THE CHEMICAL AND PHYSICAL ANALYSIS OF HIVELESS™ A PLANT BASED HONEY ALTERNATIVE

A Thesis
Presented to
the Graduate School of
Clemson University

In Partial Fulfillment
of the Requirements for the Degree
Master of Science

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December 2023

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ABSTRACT

Honey is perhaps the oldest and one of the world's most widely used natural sweeteners. It is a viscous, sweet, golden substance bees produce via natural enzymatic and physical modification of flower nectar. It has long been prized for its unique flavor and medicinal properties. It can be incorporated into many applications, such as bread, cured meats, alcohol, condiments, candy, pharmaceuticals, and skin care products. In 2022 alone, America consumed over 600 million pounds of honey (Board Reports, 2023), but less than a fifth of that was produced domestically, the rest imported from other countries. The international honey trade can be very lucrative and, therefore, sometimes attracts greed and deception, which results in honey being one of the most adulterated food products in the world. Roughly 10% of honey imported to the US is adulterated (FDA, 2022). Consumption of adulterated products not only cheats consumers financially but can also result in health complications and, in severe instances, may even lead to death. The FDA has captured and prevented numerous shipments of adulterated honey from entering US food systems. A 2022 FDA report listed that from January 2021 – March 2022, 14 of 144 shipments of honey were reported to be adulterated to some degree and refused entry into the US (FDA, 2022).

Despite being natural, honey is a non-vegan product. This means that those choosing to adopt a vegan diet must choose other sweeteners, such as maple syrup, agave, and molasses, none of which resemble honey's flavor physical or nutritional traits. In this study, a novel plant-based honey alternative that is vegan-friendly was examined.
ACKNOWLEDGEMENTS

This accomplishment could not have been achieved without the help of a vast network of people who supported me throughout the process. I want to thank my advisor, Dr. George Cavender, who has inspired and guided me throughout this research process. His aid and guidance helped me develop traits to become a better researcher and food scientist. I would also like to thank Sara Cothran for her everlasting support and motivation. My other committee members Dr. McGregor, Dr. Dawson, and Dr. Northcutt, thank you all for directing my research. Thank you also to Dr. William Kerr and his lab group at the University of Georgia for assisting and enabling me to use your Rheometer. Thank you to my friends and family, who loved and supported me throughout the project.
Table of Contents

TITLE PAGE ......................................................................................................................... 1
ABSTRACT ............................................................................................................................. 2
ACKNOWLEDGEMENTS ......................................................................................................... 3
LIST OF TABLES .................................................................................................................... 6
LIST OF GRAPHS .................................................................................................................. 7

Chapter One: Literature Review ............................................................................................ 8
Introduction ........................................................................................................................... 8
Honey Creation ....................................................................................................................... 10
Floral Varieties ...................................................................................................................... 11
Composition .......................................................................................................................... 14
Colors of Honey .................................................................................................................... 15
Viscosity .................................................................................................................................. 16
Harvesting .............................................................................................................................. 17
Honey Market ......................................................................................................................... 18
Utilization ............................................................................................................................... 18
Adulteration ............................................................................................................................ 19
Anti-Dumping ......................................................................................................................... 25
Plant-Based Honey Alternatives ............................................................................................ 26
Apples ..................................................................................................................................... 28
Tea ......................................................................................................................................... 28
Conclusion .............................................................................................................................. 29
References ............................................................................................................................... 31

CHAPTER TWO: AN INVESTIGATION INTO THE CHEMICAL AND PHYSICAL ANALYSIS OF A PLANT-BASED HONEY ALTERNATIVE. .............................................................................. 42
Abstract ................................................................................................................................. 42
Introduction .............................................................................................................................. 42
Materials and Methods ......................................................................................................... 44
Results ..................................................................................................................................... 48
Discussion ............................................................................................................................... 57
Conclusion ............................................................................................................................... 63
LIST OF TABLES

Table

2.1 Brand and origin of honey.................................................................44
2.2 Mean luminance (Y) and chromacity (x,y) of plant-base alternative sample..........52
2.3 Mean luminance (Y) and chromacity (x,y) of honey samples................................53
LIST OF GRAPHS

Graph

2.1 Graph of mean Brix values of Alternative and Honey samples

2.2 Graph of mean Aw values of plant-based alternative and honey samples

2.3 Graph of mean TPC values for plant-based alternative and honey samples

2.4 Graph of mean TPC values of plant-based alternative based on tea type and honey

2.5.a Graph of viscosity in relation to temperature of Apple alternative

2.5.b Graph of viscosity in relation to temperature of Peach alternative

2.5.c Graph of viscosity in relation to temperature of Blood Orange alternative

2.5.d Graph of viscosity in relation to temperature of Mexican Hot alternative

2.5.e Graph of viscosity in relation to temperature of Black Tea Mango alternative

2.5.f Graph of viscosity in relation to temperature of White Tea Pomegranate alternative

2.5.g Graph of viscosity in relation to temperature of Honey

2.6.a Graph of shear stress in relation to shear rate of Apple alternative

2.6.b Graph of shear stress in relation to shear rate of Peach alternative

2.6.c Graph of shear stress in relation to shear rate of Blood Orange alternative

2.6.d Graph of shear stress in relation to shear rate of Mexican Hot alternative

2.6.e Graph of shear stress in relation to shear rate of Black Tea Mango alternative

2.6.f Graph of shear stress in relation to shear rate of White Tea Pomegranate alternative

2.6.g Graph of shear stress in relation to shear rate of Honey
Chapter One: Literature Review

Introduction

Honey is perhaps the oldest and one of the world's most widely used natural sweeteners. It is a viscous, sweet, golden substance bees produce via natural enzymatic and physical modification of flower nectar. The nectar from each flower type produces a honey with unique characteristics. While honey has a long history of use as a sweetener, its popularity has soared in recent years due to consumers' rising demand for natural sweeteners. A recent survey conducted by the Kerry Group, a significant ingredient supplier focusing on taste and nutritional ingredients, found that among consumers, honey is viewed as the most natural and preferred sweetener, ranking higher than maple syrup, white and brown sugar, agave, molasses, and corn syrup (Malovany, 2018). As such, it is no surprise that the US alone consumed 600 million pounds (272,155 tonnes) of honey in 2021, representing an all-time high (Board Reports, 2023).

The recent surge in honey demand has called for increased honey production. A United States Department of Agriculture report shows that 125 million pounds (56,700 tonnes) of honey were produced domestically in 2022 (USDA, 2023) while the worldwide production of honey totaled 1.77 million metric tons (Statista, 2023). Further, the US imports more honey than any other nation, primarily due to its high level of consumption and relative lack of production. Specifically, the US produces only one-fifth of what it consumes, so it is forced to look to more productive countries such as China and Brazil, among the largest honey producers in the world, to fulfill its demand.

Unfortunately, this demand for honey sometimes attracts unethical business practices. Honey is one of the most adulterated products in the world, with reports showing "10% of US,
13% Canada, and 14% European Union" imports being adulterated (FDA, 2022). Honey is commonly adulterated by mixing in cheap bulk sweeteners like rice or cane syrup to increase the amount of "honey" produced. The motive to adulterate honey is purely economically driven. Honey is a multi-billion-dollar industry worldwide, and the ever-rising demand and price of honey tempts unscrupulous producers who realize that they can drastically increase their profits by adulterating the product.

As the demand for honey increases, veganism and the demand for plant-based alternatives also increase. The vegan and plant-based market is a multi-billion-dollar industry that continues to grow. Good Food Institute reports that in 2022, the total plant-based food market has a value of $8 billion, a 7% growth rate from 2021; 60% of households purchase plant-based products, and 80% are repeat buyers (Mount, 2023). Today, in many supermarkets, several sections throughout the store feature solely vegan and plant-based products. Where there was once one small slot for vegan or plant-based meat, there are now entire freezer sections. Plant-based and vegan alternative products have expanded to almost every food category. Meat, milk, eggs, cheese, condiments, chocolate, and seafood are plant-based and vegan-friendly options.

One category that has yet to be widely explored is honey. Honey is not vegan; therefore, it cannot be included in the formulations for vegan products. Vegan products must utilize cane sugar, corn syrup, molasses, agave, or maple syrup to sweeten them. Honey adds an entirely different flavor complexity to a product that the other sweeteners cannot achieve. Recently, a plant-based honey alternative developed by the author could alleviate problems for vegan consumers and manufacturers. Vegan manufacturers can now satisfy vegan consumers by producing products that resemble a honey flavor while aligning with vegan dietary guidelines.
Non-vegan manufacturers could also utilize this product as a bulking agent to blend with honey and lower the production price while maintaining the same flavor profile. Another benefit for manufacturers is that the plant-based alternative is replicable. The process to produce it is controlled, yielding a consistent product. Honey, on the other hand, is variable. Every honey harvest is unique, so different batches must be blended to meet a manufacturer's specifications (Eshete, 2020). Sometimes, multiple batches of honey from all over the world must be blended to get the desired product, which is costly and time-consuming. It is evident when looking at bottles of US-grade marked honey in supermarkets. Multiple countries of origin are expected to be found on these bottles because the law requires that any US-grade marked honey include all countries of origin (Country of Origin Labeling of Packed Honey, 2011). Commercial brands like Great Value, Laura Lynn, and Nature Nates honey will commonly have countries such as the USA, Brazil, and Uruguay listed as countries of origin on the bottle (Johnson, 2023).

**Honey Creation**

Bees create honey by first collecting nectar from plants in their environment. Only worker bees, which are all female, will collect nectar (MDKA, 2023). Worker bees sometimes fly multiple miles from the hive to collect nectar. When the bees land on the flower, they use their specially designed tongue to sip nectar from the plant. As the bee ingests the nectar into its honey pouch, digestive enzymes break it down (Geulph, 2023). These enzymes alter the composition of the nectar and turn it into honey. Bees have multiple stomach enzymes, such as proteases, diastase, and invertase (Villazon, 2021).

Each enzyme has a specific purpose- Proteases break down proteins, diastase converts polysaccharides like amylose to glucose, and invertase breaks sucrose down into fructose and
glucose (ALaerjani et al., 2022). The nectar solution is regurgitated and passed to multiple bees before reaching the honeycomb. Each bee adds more enzymes to the solution that continue to break down proteins and polysaccharides. Once the solution reaches the hive, it is filled into a honeycomb cell. The bees then dehydrate the solution by flapping air against it with their wings. Once enough water is removed, they cap each cell with wax to ensure no additional moisture is lost or gained (Harvey, 2023).

**Floral Varieties**

Bees pollinate and collect nectar from hundreds of different plants, which leads to the creation of hundreds of honey varieties. Over 300 marketed honey varieties are in the US alone (Honey Varietals, 2021). Monofloral honey (MFH) is the product of when bees collect nectar from primarily one plant type. Each MFH is different from the other, each processing a unique color, viscosity, sweetness, and flavor profile. "A general rule of thumb is that the darker the honey, the stronger the flavor is, and the lighter the honey, the milder the flavor is" (Honey Varietals, 2021).

Examples of monofloral honey include clover, orange blossom, lavender, sourwood, acacia, and Manuka. Culinary enthusiasts prize monofloral honey for its distinct taste, aroma, and health benefits. Some monofloral varieties like Manuka, Nepalese "Mad Honey," and Linden are very inquisitive and possess unique qualities that will only be found in that variety of honey. Coupling the unique qualities and small yield, some monofloral varieties like those listed can be costly.

One example of a monofloral honey is Manuka. Manuka honey is native to New Zealand and made from the nectar of the Manuka plant. Manuka honey processes unique physical and
flavor characteristics and an array of medicinal properties that make it cherished by consumers. It is golden to dark brown, thick like whipped honey and has a bitter mineral taste. Manuka has been shown to have antiviral, antioxidant, anticancer, anti-inflammatory, and antibacterial properties (Khandkar et al., 2020). UMF (Unique Manuka Factor) is used as a classification method, "which reflects the equivalent concentration of phenol (%, w/v) required to produce the same antibacterial activity as honey. Manuka contains high levels of MGO (methylglyoxal) formed from dihydroxyacetone (DHA), which correlates with antibacterial activity. The UMF rating of Manuka honey strongly correlates with MGO equivalence and antibacterial activity. The MGO levels of Manuka honey were 20-fold higher than other non-Manuka honeys. Manuka honey shows antioxidant and anticancer properties, which are considered due to its constituents’ phytochemicals working as active bio-compounds" (Johnston et al., 2018). Manuka honey is sold and priced depending on the MGO or UMF amount. The amount of MGO or UMF correlates with the potency of honey's medicinal properties; therefore, higher MGO and UMF levels lead to higher prices.

Nepalese "Mad Honey," a rare monofloral honey harvested only off the faces of cliffs in Nepal, also possesses unique properties. This honey has been used as a medicine, aphrodisiac, weapon of war, and hallucinogen (Ullah et al., 2018). This honey is usually consumed in small amounts. Consuming large amounts could lead to numerous complications and even death because of the grayanotoxins it contains. Grayanotoxins are found within the Rhododendron plant species (Suze a. Jansen, 2012). When bees collect nectar from these plants, they can transfer the pollen that contains grayanotoxins into the honey. Grayanotoxins can cause a plethora of complications, including ataxia, tachycardia, double or blurred vision, and nausea (Suze a. Jansen, 2012). Grayanotoxins interact with the sodium ion channels and interfere in the
action potential transmission, resulting in blockage of the channels and causing inotropy (Ullah et al., 2018). The detrimental effects of this honey have been known for over a millennia. Xenophon’s Anabasis, a book written by a Greek soldier in 370 BC, detailed how an invading Greek army was accidentally poisoned in Asia Minor by consuming honey (Wikipedia contributors, 2023).

When they began running in that way, the enemy stood their ground no longer but betook themselves to flight, one in one direction, one in another, and the Hellenes scaled the hill and found quarters in numerous villages which contained supplies in abundance. Here, generally speaking, there was nothing to excite their wonderment, but the numbers of bee hives were astonishing, and so were certain properties of the honey (4). The effect upon the soldiers who tasted the combs was that they all went for the nonce quite off their heads and suffered from vomiting and diarrhea, with a total inability to stand steady on their legs. A small dose produced a condition not unlike violent drunkenness, a large one an attack very like a fit of madness, and some dropped down, apparently at death’s door. So they lay, hundreds of them as if there had been a great defeat, a prey to the cruelest despondency. However, the next day, none had died, and almost at the same hour of the day at which they had eaten, they recovered their senses and, on the third or fourth day, got on their legs again like convalescents after a severe course of medical treatment (Bickers, 2008).

Linden honey is one of the most expensive monofloral honey in the world. It is expensive because the Linden tree blooming period is very susceptible to weather conditions. Non-optimal weather could shorten the blooming period from multiple weeks to a few days. This tree produces substantial nectar when weather conditions are optimal (Linden Honey, 2019). Linen
honey is called several different names depending on the region in which it is harvested. In the US, it is referred to as "Basswood," and in the UK, it is referred to as "Lime" (BeesWiki, 2021). Despite being produced worldwide and having different names, it all comes from the nectar of the Tillia genus of trees (Elena, 2022).

In ancient European times, Linden honey was said to be produced from the tree of life. When first harvested, it has a slight green tinge but becomes clear to amber with yellow tones as it ages (Linden Honey, 2019). Unlike most light-colored honeys, which typically have light aromas and flavors, linden is solid and bold. It has been described as having a woody, mint, menthol aroma, with medium sweetness and bold herbal, fruity, floral, and sometimes bitter flavors(Linden Honey, 2019). When Linden honey is compared to monofloral and multifloral honey, it has a higher concentration of vitamins B and C, biotin, and niacin (Elena, 2022).

In contrast to the above, polyfloral honey (PFH) is the product of bees collecting nectar from multiple types of plants. They are also commonly referred to as wildflower honey. These honeys are much more complex and have nuanced traits that represent the plants in an environment at that particular time. Each harvest of wildflower honey is unique. Every season's harvest yields different tastes and colors because of constant environmental changes (Close, 2022).

**Composition**

Honey is a natural solution produced when bees collect nectar from flowers. No standard of honey's chemical composition exists, but "generally honey has a content of 80–85% carbohydrates, 15–17% water, 0.3% proteins, 0.2% ashes and minor quantities of amino-acids, phenols, pigments, and vitamins. Besides these, other components are also found in minor concentration" (Khan et al., 2017). Trace amounts of minerals such as calcium, sodium,
magnesium, and potassium are also found in honey. Sugar is the primary component of honey. Fructose, glucose, maltose, and sucrose are the primary sugars found in honey, with ratios typically being around 38% fructose, 31% glucose, 7% maltose, and 1% sucrose (White & Doner, 1980).

The exact composition of honey varies slightly depending on the floral type, time of harvest, and harvesting method. Most commercial honey is pasteurized and filtered. Filtering aids with removing debris like pollen and beeswax, which impair the clarity of the final product, inhibit yeast growth, and delay crystallization. However, this also decreases the micronutrient content, as many components like antioxidants and polyphenols are heat-labile (Country et al. Farm, 2021). Filtering honey is a process where particles in suspension are removed from the honeylike pollen granules (Bryant, 2017). There is no legal limit on how much pollen can be removed. Filtration can disguise honey's true origin since filtering can remove pollen. Pollen can be used as a footprint to trace the honey's floral variety and geographical origin (Wirta et al., 2021). With that footprint removed, tracing honey back to its origin becomes difficult.

Raw honey is honey in its most natural form. It is not pasteurized or filtered. Therefore, it is expected to find debris like pollen that makes the honey cloudy and higher concentrations of antioxidants and polyphenols than pasteurized honey (Raman, 2023).

**Colors of Honey**

Honey comes in various colors. It can be white and translucent to amber and black. Many factors, including floral type and harvest time, determine honey's color. A single hive can produce honey with multiple different colors throughout the year. Usually, lighter-colored honey has milder flavors while darker honey is more intense; however, this rule has a few exceptions. (Honey Color and Flavor, 2020).
When sold, honey is commonly categorized by its color because of flavor attributes that correlate with color. Commercial manufacturers want to know the color of the honey purchased to predict its flavor and how it should be blended with other honey to achieve the desired taste. Honey colors are generally graded using the Pfund scale. This scale is used by the USDA and grades honey in seven different colors, including water white, extra white, white, extra light amber, light amber, amber, and dark amber (Honey et al., 2023). The color of honey can also affect the color of a finished product due to browning.

**Viscosity**

Honey is classified as a Newtonian fluid, meaning its viscosity does not change when the shear rate changes (Lever, 2005). The viscosity of honey is related to the amount and type of dissolved solids, particularly the relative amounts of different sugars in the solution and its moisture content. These factors can be influenced by many things such as floral type (which affects sugar profile), time of harvest (which affects sugar profile due to nectar availability since specific plant species blossom at different times throughout the year), harvesting and methods (Babarinde et al., 2011). The viscosity of honey is affected by changes in temperature. Viscosity is generally measured at room temperature (20°C). Honey becomes more viscous as temperatures decrease (Gómez-Díaz et al., 2009). When temperatures increase, viscosity decreases.

The adulteration of honey with liquid sugar solutions can cause its viscosity to decrease because of the increased moisture content. Moisture content is related to how much water is contained within the honey. Honey generally has a moisture content of 16% - 18% (Bäckmo, 2021). Since water has a low viscosity, the more water is added to a solution, the more viscosity will decrease. There is a correlation between adding liquid sugar solutions in honey and moisture content. It was discovered that when increasing the amount of the adulterant (liquid sugar
solutions including maple, agave, invert sugar, rice syrup and corn syrup) in honey, there was a linear increase of moisture content, thus decreasing viscosity. All the adulterated samples had lower viscosities than the unadulterated honey. The viscosity would continuously decrease with the increased addition of the adulterant (Ciursa & Oroian, 2021).

Harvesting

Honey is harvested worldwide, with 1.77 million metric tons collected in 2021 (Statista, 2023). Asia is the top honey-producing region, nearly half of the world's honey production. The world's leading honey producer is China, producing 486,00 tonnes. Turkey, Iran, Argentina, Ukraine, India, Russia, Mexico, USA, and Brazil round out the top ten honey-producing countries in the world (Zandt and Richter, 2023). The United States only produced 125 million pounds (56,700 tonnes) 2022. The top honey-producing state in the US is North Dakota, which harvested over 38 million pounds (17,236 tonnes) in 2020 (Danilovich, 2023). South Dakota, California, Florida, and Texas are among the top 5 honey-producing states.

The average bee colony produces 30-60lbs of honey annually, and powerful hives can produce upwards of 100 lbs annually (Nickson & Nickson, 2021). Beekeepers must remove the frames from the bee box to harvest the honey. The frames are then uncapped by removing the outer layer of wax to access the honey. The uncapped frames are placed into a honey extruder, which spins the frames, throwing the honey onto the walls of the extruder (Wikipedia contributors, 2023). Gravity pulls the honey down to the bottom of the extruder, where it is collected and filtered from debris like excess wax, pollen and dead bees. Microfiltration with pore sizes of 10 – 0.1 microns is the standard practice for commercial honey producers (Honey Filtration, 2021). Artisan beekeepers typically filter their honey with much larger pores, ranging between 200 – 600 microns (Hickman & Hickman, 2022).
Honey can be harvested and sold in several different ways. Most commercial operations pasteurize honey after filtering to prolong crystallization and prevent xerophilic yeasts from growing (Berry, 2023). Pasteurization also destroys natural enzymes and micronutrients found within honey. Raw and unfiltered honey is honey that is not pasteurized nor filtered, leaving the pollen and wax in the honey. Honeycomb honey is simply honey that is packaged with parts of the honeycomb. Creamed honey is honey that is processed in a manner to control crystallization. This honey has tiny, uniform sugar crystals, which prevent the growth of large crystals and give the honey a smooth and spreadable fondant consistency (Miksha, 2016). Honey can also be dehydrated to create honey powder. Honey powder is commonly used in spice rubs, baking applications, and beverages (Schmid, 2020).

**Honey Market**

The honey market was valued at $8.53 billion in 2022 and is expected to grow to $12.69 billion by 2029 with a 5.83% compound annual growth (Honey et al., n.d.). As of August 2023, the price per pound of honey sold to US processors and bulk packers averages $4.09. Wholesale prices sold to stores and distributors average $6.78 when sold one pound bottles per case of 24. The average retail price for a pound of honey is $10.38, ranging from $5.79 to $20.00 (BEE Culture, n.d.). The price of honey fluctuates during the time of year and also depends on the floral type. Monoflorals yield higher due to their unique characteristics (Beltramo et al., 2021).

**Utilization**

Honey can be found on virtually every aisle and shelf throughout a supermarket. In 2021, Americans consumed an all-time high of 600 million pounds (272,155 tonnes) of honey (Board Reports, 2023). In manufacturing, honey is used as a natural sweetener and flavoring, making it a
versatile ingredient for various industries. Honey makes alcohol, bread, cured meats, cereal, shampoos, lotion, cough medicine and many more consumer goods. Beer and spirit manufacturers use more than 35 million pounds of honey annually alone (Honey Summit, n.d.).

A particular type of honey called "Baker's honey" is commonly used by processors because it is cheaper but tastes relatively the same. Baker's honey is a lower grade of honey unfit for table use. Its hydroxymethylfurfural (HMF) levels are higher than 40 mg/kg, the limit for table-use honey (CooksInfo, 2022). HMF is an indicator of the quality of honey, and levels can rise due to improper heating. Baker's honey is still a food-safe ingredient and is commonly used today.

Most products made with honey will explicitly say "honey flavored" or "made with honey" on the front label. Some commonly found products showcasing honey on the front label include honey roasted peanuts, honey barbeque sauce and honey wheat bread. Some products like Angry Orchard Hard Cider and Branch's Candy Corn are made with honey but only show on the ingredients label.

**Adulteration**

Honey is one of the world's top 3 most adulterated food products. Reports indicate that "10% of US, 13% Canada, and 14% European Union imports are being adulterated" (FDA, 2022). Honey is a multi-billion-dollar industry worldwide. Millions of kilograms of honey are consumed annually, and demand is increasing. When coupled with production cost increases, the final price of honey becomes dearer, which can attract immoral and greedy actors to the trade. To meet consumer demands and increase profits, these unscrupulous producers will adulterate
honey - altering the product without consumer knowledge and selling it as if the product was not altered.

While many developed Western countries have systems to provide oversight to producers, oversight outside their borders is a more complicated proposal. For instance, the United States consumed over 600 million pounds (272,155 tonnes) of honey in 2021 but only produced about 20% of that, making it the largest importer of honey worldwide (Workman, n.d.). The other 80% had to be imported from countries like China, India, Brazil, and Ukraine, and these imports have been valued at millions of dollars annually. With such high demand and ever-increasing retail/wholesale prices, producers may be tempted to drastically increase their profits by adulterating the product. The motive to adulterate honey is purely economic, and importing adulterated honey poses many problems (Agilent, n.d.). Some problems that occur from it include decreasing the market price of honey, which threatens the livelihood of domestic keepers, taking money out of the domestic economy, and potentially negatively impacting the health of consumers (Center for Food Safety, 2022).

Honey is adulterated in several ways. The direct method of adulterating honey is commonly used because it is relatively easy. To directly adulterate honey, manufacturers use a cheap filler and mix it into the honey, specifically sugar syrups like corn, beet, and rice syrup (Tosun & Keleş, 2021). These sugar syrups are cheap and bulk up the amount of "honey" to be sold, ultimately increasing the manufacturer's profit (Fakhlaei et al., 2020).

Multiple tests have been designed to detect honey adulterated with sugar syrups. Many of these sugar syrups, like corn and sugarcane, are derived from plants that produce a 4-carbon (C4) intermediate during photosynthesis for the Calvin Cycle (Unacademy, 2022). Only 1% of plants produce a C4 intermediate (Leegood, 2004). The majority of plants only produce a 3-carbon
(C3). Therefore, the majority of plants bees pollinate will come from C3 plants. The SCIRA (Stable Carbon Isotopic Ratio Analysis) test can detect honey adulterated with C4 plants by measuring the 13C/12C isotope ratio (Lao et al., 2021). "It is determined by the 13C/12C isotope ratio, which is different in monocotyledonous plants (including cane and corn sugar) when compared to dicotyledons (most flowering plants from which bees collect nectar). C4 plants have higher 13C/12C stable carbon isotope ratios than C3 plants. C3 have 13C/12C ratios from −21‰ to −32‰ while C4 13C/12C ratios are −12‰ to −19‰. Honey with 13C/12C values less negative than −23.5‰ would be alarming" (Padovan et al., 2003b). Adding more of the adulterating agent (corn syrup, cane syrup) would create 13C/12C ratios higher (more positive) than -23.5‰. The isotope ratios would resemble values closer to C4 plants (−12‰ to −19‰) rather than C3 plants (−21‰ to −32‰), of which honey is mostly comprised.

Some manufacturers have found ways around the SCIRA testing method by using sugar syrups derived from C3 plants like rice and beets. Methods like SMR (Special Marker for Rice syrup) and LC-HRMS (Liquid Chromatography-High Resolution Mass Spectrometry) were developed to detect honey adulterated with those classes of sugar syrups (FAQS, n.d.).

Indirect adulteration is when beekeepers feed the bees sucrose syrup for a prolonged time during the main nectar collection period (Fakhlaei et al., 2020). The added food allows the beekeepers to get more yield from the hive, but it alters how the bees convert the nectar sugar. When bees collect and store nectar in pure honey, they convert it to primarily fructose and glucose. A study conducted in 2007 showed that when being fed a sucrose diet for a prolonged time, the honey contained higher levels of sucrose and maltose than usual. The same study also identified a decreased potassium, proline, and vitamin C content (Guler et al., 2007).

Indirect adulteration can occur when beekeepers feed their bees antibiotics to keep them
from contracting diseases and parasites. A recall occurred in January 2023 in Quebec and Ontario, Canada, with Punjab King Pure Honey because of honey that had tested positive for metronidazole. Metronidazole is an antibiotic and antiprotozoal medication that is used in humans to treat various bacterial and parasitic protozoal infections. Parasitic diseases in honeybees, like nosemacerae, can also be treated with metronidazole, although metronidazole is not approved for honeybee use in the USA or Canada (EIN Presswire, 2023).

Chloramphenicol (CAP) is another antibiotic that is common in adulterated honey. CAP is a broad-spectrum antibiotic used to treat honeybee larvae diseases (Rizzo et al., 2020). CAP is highly toxic; it can have detrimental effects if consumed by humans (Oong, 2023). CAP can occur in animal-based products, so its use has been prohibited in food-producing animals, such as honeybees. CAP is banned in many countries, including the European Union, Brazil, China, and the US. (Rizzo et al., 2020). In February 2023, the FDA issued Import Alert #36-04, titled "DETENTION WITHOUT PHYSICAL EXAMINATION OF HONEY AND BLENDED SYRUP DUE TO UNSAFE DRUG RESIDUES." The alert noted that honey shipments from specific companies in the countries listed on a "Red List," like China and Malaysia, can be detained upon importation into the United States without physical examination. Adulterated honey containing CAP or other banned substances was ordered to be rejected in the United States because it is unsafe and unfit for human consumption (Import Alert 36-04, n.d.).

Alfred L Wolff (ALW), a global raw materials and ingredients company that serves the food industry, was fined by US Customs Enforcement and Homeland Security in 2008 for knowingly importing and reselling 57 metric tons of honey containing chloramphenicol. ALW purchased a shipment of honey from a producer at a discounted rate due to its contamination with CAP. The honey was then blended and sold as CAP-free. However, it was tested by Institut
fur Honig-Analytik Quality Services International GmbH laboratory in Germany, where it was determined that the honey contained CAP. Two samples registered levels below 0.3 ppb, and the third registered 0.6 ppb ("United States of America V. Giesselbach and Von Buddenbrock," 2008). The US allows a CAP threshold of 1 ppb while the EU allows 0.3 ppb (CAP, 2023). After the trial, the company closed its Chicago office transferred all assets, and all remaining employees left the US. Charges were dropped against the company because they had "no presence in the US and were mere shells" (Honey Laundering, 2012).

Blending honey is done for numerous reasons. It can be done to disguise the true origin, dilute possible impurities that would prevent honey from being sold, or upsell a cheap honey variety with more expensive honey varieties and sell it as purely the more expensive variety. Some floral varieties like clover rapeseed honey are cheap because they are produced in abundance and easy to source. Some monofloral varieties like Manuka and acacia are expensive because they are produced predominately from one flower type and yield unique characteristics. These floral varieties are produced only in specific areas, so the yield is low. When manufacturers adulterate honey by blending floral varieties, it can easily be identified by conducting a pollen test. Each honey has its own pollen footprint that can be used to identify the types of flowers that were used to create the honey.

Each flower has specific pollen characteristics. Flowers have different pollen morphologies and pollen counts that can be found in honey. The required pollen count for a honey to be called monofloral differs for each honey because it depends on the flower type. Pollen counts are classified into three categories.

*Underrepresented pollens* - greater than 20% of the target pollen must be identified, less than 20,000 pollen grains per 10 grams of honey.
Normally represented pollens - greater than 45% of the target pollen, 20,000 - 100,000 pollen grains per 10 grams of honey.

Overrepresented pollens - greater than 70% of the target pollen is required, more than 100,000 pollen grains per 10 grams."

(Airborne Honey, n.d.)

Some flowers have small amounts of pollen that normally appear in the honey, while others have large amounts present due to the plants' structure. No honey is produced from purely one type of flower. A honey could be produced by the nectar of multiple plants and still be considered monofloral if the minimum pollen count is met. When honey does not meet the minimum requirements of the pollen count, it cannot be called monofloral. Pollen morphologies must match up as well. Understanding these parameters can help identify if manufacturers have illegally blended the honey. Manufacturers may have adulterated the product if expected pollen counts are out of range for a specific floral type.

Ultrafiltration is a practice used by foreign producers to disguise the origin of honey by removing impurities that impact clarity and increase the crystallization rate. Ultrafiltration is done by adding extra water to honey, pumping it through fine filters, and removing the water (Charles, 2011). However, this method removes all pollen but produces a product that can no longer be sold as "honey" in the US (FAQ, 2023). Traditional filtering methods remove pollen, but ultrafiltration goes far beyond that. Chinese exporters are suspected of using this method to disguise the origin of the honey to avoid paying the extra taxes imposed on Chinese honey. "The ultrafiltered "honey" is shipped to India and mixed with raw Indian honey then exported to the US so pollen test would show the honey originates from India" (Charles, 2011).
Anti-Dumping

Anti-dumping is a term used to define when the government imposes laws to level the trading market between domestic and international producers. Honey anti-dumping laws were signed in 2001 in the US to protect American beekeepers from imported honey sold in the domestic market at less than fair-prices (Abj, 2022). Before anti-dumping laws were signed, China, the largest honey producer, exported their honey to American companies at lower prices than American beekeepers could sustain (Benjamin, 2021). They were running a monopoly in the American honey market since they flooded it with cheap honey and dominated domestic competition. American beekeepers could not and still cannot match the production rates of China, so their honey had to be sold at higher prices to make a profit, which was not desirable to honey buyers.

When the anti-dumping laws were first introduced, they were explicitly aimed at China and its producers. Chinese producers found ways around these by exporting their honey to neighboring countries like Malaysia and Vietnam. These countries would then create a false label stating the honey was produced there and then would export the honey to the US. In 2016, "US Immigration and Customs Enforcement's (ICE) Homeland Security Investigations (HSI) seized nearly 60 tons of illegally imported Chinese honey valued at more than $200,000 destined for US consumers. The three shipping container loads (195 barrels) of bulk honey smuggled into the United States were falsely declared as originating from Vietnam to evade anti-dumping duties applicable to Chinese-origin honey" (HSI, 2016).

Groeb Farms was one of the biggest honey distributors in the US. They were distributing honey to some of the biggest companies, like Duchess, the creator of Honey Buns. Groeb Farms was brought to trial in 2013 for illegally importing Chinese honey that was sold at less than fair
trade prices (UNITED STATES OF AMERICA n.d.). The plaintiffs accused Groeb of intentionally importing adulterated and mislabeled honey. Groeb knew the honey was produced in China but had been illegally shipped to neighboring countries before making its journey to the United States to falsify its true origin. The prosecution continued stating that the company attempted to defraud the government and legitimate honey producers for financial gain (Bouboushian, 2013).

In 2010, honey was sold at an average price of around $1.60 per pound, but illegal imports could be sold at less than half the price (2018 Annual Honey Report, 2019). Groeb Farms admitted to its unlawful actions and revealed that between 2008 and 2012, they cost the US government more than $78 million by evading anti-dumping fees. The company agreed to pay a $2 million fine and filed for bankruptcy a year later (Bouboushian, 2013.).

Instances like the ones mentioned above have occurred multiple times throughout the years in the US. The American Honey Producers Association found that from 2008 to 2010, at least 80 million pounds of Chinese honey was imported without paying anti-dumping duties, cheating the US Treasury of $300 million (Bouboushian, 2013). In June of 2022, the US Department of Commerce and US International Trade Commission have filed anti-dumping laws on raw honey from Argentina, Brazil, India, and Vietnam in addition to the Anti-dumping laws that are still in effect against China ("Federal Register," 2022b).

**Plant-Based Honey Alternatives**

In recent years, a handful of companies have released plant-based honey alternatives. BlendItUp Bee Free Vegan Honey, Vegan UN-Honey, Wholesum Yum Zero Sugar Honey Substitute, Mellody Golden Clover, and Voney are just a few of the plant-based honey
alternatives currently on the market. These plant-based alternatives all have an emphasis on health and versatility. These companies are advertising that their alternative can be used in the same fashion as honey. These alternatives can be purchased in select supermarkets and restaurants; primary purchase options are through e-commerce. The average price of the alternatives is sold for $10 - $18 per unit, with sizes ranging from 8oz (237ml) to 12oz (355ml).

The ingredients used in the product formulations and nutritional content vary from brand to brand. Vegan UN-Honey is a single-ingredient alternative with three variations. Blonde is made with coconut nectar, Amber is cane nectar, and Copper is date nectar (Reusables & More, 2023). All versions have 45-50 calories and 6-7g of sugar per serving (8ml). Wholesum Yum Zero Sugar Honey Substitute contains no added sugar, 6g of fiber, and 15 calories per serving (1 tbsp, 19.5g). It comprises monk fruit, allulose, tapioca fiber and natural honey flavor (Wholesome et al. 2023). BlendItUp Bee Free Vegan Honey contains 16g of sugar and 62 calories per serving (1 tbsp, 21g). It comprises apple juice, sugar, and lemon juice (Blenditup n.d.). Mellody Golden Clover contains 17g of sugar and 70 calories per serving (1Tbsp, 21g) and is made of glucose, fructose, a plant extract blend (red clover, jasmine, passionflower, chamomile, seaberry), gluconic acid and natural flavors (Mellody et al.). Voney contains 2g of sugar, 36 calories per serving (1 tbsp, 21g), and is made of chicory fiber, plant extracts, natural flavor, malic acid, and salt (Meluka Australia, n.d.).

None of the alternatives are made with artificial flavors. The nutritional content of the alternatives is reasonably similar to honey, except Wholesum Yum Zero Sugar Honey Substitute, which contains no sugar and only has 15 calories. The chemical composition, flavor profile, and viscosity or the alternatives needs to be clarified. However, their appearances are all within the normal color range of honey.
**Apples**

Apples are amongst the most consumed and cultivated fruit in the US. In 2022, the US produced more than 10 billion pounds of apples, making it the second-largest grower in the world. (US Apple Crop Facts, n.d.). Washington state is the highest apple product state by a longshot, but New York, Michigan, and Pennsylvania are also significant contributors. Most apples consumed in the US are eaten fresh or unprocessed. Only about 30% of apples are processed to make apple products; 13% is used to make juice and cider (Apple Association, 2022).

Thousands of varieties are grown within the US, with some of the most popular being Pink Lady, Gold Delicious, Honeycrisp, and Granny Smith (Statista, 2023). Apples come in all different shapes, sizes, flavors, and sweetness levels. Some are better suited for products like pies or applesauce, but they can all be turned into apple juice. They also ripen at different times during the harvesting season. The harvest generally begins in late summer and continues until the end of October. Apples contain many nutrients, including fiber, carbohydrates, vitamin C, potassium, and phytochemicals (Apples, 2021). Apples can aid in preventing many ailments, such as diabetes and cancer.

**Tea**

Tea is the second most consumed beverage globally, only second to water (Stone, 2021). Tea comes in various types: green, white, black, oolong, chai, matcha, and herbal. Proper tea comes from the *Camellia sinensis* plant, not herbal tea (Wikipedia contributors, 2001). Leaves from the plant are packed with caffeine, polyphenols, and antioxidants. The flavor, depth of
flavor, and nutritional value contained within the leaves change dramatically during oxidation. As oxidation increases, the tea becomes darker, more flavorful and fuller-bodied, but nutritional value is lost.

Green tea is produced from tea leaves that have been lightly steamed to prevent the leaves from withering to oxidation. Green tea has the highest number of antioxidants and polyphenols among all tea varieties (PGDip, 2019). Matcha is made from ground green tea leaves. White tea is produced from tea leaves that have undergone very minimal processing. The leaves are withered longer than green teas, which causes light oxidation. Only a tiny amount of the original antioxidant and polyphenol content has diminished from the leaves. White teas are very light in color and flavor. Oolong tea is partially oxidized, but the oxidation level varies. Light to moderate oxidation can cause an Oolong tea to resemble a green or black tea.

Black tea is created when tea leaves have undergone the longest oxidation. The tea leaves turned black and lost a lot of their nutritional value. Brewed black tea is black, intensely flavored, and full-bodied. Chai tea is black tea mixed with a variety of spices. Chai blends usually contain cinnamon, cloves, cardamom, or ginger. Herbal teas are technically not tea because they do not contain the Camellia sinensis plant. Herbal teas are created using herbs, spices, and dried fruits. Herbal teas are typically caffeine-free. Herbal teas also contain lower levels of polyphenols and antioxidants than proper tea.

Conclusion

Honey is a very popular sweetener produced by bees. There are hundreds of different honey varieties, each processing its unique physical, chemical, and flavor characteristics. Honey is versatile in many consumer goods like cereals, cured meats, and beverages. Its versatility and popularity with US consumers have caused its demand to surge. American beekeepers cannot
fulfill the demand, so honey has to be imported from other countries. The honey industry is lucrative, and sometimes exporters get greedy and try to increase the value of their harvest by adulterating the product. Exporters will also attempt to disguise the honey’s true origin to avoid paying extra taxes.

Plant-based and vegan-friendly products are in demand. The plant-based market continues to grow annually, with new products released yearly. Honey is one area in the plant-based market that has yet to be explored as much as other sectors, such as meat and dairy, have. Honey is not vegan-friendly; vegans and plant-based consumers are forced to use other sweeteners. A honey alternative made from apples, tea, and sugar would be vegan-friendly, giving vegans the same satisfaction as honey. This product is created to look and taste like honey and has similar nutritional components. This product has the potential to mimic the different flavor profiles of honey varieties and be used as a honey substitute.
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Abstract

Honey is one of the most used natural sweeteners in the world. It is cherished for its unique flavor and other properties. Annually, Americans consume millions of pounds of honey because it is incorporated into everything from bread to alcohol and cured meats. However, America produces less than one-fifth of what it consumes. Most of the honey used in the US must be imported, and importing so much honey raises several concerns because honey is the third most adulterated food product in the world. The motive to adulterate honey is strictly based on monetary gain. Honey is a multibillion-dollar industry that continues to grow, and some honey producers will sometimes use unethical methods in harvesting or exporting honey to make extra profits.

Despite being all-natural, honey is not vegan. The vegan and plant-based communities are growing exponentially and demanding products that align with their diet. The closest liquid natural sweeteners to honey, which are plant-based, are maple syrup, agave, and molasses. None of those are remotely close to honey in terms of nutritional value, flavor profile, or physical appearance. This study shows the chemical and physical properties of a vegan-friendly honey alternative made from apples, tea, and sugar.

Introduction

Honey is perhaps the oldest and one of the world's most widely used natural sweeteners. It is a viscous, sweet, golden substance bees produce via natural enzymatic and physical...
modification of flower nectar. While honey has a long history of use as a sweetener, its popularity has soared in recent years due to consumers' rising demand for natural sweeteners. The US alone consumed 600 million pounds (272,155 tonnes) of honey in 2021, representing an all-time high (Board Reports, 2023). American beekeepers only produce about one-fifth of the consumer demand, so honey must be imported. There are many risks associated with importing honey, such as adulteration.

The vegan food industry is expanding, with new innovative products debuting yearly. None of these can contain honey in their formulations because honey is not vegan. Other sweeteners like maple syrup, agave, and molasses can be used, but none resemble the same flavor profile or nutrition of honey. The word itself, "honey," has a connotation that is synonymous with sweet, golden, and deliciousness, and no other sweetener has the same implication. According to a survey conducted by Kerry, an international taste and nutrition company (Krawiec, 2020), honey is the most preferred and considered natural sweetener. Taking into consideration these factors, it would be wise to create a plant-based honey alternative. "Hiveless," a new plant-based product, is vegan-friendly and resembles honey's chemical and physical properties. This product has a proprietary blend of apples, tea, and sugar. This product could revolutionize the entire food industry by being incorporated into vegan and non-vegan products.

Vegan food manufacturers will now have the ability to create "honey" flavored versions of their products. Many manufacturers are already creating vegan versions of their flagship products, such as Hellman's vegan Mayo and Hershey's plant-based chocolates. This plant-based honey alternative would enable companies to create vegan options with a honey-like flavor. General Mills could create a vegan version of their Honey Nut Cheerio, or Sweet Baby Rays
could make a vegan-friendly "Honey" BBQ sauce. Manufacturers could also blend the cheaper plant-based honey alternative with natural honey in their product formulations to save money. This study will focus on the chemical and physical analysis of "Hiveless," a plant-based honey alternative, in comparison to commercially available brands of honey.

**Materials and Methods**

2.1 Materials

The plant-based honey alternative, "Hiveless ™," is created using a proprietary blend of apples, tea, and sugar. Six flavors of the plant-based alternative were created. Four samples were created with herbal tea blends (apple, peach, blood orange, and Mexican hot). The remaining two (Black Tea Mango and Pomegranate White Tea) were created with *Camellia saliensis*. Commercial brands were samples and purchased at various supermarkets in Clemson, SC. The commercial honey brands are sourced from all over the world.

<table>
<thead>
<tr>
<th>Brand</th>
<th>Country of Origin</th>
</tr>
</thead>
<tbody>
<tr>
<td>Laura Lynn Clover</td>
<td>USA, Canada, Argentina</td>
</tr>
<tr>
<td>Harvest Farms Organic</td>
<td>Brazil</td>
</tr>
<tr>
<td>Local Hive Southeast</td>
<td>Southeast USA</td>
</tr>
<tr>
<td>Great Value</td>
<td>Argentina, Canada, USA</td>
</tr>
<tr>
<td>Nature Nate's Organic</td>
<td>Brazil, Uruguay</td>
</tr>
<tr>
<td>Bee Well</td>
<td>Pickens, SC</td>
</tr>
<tr>
<td>Virginia Brand</td>
<td>India</td>
</tr>
</tbody>
</table>

Table 2.1 Brand and origin of honey

2.2 Brix Determination

Each sample was assayed using a Digital Refractometer (Model MA871, Milwaukee...
Instruments, Rocky Mount, NC, USA) to determine the Brix. After calibration according to manufacturer instructions, aliquots of each sample were transferred onto the lens of the Refractometer. The refractometer reported a result seconds after pressing the "READ" button. Between samples, the lens was cleaned with a wet paper towel and blanked with distilled water to remove all residues from previous samples. Assays were performed in triplicate, and results were recorded in °Bx where (1 degree Brix (°Bx) = 1g of sucrose / 100g of solution) and temperature (°C),

2.3 Water Activity

Water Activity (Aw) was calculated using a water activity meter (Aqualab CX-2, ADDIUM Inc. Pullman, WA, USA). 5ml of Lithium Chloride, Aw (0.285), was placed into the sample tray and loaded into the machine for calibration. Roughly 5 ml of each sample was placed into a sample tray and loaded into the machine for testing. Each sample was reported in between 120 and 150 seconds. Assays were performed in triplicate.

2.4 Total Phenolic Content (TPC)

The Folin-Ciocalteu Colorimeter method determined TPC (Everette et al., 2010). Samples were diluted by 1:10 by adding 2g of sample to a test tube with 18mg of deionized water. The tubes were then set into a 40°C water bath for 20 minutes to dissolve the samples into homogenous solutions. After 20 minutes, a 40 μl (0.04ml) sample of the solution was pipetted into a separate test tube and mixed with 3.16 ml of water, 200 μl (0.2ml) of Folin-Ciocalteu Reagent (FCR), and 0.6 ml sodium carbonate. The tubes were then incubated for 30 min in a 400°C water bath. 250 μl of each sample were pipetted in a 96-well microplate (Benchmark SmartReader™, MR9600, Accuris Instruments, Edison, NJ) and read at an absorbance of 765nm.
These values were used to calculate gallic acid equivalents based on the equation of a standard curve prepared the same day using solutions of gallic acid (0, 50, 100, 150, 200, 250, and 300 ppm). Assays were performed in three triplicates (9 total samples), and values were reported as mg gallic acid equivalents (GAE) /l.

2.5. Colorimeter

Color was measured by a handheld colorimeter (Minolta Chroma Meter CR 400, Konica Minolta Holdings, Tokyo, Japan) utilizing the CIE x,y,Y color space, where x and y indicate Chromacity, and Y indicates Luminance. Prior to measurement, the manufacturer’s procedure for calibration was performed. Measurements were taken by adding 16g of each sample into a cleaned, transparent petri dish. The top of the petri dish was then inverted and pressed against the sample to distribute it among the bottom of the petri dish evenly. The dish was laid atop the "white blank square" to maximize luminance. The blank has a designed reading of (Y= 83.7, x=.3199, y=.3266) at D65 (luminance). Assays were performed in triplicate.

2.6 Viscosity

Stress (Pa), shear rate (1/s), and viscosity (Pa.s) were all measured using a hybrid rheometer (Discovery HR-2, TA Instrument Inc., New Castle, DE, USA). This system is capable of controlling the environment immediately around samples and applying and measuring stress, strain, and strain rate (TA Instruments, 2023). For each assay, a small drop of the sample, sufficient to cover the base plate was placed on its center and the conical top probe was lowered to the recommended height. The system then measured stress, shear rate, viscosity, temperature, and time-lapse as it manipulated the conical top probe axially. The first analysis measured viscosity with increasing temperatures from 20°C to 45°C. The shear rate was conducted for 55
seconds at a constant temperature (20°C, room temperature). Each sample was analyzed twice. The second analysis measured stress due to increasing shear rate while maintaining a constant temperature of 20 °C.
Results

1. Brix Determination

Graph 2.1 demonstrates that all samples of both the alternative and honey recorded a Brix (Bx) that was within the standard range of honey (70-88) (Anton Paar n.d.). This is hardly surprising as the alternative was designed to have a similar amount of sugar (17g) per serving, (1 Tbsp or 21g) as honey (Barkman Honey, 2017).

Graph 2.1: Graph of mean Brix values of Alternative and Honey samples. (n=3). Mean Brix Score for all samples $80.3 \pm (1.51)$. Figures with the same letter are not statistically different at $\alpha \leq 0.05$. 
2. Water Activity

As seen in Graph 2.2 the water activity ($A_w$) of all samples was examined to be below .85, which would inhibit the growth of bacteria. The FDA requires shelf-stable food or food that does not need to be refrigerated to have an $A_w$ of 0.85 or lower (Affairs, 2014). The alternative had a slightly higher mean $A_w$ (0.59) than honey (0.57). The alternative water activity averages below 0.6, which would inhibit most microbial growth including mold, yeast and fungi (Quality Control: Water Activity Considerations for Beyond-use Dates, 2018).

Graph 2.2 Graph of mean $A_w$ values of plant-based alternative and honey samples. (n=3) for each sample. Mean $A_w$ 0.58 ± (0.02). Figures with the same letter are not statistically different significance at $\alpha \leq 0.05$
3. Total Phenolic Content (TPC)

As seen in Graph 2.3, alternatives created with white tea recorded the highest average concentration of phenolic compounds, 1.02 mg/l. Alternatives made with black tea recorded the second highest average concentration of polyphenols, 0.39 mg/l. Graph 2.3 also demonstrates that all alternative samples were higher or equal in polyphenol concentration than honey. The average polyphenol concentration of the alternatives based on tea type is shown in Graph 2.4. The average polyphenol concentration of the alternatives, 0.35 mg/l, was nearly three times higher than the honey average of 0.12 mg/l. Alternative samples made with herbal teas averaged 0.17 mg/l polyphenols, 35% more than the honey average. Alternative samples with either black or white tea averaged 0.71 mg/l, 600% more polyphenols than the honey samples.

Graph 2.3: Graph of mean TPC (mg GAE/l) values for plant-based alternative and honey samples. (n=9) for each sample. Mean polyphenolic concentration for sample set 0.22 ± (0.24). Figures with the same letter are not statistically different significance at $\alpha \leq 0.05$. 

50
Graph 2.4: Graph of mean TPC (mg GAE/ l) values of plant-based alternative based on tea type and honey. Mean polyphenolic concentration for all alternatives (herbal and black tea and white tea) (0.35 ± 0.31), Herbal tea (0.18 ± 0.01), black and white tea (0.71 ± 0.33), honey (0.12 ± 0.03). Figures with the same letter are not statistically different significance at α p ≤ 0.05.

4. Colorimeter

In the US, honey is graded by color using the Pfund scale. This scale grades honey from water white to dark amber. Table 2.2 shows the results of the plant-based alternative colors. The alternatives showcase an array of colors ranging from light amber to dark amber. Table 2.3 showcases the color of some commercial honey brands sold in the upstate South Carolina. The results indicate that most commercially branded honey in this area is similar in color, ranging from white to light amber on the Pfund scale.
<table>
<thead>
<tr>
<th>Plant Base Alternative</th>
<th>Y</th>
<th>X</th>
<th>y</th>
<th>Gradient</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apple Alternative</td>
<td>67.52</td>
<td>0.3400</td>
<td>0.3496</td>
<td></td>
</tr>
<tr>
<td>Peach Alternative</td>
<td>63.6</td>
<td>0.3445</td>
<td>0.3553</td>
<td></td>
</tr>
<tr>
<td>Blood Orange Alternative</td>
<td>52.65</td>
<td>0.3918</td>
<td>0.3934</td>
<td></td>
</tr>
<tr>
<td>Mexican Hot Alternative</td>
<td>41.95</td>
<td>0.4761</td>
<td>0.4302</td>
<td></td>
</tr>
<tr>
<td>Black Tea Mango alternative</td>
<td>51.2</td>
<td>0.4231</td>
<td>0.4234</td>
<td></td>
</tr>
<tr>
<td>White Tea Pomegranate Alternative</td>
<td>57.06</td>
<td>0.3847</td>
<td>0.3915</td>
<td></td>
</tr>
</tbody>
</table>

Table 2.2: Mean luminance (Y) and chromacity (x,y) of plant-base alternative samples. Gradient shows a gradual 10% brightness decrease. No. of replicates (n=3) for each sample.
<table>
<thead>
<tr>
<th>Honey Source</th>
<th>Mean Luminance (Y)</th>
<th>Chromacity (X, y)</th>
<th>Gradient</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bee Well</td>
<td>Y 54.99</td>
<td>X 0.4008</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>y 0.4175</td>
<td></td>
</tr>
<tr>
<td>Harvest Farms</td>
<td>Y 54.95</td>
<td>X 0.3858</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>y 0.3937</td>
<td></td>
</tr>
<tr>
<td>Laura Lynn Clover</td>
<td>Y 63.78</td>
<td>X 0.3491</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>y 0.3647</td>
<td></td>
</tr>
<tr>
<td>Nature Nate’s Organic</td>
<td>Y 56.03</td>
<td>X 0.3917</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>y 0.4019</td>
<td></td>
</tr>
<tr>
<td>Local Hive Southeast</td>
<td>Y 63.54</td>
<td>X 0.3597</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>y 0.3733</td>
<td></td>
</tr>
<tr>
<td>Virginia Brand</td>
<td>Y 60.89</td>
<td>X 0.3634</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>y 0.3757</td>
<td></td>
</tr>
<tr>
<td>Great Value</td>
<td>Y 61.64</td>
<td>X 0.3691</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>y 0.3766</td>
<td></td>
</tr>
</tbody>
</table>

Table 2.3: Mean luminance (Y) and chromacity (x,y) of honey samples. Gradient shows a gradual 10% brightness decrease. No. of replicates (n=3) for each sample.
5. Viscosity

Both honey and the plant-based alternatives decreased in viscosity as temperature increased as shown in Graph 2.5. The initial viscosities taken at room temperature (20 °C) were different amongst the alternatives. The initial viscosity of White Tea Pomegranate alternative and honey were similar. Both samples decreased in viscosity are nearly the same rate as temperature increased.

In Graph 2.6 the shear stress was examined due to shear rate at a constant temperature (20 °C). A linear line was shown in all samples indicating the sample resisted force proportionally to the stress subjected to it meaning viscosity stayed the same. As shear rate increased no samples showed evidence of shear thinning. The results in both Graph 2.6 and Graph 2.7 indicate that both the plant-based alternative and honey are Newtonian fluids. Their viscosity only changed due to temperature changes, not shear stress.
Graph 2.5: Graphs viscosity (Pa·s) in relation to temperature (°C) increase of plant-based alternatives and honey samples (a-g)
Graphs 2.6: Graphs shear stress (Pa) in relation to increase of shear rate (1/s) of plant-based alternatives and honey samples (a-g).
Discussion

The primary goal of this study was to explore the physical and chemical traits of the plant-based alternative to honey. The alternative was designed and created to imitate honey. Various tests were performed to measure its properties including brix, polyphenol content, water activity, color, viscosity concerning temperature, and shear stress vs shear rate.

Brix (Bx) is a standard test used to identify the quality of honey. Bx is used to measure total dissolved solids, primarily sugar, which also correlates with moisture content (Bäckmo, 2021). The higher the Bx measurement is, the lower the moisture content is. 1 °Bx is equivalent to 1g of sucrose / 100g solution. Honey refractometers measure moisture content by subtracting the Bx score from the maximum % solids of the Refractometer. The moisture content in honey is predictive of its ability to resist fermentation and crystallization (Iqbal et al., 2018). Fermentation and crystallization can impart qualities on honey that consumers may deem undesirable, such as rancid taste and gritty texture, while high moisture content will cause honey to crystallize and yeast to induce fermentation quicker and easier. Honey is hygroscopic, so it will absorb water in humid climates, thus increasing its moisture content and speeding up the onset of fermentation and crystallization. In processing, honey is heated to destroy yeasts and reduce moisture content, which would aid in delaying fermentation and crystallization.

Bx is impacted by factors such as floral type, so there is a wide range of standard Bx scores for honey. Typically, honey has a Bx score of 70-88, with honey that contains a higher sugar concentration yielding higher brix scores (Mettler-Toledo et al, 2023; Obakpororo et al., 2022). High Bx scores would correlate with low moisture contents and predict an increased delay of crystallization and fermentation. Fortunately, it was discovered that all plant-based and honey
samples in the data set were all within the normal Bx range expected of honey, and the mean Bx of both the plant-based alternatives and the honey samples were statistically indifferent (81.3 vs 79.5), suggesting that neither should have significant differences in onset of crystallization or fermentation, although shelf-life testing should be performed to ensure that is indeed the case.

Water activity (Aw) is critical to food preservation and stability. The FDA requires shelf-stable, non-thermally processed foods to have an Aw of 0.85 or lower (Affairs, 2014b). Aw is a measurement that determines the amount of unbound to bound water in a sample. Bound water is bound to solutes in the food and unavailable for microbes. Unbound or free water is surface water that microbes can utilize for metabolic activities. Aw is measured by the ratio between food vapor pressure and pure water vapor pressure (Agriculture, n.d.). There are certain Aw requirements for specific microbes (yeast, mold, bacteria) to survive and, and in some cases produce toxins. Most bacteria are inhibited at a minimum Aw of 0.85, while some yeast and molds can survive Aw as low as 0.6 (Agriculture, n.d.). As Aw decreases, product shelf life's longevity increases because microbe's ability to survive diminishes. This is evident when comparing products like crackers and peanut butter to meat and bread. Crackers and peanut butter both have low Aw, which inhibits the growth of microbes, allowing them to have sustainably long shelf life’s, lasting several months and possibly years in correct storage. Meat and bread, in contrast, have higher Aw, which are prime for microbial survival, so these products spoil quickly and have short expiration dates.

Honey has a naturally low Aw usually between 0.5-0.65 (Chen, 2019). Yeasts are naturally present in honey are generally inhibited from growing at Aw values at or below 0.61-0.62 but can survive in a dormant state within honey (Chen, 2019). Raw honey is not pasteurized and contains live yeast. Yeast can cause fermentation in honey, but only once the
moisture content has risen and is within the organism’s desirable range. Until this moisture content has risen, the yeast will not ferment the product. Commercial operations generally pasteurize honey to destroy yeast cells, which greatly diminishes the possibility of fermentation.

All plant-based alternatives, along with the honey samples except for one brand (Nature Nates) are pasteurized products, and All samples’ Aw were within the normal range of honey (0.5-0.65). No honey sample broke the 0.6 Aw level. With two exceptions, none of the plan-based samples exceeded 0.6 Aw; and even those two were no higher than 0.65 Aw, which is the upper limit for honey. Just as in commercial honey, pasteurization and an acidic environment, low Aw and low moisture contents should make it extremely difficult for any microbe to survive in the plant-based alternative.

Polyphenols are very popular within the food industry due to their numerous health and food stability benefits. The global polyphenol industry was valued at $1.9 Billion in 2022 and is expected to be $2.7 Billion by 2028 with a compounding annual growth rate of 6.4% from 2023- (Business Wire). Polyphenols are commonly used in the food and beverage industry because they help prevent oxidation and increase shelf life. Consumers are attracted to polyphenols because they have antioxidant properties, including the ability to neutralize free radicals, and may aid in protection from various ailments like cancer, diabetes, cardiovascular and neurodegenerative diseases (Nock,2021).

Free radicals are molecules that have at least one unpaired electron. They can be toxic to the human body and occur from internal sources like cell metabolisms or external sources like smoking, UV radiation and pollution (Lien et al., 2008). Oxidative stress occurs when an abundance of free radicals forms inside the body. Both chronic and degenerative illnesses like cancer are enabled by oxidative stress (Lien et al., 2008). Polyphenols combat oxidative stress by
acting as reducing agents or antioxidants. Polyphenols can donate electrons and neutralize free radicals, thus stopping them from inducing more damage (V. Lobo, 2010). Polyphenols are a wide range of chemical compounds. Flavonoids, phenolic acids, and catechins are examples of polyphenols. In all, there are more than 8000 different identified polyphenols (WebMD et al., 2020). Foods like fruits, dark leafy greens, chocolate, and tea contain polyphenols.

Tea made of Camellia Sinensis tea leaves has high concentrations of polyphenols and is beneficial for human health. Green tea leaves have the highest concentrations of polyphenols, followed by white and black tea. This is due to the processing of the tea leaves. To create white and black teas, green tea leaves are oxidized, which decreases their phenolic content. Herbal teas do not contain Camellia Sinensis or tea leaves; they are composed of herbs, spices and flowers with even lower concentrations of polyphenols than black tea.

Honey naturally contains some polyphenols that originate from the nectar of the plants they pollinate (Danila Cianciosi, 2018). The total phenolic content of honey depends on many factors, such as floral type and processing methods. Typically, darker-colored honey has higher concentrations of phenolics than lighter honey (Bertoncelj et al., 2007). Raw honey that has not been pasteurized also contains higher phenolic concentrations since high heat can degrade phenolic content (Yahya Maghsoudlou, 2019). Honey generally has a total polyphenol content of approximately 56–500 mg/kg (Hossen et al., 2017). In the sample set, honey recorded an average of 0.116mg/l, while the plant-based alternative was 0.35mg/l, though this difference from previously reported values could be due to differences in the assay methodologies used, particularly with regard to the compound used to generate the standard curve- this study utilized gallic acid, while the reported values came from studies that utilized either a TPC procedure standardized to catechin or relied on HPLC analysis.
Plant-based alternatives consisting of herbal teas contained 35% more phenolics (0.18mg/l) than honey. The alternative made with black tea leaves contained 0.39 mg/l of phenolics, more than 350% more than honey, while the white tea contained 1.02 mg/l, more than 900% more than honey. The total phenolic content of the current plant-based honey alternatives available on the market is still being determined, but none are made with tea leaves. Some are comprised of herbs, while others are made with none. It can be assumed that the phenolic content of these products is lower than the plant-based alternative studied in this project since they are made with either herbal teas or tea leaves.

The plant-based alternative, just like honey, comes in many different colors. Honey can range from nearly translucent all the way to black (Honey et al., 2020b). Honey colors vary depending on the environment and plant it is sourced. Some plants, like buckwheat, produce nearly pitch-black colored honey, while others, like tupelo honey are light amber colored. The tea blend used in its formulation contributes to the color of the plant-based alternative, as the . water-soluble pigments like flavonols, anthocyanins, and flavanones, are responsible for the color of brewed/ infused tea (Bai et al., 2023). Depending on the region inhabited, one might be apt to see a particular honey color, and this has led to regional variations in consumer preferences for the color of honey around the globe. The plant-based alternatives come in various colors to appease all consumer color preferences, since some consumers prefer lighter-colored honey, while others like dark or amber honey (Altmann et al., 2023).

The color of honey can also be correlated with different flavor profiles. For example, Cabrera & Santander (2022) found that “Darker honey is sometimes associated with bitterness and astringency while amber honey tends to be sweeter and more acidic than other honey colors”. The plant-based alternative colors should have little to do with flavor profile, being more
influenced by the tea blend used. Different tea bases (white, black, herbal) that are identically flavored may impact color differently but still have similar flavor profiles.

Honey color can also be predictive of how honey can be changed during processing. With darker honey tending to brown more readily compared to lighter colored honey due to their increased concentrations of colored water-soluble antioxidant compounds and naturally occurring melanoidins, -the brown molecules formed at the end of Maillard reactions (Starowicz et al., 2021). Browning and color are factors in baked goods that contribute to consumer preference (Purlis, 2010). Various degrees of browning are preferential depending on the baked good type. The color of honey and its production of melanoidins can help contribute to browning in baked goods, thus potentially increasing the product's consumer preference. The plant-based alternative can also undergo Mallard reactions and produce melanoidins, imparting browning on consumer goods. This strengthens cases for manufacturers to use the alternative in consumer products such as baked goods.

Viscosity is a critical metric in processing. The viscosity of ingredients significantly impacts a finished product's composition and consumer preference (Zhu et al.2013). During processing, the viscosity of honey at different temperatures impacts the ease of flow. Honey is a Newtonian fluid, and viscosity changes due to heat, not shear stress (Yanniotis et al., 2006). At colder temperatures, honey increases viscosity, thickening and becoming more solid. Warmer temperatures decrease viscosity, causing honey to become more fluid. Honey is commonly heated to increase viscosity and flow when bottling (Iqbal et al., 2018). Using honey as a food ingredient, such as in ice cream, can also alter the final product's viscosity (Özdemir et al., n.d.). The plant-based alternative was demonstrated to have similar viscosity properties to honey, so similar considerations should be made in its processing.
Conclusion

Based on the data, the examined plant-based honey is both chemically and physically similar to traditional bee-produced honey. Both Brix scores and Aw of honey and the plant-based alternative were similar, while with regard to polyphenol content, the average plant-based alternative was significantly higher than the honey average. Further, the plant-based alternatives made with either black or white tea contained significantly more polyphenols than both honey and the plant-based alternatives made with herbal teas. While examining color, some of the plant-based alternative darker than honeys in the sample set but all were still within the normal range of honey. Viscosity tests also showed similarities between the plant based alternative and honey. Overall, his suggests that the plant-based alternative was functionally identical to honey both physically and chemically and therefore should be capable of fulfilling similar roles to honey in the food industry, though further study is needed to confirm this and determine consumer acceptance.
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