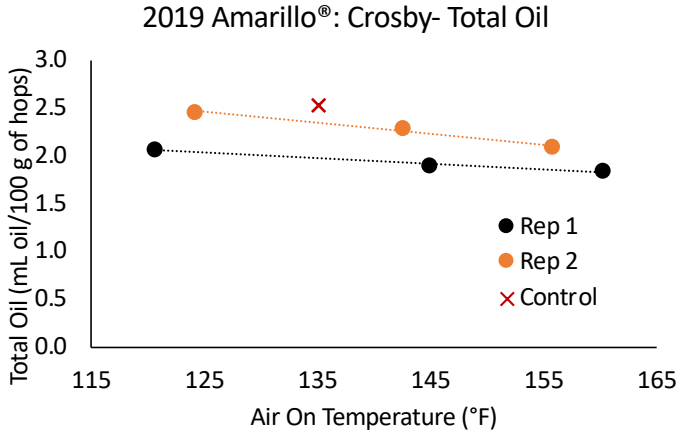
OSU Chemistry Analysis

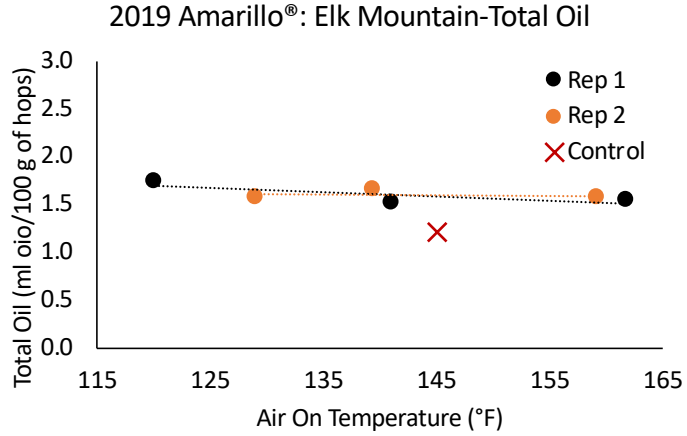
- **ASBC Hops 6 – Spectrophotometry**
  - α-and β-Acids and Hop Storage Index (H.S.I) in Hops
- **ASBC Hops 14 – High performance liquid chromatography (HPLC)**
  - α-and β-Acids in Hops
- **ASBC Hops 13 – Steam Distillation**
  - Total oil content
- **ASBC Hops 17 – Hop Oil Compositional Analysis**
  - Modified analysis technique (GC-FID)
- **Enzymatic dextrin reducing power of hops**

2019 Total oil

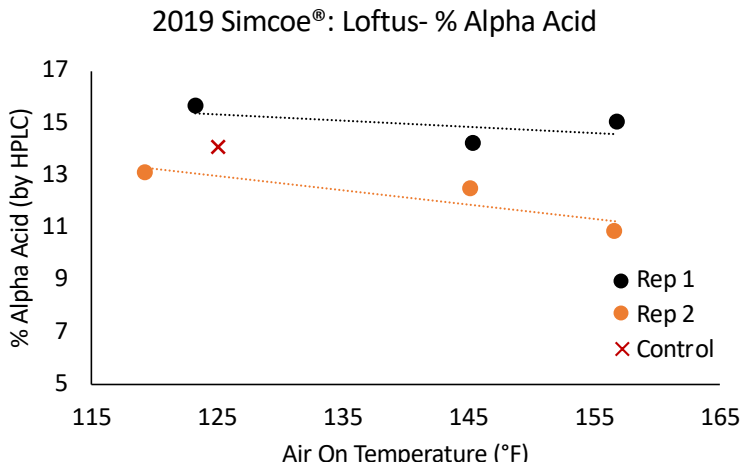


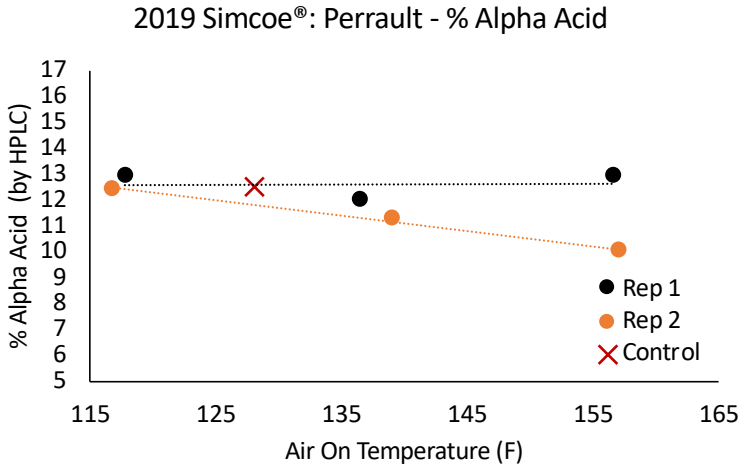


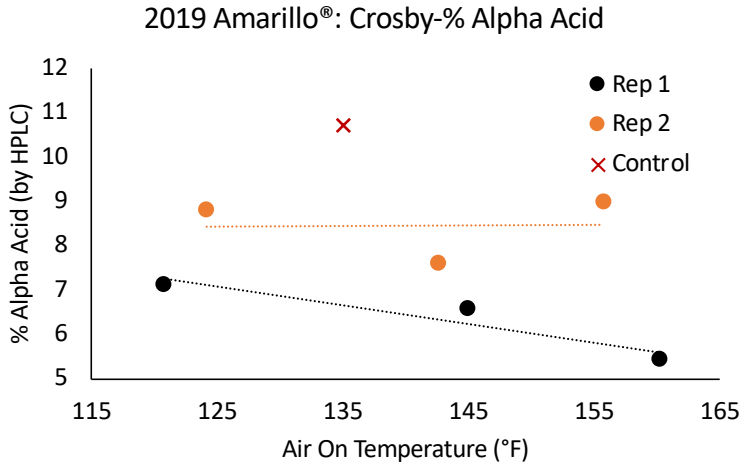


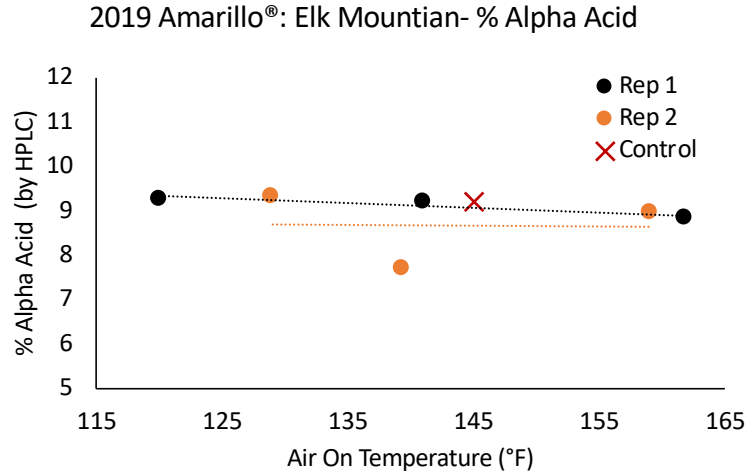


2019 %Alpha Acid

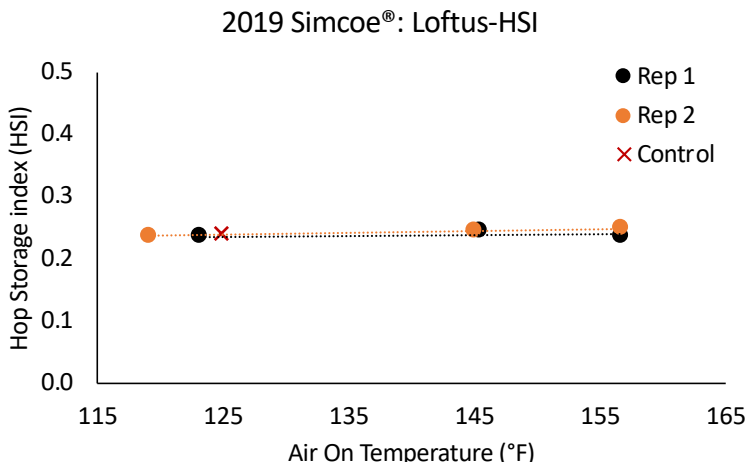


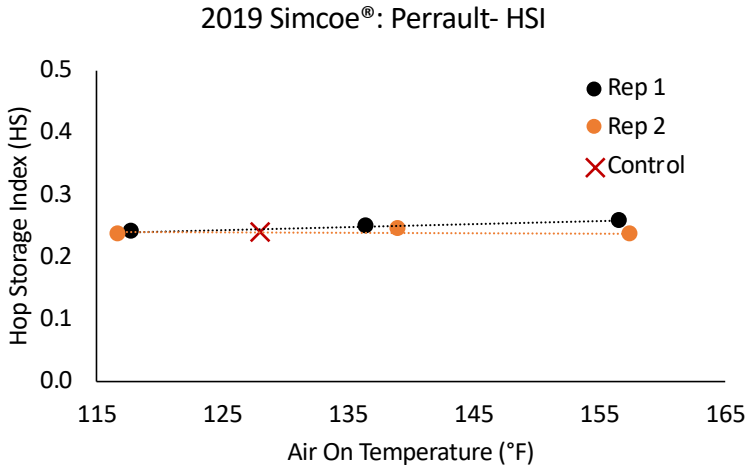


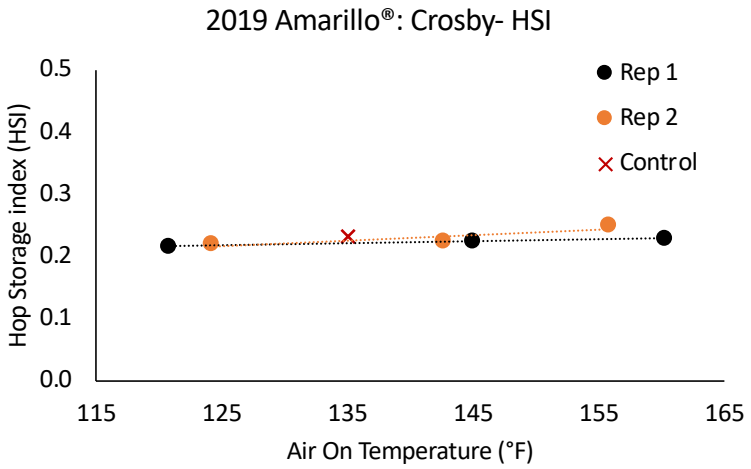


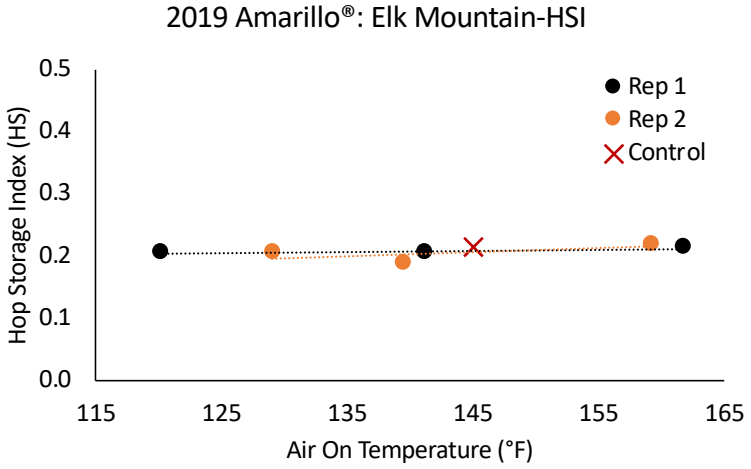


2019 Hop Storage Index







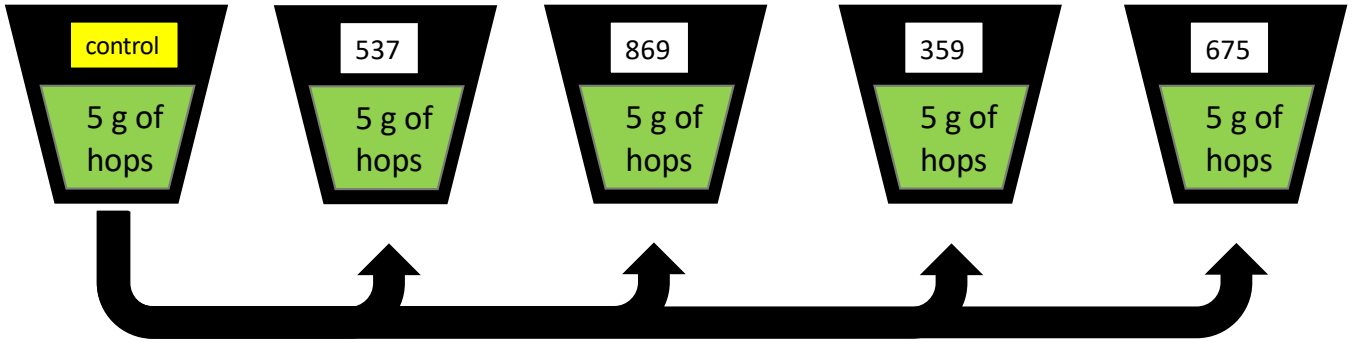


SENSORY

DIFFERENCE FROM CONTROL (DFC)

Oregon State University

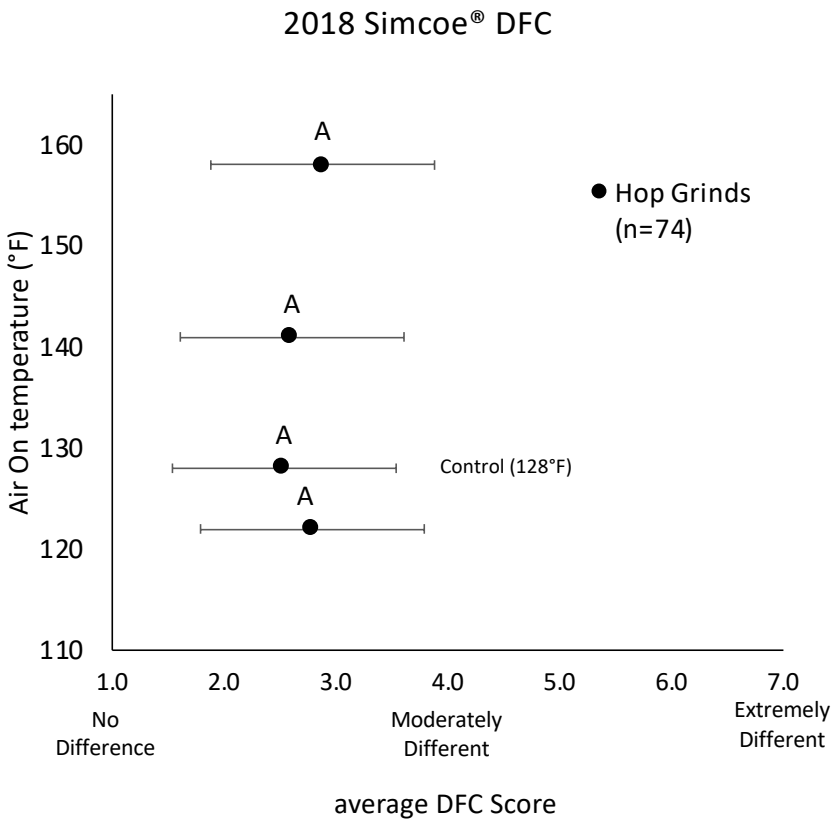
Sensory Descrimination Testing Difference from Control (DFC)

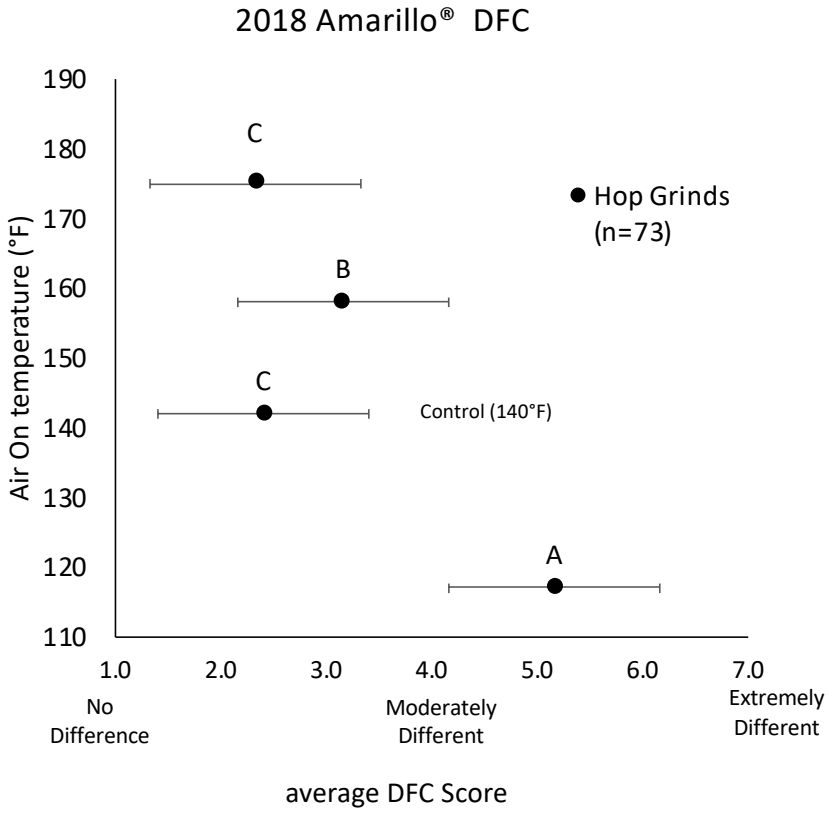


537 Please evaluate sample 537 by smelling Rate the difference from the control on a scale from 1 to 7, with 7 representing an extremely large difference from the control sample.

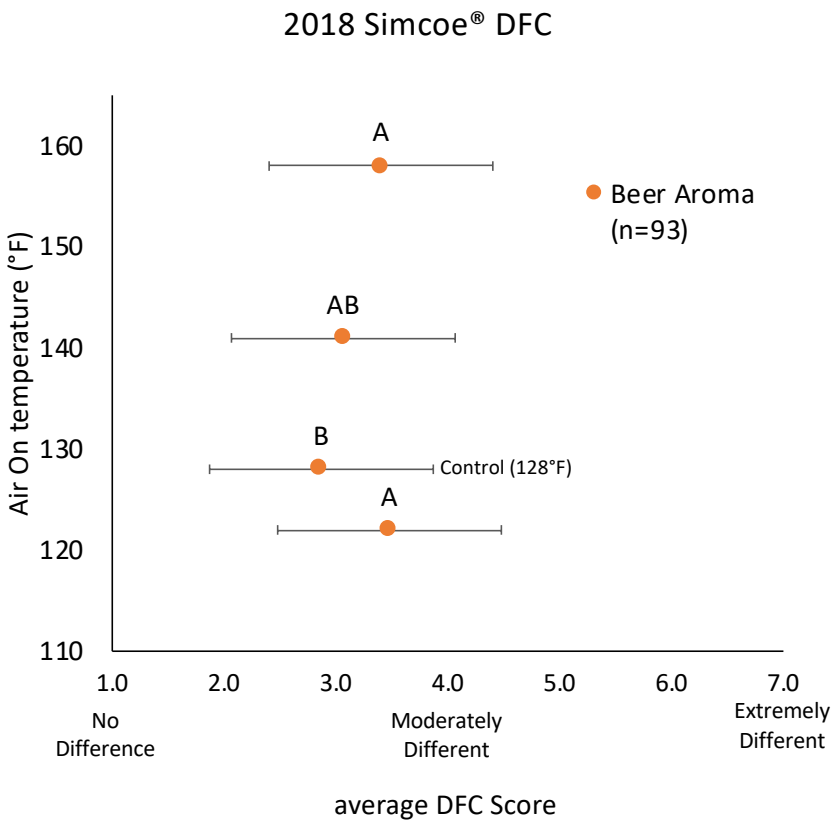
No difference 1 2 3 Moderate difference 4 5 6 Extremely large difference 7

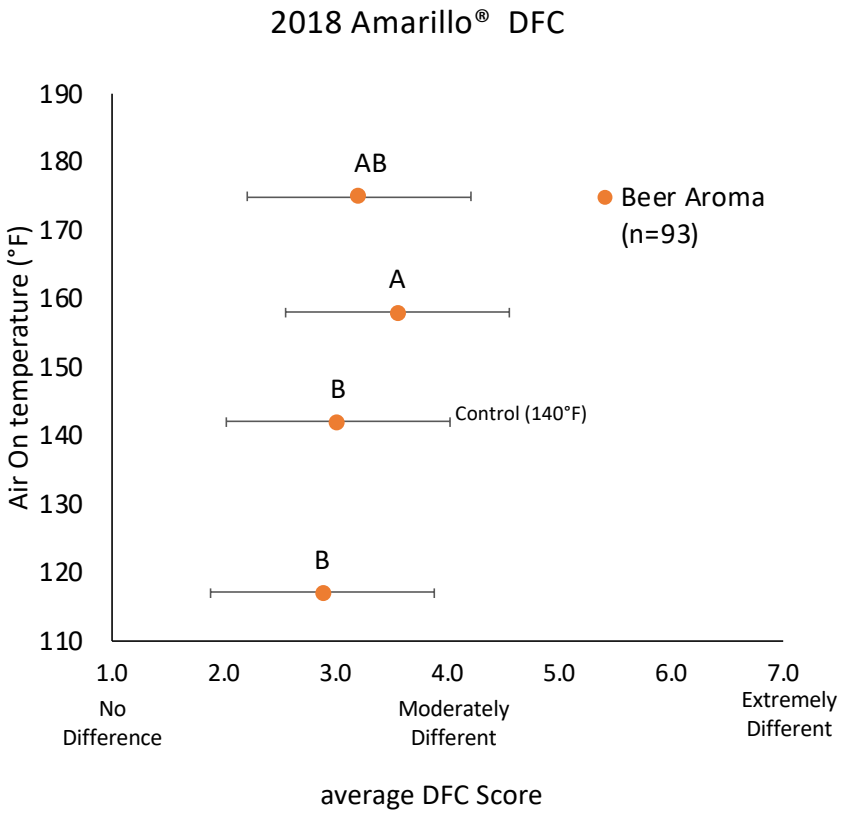
HY 2018 DFC results- Hop Grinds





HY 2018 DFC results- Beer Aroma





Overall Conclusions to date regarding hop kilning temperature

Spanning from 120 (low) and 160 (high) we see:

- Higher kiln temperatures can reduce drying times
- Higher kiln temperatures did not have a great impact on hop chemistry
- Sensory seems to be modestly-negligibly effected
- enzymatic power of hops is significantly reduced

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HOP CREEP

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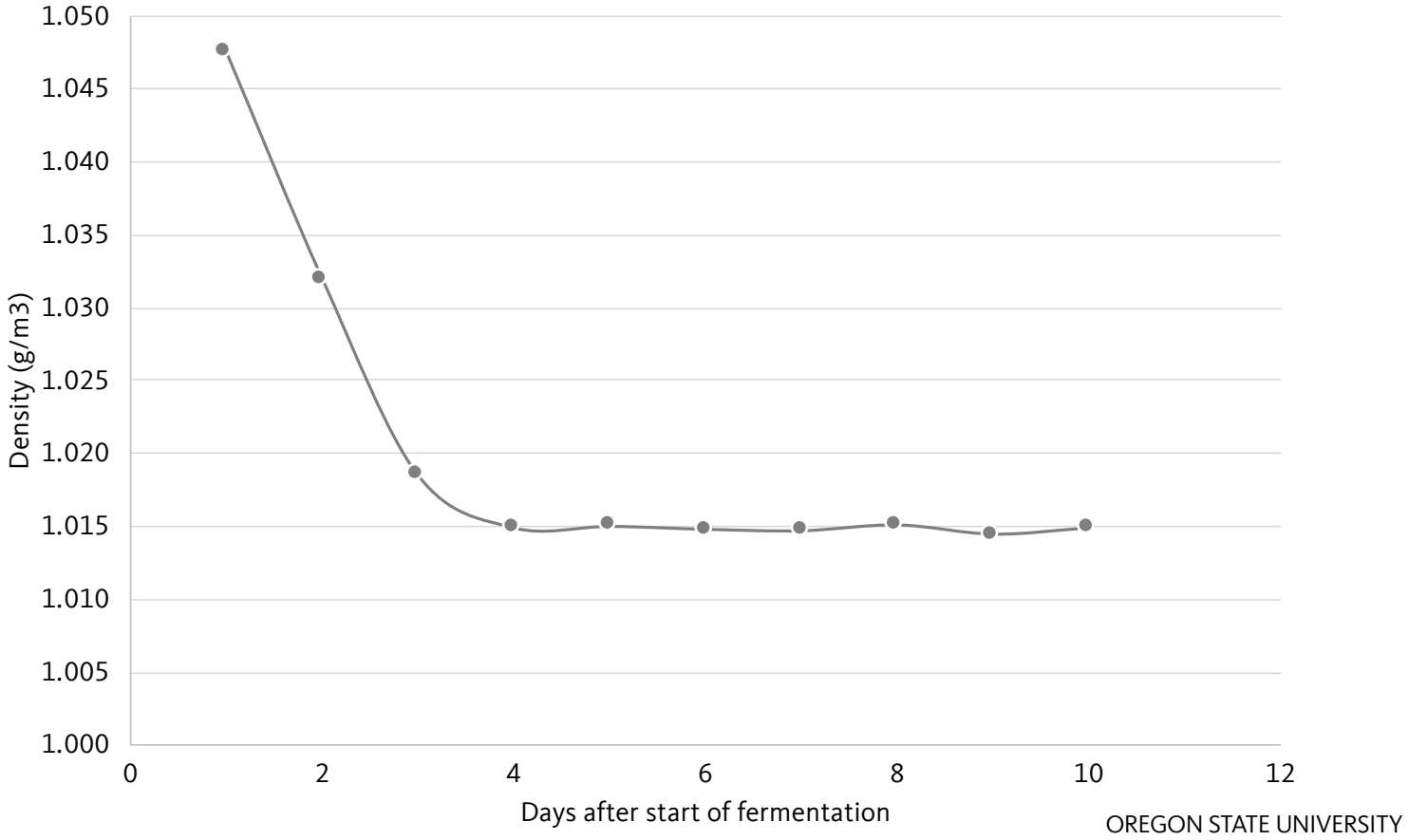
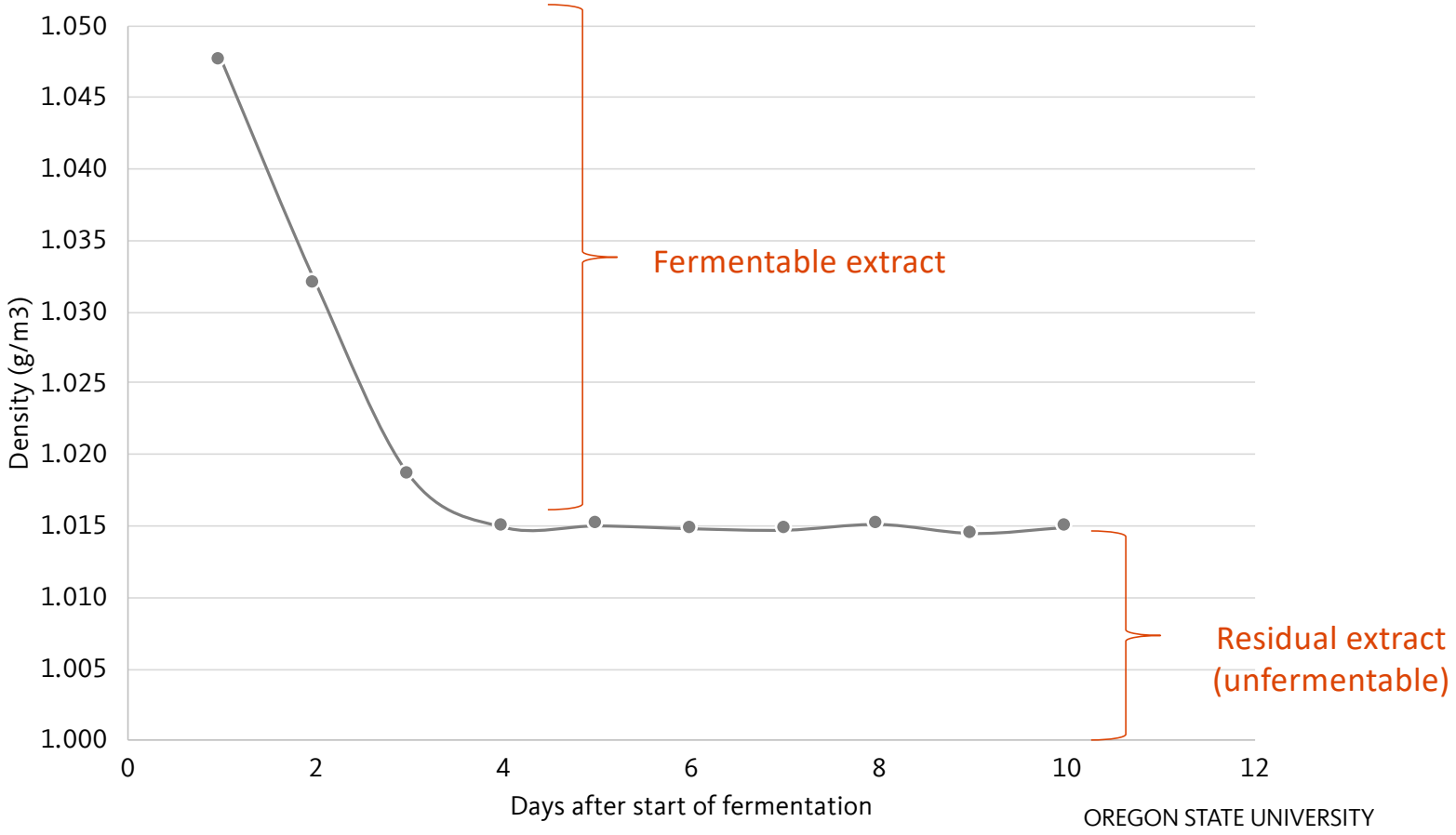
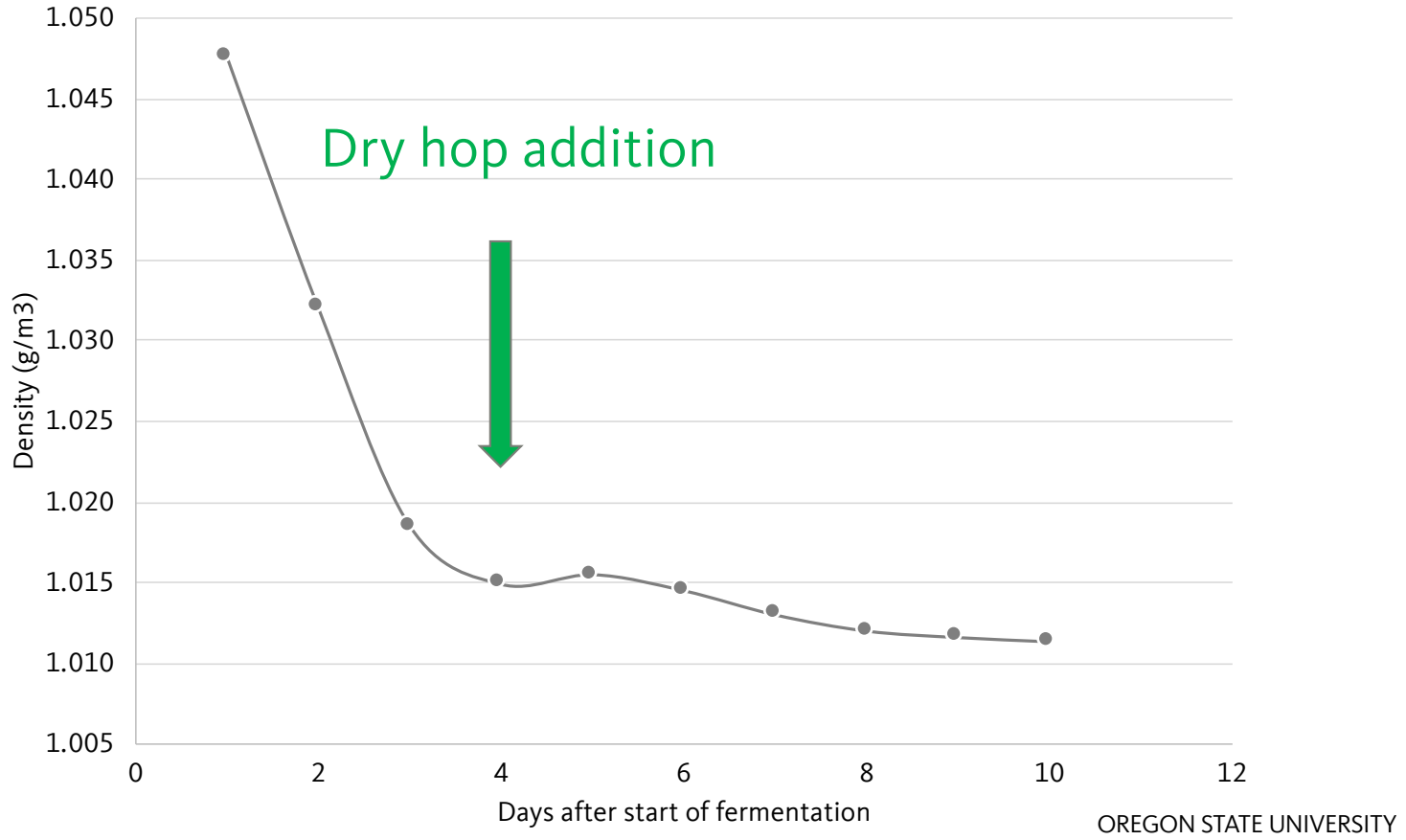
Typical fermentation, no dry-hopping



Typical fermentation, no dry-hopping



Dry-hopping can create “Hop Creep”



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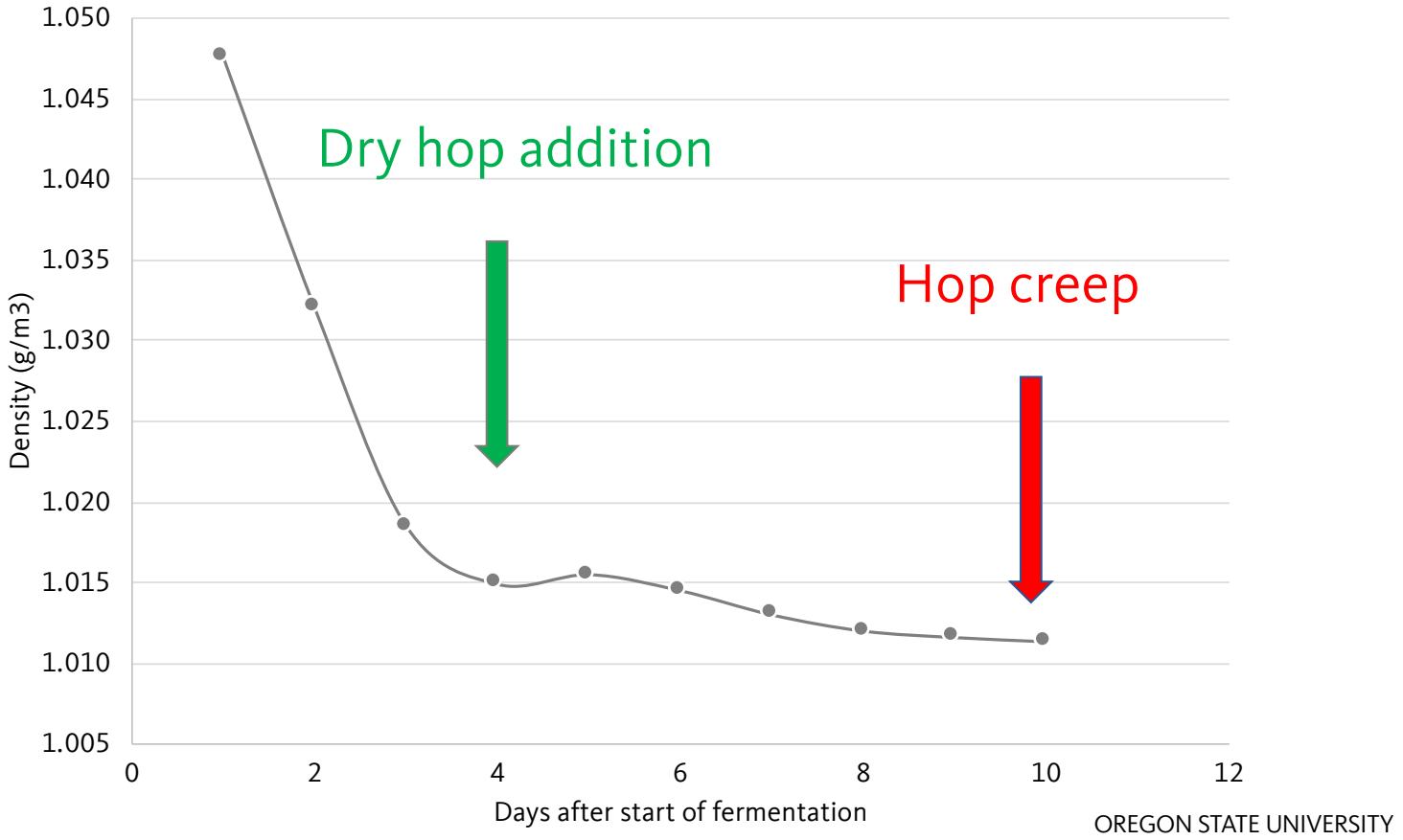

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FIELD-TO-FIELD VARIATION & IMPACT OF HOP KILNING TEMPERATURE

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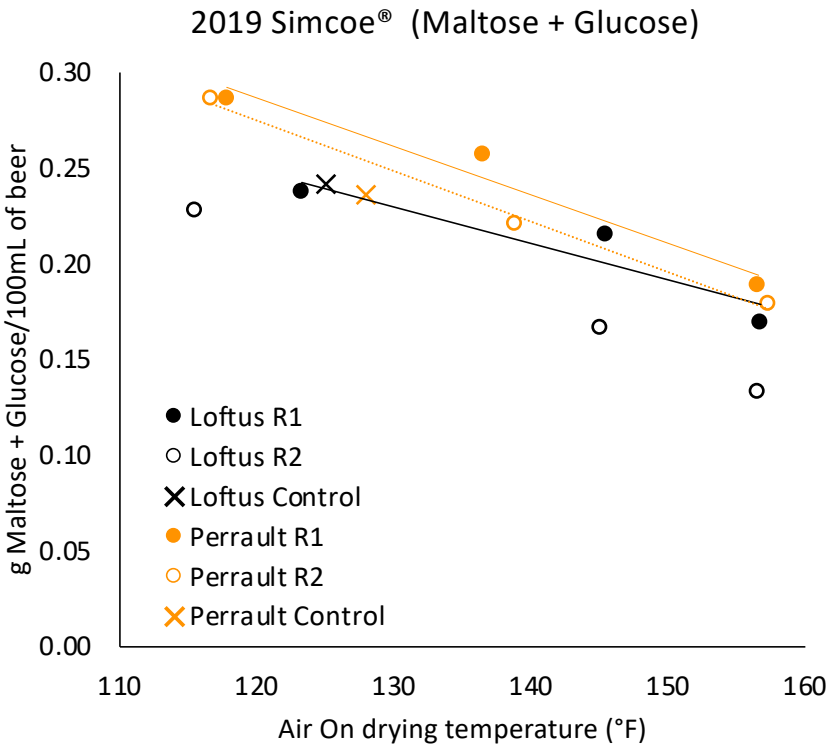
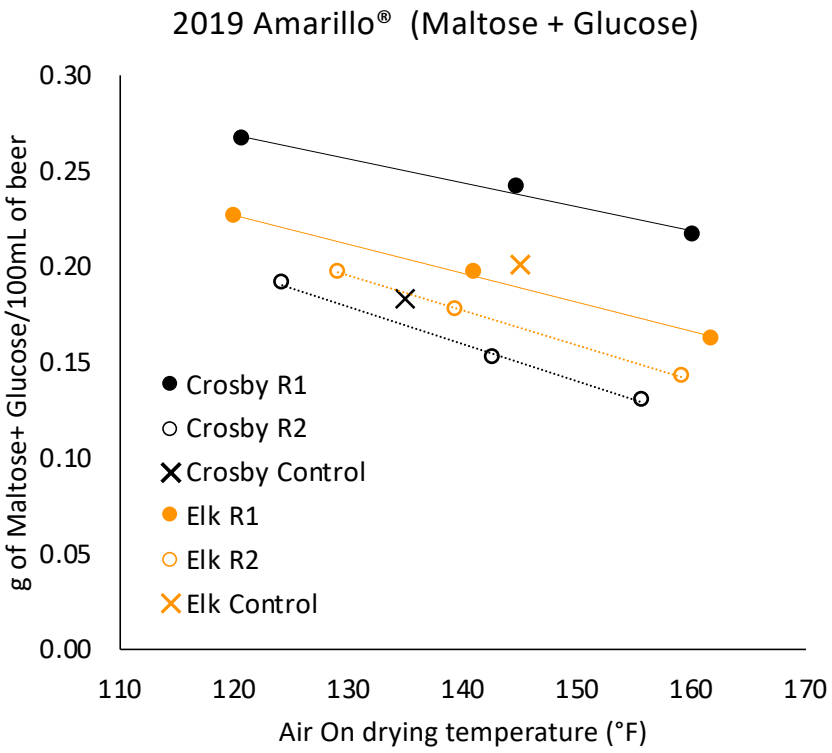
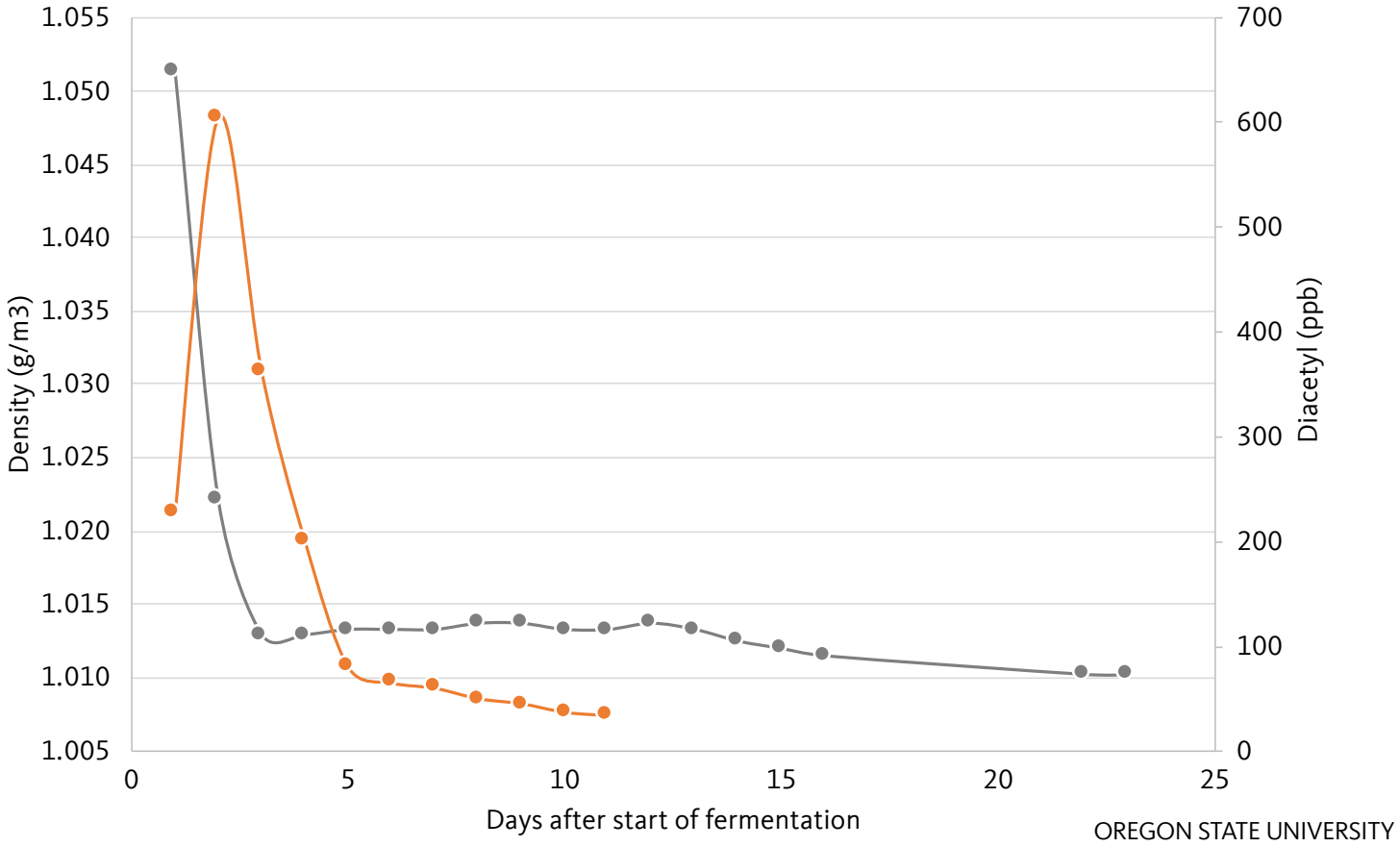
2019 HY kilning trials & Hop Enzyme activity

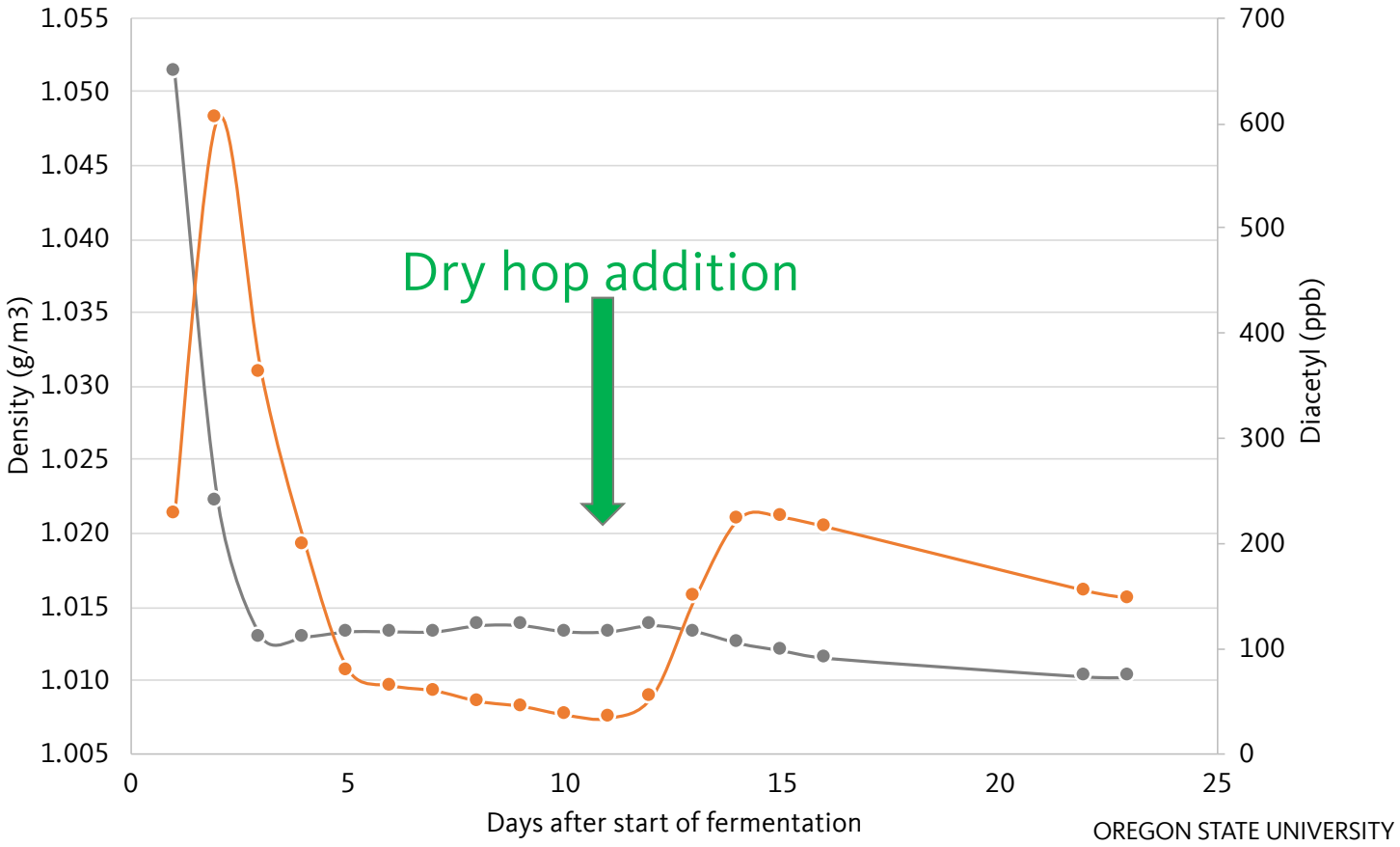




Hop Creep & Diacetyl issues



Hop Creep & Diacetyl issues



Conclusion

- Hop-derived enzymes can alter carbohydrate make up of Real Extract
  - Refermentation in the presence of yeast (for example – bottle conditioning)
  - Lead to diacetyl spikes
  - SOLUTION: dry hop timing, temperature, hop variety, pasteurization
- Hop kilning temperature can influence residual enzyme activity
  - Higher kiln temperatures results in lower activity
  - Considerable variation field-to-field in enzyme activity
- Hop enzymes persist in finished beer
  - The potential for refermentation exists in many cases

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Perrault Hop Farm
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Yakima Chief
Elk Mountain Farm
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Craft Brew Alliance
Bridgeport Brewery
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Thank you

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