2019 Hop Harvest Timing

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In the Northeast, hop harvest generally begins in mid-August and continues through mid-September. Harvest date is primarily dependent on the hop variety, but weather can delay or hasten maturation and impact when harvest will occur. In addition to weather, various pests, such as spider mites and downy mildew, can similarly impact harvest timing. The time at which you harvest hops can affect the various qualities of your finished product. Alpha and beta acid content peaks before many essential oils have fully developed. Delaying harvest can provide time for these oils to develop, but increases the amount of time the hops are left vulnerable to disease and late season rainfall, which can result in degradation of resins.

Although typical harvest dates are well established for Europe and the Pacific Northwest, the Northeast experiences a distinct climate with unique growing conditions that can greatly impact the various resins and oils in hops. A general window for harvest timing can be gleaned from these other locations, but region specific information is required for producing a fully mature hop cone with the desired aroma and flavor profiles in the Northeast. Traditionally, harvest timing is determined by dry matter and resin content. This method encourages adequate acid production over aromatic oil production, thereby limiting options for end users. To better understand how factors such as cone smell, look and dry matter content correspond to the development of resin and oils, a harvest timing trial was initiated in 2017 in Northfield, MA as a preliminary study and has continued in Alburgh, VT through 2019 as a replicated study. We aim to use these data to develop regional harvest timing standards that can assist hop growers in producing the highest quality hops.

MATERIALS AND METHODS

Cascade hops from Borderview Research Farm in Alburgh, VT were collected, analyzed, and reported over the harvest period for the study. The hop variety Cascade was chosen for this study because it has aromatic qualities, it is a hop variety that most northeastern hop yards already have in the ground, and it is a non-proprietary hop used by local brewers.

Three plots were randomly designated within the Cascade hops planted in the UVM hop yard. Plots contained 7 hop hills (14 strings) and were marked with ground flags and flagging tape to make sure they were not harvested with the rest of the crop. In 2019, there were 3 collection dates throughout the harvest season falling into the following categories: Early, Normal, and Late (Table 1). Samples were taken at weekly intervals.

Table 1. 2019 Cascade harvest dates (HD).

Harvest Date		
Early	HD 1	3-Sep
Normal	HD 2	10-Sep
Late	HD 3	17-Sep

Samples were handpicked from each plant within plots and taken from ground level to the top wire for representative samples. Each sample, 200g of wet hop cones, was shipped to Cornell Agritech in Geneva, NY overnight. The collected samples were shipped as wet cones over the three-week period. Cornell Agritech conducted their Brew Quality and Essential Oil packages using the American Society of Brewing

Chemists procedures 4c, 12, 13, 14, and 17. Measurements included in this test are percent moisture, hop storage index (HSI), alpha and beta acids, total oil content, and volatile oil profile.

Data was analyzed using SAS Version 9.4. For the hop quality data, we conducted a linear mixed model analysis with repeated measures (PROC MIXED). Fixed effects included collection date, replicate, year, and collection date by year. All statistics will be run at the 0.10 level of significance and generated using SAS Version 9.4 (Copyright 2014, SAS Institute Inc., Cary, NC, USA).

Variations in project results can occur because of variations in genetics, soil, weather, and other growing conditions. Statistical analysis makes it possible to determine whether a difference among treatments is real or whether it might have occurred due to other variations in the field. At the bottom of each table, a LSD value is presented for each variable (e.g. yield). Least Significant Differences (LSD's) at the 10% level of probability are shown. Where the difference between two treatments within a column is equal to or greater than the LSD value at the bottom of the column, you can be sure in 9 out of 10 chances that there is a real difference between the two values. Treatments that were not significantly lower in performance than the highest value in a particular column are indicated with an asterisk. In the following example, treatment A is significantly different from treatment C but not from treatment B. The difference between A and B is equal to 200, which is less than the LSD value of 300. This means that these treatments did not differ in yield. The difference between A and C is equal to 400, which is greater than the LSD value of 300. This means that the yields of these treatments were significantly different from one another.

Treatment	Yield
A	**2100***
B	1900*
C	1700
LSD	300

RESULTS

Table 2 shows a summary of the temperature, precipitation and growing degree-day (GDD) summary. In the 2019 growing season, there were an accumulated 2322 GDDs, 110 more than the historical 30-year average with greatest deviations from the norm occurring in April and July. The 2019 growing season experienced a wet spring followed by a dry summer with well below average precipitation occurring during the month of July.

Table 2. Temperature, precipitation and growing degree day summary, Alburgh, VT, 2019.

Alburgh, VT	March	April	May	June	July	August	Sept
Average temperature (°F)	28.3	42.7	53.3	64.3	73.5	68.3	60.0
Departure from normal	-2.79	-2.11	-3.11	-1.46	2.87	-0.51	-0.62
Precipitation (inches)	1.36	3.65	4.90	3.06	2.34	3.50	3.87
Departure from normal	-0.85	0.83	1.45	-0.63	-1.81	-0.41	0.23
Growing Degree Days (Base 50)	9	59	189	446	716	568	335
Departure from normal	9	59	-9	-29	76	-13	17

Based on weather data from a Davis Instruments Vantage Pro2 with WeatherLink data logger. Historical averages are for 30 years of NOAA data (1981-2010) from Burlington, VT. (http://www.nrcc.cornell.edu/page_nowdata.html).

Alpha acid, beta acid, HSI, and moisture were measured for each harvest date (Table 3). Alpha acids were highest during HD 1 and HD 2 (5.8% each) however, differences between harvest dates were not significant.

Similarly, beta acids were not different amongst treatments but was highest in HD 2 at 7.5% for the trial. Hop Storage Index (HSI) can be a good indicator for hop quality and can be indicative of the degradation of alpha and beta acids over time. Lower values below 0.300 are indicative of good quality, whereas values above 0.300 are indicative of poor quality. HSI can be impacted by a number of environmental factors in addition to harvest timing. During this three-week window, lowest values for HSI were observed during the second harvest date at 0.186 and was statistically similar to harvest date 3 at 0.191. Harvest moisture was highest for HD 1 at 80.1% and dropped in the second and third weeks to 76.9 and 77.0% respectively. Each of these values falls within "normal" desirable ranges for hop harvest if using moisture as the sole means of determining harvest timing. Harvesting before aromas fully develop can result in lesser quality hops, making it important to use additional means of measuring hop readiness to determine ideal harvest windows.

Table 3. Brewing quality for Cascade hops harvested over a 3 week period in 2019.

Harvest Date	Alpha acid %	Beta acid %	HSI	Harvest moisture %
HD 1	5.8	6.9	0.252	**80.1**
HD 2	5.8	7.5	**0.186**	76.9
HD 3	5.5	7.0	0.191*	77.0
LSD (0.10)	NS	NS	0.018	1.75
Trial mean	5.7	7.1	0.210	78.0

*Treatments with an asterisk are not significantly different than the top performer in **bold**.
LSD – Least significant difference.
NS – No significant difference between treatments.

Samples were analyzed for total oils and essential oil profiles (Table 4; Figure 1). Total oils were highest during HD 2 at 1.84 ml/100g of hops with HD 1 statistically similar at 1.78 ml/100g of hops (Table 4). Lowest total oil was seen in HD 3 at 0.800 ml/100g of hops. While total oil appeared to drop drastically from HD 2 to HD 3, values are within expected ranges for Cascade hops which can be expected from 0.8-2.5 ml/100g when compared to Pacific Northwest values. Within the essential oil profile, levels of beta-pinene, myrcene, limonene, and linalool peaked at HD 2 (0.140, 10.9, 0.038, and 0.071 mg/g of hops respectively) and were significantly different from HD 3, but not HD 1, which saw sharp reductions of these compounds and were less than half of HD 2 and HD 1. Geranyl acetate was highest at HD 1 with 0.452 mg/g hops and was statistically similar to HD 2 at .351 mg/g hops, whereas beta-citronellol and geraniol were highest at HD 3 with 0.005 mg/g hops and 0.069 mg/g hops respectively. Differences in caryophyllene, humulene, and nerol were not statistically significant.

Table 4. Total oil and essential oil profile for Cascade hops harvested over a 3-week period in 2019.

Harvest date	Total oil ml/100g hops	Beta pinene mg/ g hops	Myrcene mg/ g hops	Limonene mg/ g hops	Linalool mg/ g hops
HD 1	1.78*	.097*	7.03*	0.029*	0.71*
HD 2	**1.84**	**0.140**	**10.9**	**0.038**	**0.071**
HD 3	0.800	0.058	2.89	0.017	0.047
LSD (0.10)	0.833	0.079	5.77	0.016	0.022
Trial mean	1.47	0.098	6.93	0.028	0.0629

*Treatments with an asterisk are not significantly different than the top performer in **bold**.
LSD – Least significant difference.

Table 4 continued: Total oil and essential oil profile for Cascade hops harvested over a 3-week period in 2019.

Harvest date	Caryophyllene mg/ g hops	Humulene mg/ g hops	Geranyl acetate mg/ g hops	Beta citronellol mg/ g hops	Nerol mg/ g hops	Geraniol mg/ g hops
HD 1	1.05	2.58	**0.452**	0.000	0.227	0.031
HD 2	0.833	2.00	0.351*	0.002*	0.170	0.025
HD 3	0.864	2.35	0.217	**0.005**	0.223	**0.069**
LSD (0.10)	NS	NS	0.226	0.004	NS	0.010
Trial mean	0.914	2.31	0.340	0.002	0.2065	0.042

*Treatments with an asterisk are not significantly different than the top performer in **bold**.
LSD – Least significant difference.
NS – No significant difference between treatments.

Total oil and essential oil profiles changed over the course of the three-week harvest period with essential oils presented in terms of milligrams of oil per gram of hops (Figure 1). Each essential oil is presented this way to avoid differences in total oil volume and to more accurately compare the impacts of harvest date treatments. The significant decline in total oil and its major constituents from HD 2 to HD 3 could potentially be explained by the degradation of lupulin glands within hop cones. Increased disease pressure could have adversely impacted cone quality in the third week of the study.

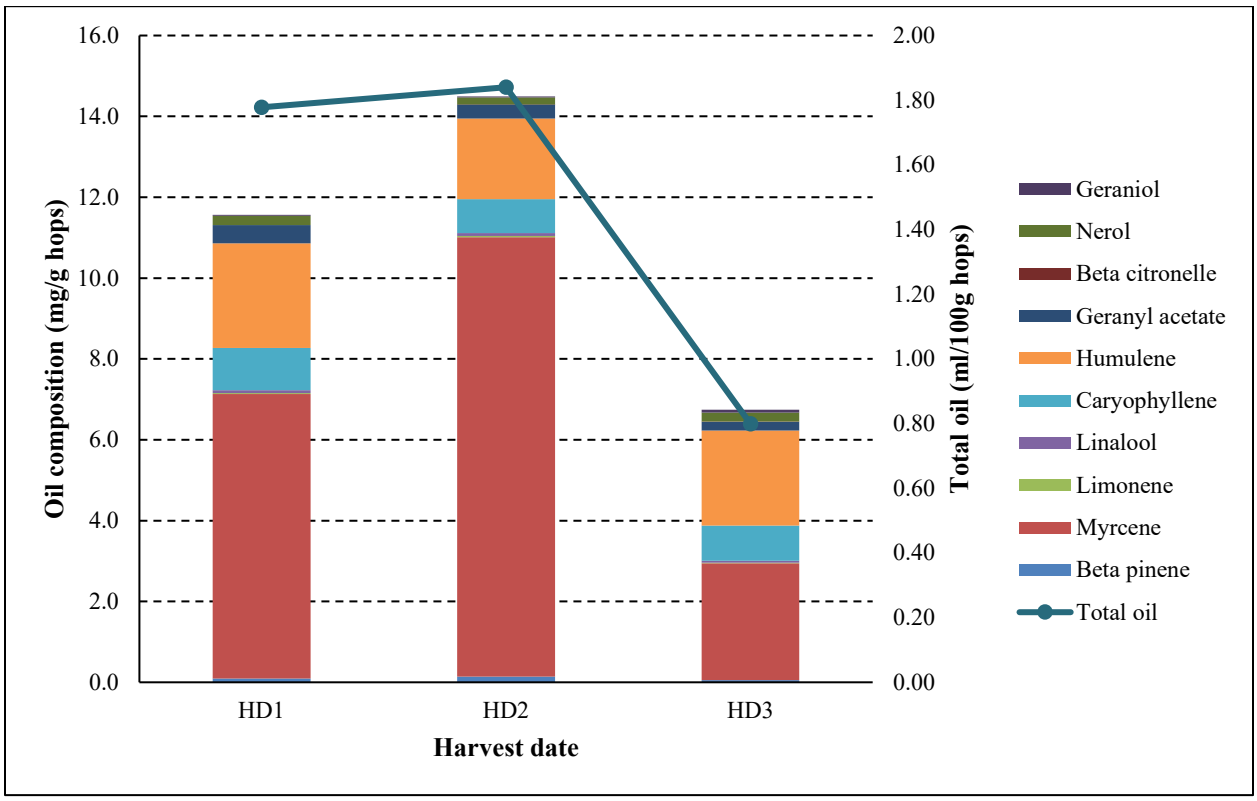

Figure 1. Total oil and essential oil composition for Cascade hops harvested over 3 week period in 2019.

Because many suppliers and industry standards reflect these essential oil profiles as a percentage of total oil, this has also been included within this report, factoring in the density of each analyzed compound (Figure 2). This can also provide an interesting picture when comparing proportions of each essential oil in relation to the total oil. Of the ten analyzed essential oils, these appeared to make up 78.4% of the total oil for HD 1 compared to HD 2 and HD 3 which make up 96.5% and 99.6% of the total oil respectively. This could potentially be explained by the presence of other non-analyzed compounds or precursors or degradative compounds to those analyzed. While HD 3 contained the smallest total oil at .800 ml/100 g hops, these 10 essential oils made up nearly 100% of total oil and showed greatest percentage of humulene, caryophyllene, and nerol compared to the other two harvest dates.

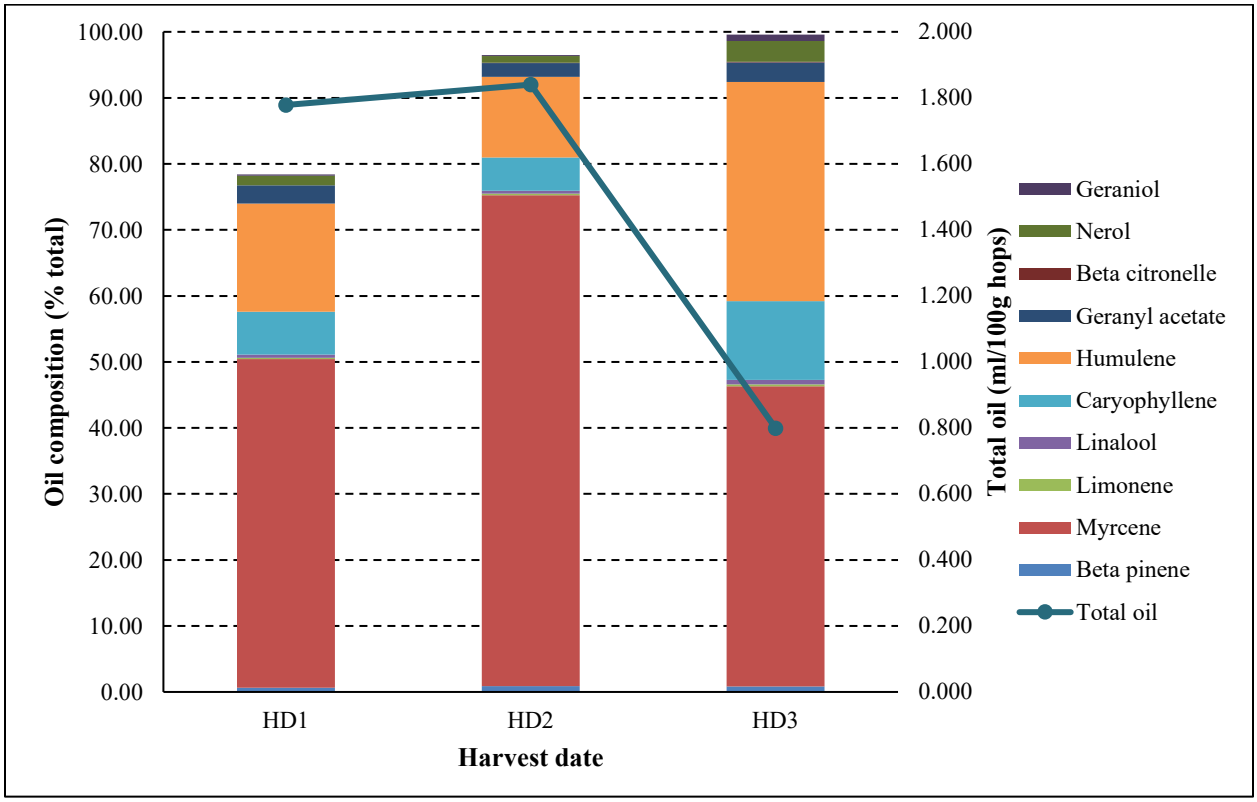

Figure 2. Total oil and essential oil proportions for Cascade hops harvested over 3 week period in 2019.

DISCUSSION

In addition to hop alpha and beta acids, total oil and essential oil profiles can be important constituents for brewers adding flavor and aroma to beers. While alpha and beta acids did not appear to be affected by harvest date in this year of the study, 2018 results showed greater differences taking place over a 5 week period (20-Aug through 17-Sep). Essential oils were not analyzed in 2018 because of poor laboratory handling and processing, but alpha and beta acids were analyzed. The results from 2018 showed an increasing trend in alpha and beta acids over the 5 week period with HD 1 (20-Aug) alpha acid at 4.2% and beta acid at 5.6%. This increased to 7.6% alpha acid and 8.5% beta acid for HD 5 (17-Sep). 2019 data showed peak values at HD 2, whereas 2018 data showed peak values during the last harvest date.

With this first year of hop oil analysis, oils peaked at our second harvest date and severely dropped after that point. Each of the ten analyzed compounds is known to impact the aromatic profiles in hops and can change throughout the brewing process. These may not develop as quickly as alpha and beta acids within hop cones and are highly subject to volatilization throughout processing. Not only did the total oil change over the three-week period, but also composition of essential oils and their proportions in relation to total oil.

This year of study showed that our maximum potential for hop resins and essential oils for Cascade hops occurred during the second harvest date, however a number of factors could influence this timing. Harvesting too early will also disrupt the various flavor constituents of hops as neither oils nor alpha and beta acids have had the ability to reach peak levels. However, harvesting too late can also reduce brewing quality and aroma through degradation and increased exposure to pests, diseases, and various weather conditions. In 2019, cones became noticeably browner in the week following HD 2 and major cone affecting diseases such as downy mildew and alternaria were found throughout the hops, perhaps impacting the brewing quality and aromatic profiles of the hops. Later harvested hops are also at risk of accelerated oxidation in storage through the loss of volatile aroma compounds. Later harvested hops usually suffer from shortened storability as do cones that have been damaged by diseases and or pests. As we continue this study, we hope to determine how harvest timing can impact the various aromatic compounds that help to contribute to aromatic and flavor characteristics for hops through in depth sensory analysis in beers. We also hope to provide additional insight on proper harvest timing to accentuate resins and oils in hops for farmers in the Northeast.

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