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Breakthroughs in Honey Bee Health: Local Summer Weather Humidity Conditions Influence Winter Colony Survival (Part III)

Kaitlyn N. Culbert[1] *

[1]Toms River High School North, Toms River, NJ, USA
*Corresponding Author: culbertkaitlyn@gmail.com

Advisor: Christine Girtain, cgirtain@trschools.com

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Abstract

Honey bees (*Apis mellifera*) are a vital species in our ecosystem. They pollinate 73% of the world's cultivated crops and have an economic impact of $20 billion in the United States and $183 billion dollars globally. Unfortunately, in 2006, beekeepers reported colony losses of 60-90%. Commercial beehives in the US have decreased over 50% in the last 70 years. The greatest single contributor to the decline of honey bee health is the *Varroa destructor* mite. Currently, all commercially available thymol-centered systems are gel-based and work by direct contact with the mite. These systems are also highly dependent on temperature and humidity for effectiveness. An earlier laboratory investigation (Part I) and field study (Part II) examined the use of thymol-based essential oil for miticide efficacy and the effective use of mist diffusers to eliminate the dependence of the essential oils on temperature and humidity conditions. Recognizing the significance and impact of hive humidity to *Varroa* mite survival and honey bee *Varroa* mortality, a linear regression model analysis was developed to investigate the significance of weather-related variables, particularly temperature and humidity, to colony loss. Weather data was collected from the National Oceanic and Atmospheric Administration (NOAA) and the National Centers for Environmental Information. Percent colony loss data was provided by the Bee Informed Partnership from 2009-2021 for the state of New Jersey. To date, this research represents the first and only available study examining local weather-related humidity variables to colony losses. The summer humidity-related weather variables of relative humidity, dewpoint, vapor pressure deficit, and temperature were found to be statistically significant to the percent of winter colony losses.

Keywords: Varroa destructor; Apis mellifera, Mites, Honey bees, Weather, Humidity, Colony Collapse Disorder, Regression analysis

1. Introduction

Honey bees, *Apis mellifera,* provide vital ecosystem services. They serve as crucial pollinators for agriculture, responsible for 73% of all cultivated crops (Randall, 2020). As much as one-third of our food depends on pollinators and bees are fundamental to the world's food security (Ramsey et al., 2017). In fact, bee pollination accounts for approximately US$20 billion in added crop value (USDA, 2021). Additionally, honey bees also produce honey, pollen, royal jelly, beeswax, propolis, and venom for nutritional and medicinal uses for an additional US$300 million annually (Calovi et al., 2021). In the United States, there are approximately 2.5 million commercially farmed honey bee hives and around 500,000 colonies kept by hobbyists and semi-professional bee keepers (Penn State Extension, 2013). Unfortunately, these numbers are declining at a rapid rate. Losses are attributed to Colony Collapse Disorder which occurs when there is a sudden loss of a colony's worker bee population yet the queen, brood and a relatively abundant amount of honey and pollen reserves remain. Various reports have suggested losses between 30% to 50% of winter bee colonies in the US, its lowest point in the past 50 years (EPA, 2021). Annual fluctuations in winter colony losses have been linked to pests and diseases, bee management, including bee keeping practices and breeding, agricultural practices, pesticide use and the change in climatic conditions. Regional factors including honey flow dynamics and the interplay of weather conditions, topographic variables affecting temperature and moisture, and the composition of the surrounding landscape have also been examined (Johannesen et al., 2022; Calovi et al., 2021)

During winter months, colonies rely on existing honey stores, cease foraging for nectar and pollen, and halt brood rearing. Winter bees live several months while summer worker bees live for only a few weeks. Honey bee colonies; however, do not remain dormant during the winter and remain active to maintain the hive temperature between 24-34 degrees Celsius (75.2-93.2 degrees Fahrenheit) by forming a thermoregulating cluster (Calvoli et al., 2021). The ability to form a thermoregulating cluster enables them to survive sustained periods of cold temperature. A critical component to increasing the lifespan of winter bees is the control of *Varroa destructor* mites. A single *Varroa* mite can shorten the lifespan of a bee by one-third, and two mites can shorten it by one-half (Bryant, 2006). *Varroa* is an ectoparasitic mite that feeds on the fat bodies of developing honey bee larvae and adult bees and aggressively reproduces within an infected bee colony. Recent research brings to light the *Varroa* mite's focus on the fat body tissue (Ramsey et al., 2019). Because *Varroa* weakens and ultimately kills colonies by out-reproducing their host, bee keepers initially used acaricides, pyrethroids, and organophosphates pesticides (Bahreni et al., 2020). The frequent use of these synthetic miticides resulted in the development of resistance to many of the chemical components of these miticides (Bahreni et al., 2020; Traynor et al., 2016).

Essential oils are an alternative to chemical pesticides. They are cheaper, environmental-friendly, and pose fewer risks to the health of bees and consumers. Most importantly, *Varroa* have not developed resistance to essential oils for honey bee mite control (Ghasemi et al., 2011; Damiani et al., 2009). Currently, numerous essential oil compounds have been evaluated for miticidal activity. One of the proven successful essential oils is thymol. It works by disorienting the mite and blocking its pores (Tennessee's Honey Bees, 2021). Thymol is the only compound of essential oils widely used in beekeeping with 70%-90% efficacy against *Varroa* (Garrido, 2018). The most widely used beekeeping products with thymol are Apiguard®, ApiLifeVar® and Thymovar® (Garrido, 2018). None of these systems utilize thymol to reach reproducing *Varroa* mites in the brood cell. These systems only kill the mites on the adult bees (Garrido, 2018). All commercially available thymol-based systems are gel-based and its effectiveness is highly dependent upon the ambient temperature and relative humidity within the hive. Temperature and humidity affect the rate of essential oil evaporation (Sabahi, 2017) and since these systems are gel-based, they are only effective when there is direct contact with the mite (Garrido, 2018).

Following a laboratory investigation (Part I, Culbert, 2022) demonstrating the potential utility of battery-operated mist diffusion of thymol-based essential oils, a field study (Part II, Culbert, 2023) was conducted in *A. mellifera* colonies with bee hives naturally infested by *Varroa destructor* mites. The field study demonstrated that thymol-based essential oils delivered with battery-operated mist diffusers can achieve a high level of *Varroa* mite control. The battery-operated mist diffusion system effectively eliminated fluctuations in temperature and relative humidity and enabled a continuous-release mist diffusion of thymol-based essential oils throughout the hive.

Recognizing the significance and impact of hive humidity and temperature to *Varroa* mite survival, a linear regression model analysis (Part III) was conducted to investigate the significance of local, atmospheric weather-related variables to colony loss. To date, few studies have evaluated the effects of weather-related factors on honey bee colony winter survival. A study of honey bee winter survival in Germany showed high rates of loss in the winter which were then followed by low rates the following autumn based on foraging activity (Johannesen et al., 2022). The authors concluded that colony loss rates in winter are influenced by the honey flow dynamics of the preceding one and a half years. In a recent study conducted in Michigan utilizing a random forest regression model to determine the importance of climate, weather, and land cover on honey bee colony productivity, the investigators concluded broad climate conditions constrained regional floral communities while land use and weather act to further modify the quantity and quality of pollinator nutritional resources (Quinlan et al., 2022). Investigators from Penn State also examined the importance of weather, topography, land use, and management factors on overwintering mortality (Calovi et al., 2021). The authors concluded growing degree days and precipitation from the proceeding summer were the strongest predictors of overwintering survival. Landscape quality factors were found not to be significant. No measurements involving local humidity-related weather variables were included in any of the aforementioned studies. In a search of the National Institutes of Health PubMed® database, no studies incorporating local-humidity related factors and colony collapse are available.

Acknowledging the impact of hive humidity and temperature to *Varroa* mite survival, a linear regression model analysis (Part III) was conducted to investigate the significance of atmospheric weather-related variables to colony loss. Recognizing that a complex suite of factors would enable beekeepers to make more informed decisions when treating their colonies in the fall, an investigation into the weather-related humidity variables was undertaken. Percent colony loss data provided by the Bee Informed Partnership (BIP) from 2009-2021 for the state of New Jersey and local weather-related variables, including humidity variables, were analyzed. The BIP data is the most comprehensive (capturing summer colony loss and winter colony loss from 2009) and provides the most complete information for the hundreds of apiaries located in New Jersey. Using this unique dataset, the humidity-related variables of relative humidity, dewpoint, vapor pressure deficit, and temperature of the preceding summer were found to be statistically significant to the percent of winter colony losses. Humidity-related summer local meteorological variables may be utilized to predict and alert beekeepers to actively treat for *Varroa* in the fall to prepare for upcoming winters when high colony losses are anticipated. It is important, this research is studied as it may contribute towards the development of a model to understand the contribution of humidity-related variables and its relationship to *Varroa* and honey bee overwintering survival will help to support honey bee management in New Jersey.

2. Materials and Methods

The following section is structured into two subsections. First, the empirical dataset includes a 12-year dataset of honey bee colony wintering survival in addition to the observational weather dataset. Seven meteorological variables were defined to detect and evaluate specific weather variable against the percent of colony loss. Second, the methods of data processing and statistical analysis are described.

2.1 Empirical Data Source: Overwintering Colony Survival

The percent of winter colony lost dataset is derived from the BIP Winter Loss Survey from the years 2009-2021. BIPs flagship service, The BIP National Loss and Management Survey is the longest national effort to monitor honey bee mortality rates in the US. Sent to more than 22,000 beekeepers, the survey functions as a pivotal indicator of honey bee health in the US. (Bee Informed Partnership, 2022). Although winter loss surveys are also available from the USDA/NASS (United States Department of Agriculture/National Agricultural Statistics Service), those reports are only available from 2016-2021 and specific colony locality data is not available. Due to the time and geography limitations of the USDA/NASS dataset, the BIP dataset was utilized for this investigation.

Based upon the BIP surveys, the average number of NJ colonies participating in the winter loss survey varied from 674 to 34,273 colonies with an average of 6,806 within the state. In total, the survey represents 88,478 colonies and 1,455 beekeepers in NJ over a twelve-year period from 2009-2021.

2.2 Empirical Data Source: Weather Variables

Daily and monthly weather variables were obtained from the National Weather Service (NWS), an agency of the US federal government tasked with providing weather forecasts, warnings of hazardous weather, and other weather-related data to organizations and the public for the purposes of protection, safety, and general information. The NWS is a part of the NOAA branch of the Department of Commerce. Sixty weather stations are located throughout New Jersey. To ensure locality of data, all weather variables were cross-referenced to the closest weather station of the colonies participating in the BIP National Loss and Management Survey. For each apiary location, weather variables, more specifically, temperature, precipitation, humidity, dewpoint, wind, and wind gust data was derived from NJ weather (NJ weather, 2023) and data for vapor pressure deficit was sourced from the Iowa State University, Automated Data Plotter (Iowa State University, 2023).

The NOAA provides each station's data in an MS Excel sheet which is broken down to 5-minute intervals. Since the BIP honey bee dataset is reported in summer and winter intervals only, the NOAA data was aligned to the same reporting intervals. The data was split into four quarters, each containing three months. After doing so, the averages were calculated and used to represent each quarter. All variables that were not reported to the weather station as well as columns with null values were removed. Topographical, forage resource index, and insecticide toxic loads were also not included as these variables had minimal impact in comparison to the significance of climatic variables (Calovi et al., 2021). The dataset of all measured variables is defined in Table 1.

Table 1: Dataset of Measured Variables

% winter colony loss	Percent of colonies lost as reported by beekeepers in winter (December-February)
Quarters	Grouped by 3 months: March-May, June- August, September-November, December-February)
Monthly Mean Temperature	Average monthly average temperature (Fahrenheit) during the quarter
Monthly Total Precipitation	Average monthly total precipitation in the quarter
Monthly Relative Humidity	Average monthly relative humidity in the quarter
Monthly Vapor Pressure Deficit	Average monthly vapor pressure deficit in the quarter
Monthly Dewpoint	Average monthly dewpoint in the quarter
Monthly Wind Speed	Average monthly wind speed in the quarter
Monthly Wind Gust	Average monthly wind gust in the quarter

2.3 Statistical Analyses of Datasets

The analysis of the datasets was accomplished with linear regression. Linear regression was selected for two key reasons 1) enabled forecasting/predictive modeling based on a previously observed numerical data set of values 2) the goal of this research was to explain variation in the response variable based on variation in the explanatory variables. In particular, to determine whether specific explanatory variables may have or not have a linear relationship with the response of percent of winter colony losses.

All datasets were combined into one Excel spreadsheet. The data set was uploaded and run on dataclassroom.com to produce the resulting graphs.

2.4 Statistical Analyses Variables

When building the models, it was pivotal to select variables which were most representative of the entire quarter, therefore the use of monthly minimum, and maximum temperatures were not utilized to build the models as they only utilize one value to represent the entire month. Average monthly snowfall was also not considered in the analyses as not all stations reported these values. Colony stressors were also not used in the models as they are not available in the BIP dataset; however, colony stressors are recorded in the USDA dataset, with *Varroa* mites recorded to be the most common of the stressors. Since winter is the season where NJ beekeepers experience the most drastic loss, the analyses focused on winter loss as the other quarters do not experience nearly as severe losses. The BIP survey data specifically tracks winter and summer losses. Summer loss differs from winter loss as the major factor in summer loss is the health of the queens.

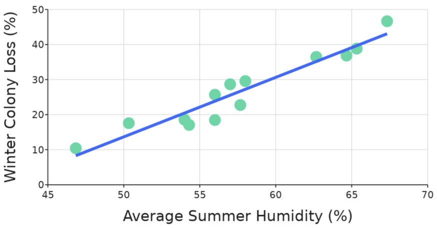
3. Results

The p-value in regression analysis is used to determine whether the regression model fits the data better than the model with no predictor variables. A predictor that has a low p-value is likely to be a meaningful addition to the model because changes in the predictor's value are related to changes in the response variable. A p-value of ≤ 0.05 is statistically significant. The linear regression p-value for each independent variable tests the null hypothesis that the variable has no correlation with the dependent variable.

The five most important variables for the percentage of winter colony loss included: relative humidity, dewpoint, vapor pressure deficit, precipitation, and temperature from the proceeding summer/warmest quarter (June, July, August). The variables of wind speed and wind gusts were not found to be statistically significant to winter colony loss.

3.1 Measured Variables

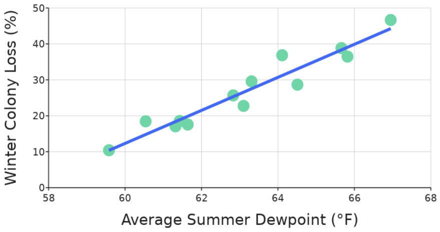
Relative Humidity (RH) refers to the moisture content (i.e. water vapor) of the atmosphere, expressed as a percentage of the amount of moisture that can be retained by the atmosphere at a given temperature and pressure without condensation. Based on the linear regression analysis, as depicted in Figure 1, the average summer RH was found to be statistically significant (p-value ≤ .05) to winter colony loss. As RH increases in summer, the percent of winter colony loss increases.



	r^2	Degrees of Freedom (df)	Slope	Std. Error (SE)	T-Score (Slope / SE)	P-value
Average Summer Humidity (%)	0.914	11	1.7	0.157	11	$3.282e^{-07}$

Figure 1: % Winter Colony Loss versus % of Summer Relative Humidity 2009-2021

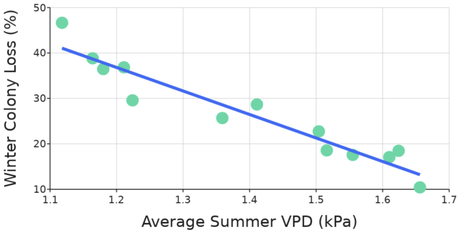
Dewpoint is the temperature the air needs to be cooled to (at constant pressure) in order to achieve a relative humidity (RH) of 100%. It is only dependent on the amount of moisture in the air. Based on the linear regression analysis, as shown in Figure 2, the average dewpoint was found to be statistically significant (p-value ≤ .05) to winter colony loss. As dewpoint increases in the summer, the percent of winter colony loss increases.



	r^2	Degrees of Freedom (df)	Slope	Std. Error (SE)	T-Score (Slope / SE)	P-value
Average Summer Dewpoint (°F)	0.923	11	4.6	0.399	12	$1.773e^{-07}$

Figure 2: % Winter Colony Loss versus % of Summer Dewpoint 2009-2021

Vapor Pressure Deficit (VPD) is the difference between the amount of moisture in the air and how much moisture the air can hold when it is saturated. VPD is used to measure dryness, or aridity, near the Earth's surface. Based on the linear regression analysis, as demonstrated in Figure 3, summer VPD was found to be statistically significant (p-value ≤ .05) to winter colony loss. As VPD increases in the summer, the percent of colony collapse decreases.

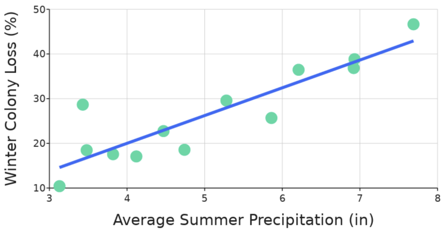


	r^2	Degrees of Freedom (df)	Slope	Std. Error (SE)	T-Score (Slope / SE)	P-value
Average Summer VPD (kPa)	0.914	11	-51.8	4.79	-11	$3.357e^{-07}$

Figure 3: % Winter Colony Loss versus % of Summer Vapor Pressure Deficit 2009-2021

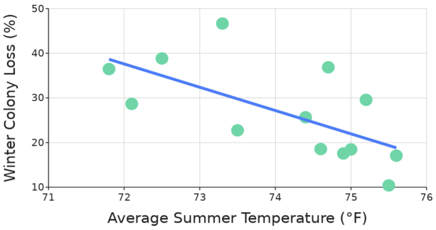
Precipitation is any product of the condensation of atmospheric water vapor that falls under gravitational pull from clouds. Precipitation occurs when a portion of the atmosphere becomes saturated with water vapor (reaching 100% relative humidity), so that the water condenses and "precipitates" or falls. Based on the linear regression analysis, as depicted in Figure 4, summer precipitation was found to be statistically significant (p-value ≤ .05) to winter colony loss. As precipitation increases, the percent of colony collapse increases.

Based on the linear regression analysis, as depicted in Figure 5, summer temperature was found to be statistically significant (p-value > .05) to winter colony loss. As temperatures in the summer increase, the percent of colony collapse decreases.



	r^2	Degrees of Freedom (df)	Slope	Std. Error (SE)	T-Score (Slope / SE)	P-value
Average Summer Precipitation (in)	0.791	11	6.21	0.963	6.5	$4.725e^{-05}$

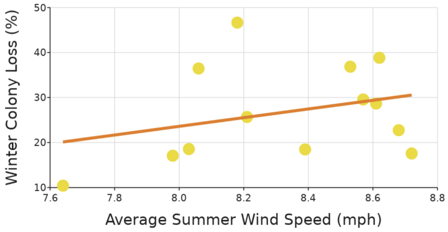
Figure 4: % Winter Colony Loss versus % of Summer Precipitation 2009-2021



	r^2	Degrees of Freedom (df)	Slope	Std. Error (SE)	T-Score (Slope / SE)	P-value
Average Summer Temperature (°F)	0.412	11	-5.21	1.88	-2.8	0.01806

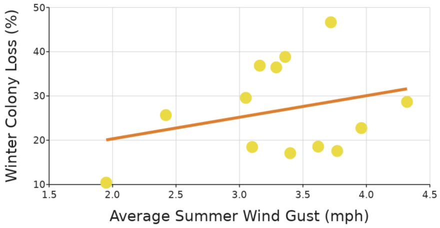
Figure 5: % Winter Colony Loss versus Average Summer Temperature 2009-2021

The variable of average monthly summer wind speed in Figure 6 was not found to be statistically significant (p>.05) to winter colony loss.



	r^2	Degrees of Freedom (df)	Slope	Std. Error (SE)	T-Score (Slope / SE)	P-value
Average Summer Wind Speed (mph)	0.0923	11	9.65	9.12	1.1	0.313

Figure 6: % Winter Colony Loss versus Summer Wind Speed 2009-2021



	r^2	Degrees of Freedom (df)	Slope	Std. Error (SE)	T-Score (Slope / SE)	P-value
Average Summer Wind Gust (mph)	0.0829	11	4.87	4.89	1	0.3402

Figure 7: % Winter Colony Loss versus Summer Wind Gusts 2009-2021

The variable of average monthly summer wind gust in Figure 7 was not found to be statistically significant (p-value > .05) to winter colony loss.

3.2 Predictive Regression Analysis Model

The linear regression analysis revealed the summer conditions of vapor pressure deficit, humidity, dewpoint, precipitation, and temperature were found to be most significant to colony losses of the subsequent winter season. Utilizing the most significant winter colony losses as reported by the BIP NJ beekeepers, a predictive analysis was undertaken. In the 2015/2016, NJ beekeepers reported an average of 46.65% in winter colony losses. Utilizing the statistically significant summer models to run a predictive analysis of the 2015/2016 winter colony losses, the 2015 summer values of 1.118 k/Pa, 67.33%, 66.95 °F, 7.69, and 89°F were inputted. After applying these values into the linear regression models for VPD, humidity, dewpoint, precipitation, and temperature respectively, the model predicted 2015/2016 winter colony losses of 41.05%, 43.05%, 44.27%, 42.93% and 51.04% respectively with an average 2015/2016 winter colony loss prediction of 44.47% which was well within the ±5% margin of error to actual winter colony losses of 46.65% as reported by BIP NJ beekeepers. BIP beekeepers reported nationwide winter colony losses at 44.1% in 2015/2016.

3.3 2022-2023 Winter Colony Loss Prediction

By inputting the statistically significant variables of VPD, humidity, dewpoint, precipitation, and temperature into the linear regression models, at the time of the submission of this manuscript on February 2023, the models predicted an average 2022/2023 colony loss of 31.6% (±5%) for NJ beekeepers. On June 22, 2023, the BIP published their preliminary survey analysis of 2022-2023 (1 April 2022 – 1 October 2022) losses at an estimated 37.4% for managed colonies in the United States as a whole. While this number is not specific to NJ beekeepers and is only a preliminary nationwide estimate, our regression analysis appears to be within a ±6% margin of error. The final 2022/2023 BIP Loss and Management Survey report of NJ losses and national colony losses may be released up to two years following the availability of the preliminary survey results.

4. Discussion

Beekeepers who use management practices to control *Varroa* mite levels have an overall higher winter survival. However, even with management of *Varroa*, beekeepers still experienced high losses (25-60% mortality) (Calovi, et al. 2021). This analysis examined the influence of local weather variables on colony survival. Summer humidity-related factors were found to be strong predictors of overwintering survival. Of the analyzed weather variables, relative humidity, dewpoint, vapor pressure deficit, precipitation, and temperature of the proceeding summer (June-August) were found to be statistically significant to the subsequent winter colony losses (December-February). A dependence pattern of survival and humidity variables were correlated and the graphic visualization provides a powerful interpretation of how the humidity variables may affect the probability of winter colony survival.

One of the reasons for the proposed impact of weather is the limitation of honey bee foraging time. Honey bees forage for nectar, pollen, water, and propolis, to provide the resources which support colony health. For this reason, the average monthly temperature, wind speed, and wind gust were also investigated. In fact, past studies have demonstrated winter mortality of colonies are positively correlated with uncontrolled *Varroa* mite populations (Genersch et al., 2010; van Dooremalen et al., 2012). Once again, the specific timing of treatment was not available on the BIP dataset. Furthermore, supplemental feedings in the winter were also not tracked in the BIP survey data and may mitigate some of the colony loss reported. Lastly, the BIP survey data does not capture information on the colony size. Smaller and less dense colonies are less likely to overwinter than "high density" colonies.

This is the first study examining the influence of local weather-related humidity variables to colony losses. The humidity-related weather values of relative humidity, dewpoint, vapor pressure deficit, and precipitation, and temperature were found to be significant. The significance of the humidity-related variables may be linked to the bees' ability to thermoregulate the hive effectively during the winter which ultimately can reduce the lifespan of winter bees and contribute to colony mortality. Furthermore, because *Varroa destructor* is known to lose fecundity at absolute humidity of 4.3 kPa, the control of *Varroa* based on humidity-related variables may be linked to honey bee overwintering survival. These findings suggest that honey bees have a "goldilocks" preferred range of summer humidity conditions. Falling outside of this range decreases the probability of surviving the winter. Based on the linear regression model using the most statistically significant summer weather variables of relative humidity, dewpoint, vapor pressure deficit, precipitation, and temperature linear regression analysis predicts NJ winter colony losses for 2022/2023 to be 31.6 % (±5%). The results of this investigation and its subsequent predictive analysis may allow for the development of a comprehensive beekeeping system which includes thymol-based mist diffusion of essential oils and a predictive tool for forecasting honey bee winter survival to support beekeepers' management decisions. The incorporation of humidity-related, local summer weather variables may be utilized to predict and alert beekeepers to actively treat for *Varroa* in the fall to prepare for upcoming winters when high colony losses are anticipated.

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References

Bahreini, R., Nasr, M., Docherty, C. et al. (2020). Evaluation of potential miticide toxicity to *Varroa destructor* and honey bees, *Apis mellifera*, under laboratory conditions. *Sci Rep* 10, 21529.

Beekeeping - Honey Bees. (2013, June). Penn State Extension. June 2023, from https://extension.psu.edu/beekeeping-honey-bees.

Bryant, D. (2006, February 16). *USDA Bee Lab Teams Pursue Varroa Mite Controls*. Farm Progress. January 22, 2021 from https://www.farmprogress.com/usda-bee-lab-teams-pursue-varroa-mite-controls.

Colony Collapse Disorder (2021, January).US Environmental Protection Agency, from https://www.epa.gov/pollinator-protection/colony-collapse-disorder.

Calovi, M., et al. (2021). Summer weather conditions influence winter survival of honey bees (*Apis mellifera*) in the northeastern United States. *Sci Rep* 11, 1553 (2021). https://doi.org/10.1038/s41598-021-81051-8.

Culbert, K. (2022). "Breakthroughs in Honey Bee Health: Continuous-Release Mist Diffusion of Thymol-Based Essential Oils." *Journal of Research High School*. 2022 (1) 59 – 65. https:// ebf144_0d75aae6c19b43ffa4067efbba37afbe.pdf (journalresearchhs.org.).

Culbert, K. (2023). "Breakthroughs in Honey Bee Health: Continuous-Release Mist Diffusion of Thymol-Based Essential Oils, The Field Study". *Journal of Research High School*. 2023 (1) 46-52. https:// ebf144_d500600c3427454898d548b0627aa88b.pdf (journalresearchhs.org.).

Damiani N, et al. (2009). "Acaricidal and insecticidal activity of essential oils on *Varroa destructor* (Acari: Varroidae) and *Apis mellifera* (Hymenoptera: Apidae)." *Parasitol Res.*106(1):145-52.

Garrido, C. (2018, February 27). Thymol *Varroa* Control. *Bee Culture,* from https://www.beeculture.com/thymol-varroa-control/.

Ghasemi V, Moharramipour S, Tahmasbi G. (2011). Biological activity of some plant essential oils against *Varroa destructor* (Acari: Varroidae), an ectoparasitic mite of *Apis mellifera* (Hymenoptera: Apidae). *Exp Appl Acarol.* 55(2):147-54.

Helping Agriculture's Helpful Honey bees. (2021, January). US Food and Drug Administration, from https://www.fda.gov/animal-veterinary/animal-health-literacy/helping-agricultures-helpful-honey-bees.

Iowa State University, Automated Data Plotter for Vapor Pressure Deficit. August 23, 2022, from https://mesonet.agron.iastate.edu/plotting/auto/?_wait=no&q=126&network=NJ_ASOS&zstation=EWR&year=2017&var=vpd&_r=t&dpi=100&_fmt=png.

Johannessen J, et al. (2022). *Annual Fluctuations in Winter Colony Losses of Apis mellifera Are Predicted by Honey Flow Dynamics of the Preceding Year*. Insects 13 (829). https:// (PDF) Annual Fluctuations in Winter Colony Losses of Apis mellifera L. Are Predicted by Honey Flow Dynamics of the Preceding Year (researchgate.net).

Loss and Management Surveys. Bee Informed Partnership. August 2022, from https:// Loss & Management Survey – Bee Informed Partnership.

National Centers for Environmental Information (NCEI). August 31, 2022, from National Centers for Environmental Information (NCEI) (noaa.gov).

National Weather Service: NOAA. August 31, 2022, from National Oceanic and Atmospheric Administration from https://www.weather.gov/wrh/climate.

New Jersey Weather. August 2022, from *https://njweather.org/*

Quinlan, GM, et al. (2022) Grassy-herbaceous land moderates regional climate effects on honey bee colonies in the North Central *US. Environ Res Lett 17* from https://(PDF) Grassy–herbaceous land moderates regional climate effects on honey bee colonies in the Northcentral US (researchgate.net).

Ramsey SD, Ochoa R, Bauchan G, et al. (2019). *Varroa destructor* feeds primarily on honey bee fat body tissue and not hemolymph. *Proceedings of the National Academy of Sciences*. 116 (5) 1792-1801.

Randall, B. (2020, June 22). The Value of Birds and Bees from USDA. From https://www.farmers.gov/blog/conservation/value-birds-and-bees.

Sabahi Q, et al. (2017). Continuous release of oregano oil effectively and safely controls *Varroa destructor* infestations in honey bee colonies in a northern climate. *Exp Appl Acarol*.72:263-275.

Traynor, K., et al. (2016). In-hive Pesticide Exposome: Assessing risks to migratory honey bees from in-hive pesticide contamination in the Eastern United States. *Sci Rep* 6, 33207.

Three Primary Essential Oils are Useful in Beekeeping. (2021). Tennessee's Honey Bees from https://www.tennesseeshoneybees.com/index.php?main_page=page&id=27&chapter=0.

Honey Bee Surveys and Reports. (2022, August 23). U.S. Department of Agriculture, National Statistics Service. from USDA - National Agricultural Statistics Service - Surveys - Honey Bee Surveys and Reports.

van Dooremalen C., et al. (2012). Winter survival of individual honey bees and honey bee colonies depends on level of *Varroa destructor* infestation. April 27. PLoS ONE 7:e362 from https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0036285.