NORTHWEST CROPS & SOILS PROGRAM

# 2019 Hop Germplasm Study

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THE UNIVERSITY OF VERMONT EXTENSION

**2019 HOP GERMPLASM STUDY**

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Until now, commercial hop (*Humulus lupulus* L.) production has not occurred in the northeast (NE) region of the United States for 150 years. Vermont production peaked in 1860 when the state produced 638,767 lbs of dried hops (Kennedy, 1860). A combination of the spread of hop downy mildew, the expansion of production in western states, and prohibition laws from the 1920's contributed to the decline of the 19th century NE hop industry. Today, the Pacific Northwest states of Washington, Oregon, and Idaho remain the dominant hop production sites of the U.S. However, hop production in non-traditional regions is growing and now accounts for over 2% of the total U.S. hop acreage (George, A., 2014). Nationally, there has been recent and unprecedented growth in the craft beer sector which has dramatically increased demand for local hop production.

Hops are native across North America, but European hops and North American landraces were cultivated in northern states from colonization to prohibition. Genetic markers have been used to classify wild North America germplasm (Bassil et al., 2008; Peredo et al., 2010). Wild or naturalized hop plants are in the Northeast landscape, yet they are not grown on a commercial scale. Downy mildew disease pressure is currently one of the biggest concerns in NE hop production. It is possible that naturalized plants have evolved arthropod and disease pest resistance traits allowing them to persist in the environment. It is critical that we begin an active evaluation of existing wild cultivars and emerging hop varietals to explore their potential to increase NE hop production. Furthermore, assessment of germplasm could aid with the discovery of novel and unique hop characteristics and flavor profiles that could be made widely accessible to producers and brewers.

## MATERIALS AND METHODS

Wild hop plants were initially collected from eight locations within Massachusetts, New York, and Vermont in the fall of 2016 (Figure 1, Table 1). Multiple rhizome cuttings, approximately 6" in length, were taken from each site, placed in plastic bags and kept in refrigerated storage. Cuttings were occasionally inspected for spoilage and any compromised samples were discarded. After three months of cold storage, the remaining cuttings were planted into 4" pots with Fafard 3B potting media (Kent, New Brunswick) at the UVM greenhouse. Mother plants were produced from the cuttings, maintained at a temperature of 65-70° F and watered as needed by greenhouse staff. Vegetative cuttings were taken from the mother plants to obtain additional plant stock. Cuttings consisted of approximately three nodes and were treated with Hormodin 1™ (Mainland, Pennsylvania) rooting hormone prior to planting into 4" pots with vermiculite. The plants were removed from the greenhouse and placed outside to harden off in mid-May.

The plants were transplanted on 20-Jun and 21-Jun 2017 at Borderview Research Farm in Alburgh, VT. Approximately 14-18 individuals from each of the 10 wild hop varieties were planted totaling 163 plants overall. Plants were spaced 3' apart and planted into weed barrier fabric. In 2018, plants were once again propagated and moved into the main hop yard, each variety occupying one 35' plot at 5' spacing for a total of 7 hills per variety.


**Figure 1. Map of original wild hop rhizome collection sites.**

**Table 1. Wild hop varieties and collection location.**

| Variety | Town, State | Latitude | Longitude |
|---|---|---|---|
| Northfield 001 | Northfield, MA | 42.71502 | -72.465087 |
| Northfield 003 | Northfield, MA | 42.71502 | -72.465087 |
| Peacham 001 | Peacham, VT | 44.38361 | -72.1863889 |
| Peacham 002 | Peacham, VT | 44.38361 | -72.1863889 |
| Wolcott 001 | Wolcott, VT | 44.54417 | -72.4186111 |
| Mount Toby 001 | Sunderland, MA | 42.50383 | -72.531131 |
| Argyle 001 | Argyle, NY | 43.23797 | -73.495185 |
| Kingdom 001 | Tunbridge, VT | 43.92181 | -72.5718315 |
| Kingdom 002 | Tunbridge, VT | 43.92181 | -72.5718315 |
| Morrisville 001 | Morrisville, NY | 42.83296 | -75.567996 |

In 2019, germplasm varieties were fertilized using calcium ammonium nitrate on 10-May (100 lbs N $ac^{-1}$) and 30-May (50 lbs N $ac^{-1}$). Each hill was strung on 13-May using a double coir string leading up to the top wire and trained 30-May. Beginning on 24-May, the entire hop yard was sprayed with Champ WG (Alsip, IL) at a rate of 0.50 lbs in 50 gallons of water and was sprayed on a weekly basis through 28-Jun. Plants were scouted for downy mildew spikes aerial and basal spikes from 5-May through 8-Jul. Plants were additionally scouted on a weekly basis starting 17-Jun for pest and beneficial insects through 19-Aug. Two plants and three random leaves per plant within each plot (variety) were visually inspected. The populations of three pests and one beneficial insect including potato leaf hoppers (PLH), hop aphids (HA), two-spotted spider mites (TSSM), and spider mite destroyers (SMD) present on each leaf was recorded.

All ten varieties were harvested and total yield and quality data were obtained on 12-Sep. Plants were harvested using a Hopster 5P hop harvester (HopsHarvester LLC, Honeoye, NY). The number of individual plants harvested and total cone yield was recorded for each line in the germplasm collection. Cone samples were weighed and dried to determine dry matter content. Cones were also rated in browning severity on a 1-10 scale where 1 indicates low browning and 10 indicates severe browning. Samples of harvested varieties were vacuum sealed and shipped for analysis. These samples were sent to Cornell Agritech (Geneva, NY) for brew quality analysis as well as essential oil profile and total oil content. Trial was non-replicated with each plot consisting of seven hills for each germplasm variety.

## 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, 157 less 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. Supplemental irrigation was applied to plants at a rate of 4500 gal $ac^{-1}$, however drier summer months and limited well capacity limited the ability to provide adequate water to the crop.

**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 | -13 | -52 | -103 | -36 | 86 | -14 | -25 |

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).

Although these data were not analyzed for statistical differences, it is worth noting the observed differences in pest pressure, yield, cone quality, and brewing quality.

The germplasm lines appeared to differ in their susceptibility to pests (Table 3). With the wet spring and above average precipitation in April and May, conditions were conducive for heavy downy mildew pressure within the hop yard. Aerial spike and basal spike data is presented as an average number of spikes per plot with basal spikes more prevalent early in the growing season before training, and aerial spikes present later in the growing season after training. Wolcott 001 showed the highest yearly occurrences for downy mildew aerial and basal spikes at 10.0 and 8.0 spikes plot$^{-1}$ whereas Peacham 002 showed the lowest average number of aerial spikes at 0.5 spikes plot$^{-1}$ and Argyle 001 had the lowest average number of basal spikes at 0.4 spikes plot$^{-1}$.

**Table 3. Insect and disease scouting incidence for Germplasm varieties, Alburgh, VT 2019.**

| Variety | Aerial spike plot$^{-1}$ | Basal spike plot$^{-1}$ | HA leaf$^{-1}$ | PLH leaf$^{-1}$ | TSSM leaf$^{-1}$ | SMD leaf$^{-1}$ |
|---|---|---|---|---|---|---|
| Peacham 002 | 0.5 | 1.0 | 9.3 | 4.5 | 0.0 | 0.8 |
| Northfield 003 | 2.8 | 1.4 | 5.8 | 6.0 | 1.0 | 1.2 |
| Kingdom 002 | 3.4 | 1.4 | 11.3 | 4.9 | 0.5 | 0.3 |
| Kingdom 001 | 1.2 | 1.8 | 7.6 | 3.4 | 5.5 | 0.0 |
| Argyle 001 | 6.2 | 0.4 | 6.4 | 2.1 | 3.3 | 0.0 |
| Northfield 001 | 5.0 | 0.8 | 7.4 | 2.9 | 4.0 | 0.0 |
| Morrisville 001 | 8.4 | 5.3 | 3.9 | 2.6 | 0.0 | 0.0 |
| Wolcott 001 | 10.0 | 8.0 | 14.4 | 3.1 | 1.8 | 0.0 |
| Mount Toby 001 | 6.4 | 1.6 | 7.0 | 1.9 | 1.7 | 0.2 |
| Peacham 001 | 2.6 | 1.0 | 4.4 | 4.1 | 0.4 | 0.0 |

HA= hop aphid. PLH = Potato leaf hopper. TSSM = two-spotted spider mites.

This season we also noticed high aphid populations throughout the scouting period compared to the 2018 growing season in which TSSM were the more prevalent pests (Figure 2). Highest populations for HA were seen on Wolcott 001 at 14.4 HA leaf$^{-1}$ compared to highest 2018 populations (also observed on Wolcott 001) at 0.82 HA leaf$^{-1}$. Northfield 003 had highest PLH populations at 6.0 PLH leaf$^{-1}$ compared to the lowest populations seen on Mount Toby 001 at 1.9 PLH leaf$^{-1}$. Two-spotted spider mite populations were lowest of the three main observed pests with none observed on Peacham 002 or Morrisville 001 and highest populations seen on Kingdom 001 at 5.5 TSSM leaf$^{-1}$. Wolcott 001 showed the highest overall pest populations, largely as a result of high aphid pressure, compared to Morrisville 001 which showed overall lowest populations for HA, PLH, and TSSM. As we continue the study, we plan to continue scouting germplasm varieties on a weekly basis and hope to observe any difference in cultivar susceptibility.

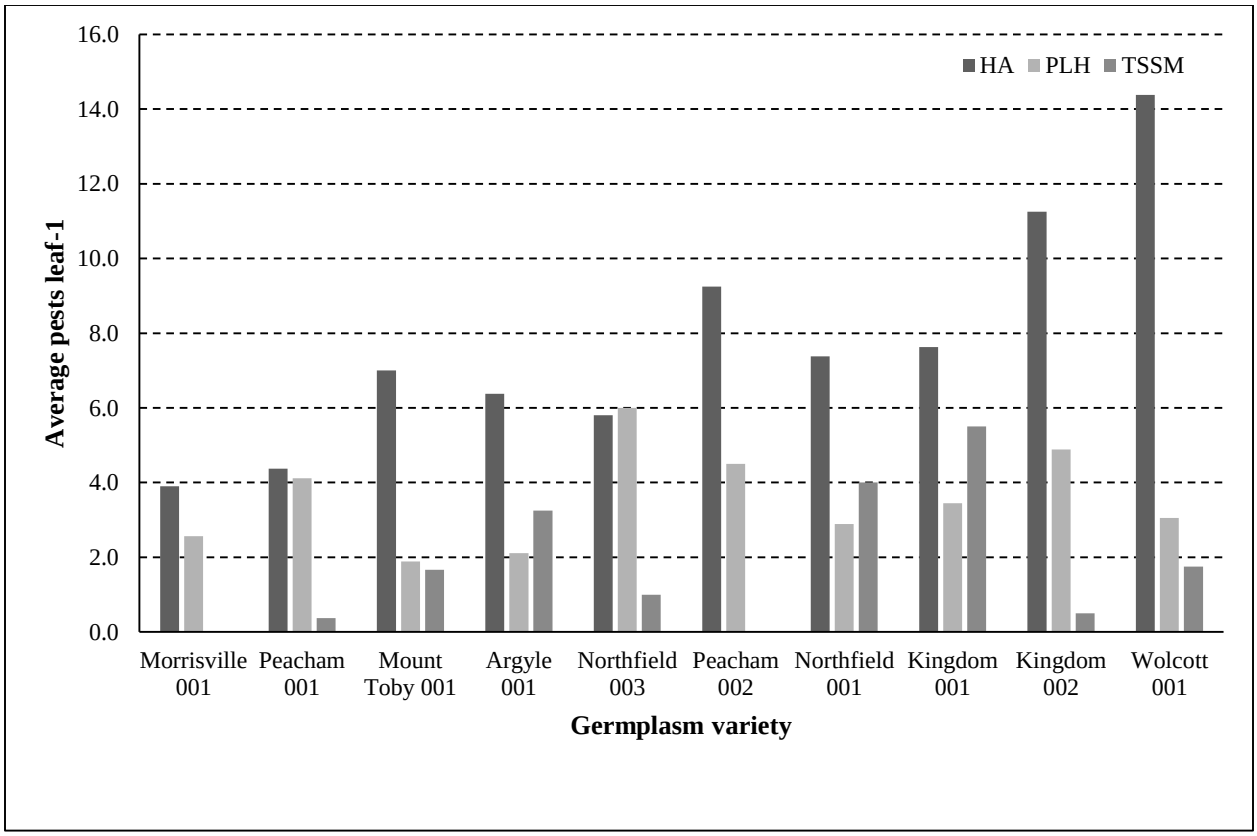


**Figure 2. Average number of HA, PLH, and TSSM per leaf on each germplasm lines, 2019.**

Hop varieties also differed in yield and harvest characteristics (Figure 3, Table 4). Peacham 002 and Mount Toby 001 were the highest yielding varieties at 822 and 688 lbs $ac^{-1}$ respectively and showed much higher yields compared to 2018 where Peacham 002 yielded only 242 lbs $ac^{-1}$ and Mount Toby 001 yielded only 370 lbs $ac^{-1}$ as the top performers of 2018. Increased yields were expected as plots were in their second year of growth. Higher yields could be expected in subsequent years as plants further establish. Based on dry matter alone, and when compared to widely grown commercial varieties, many of the germplasm varieties were likely harvested beyond an ideal window and dried down much faster than previous years. Most hops are generally harvested between 20-26% dry matter, whereas a number of these varieties were harvested above 30% dry matter.

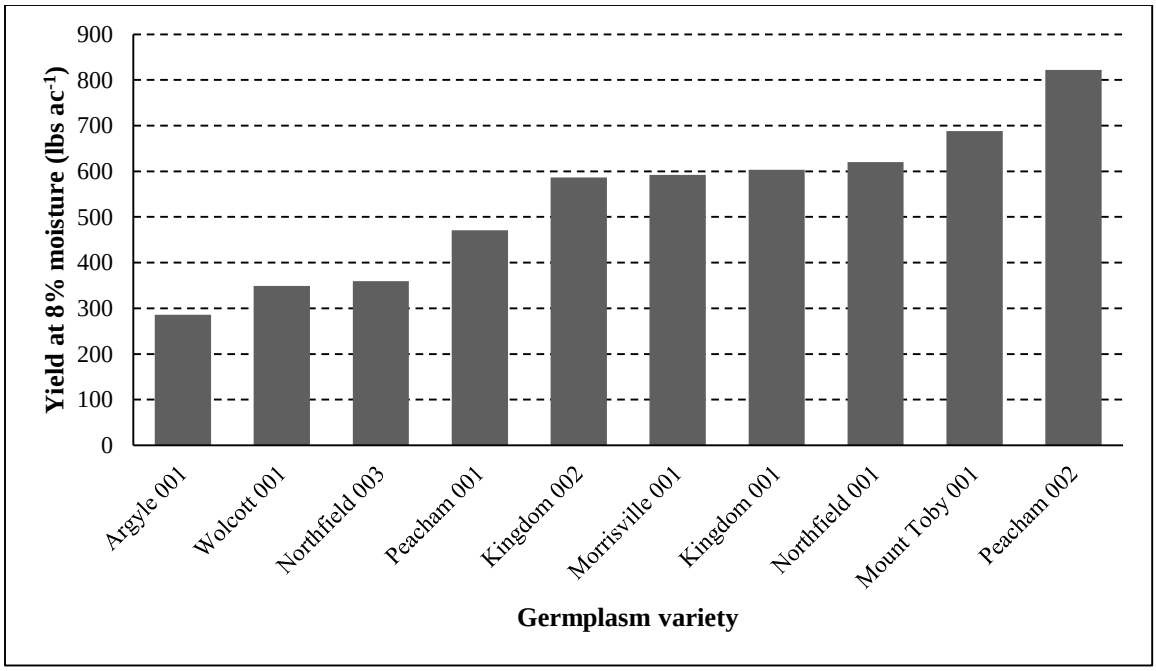


**Figure 3. Hop germplasm cone yields at 8% moisture, 2019.**

Kingdom 002 had the highest 100 cone weight at 39.6 g, whereas Wolcott 001 had the lowest 100 cone weight at 12.0 g. Cone size and shape varied greatly across germplasm varieties. In 2019, cones became noticeably browner in the week leading up to harvest 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 in addition to yields. All varieties as a result showed high incidence of cone disease and severity throughout the study.

**Table 4. Germplasm yields and cone quality, 2019.**

| Variety | Yield at 8% moisture | Harvest dry matter | 100 cone weight | Cone disease incidence | Cone disease severity† |
|---|---|---|---|---|---|
| | lbs ac$^{-1}$ | % | g | % | 1-10 |
| Peacham 002 | 822 | 24.3 | 25.2 | 88 | 8 |
| Northfield 003 | 360 | 27.1 | 22.3 | 96 | 9 |
| Kingdom 002 | 586 | 25.5 | 39.6 | 84 | 7 |
| Kingdom 001 | 604 | 34.3 | 26.6 | 93 | 8 |
| Argyle 001 | 286 | 30.6 | 27.1 | 88 | 7 |
| Northfield 001 | 620 | 23.9 | 26.2 | 94 | 8 |
| Morrisville 001 | 592 | 24.9 | 30.4 | 85 | 7 |
| Wolcott 001 | 349 | 32.2 | 12.0 | 95 | 9 |
| Mount Toby 001 | 688 | 31.0 | 19.3 | 97 | 8 |
| Peacham 001 | 471 | 29.5 | 22.3 | 100 | 9 |

†Cones were also rated in browning severity on a 1-10 scale where 1 indicates low browning and 10 indicates severe browning.

Hop varieties varied dramatically in alpha and beta acids (Table 5). In addition to varietal differences, hops also have potential to be influenced by various growing conditions such as fertility, temperatures, precipitation, disease pressure and many others, impacting their profiles. Kingdom 002 and 001 had the highest overall alpha acid percentage within the study (9.8% and 6.1% respectively), whereas all other varieties within the study were below 4.0% alpha acids. Highest percentage of beta acids were seen in Peacham 002 (4.4%) and Kingdom 002 (3.8%). Both Peacham samples showed some similarities this year in alpha and beta acids. These two groups could be similar varieties as they were collected from similar areas, although genetic testing would need to be conducted to determine similarities or differences in the varieties. High disease pressure may have contributed to overall lower values for brew values in this year of the study.

**Table 5. 2019 Wild hop variety brew quality.**

| Variety | Alpha acid % | Beta acid % | HSI |
|---|---|---|---|
| **Peacham 002** | 1.3 | 4.4 | 0.191 |
| **Northfield 003** | 1.1 | 2.7 | 0.179 |
| **Kingdom 002** | 9.8 | 3.8 | 0.217 |
| **Kingdom 001** | 6.1 | 2.3 | 0.215 |
| **Argyle 001** | 3.9 | 3.3 | 0.199 |
| **Northfield 001** | 1.6 | 3.0 | 0.173 |
| **Morrisville 001** | 3.3 | 2.1 | 0.156 |
| **Wolcott 001** | 1.8 | 2.0 | 0.150 |
| **Mount Toby 001** | 2.0 | 1.7 | 0.185 |
| **Peacham 001** | 1.2 | 3.7 | 0.157 |

Total oil and essential oil profiles varied greatly across the tested germplasm varieties (Table 6, Figure 4). Essential oils are presented in terms of milligrams of oil per gram of hops to accurately compare varieties on an equal mass basis and avoid differences in total oil volume. Wolcott 001 had the lowest overall total oil at 0.581 ml/100 g hops compared to Kingdom 002 which had 1.93 ml/100g hops, and cones of Wolcott 001 were visually smaller compared to the larger cones of Kingdom 002 in addition to the smallest and largest 100 cone weights within this study. Each of the analyzed essential oils has a number of purported health benefits in addition to associated aromas. Essential oil compositions would contribute to distinct aromatic profiles and could have the potential for unique uses or substitutions in the brewing process.

**Table 6. Total oil and essential oil profiles for germplasm varieties, 2019.**

| Essential oil mg/g hops | Wolcott 001 | Morrisville 001 | Northfield 001 | Peacham 002 | Peacham 001 | Argyle 001 | Kingdom 001 | Kingdom 002 |
|---|---|---|---|---|---|---|---|---|
| **Total oil (ml/100g hops)** | 0.581 | 0.574 | 0.791 | 0.808 | 0.931 | 1.13 | 1.64 | 1.93 |
| **Beta-pinene** | 0.018 | 0.024 | 0.045 | 0.06 | 0.075 | 0.053 | 0.064 | 0.089 |
| **Myrcene** | 1.43 | 1.48 | 2.93 | 3.77 | 4.93 | 3.16 | 5.66 | 7.3 |
| **Limonene** | 0.005 | 0.007 | 0.012 | 0.014 | 0.018 | 0.015 | 0.018 | 0.023 |
| **Linalool** | 0.035 | 0.005 | 0.030 | 0.042 | 0.047 | 0.040 | 0.096 | 0.105 |
| **Caryophyllene** | 0.390 | 0.813 | 0.624 | 0.476 | 0.479 | 0.984 | 1.96 | 1.97 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Humulene** | 0.769 | 1.79 | 1.83 | 1.47 | 1.47 | 2.55 | 4.26 | 4.31 |
| **Geranyl Acetate** | 0.015 | 0.154 | 0.134 | 0.115 | 0.121 | 0.558 | 0.294 | 0.289 |
| **Beta-citronellol** | 0.002 | 0.005 | 0.00 | 0.007 | 0.008 | 0.017 | 0.026 | 0.024 |
| **Nerol** | 0.067 | 0.023 | 0.086 | 0.062 | 0.058 | 0.104 | 0.140 | 0.156 |
| **Geraniol** | 0.008 | 0.00 | 0.027 | 0.011 | 0.018 | 0.023 | 0.00 | 0.00 |

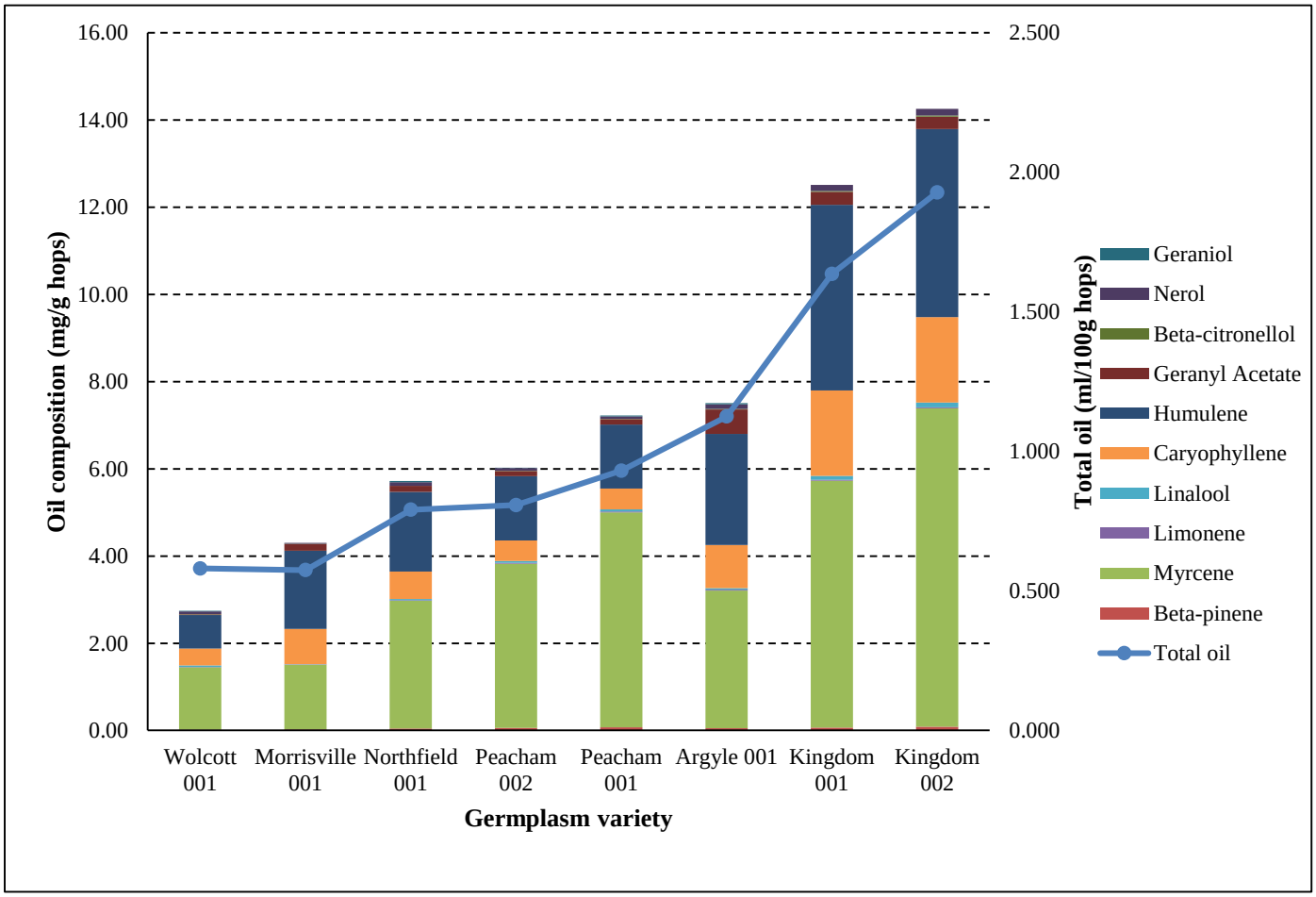


**Figure 4. Total oil and essential oil composition for germplasm varieties, 2019.**

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 5). 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 94.4% of the total oil for Peacham 001 compared to the profile for Wolcott 001 in which analyzed oils were 56.4% of the total oil. This could potentially be explained by the presence of other non-analyzed compounds or precursors or degradative compounds to those analyzed. In addition to having the lowest proportions of these analyzed essential oils, Wolcott 001 also had the lowest overall total oil at 0.581 ml/100 g hops compared to Kingdom 002 which had 1.93 ml/100g hops.

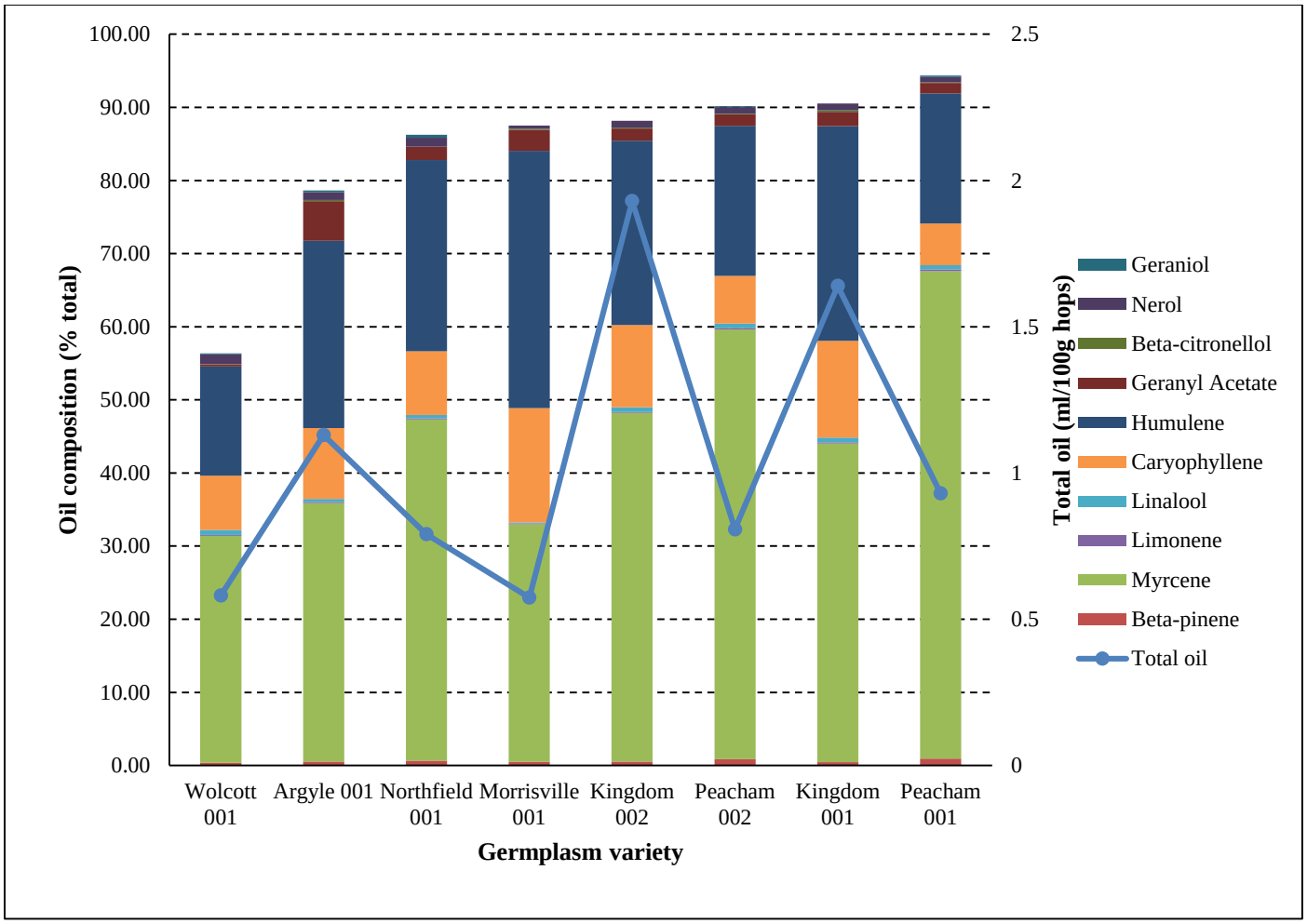


**Figure 5. Total oil and essential oil proportions for germplasm varieties, 2019.**

## DISCUSSION

In 2019, cones became noticeably browner in the week prior to germplasm harvest 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. Disease and pest pressure also impacted overall yields on top of inadequate water supply, limited by both weather conditions during critical cone forming periods and limited well capacity for irrigation. Many of these varieties may have also benefited from earlier harvest date. Despite poor cone quality as a result of delayed harvest, these varieties showed some distinct differences in alpha and beta acids in addition to essential oil profiles. Unique characteristics from these germplasm varieties could provide unique branding opportunities for growers or brewers. As the project continues to develop, we hope to obtain additional wild hop samples from across the Northeast to build a database of genetically distinct cultivars of our wild hop species (*Humulus lupulus* var. *lupulus* and *Humulus lupulus* var. *lupuloides).* This year, three new varieties were collected from Ferrisburgh, VT, Franklin, VT, and Plattsburgh, NY, however yield data and other metrics were not collected as the plants were in their establishment year. Wild hop varieties could provide new and distinct flavor profiles through variable acid and oil profile combinations for use by brewers. With the aim to build this database, new

varieties could become available to regional hop producers that are more suitably adapted to our growing region through greater resistance to downy mildew and other prevalent and damaging pests and diseases. Furthermore, this could offer the potential to open up regionally adapted breeding experiments, which could allow us to select hop traits that would be beneficial for our growing region. Ideally, this would lead to improvements in the quality and consistency of hops for our growers and brewers in our ever-expanding craft brewing industry in Vermont and the rest of the Northeast.

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