FINAL PERFORMANCE REPORT

The completed Final Performance Report will be posted to the AMS website.

FINAL PROJECT REPORT

Final Performance Reports must illustrate the completion of the project within the grant agreement.

PROJECT INFORMATION

Project Title	**Investigating the terroir-influenced quality attributes of hops (Humulus lupulus)**			
Recipient Organization Name:	Michigan State University			
Period of Performance:	**Start Date:**	5/1/2019	**End Date:**	8/1/2021
Recipient's Project Contact				
Name:	J Robert Sirrine			
Phone:	231-499-8965			
Email:	sirrine@msu.edu			

PERFORMANCE NARRATIVE

PROJECT BACKGROUND

The craft brewing sector has increased exponentially over the last several years. The state of Michigan is no exception- there are more breweries in the state today than there were in the entire United States in the 1980's. In total, Michigan beer production accounts for nearly $1 billion and 10,000 jobs in total economic contributions (Miller et al., 2019). These figures demonstrate the importance of investment in Michigan's beer value chain. Much of the growth in demand can be attributed to an increase in consumer preference for flavor-forward, hop heavy India Pale Ales (IPAs). Of the four primary ingredients in beer (water, malt, hops, yeast), hops are the main contributor to flavor and aroma. Because of hops' chemical complexity, maintaining consistent flavor and aroma in beer can be difficult- this represents a major quality control issue for brewers. Research suggests that many factors influence hop aroma: genetics, environment, and production practices. Cultivar, alpha/beta acids, total oil, and Hop Storage Index are typical measures of hop quality; a key variable commonly omitted is geographic location/terroir. Because terroir can impact hop brewing values, more nuanced testing of hop oil profiles is necessary. Our project seeks to utilize descriptive sensory and analytical techniques to determine how growing location may affect hop brewing values, which will help hop producers and brewers improve the quality and consistency of craft beer.

For the last century U.S. hop production has been concentrated in the Pacific Northwest (Washington, Oregon, and Idaho). One consequence of the exponential increase in craft brewing is increasing consumer demand (and therefore brewer demand) for locally sourced hops, which has fueled the establishment of hop acreage in new regions. Michigan has emerged in the forefront of the re- emerging hop-growing states, ranking 4th in hop acreage (HGA 2019). Nielsen Craft Beer Insights suggests that organoleptic properties (sensory characteristics such as flavor and aroma) are key drivers of consumer demand for craft beer (Watson, 2017). With geographically distinct soils and environmental conditions, Michigan hops may provide unique flavor profiles that brewers can leverage in an increasingly competitive marketplace, as evidenced by Brewmaster Matt Brynildson's use of Michigan-grown hops in Firestone Walker's Luponic Distortion Revolution No. 006. Brynildson suggests "This beer showcases what happens when you take two familiar Northwest hop varieties and grow them 2,000 miles to the east. The typical piney, dank attributes of these hops are transformed into something much brighter, with a racy citrus quality. It's a perfect example of how terroir plays into hop growing, and how it ultimately shapes beer flavor and aroma". Investigating hop quality attributes that contribute to quality differences and consumer liking in craft beer will provide critical information to hop producers and brewers.

ACTIVITIES PERFORMED

Methods, Procedure, & Results

Hypothesis 1: Hops grown in different regions will produce distinct *terroir*-influenced quality attributes.

T-90 Chinook hop pellets (2019 harvest) were sourced from Michigan (2 locations), Oregon, and Washington. LC/MS-SPME-GC/MS hop oil profiling and descriptive sensory analysis were conducted. We found differences between all four samples (Figure 1). Notably, both Michigan Chinook samples had alpha-pinene levels below the limits of detection and lower beta-pinene levels than the OR and WA hops, which may provide initial evidence for the "racy citrus quality" of Michigan hops described above.

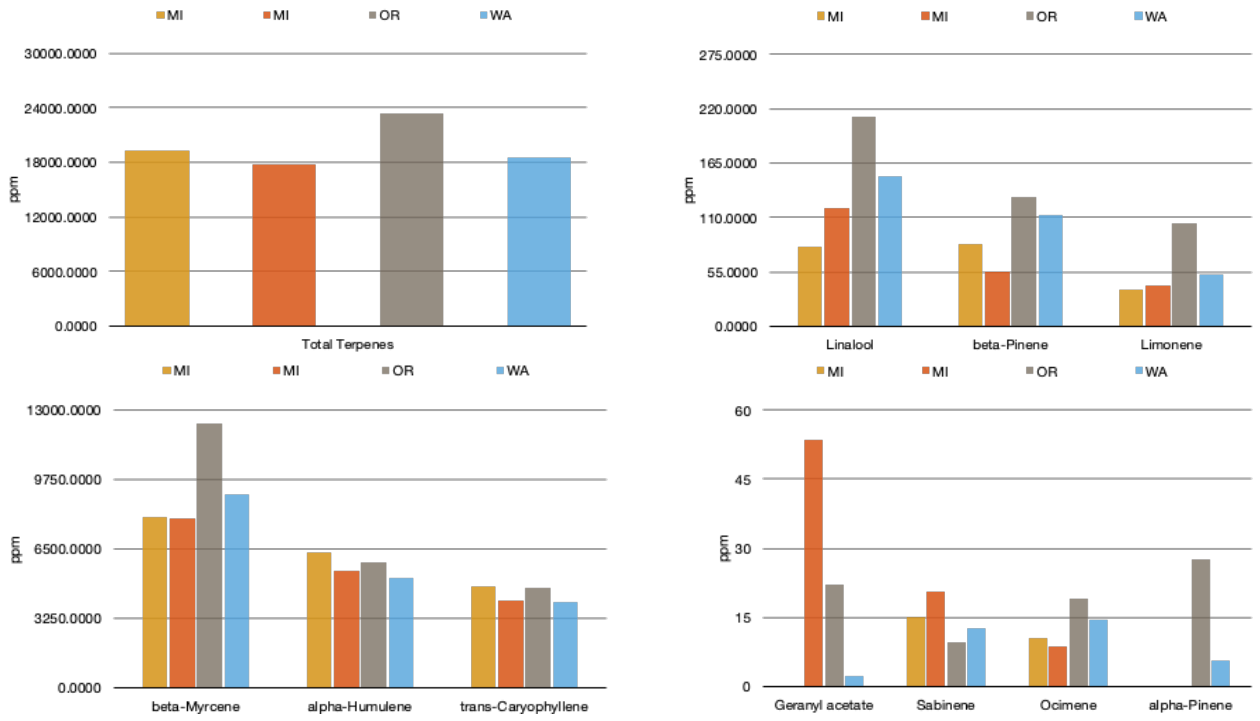


Figure 1. Chinook hop oil profile comparison (MI, MI, OR, WA).

In May 2021, Michigan hop producers submitted multiple cultivars of T-90 hop pellets (2020 harvest) from across the state for LC/MS-SPME-GC/MS chemical analysis (Figure 2) and descriptive sensory analysis (Figure 3). The results further support our hypothesis that hops grown in different regions will produce distinct terroir-influenced quality attributes.

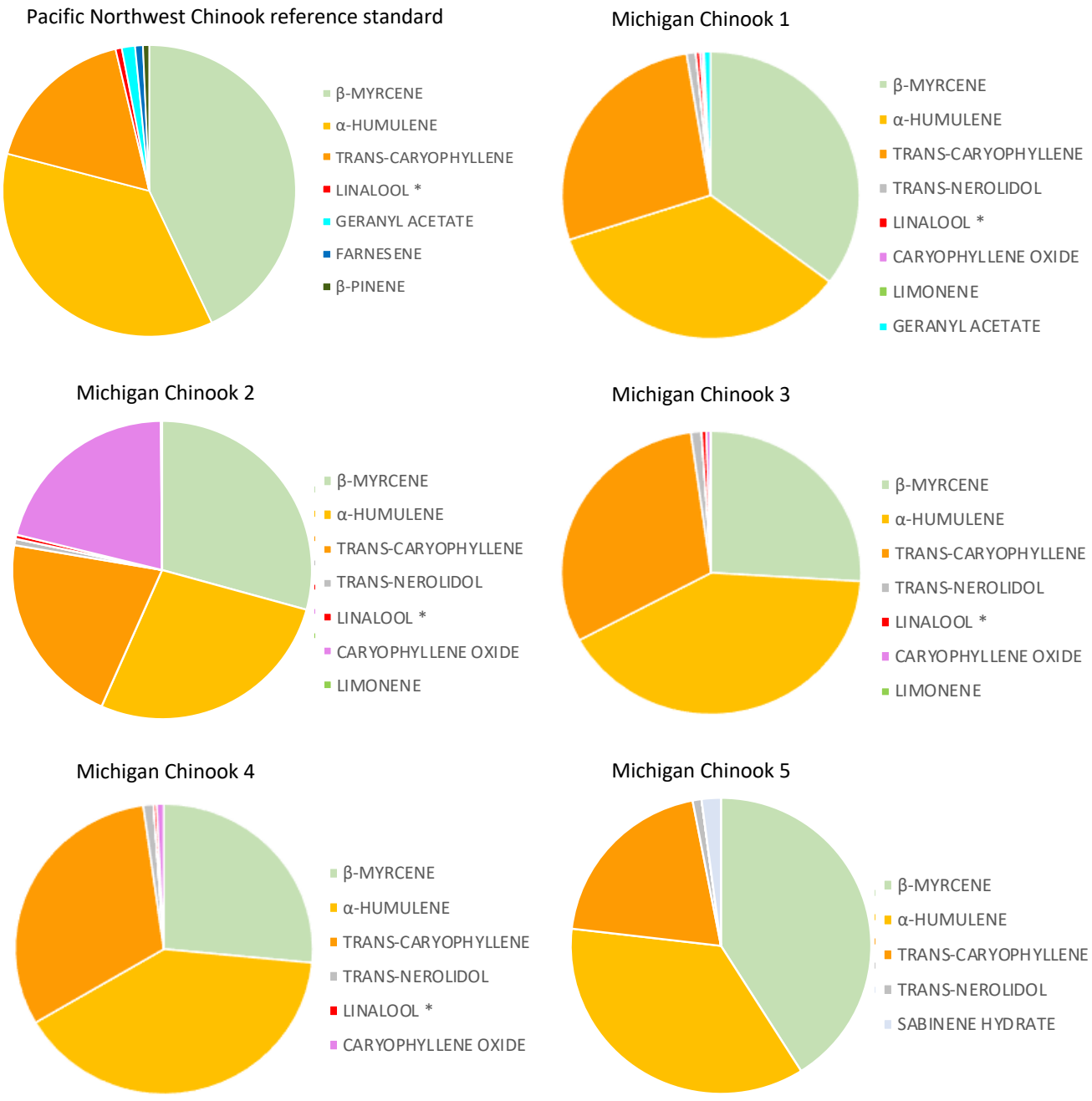


Figure 2. 2020 harvest Chinook hop oil profiles from 5 locations across Michigan and Chinook reference standard from 2016 Yakima Chief Hop Variety Handbook. Michigan hop oil profile complete by Cambium Analytica July 2021.

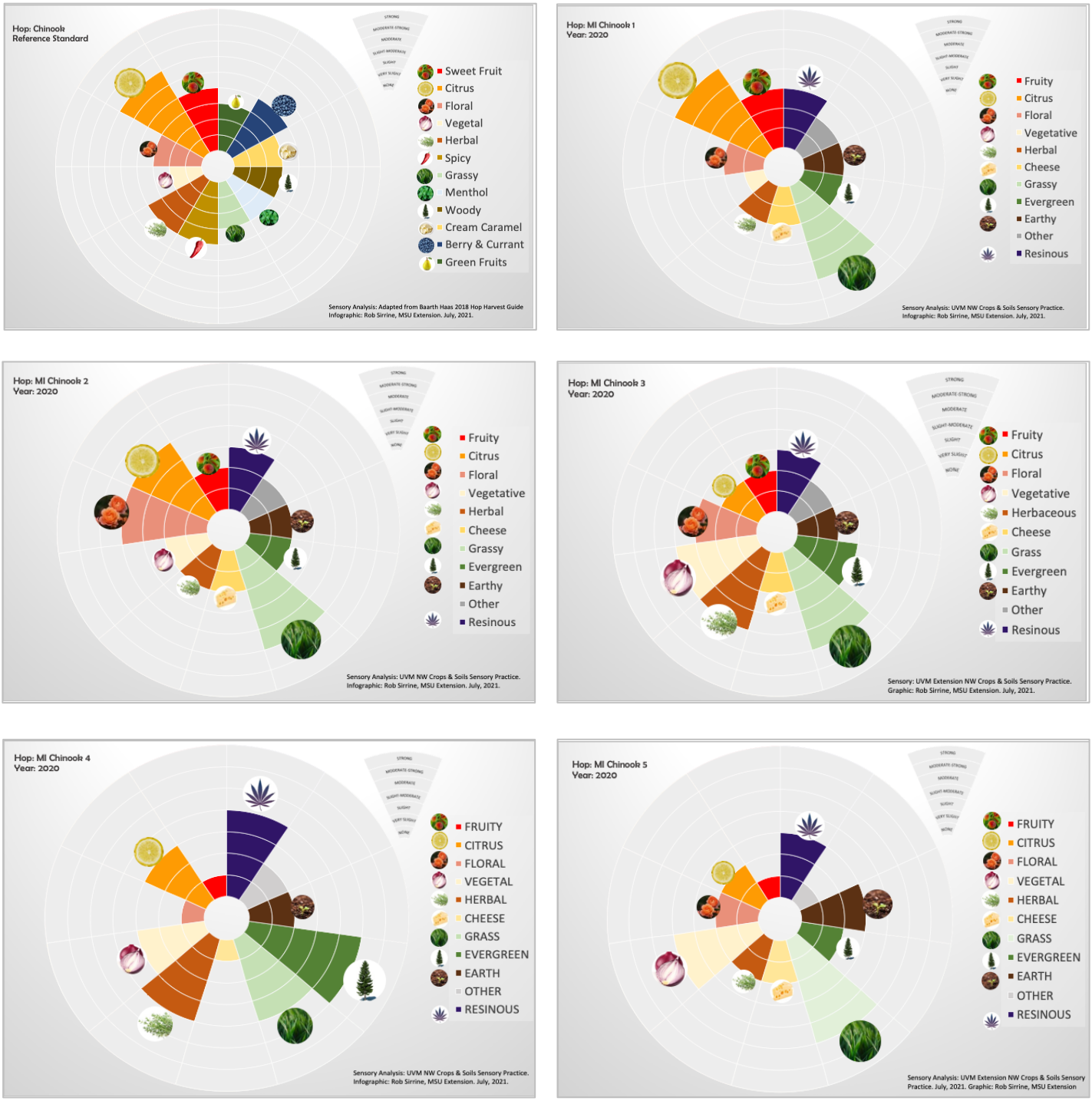


Figure 3. 2020 harvest Chinook hop sensory analysis results from 5 locations across Michigan and Chinook reference standard adapted from 2018 Barth Haas Hop Harvest Guide. Sensory analysis performed by UVM NW Crops & Soils Sensory Practice.

Hypothesis 2: Terroir-influenced hop quality attributes will result in single-hop beers with distinct organoleptic properties.

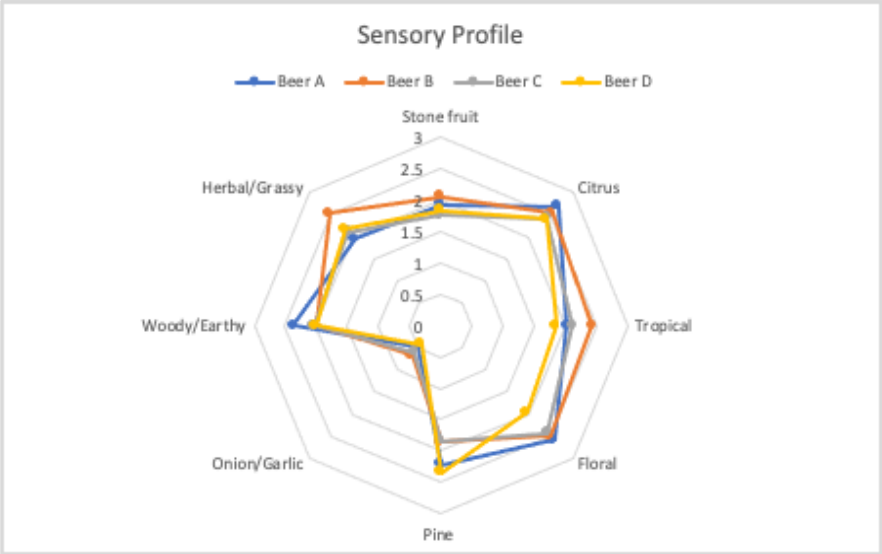
We brewed a five-barrel baseline beer, divided the beer into five one-barrel fermenters, “dry-hopped” four of the fermenters each with Chinook hops from one distinct growing region. Identical raw materials were used for the beer-the only changing variable was the dry-hop origin. We then conducted a blind taste test of beer aroma characteristics at the 2020 Great Lakes Hop & Barley Conference via descriptive sensory analysis (N=47) using a sensory profile ranking system (Table 1 below).

Table 1: Sensory profile ranking system as presented to the participants

0	1	2	3	4	5	6	7
none	very low	low	low-medium	medium	medium-high	high	very high

Aroma characteristics	Beer A	Beer B	Beer C	Beer D
Stone fruit				
Citrus				
Tropical				
Floral				
Pine				
Onion/garlic				
Woody/earthy				
Herbal/grassy				

Results suggest that sensory evaluators detected noticeable differences between the four beers made with Chinook hops from different growing regions.



Beers A & B. MI-grown Chinook; Beer C. OR-grown Chinook; Beer D. WA-grown Chinook.

Hypothesis 3: Consumer preference will vary based upon different terroir-influenced hop attributes.

Once the respondents completed the sensory portion of the analysis, they were asked to answer valuation questions, provide demographics, and report craft beer consumption habits. Respondents were asked to state their overall liking of each beer, assessed via a seven-point Likert scale, and to rank the beers from most favorite to least favorite (Table 2).

Table 2. Blind taste test aroma, bitterness, and valuation summary statistics

	Sample Average (st. dev.)			
Characteristic	**Beer A**	**Beer B**	**Beer C**	**Beer D**
Aroma				
Stone fruit	1.70	1.84	1.69	1.60
	(1.70)	(1.93)	(1.66)	(1.65)
Citrus	2.53	2.42	2.33	2.29
	(1.90)	(1.64)	(1.59)	(1.74)
Tropical	1.98	2.41[a]	2.09	1.79[a]
	(1.86)	(2.07)	(1.61)	(1.70)
Floral	2.49	2.40	2.31	1.98
	(1.96)	(1.75)	(1.54)	(1.61)
Pine	2.11	1.66	1.66	2.05
	(1.91)	(1.54)	(1.46)	(1.68)
Onion or Garlic	0.56	0.76	0.65	0.63
	(1.20)	(1.36)	(1.31)	(1.23)
Woody or Earthy	2.06	1.89	1.81	1.79
	(1.98)	(1.94)	(1.75)	(1.61)
Herbal or Grassy	2.09	2.36	1.96	1.94
	(1.51)	(1.99)	(1.61)	(1.51)
Bitterness	3.42[b]	2.84[b]	2.88[b]	3.09
	(1.46)	(1.44)	(1.27)	(1.42)
Overall liking (1 to 7)	4.97	4.61	4.75	4.73
Average rating (1=favorite, …, 4=least favorite)	2.39	2.40	2.58	2.61
Average WTP per pint	$4.56	$4.50	$4.47	$4.53

[a] Indicates a statistically significant difference at the 10% level.
[b] Indicates a statistically significant difference between Beer A and Beers B and C at the 5% level.
Footnotes: Sample sizes differ between aroma characteristics and valuations (average rating, overall liking, and WTP per pint) due to misinterpretations on behalf of respondents.

The findings of differences in mean scores for the sensory attributes, as well as different chemical compositions of hop terpenes and the unknowns analysis, provide supporting evidence for hop terroir.

OBJECTIVES

#	Objective	Completed?	
		Yes	No*
1	Improve hop quality and consistency	x	x
2	Determine unique hop aroma and flavor profiles that help brewers produce flavorful beer that consumers prefer.	x	

**If no is selected for any of the listed objectives, you must expand upon this in the challenges and lessons learned sections.*

ACCOMPLISHMENTS

List your accomplishments for the project's period of performance, including the impact they had on the project's beneficiaries, and indicate how these accomplishments assist in the fulfillment of your project's objective(s), outcome(s), and/or indicator(s).

#	Accomplishment or Impact	Relevance to Objective, Outcome, and/or Indicator
1	Increased knowledge of distinct terroir-influenced hop quality attributes based upon growing location	Short-Term: Producers leverage the distinct quality attributes of their hops Medium-Term: Producers increase quality control Long-Term: Development of "regional identities" that benefit farmers, farming communities and brewers Long-Term: An understanding of the relationships between hop quality attributes and environmental, biological, and production factors Long-Term: An understanding of how to modify factors to improve hop brewing values
2	Increase knowledge of consumer preference for single-hop beer flavor and aroma	TBD. Medium-Term: Improved consistency and quality of single-hop beers that optimizes consumer preference and help brewers meet consumer demand for unique beer with local ingredients.
3	Increased K of hop quality attributes that correlate with consumer preference	TBD. Further research is needed. Medium-Term: A methodological model for research on other specialty crops

CHALLENGES AND DEVELOPMENTS

Provide any challenges to the completion of your project or any positive developments outside of the project's original intent that you experienced during this project. Also, provide the corrective actions you took to address these issues. If you did not attain an approved objectives, outcome(s), and/or indicator(s), provide an explanation in the Corrective Actions column.

#	Challenge or Development	Corrective Action or Project Change
1	The COVID-19 pandemic presented a major challenge to the full completion of our project. While we were able to validate our three hypotheses, and complete Objective 2, we were only able to partially complete Objective 1. We will need to conduct additional in-depth consumer preference surveys and further outreach, education, and evaluation.	We requested and received multiple project extensions. Because Objective 1 was a longer-term objective, we pivoted to expand the scope of Objective 2 and completed hop chemical profile analyses and descriptive sensory analyses for over 40 hop samples. These results will help Michigan hop producers differentiate their hops from those grown in the Pacific Northwest and provide the initial base of knowledge to improve hop quality and consistency. In the following months we will also develop a Qualtrics survey of Michigan hop growers that submitted hop samples.

LESSONS LEARNED

Provide recommendations or advice that others may use to improve their performance in implementing similar projects.

We were able to validate our three hypotheses and complete one of two project objectives in the grant time-frame in spite of the pandemic. However, objective 1 is a longer-term objective that may not have been fully achievable even without a global pandemic. For future proposals we will ensure that objectives are achievable in the grant time-frame.

CONTINUATION AND DISSEMINATION OF RESULTS (IF APPLICABLE)

Describe your plans for continuing the project (sustainability; capacity building) and/or disseminating the project results.

Project Continuation

Project collaborators intend to continue hop-terroir research. Descriptive hop sensory and oil profile analyses demonstrated evidence of marked differences among hop cultivars based upon growing location. We intend to repeat the analyses for 2021 harvest year hops so Michigan hop producers can leverage the distinct quality attributes of their hops and continue outreach and promotion efforts to craft beer stakeholders to meet brewer demand for unique beers with locally grown ingredients.

Project results will continue to be disseminated through academic and industry publications as well as conference presentations such as the Michigan Brewers Guild Annual Conference and the Master Brewers Conference. Finally, we intend to collaborate with Hop Growers of Michigan to continue terroir-based research, promotion, and marketing efforts.

BENEFICIARIES

Number of project beneficiaries: 60+

ADDITIONAL INFORMATION

Provide additional information available (i.e., publications, websites, photographs) that is not applicable to any of the prior sections.

Publications

- Staples, A.J., J R. Sirrine, A. Adams, A. Mull, S. Stuhr, T. Malone. 2021. Untapping Beer Terroir: Experimental Evidence of Regional Variation in Hop Flavor Profiles. Submitted to Journal of Wine Economics. JWE-2021-027. *In Review.*
- Staples, A.J., T. Malone, J R. Sirrine. 2020. Hopping on the Localness Craze: What brewers want from state-grown hops. *Managerial and Decision Economics*. Volume 42, Issue 2, March 2021, Pages 463-473. **https://doi.org/10.1002/mde.3246**
- Miller, S.R., J R. Sirrine, A. McFarland, P. Howard, T. Malone. 2019. Craft beer as a means of economic development: An economic impact analysis of the Michigan value chain. Beverages. 5(2): 35; https://doi.org/10.3390/beverages5020035

Presentations

- Staples, A.J., J R. Sirrine, T. Malone. 2021. Untapping terroir: Experimental evidence of regional variation in hop flavor profiles. Master Brewers Association of the Americas Conference. October 28, 2021.
- Staples, A.J. Michigan Grown and Michigan Brewed: Establishing and Expanding Local Beer Value

Chains. Penn State University Extension Zoom Webinar. June 15, 2021.

- Staples, A.J., J R. Sirrine, T. Malone. 2021. Untapping terroir: Experimental evidence of regional variation in hop flavor profiles. American Hop Convention/HRC Annual Meeting. Virtual. January, 2021.
- Adams, A., A. Mull, J R. Sirrine. 2021. Hop terroir, cannabis, ad Alice in Wonderland: The potential for analytics to improve beer flavor and aroma. Michigan Brewers Guild, MBAA, MSU Extension Annual Meeting. Virtual. January, 2021.
- Sirrine, J R., A. Staples, A. Adams, A. Mull, S. Stuhr, T. Malone, D. Jones. 2021. Untapping terroir: Experimental evidence of regional variation in hop flavor profiles. Small grains for malting/craft beverages research virtual happy hour presentation. March, 2021.
- Staples, A., J R. Sirrine, T. Malone. 2020. Untapping terroir: Experimental evidence of regional variation in hop flavor profiles. Food Distribution Research Society Annual Conference. October, 2020.
- Sirrine, J R. 2020. Investigating the terroir-influenced quality attributes of hops. Great Lakes Hop and Barley Conference. March, 2020.
- Sirrine, J R. 2020. Horticultural Best Practices for Disease Management, Quality, and Yield Benefits in Hop. Ohio State Hop Conference. February, 2020. Virtual.
- Malone, T., J R. Sirrine, E. Lizotte, V. Caputo., A. Adams. 2019. What's local have to do with it? Exploring hop terroir in craft beer. Beeronomics Conference. Pilsen, Czech Republic.

Michigan Hop Terroir Press

- "Qualities that may change the flavor profile of hops (terroir)" https://michigangrown.org/seantrowbridge_podcast/
- "Beer starts in the soil" https://www.experiencegr.com/articles/post/beer-starts-in-the-soil/
- "…Michigan hops express the unique terroir of the region." https://hopheadfarms.com/why-michigan-hops/
- "Hope for Leelanau's hop industry" https://www.leelanauticker.com/news/hope-for-leelanaus-hop-industry/
- "Beer heroes battle hops disease in Great Lakes State". https://www.forbes.com/
- "Taste our terroir: brewing a 100% Michigan beer at home" https://www.drinkible.com/tag/michigan-hop-alliance/
- "Terroir creates surprising flavors". https://www.porchdrinking.com/articles/2020/03/09/hop-farming-spreads-across-us/
- "What are brewers' favorite hops in 2020?" https://www.hopculture.com/yakima-hop-farms-trends-craft-beer-2020/
- "Michigan hops are tasty". https://podcasts.apple.com/us/podcast/msu-hop-podcast/id1561693914
- "…based in the terroir of growing regions." https://bluelakehops.com/about-us/
- Hops insider: time to talk terroir. https://brewingindustryguide.com/hops-insider-time-to-talk-terroir/
- "We aim to showcase the 'terroir' of Michigan in each glass". https://www.breweryoutre.com/about

The Authorized Individual must sign this statement after the applicable report form is completed.

I certify that the statements and information contained in these documents are true, accurate, and complete.

Signature of Responsible Official: 

Date: August 18, 2021