8-2022

An Economic Analysis of a Case Farm Involved in Hemp Production for CBD at Small Scale

Benjamin Daniel Joost Jacobs
University of Arkansas, Fayetteville

An Economic Analysis of a Case Farm Involved
in Hemp Production for CBD at Small Scale

A thesis submitted in partial fulfillment
of the requirements for the degree of
Master of Science in Agricultural Economics

by

Benjamin D. J. Jacobs
Haute École Provinciale du Hainaut-Condorcet
Bachelor in Agronomy, Warm Climate Regions, 2020

August 2022
University of Arkansas

This thesis is approved for recommendation to the Graduate Council.

____
Michael P. Popp, Ph.D.
Thesis Director

____
Sunjin Ahn, Ph.D.
Committee Member

____
Wim Verbeke, Ph.D.
Committee Member

Abstract

This thesis is comprised of studies examining cost of production differences between outdoor (open-air) and indoor (greenhouse) production of hemp flower on a small-scale hemp farm. Investigated also are oil extraction processes as well as drying costs and methods i) under controlled ambient conditions (air-drying) for 14 days at 65-70°F and 45-60% ambient humidity, ii) using infrared radiation (IR) for varying durations at an intensity of 2.51 kW per square meter, and iii) freeze-drying or lyophilization based on literature review. Critically, these drying methods involve tradeoffs related to time required, amount of energy consumed, and investment required. Also, they impact dried hemp flower characteristics (cannabinoids, terpenes, presence/absence of molds and fungi) that in turn are expected to drive Cannabidiol (CBD) oil quality. With costs for quality attributes of crude CBD oil quantified, the study examined the consumer willingness to pay (WTP) for CBD oil at varying CBD concentrations for alternative drying methods. Willingness to pay estimates assist growers with decision-making about what end users to target to maximize profit, whether consumer preferences could dictate one of the three drying methods and at what CBD concentration to sell. Cannabinoid conversion was increased when using IR-drying whereas air-drying significantly increased the synthesis of cannabinoids in their acid forms. Results have shown that hemp production can be profitable at small scale (< 1 acre) and that production and processing methods used need to take final product attributes into consideration. CBD concentration in CBD oil is reflected in prices charged and among the major factors driving consumer preference as well as cost of production. Lastly, WTP results suggest that most consumers are not sensitive to drying method. These findings provide information to this emerging industry by providing recommendations that assist with marketing CBD oil while managing cost of production.

Acknowledgments

Thesis submitted in partial fulfilment of the requirements for the degree of Master of Science in Agricultural Economics issued by the University of Arkansas (United States of America) and the joint academic degree of International Master of Science in Rural Development from Ghent University (Belgium), Agrocampus Ouest (France), Humboldt University of Berlin (Germany), Slovak University of Agriculture in Nitra (Slovakia), University of Pisa (Italy) and University of Córdoba (Spain) in collaboration with Can Tho University (Vietnam), Escuela Superior Politécnica del Litoral (Ecuador), Nanjing Agricultural University (China), University of Agricultural Science Bengaluru (India), University of Pretoria (South-Africa) and University of Arkansas (United States of America).

This thesis was elaborated and defended at the University of Arkansas within the framework of the European Erasmus Mundus Joint Master Degree International Master of Science in Rural Development (Course N° 2019 - 1507 / 001 - 001) and the EU-US Cooperation Programme in Higher Education and Vocational Training (Transatlantic Degree Consortia Projects) nr. 2008-1745/001 – 001 CPT-USTRAN and the Fund for the Improvement of Postsecondary Education (EU-US Atlantis Program grant P116J080034, U.S. Department of Education). However, the contents of the thesis do not necessarily represent the policy of the supporting agencies, and you should not assume endorsement by the supporting agencies.

Further I would like to express my deepest gratitude to those persons and institutions who supported and assisted in the accomplishment of my master’s thesis. Primarily, to Dr Michael Popp, thank you for all your support, encouragement, patience, tutoring, and mentoring. To Mr. Morgan, for taking me in as a family member and providing me with invaluable insights and experience within the U.S. hemp production. To Dr Sunjin Ahn thank you for all your patience and assistance in the thesis process, and to my colleague Dr Wim Verbeke from Belgium thank you for accepting to collaborate with me. To my colleagues at the University of Arkansas, Dr Griffiths Atungulu and Mr. Abass Adekoyejo Oduola, thank you for your support, acknowledgment, and commitment during the primary data collection of this thesis and your constant availability for further discussions. I would like to express my appreciation to Dr Brandon McFadden for your help in the creation and distribution of the hemp survey. Then, my gratitude goes to the University of Ghent, Cordoba, Nitra, Pisa, and Arkansas as well as to the Fulbright Program and the Fulbright Commission of Belgium and Luxembourg for all their support throughout my IMRD Masters. Without all of you, your work, and your dedication, this research would not have been possible.

Lastly, I would like to express my gratefulness to my family and friends in the U.S. and abroad for always standing by my side and supporting me in challenging times. My mother, all my friends from Luxembourg, Belgium, Mexico, Tunisia, Nepal, and elsewhere I thank and appreciate you for who you are and for reminding me what I am capable of. Without you I would not be standing where I am today.

Table of contents

List of Tables

List of Figures

Chapter I. Introduction

A. Problem Statement and Study Justification

The recent decriminalization of hemp (*Cannabis sativa*) in the 2018 U.S. Farm Bill has significantly increased its cultivation and demand. Besides legalizing hemp production and adding it to crop insurance laws, the 2018 Farm Bill newly defined industrial hemp, and products derived thereof. Section 12619 removes hemp from the Controlled Substances Act definition of marijuana and section 10113 newly defines hemp as "*the plant Cannabis sativa L. and any part of that plant, including the seeds thereof and all derivatives, extracts, cannabinoids, isomers, acids, salts, and salts of isomers, whether growing or not, with a delta-9 tetrahydrocannabinol concentration of not more than 0.3 percent on a dry weight basis*." (U.S. Department of Agriculture, 2018, p. 1)

While growers and processors can market a multitude of hemp-derived products such as, food from hemp seeds, fiber from the stalks, or oil from the flowers and seeds, this study targets hemp flower-derived Cannabidiol (CBD) oil. While CBD is available in a multitude of forms, one-ounce bottles, to allow for ingestion of droplets at a time, are most common in the marketplace. This is a product that can be easily produced by small-scale growers as it is storable, requires minimal processing (drying of hemp flower, oil extraction and subsequent blending of crude CBD oil with a carrier oil for bottling at the desired level of CBD concentration), and lends itself to branding for local and/or on-line sales. Hypothesized is that both the drying process and choice of CBD concentration affect the grower's profitability via cost of production and consumer acceptance.

Challenges for this newly developing industry are diverse and vary from State to State and country to country. Major legal, agronomic, and economic challenges for the U.S. hemp industry have been summarized by Tyler et al. (2020) which include, among others: common challenges for new emerging industries, overall competition between and within industries, lack of transparency in the market and data, diverse federal and state legislations, gaps about the characteristics of various *Cannabis* cultivars, and lack of expertise with high-value and/or labor-intensive specialty crops.

However, the major challenge that is pointed out by the authors is the "*lack of reliable, transparent data and peer-reviewed research and market information*" (Tyler et al., 2020, p. 38). The transparency in the collected data is essential for decision-makers, investors, producers, and processors to make appropriate pricing, marketing, and production decisions.

B. Objectives

To partially fill the knowledge gaps related to hemp production for retailing CBD oil, this study uses literature review as well as on farm and laboratory collected data to assess cost of production on small-scale hemp farms by differentiating between outdoor (open air) and indoor (greenhouse) production methods, as well as costs for drying hemp flower using alternative methods. Drying is a crucial step in the CBD oil supply chain between harvest and oil extraction. The study investigates drying i) under controlled ambient conditions (air-drying), ii) using infrared radiation (IR), and iii) freeze-drying or lyophilization in terms of: i) cost, ii) time, iii) energy, and iv) impact on dried hemp flower characteristics (cannabinoids, presence/absence of mold) that in turn are expected to drive CBD oil quality. Simultaneously, the research assesses consumer WTP for these drying methods, CBD concentrations, and whether or not an information treatment about drying methods impacted WTP to assist stakeholders with making production and marketing choices.

Given cost of production differences driven by, production environment, cultivar choice and drying method, profit-maximizing CBD concentration in blended oil can be estimated by equating marginal cost of CBD/ounce of blended oil to marginal revenue for CBD oil concentration. As such, this study assists with the choice of production environment (greenhouse or open air), drying method (conventional, IR, or freeze-drying) and concentration of CBD. Preferences for scale of grower, and knowledge about CBD, will assist start-up success for growers by making appropriate pricing, marketing, and production decisions for this growing agricultural sector.

C. Overview of Methods

For this research, on-farm cost of production and hemp flower samples were collected from an experienced small-scale hemp producer who currently grows different varieties of hemp both in-door and out, using conventional air-drying in a temperature and humidity controlled drying room. Hemp flowers were collected and dried using both conventional air-drying and IR-drying to assess differences in dried hemp flower quality attributes by drying method. Scientific literature and results using farm data are used for an information statement as a treatment effect in a discrete choice experiment employing a 3 by 3 factorial treatment involving three tiers of drying method, CBD concentration, and price. Pricing and CBD concentration levels are based on an internet market study of 206 different one-ounce CBD oil bottles with varying labeled CBD concentrations as marketed in the fall of 2021 by U.S. retailers. To assess information effects on WTP for CBD oil, a series of nine choice set questions, where a participant chooses one of three product combinations or none, was presented to respondents where roughly half were informed about drying methods and the other half was not. All respondents were presented with a standard cheap talk statement to ensure least-biased responses. Finally, participants were also asked about their consumption rates, knowledge about the product, current prices they pay, their ideal CBD concentration and preference for scale of grower.

D. Overview of Chapters

Chapter II serves as literature review to understand the background of industrial hemp in the U.S., its history, and recent evolution. The literature review also describes what hemp derived CBD oil is and its market importance within the hemp industry. Hence, chapter II also is the first step of this research and contains information collected from field research and literature review. The chapter details small-scale hemp farm management while investigating costs of production and processing. Chapter III is the second step in this process and studies consumer preferences for CBD concentration in CBD oil using the results of a national on-line choice experiment. Lastly chapter IV summarizes results, discusses their impact, and concludes with the study's limitations to direct future work.

E. References

Tyler, M., Shepherd, J., Olson, D., Snell, W., Proper, S., and Thornsbury, S. 2020. *Economic Viability of Industrial Hemp in the United States: A Review of State Pilot Programs,* EIB-217. Washington DC: U.S. Department of Agriculture, Economic Research Service. Retrieved January 25th, 2022, from https://www.ers.usda.gov/publications/pub-details/?pubid=95929

U.S. Department of Agriculture. 2018. *2018 Farm Bill – Subtitle G – Hemp Production*. Agricultural Marketing Service. Washington DC, Retrieved January 28th, 2022, from https://www.ams.usda.gov/sites/default/files/media/2018FarmBill.pdf

Chapter II. Industrial Hemp and Farm Management

A. Introduction

To understand the current position of the hemp industry in the U.S., one must acknowledge its latest evolutions and understand what the production of industrial hemp entails. *Cannabis* is a very ambiguous word and glossaries of acceptable terms and standards within the industry are yet to be established. Words such as industrial hemp, *Cannabis*, and marijuana must all be distinguished and processing industrial hemp flowers, although being the same plant, does not target the same markets that are designated for products derived from marijuana.

Industrial hemp alone can be used to produce approximately 25,000 distinct products (Crini and Lichtfouse, 2020) that are, directed at different consumer needs and wants. Hemp flower derived Cannabidiol (CBD) rich oil, which is targeted in this study, is one of many products and is a relatively new emerging industry and market. As with any emerging industry, it is difficult to foresee the future. Current extension efforts and research on how to produce and process industrial hemp is mainly focused on marijuana, fiber, or seed production, leaving a research gap for production and processing methods as well as cultivars to grow to harvest hemp flowers with high amounts of CBD (Crini and Lichtfouse, 2020) for the purpose of extracting crude hemp oil with high amounts of CBD.

Producers are still mainly learning by doing and are using production methods common for the marijuana industry as a baseline. As such, new entrants lack critical decision making and record keeping skills to make profit-maximizing decisions (Crini and Lichtfouse, 2020). A multitude of factors such as production location, production environment, flower drying, and processing play a major role in hemp production as end-product costs and quality attributes are impacted.

Providing present and future hemp farmers with production method information and assessing cost differences for different production methods is thus considered a critical step toward a more resilient industry (Jelliffe, Lopez, and Ghimire, 2020). This chapter provides: i) a history of U.S. policy toward industrial hemp; ii) definitions of industry specific terms that are used throughout this study; iii) insights about hemp flower production for CBD oil based on current literature as well as the case farm studied during this research. Given that background, cost of production differences are documented between outdoor (open air) and indoor (high tunnel) production methods to arrive at cost estimates for fresh hemp flower ready for further processing with the case farm used as a specific example.

Drying freshly harvested hemp flower is the next crucial step in the CBD oil supply chain and is required before extraction of crude CBD oil can occur. As pointed out by research of Tyler et al. (2020), Lazarjani et al. (2021), and Crini and Lichtfouse (2020), among others, research, and knowledge about hemp and about drying methods to produce hemp flowers is still lacking. Thus, aside from studying hemp production methods and costs, this chapter also investigates drying i) under controlled ambient conditions (air-drying), ii) using infrared radiation (IR), and iii) freeze-drying or lyophilization in terms of: i) cost, ii) time, iii) energy, and iv) impact on dried hemp flower characteristics (cannabinoids, terpene profiles, and presence/absence of mold) that in turn are expected to drive crude CBD oil quality using hemp flower tracked from on-farm production through retail product (one-ounce bottle of CBD oil) from this case farm as an example. As such, labor requirements and cost differences are presented for different production methods leading to alternative dried hemp flower characteristics or quality attributes. Expectations of how those attributes are impacted by oil extraction conclude the chapter by providing before and after CBD concentrations.

B. Industrial Hemp in the United States

Industrial hemp was commercially grown in the United States until the late 1950s for food, fiber, and textile uses. After WWII, industrial hemp was gradually replaced by other crops and synthetic materials, and hemp was placed under the same definition as marijuana which, compared to hemp, contains significant amounts of delta-9 tetrahydrocannabinol (THC) – the *Cannabis* psychoactive component. Nevertheless, the U.S. continuously imported hemp and products derived thereof from abroad especially from Canada and Europe (Tyler et al., 2020). This discrepancy of allowing imports of nationally restricted products led to public disagreements and attempts to review the legislation on hemp production and processing (Tyler et al., 2020).

After years of political and public conflicts, hemp production was reintroduced in the U.S. The Agricultural Act of 2014, Public Law 113-79 (the 2014 Farm Bill) allowed state pilot programs where universities could legally produce hemp for research and growers could apply for licenses to partake in the program. In 2016, the USDA added hemp to the organic certification program and the DEA introduced the "Statement of Principles" on industrial hemp seeds to facilitate decision-making among hemp producer on which seeds to buy.

By 2018, field- and greenhouse growers combined, reported about 90,000 acres of hemp production throughout 22 U.S. States (Tyler et al., 2020). Whilst long-term economic viability remains uncertain (Tyler et al., 2020; Crini and Lichtfouse, 2020), this overall achievement of the pilot programs led to the legalization of commercial industrial hemp production by the Agricultural Improvement Act of 2018, Public Law 115-334 (the 2018 Farm Bill). Since 2019, all states (except

Idaho, Mississippi, and South Dakota) are producing hemp. However, "[…] *the industrial hemp industry still faces challenges in transitioning from the pilot programs to a mature industry with economically viable, sustainable commercial production*" (Tyler et al., 2020, p. 26).

C. *Cannabis*, Industrial Hemp, and Cannabidiol (CBD)

Cannabis as a botanical genus is defined as an annual plant from the family of Cannabaceae and incorporates 3 widespread species *C. sativa*, *C. indica*, and *C. ruderalis* which can all be used to produce marijuana or industrial hemp (Schreiber, 2022). The species *C. sativa*, especially the shorter female plants whose inflorescences contain high amounts of cannabinoids such as the psychoactive delta-9 tetrahydrocannabinol (THC) and the non-psychoactive cannabidiol (CBD), are mostly used in both industries for their recreational and/or medicinal properties.

Today, over 140 cannabinoids have been discovered within the *Cannabis* plants (Crini and Lichtfouse, 2020). Cannabinoids are compounds that interact with an animal's (including humans) cannabinoid receptors CB1 and CB2, and its endocannabinoid system (Rosenthal et al., 2021). When produced by a plant, one speaks of phyto-cannabinoids. However, for the sake of simplification in this study, these compounds will be referred to as cannabinoids. In *Cannabis*, cannabinoids are accumulated by the plant in the trichomes (small and longitudinal glandular glands) of their inflorescences commonly referred to as flowers. The more flowers a plant produces, the more trichomes, the more cannabinoids as well as terpenes or volatile compounds. Although more research is needed, cannabinoids are believed to help against rheumatism, gout, malaria, and attention deficit disorder (Ramirez, Fanovich, and Churio, 2019). Also, a specific cannabinoid, cannabidiol (CBD) has been associated with antiepileptic, anti-inflammatory, and analgesic effects (Ramirez, Fanovich, and Churio, 2019; Crini and Lichtfouse, 2020, Gould, 2015).

Terpenes, in association with cannabinoids, are also in need of further research with respect to pharmacological properties (Ramirez, Fanovich, and Churio, 2019).

Marijuana and industrial hemp are mainly differentiated by the amount of THC that the plants produce. Merriam-Webster (2022) defines marijuana as "*the psychoactive dried resinous flower buds and leaves of the female hemp or cannabis plant […] that contain high levels of THC and are smoked, vaped, or ingested […]*" whereas industrial hemp must contain less than 0.2 or 0.3% of THC in Europe, and the U.S., respectively. Both, marijuana, and industrial hemp can be used to produce a variety of products. However, marijuana is mostly used for high THC, smokable dried flowers, whereas industrial dried hemp flowers high in CBD are the focus of this study. Cannabidiol (CBD) rich crude oil derived from dried hemp flowers is usually blended with a carrier oil to dilute the often-bitter taste of crude hemp oil to enhance palatability and to achieve a total THC content below the legal limit of 0.3%. Important to this study is the question of how much carrier oil to use when preparing CBD oil for retailing that can contain a large array of compounds to which individual end users may react differently. Further yield and potency of hemp flowers are mainly dependent on *Cannabis* cultivar grown as well as agricultural practices encompassing sowing date, fertilization, seeding rate, water availability, harvest time, and drying method as explained further below. Finding a path to profitably meet and exceed consumer expectations is thus a complex task.

D. Hemp Flower Production and Processing Techniques

Hemp production for CBD is managed as a horticultural crop. The following introductory insights are based on a thorough literature review as well as on-farm collected information to compare what is commonly done and what was observed in practice on a small-scale hemp farm.

Overall, the target farm size is small (below one acre). Further, hemp can be produced indoor in greenhouses or high tunnels, or outdoors. Length of growing season differs based on, among other factors, farm management, hemp variety, and climate conditions. Research and practical experience on a local hemp farm showcase very different results between outdoor and indoor production in comparison to a study conducted by Jelliffe, Lopez, and Ghimire (2020). Detailed are, farm characteristics in terms of soil texture, farm size and access to water, seeds and seedling production, land preparation methods, transplanting methods, post-plant irrigation and fertigation, roguing (the process of eliminating male plants), pruning, pest management, harvesting methods and activities such as testing, defoliation, and drying. Finally, post-harvest activities such as clean-up methods, and oil extraction methods are detailed. All the above factors impact yield per acre and profitability.

1. Farm Description

i. In General

Well-drained land composed of loamy or clayey loamy soils are considered an advantage for hemp production (Jelliffe, Lopez, and Ghimire, 2020) as is the presence of a well. Hemp can be produced out-doors as well as in-doors. Depending on a variety of factors, the farmer may opt for one, the other, or a combination of the two. Outdoor production is either done in single grow bags (Rosenthal et al., 2021) or in soil covered with a plastic mulch (Jelliffe, Lopez, and Ghimire, 2020). In regions prone to hail, outdoor production can be protected from hail and storms using anti-hail netting. Indoor production can take many forms. The environment may be completely closed and controlled including artificial lights or in, greenhouses where light penetrates the environment. Yet another option are high tunnels where sidewalls can be curtained along with keeping tunnel ends open or closed. Most farmers will choose what strategy to pursue based on cost or available capital at start up. Generally, entirely closed, and controlled environments are more expensive than greenhouses and those are in turn more expensive than high tunnels. At the same time, the more controlled the environment the greater the potential for increased yield per plant given lesser disease and pest pressure. As such, indoor production is advantageous for facilitating integrated pest management, control of irrigation and fertilization, as well as season extension (Freeman et al., 2015). Hence, yield and quality of flower drive the feasibility of investing in controlled environment facilities. For indoor production of hemp, high tunnels, sitting on straight sidewalls 4 to 6 foot in height are most common because of the height of hemp plants. The tunnels can handle snow loads, protect from the outside environment, are a cheap option for indoor production, and are easier and cheaper to manage compared to greenhouses (Ames, 2016). Nonetheless, one must take care to control high temperature pests (e.g., Aphids, Whiteflies, Mites, etc.) (Freeman et al., 2015).

ii. Case Farm

The case farm occupies approximately 1 acre (an English to Metric conversion table is provided in Appendix A - English to Metric Unit Conversion table as a reader reference with 0.37 acres in hemp production comprised of 0.3 and 0.07 acres of outdoor and high tunnel production, respectively. The high tunnel is 30 ft. wide and 96 ft. long with 8 ft. tall sidewalls and is closed off at both ends. The sides are protected with a net and with string reinforced poly plastic during winter. The roof is covered with a reinforced poly plastic and has 3 ft. wide netting sown in the ridge line to aid with ventilation. Eight different hemp cultivars were produced during the 2020 and 2021 growing seasons. Most indoor plants were a *sativa* dominant strain by the varietal name of White (W) as it could not withstand the disease pressures of outdoor production. Outdoor plants that were part of our sampling were from an *indica* dominant strain by the varietal name of Bubba Kush (BK). A drying and processing room is adjacent to the high tunnel and serves to store tools and houses the irrigation system. The drying room is 30 ft. wide, 36 ft. long, and 8.5 ft. tall.

The farm is in Washington county in Northwest Arkansas at a latitude of about 36 degrees North and a longitude of about 94 degrees West. Climate data has been retrieved in 2022 (Appendix B – Northwest Arkansas Climate Data). The local soil composition does not play a very important role on this farm as hemp plants are grown in smart pot fabric bags with a capacity to hold 45 gallons of soil. They contain lining starting at two inches from the top down to 6 inches above the bottom. The bags are 15-inch tall and 19-inch wide. The bags also contain draining holes at the bottom and are filled with mostly potting soil and compost. The containers sit on a bed of gravel on 0.17 acres (entire indoor and partly outdoors). Adding gravel to the production area allows good root development and easy cleaning and spacing management. The remaining 0.2 acres of outdoor production occurs in 3 ft. deep and 2 ft. diameter pre-drilled holes filled with native soil and rocks, packed sand, a mix of 40% topsoil, 40% sand, and 20% compost, as well as super soil[1] from bottom to surface in a 1x, 2x, 4x, 8x ratio, respectively, for a reconstitution of soil layers as shown in *Figure 2.1*. On the surface the grow holes are delimited by 12-inch tall, circular PVC material cut from recycled food storage barrels that are buried to a depth of 8 inch. The PVC material maintains a physical barrier between the growing soil and serves to protect from weeds and grass allowed to grow around the plants.

Figure 2.1. On farm picture of miniature example of soil layers in the growing holes.

[1] Potting soil sold under the name of super soil. Specific brand information has not been shared by the case farm.

In 2020 and 2021, 300 and 430 hemp plants in total were grown on the farm, respectively. In both years 88 plants were grown indoors in fabric bags whereas 212 (2020) and 342 (2021) plants were grown outdoors. In 2021, 10 plants failed due to pathogens or other diseases. The W variety was grown exclusively in the high tunnel whereas the BK variety was used outdoors. Within-row and row spacing varied from 6-8 ft. to assess optimal spacing. According to the producer, the optimum is 7 ft. within-row spacing with rows spaced 8 ft. apart which is advantageous for air flow and allows for easier plant access and harvesting. With that spacing, 778 plants per acre are achievable. Jelliffe, Lopez, and Ghimire, (2020) report planting densities between 681 to 1,742 plants per acre achievable with 5-8 ft row and within-row spacing.

2. Seedlings

Buying certified feminized seeds eliminates the need to terminate male plants as roguing is required for producing hemp flowers rich in CBD (Ramirez, Fanovich, and Churio, 2019). Male plants will pollinate female plants leading to hemp seed rather than hemp flower production. Further, replanting costs are minimized by not having to replace male plants when using certified feminized seed. As a result, producers preferably grow their own seedlings or alternatively practice direct seeding (Jelliffe, Lopez, and Ghimire, 2020). Jelliffe, Lopez, and Ghimire (2020) estimated the price of purchased seedlings in 2020 at $4 per seedling grown 4 to 5 weeks before the planting season but quality assurance is an issue.

The case producer grows seedlings in the high tunnel planting approximately 4 weeks before transplanting when soil temperatures indoors and out are consistently above 50°F coinciding with mid-May. In 2021 seedling production started on April 8th in about 3-inch-deep inserts filled with potting soil and microbials which are laid in trays to retain and/or drain excess water in the soil. Every insert receives one seed, water and trays are then positioned underneath growing lights (T5HO 44 54W Fluorescent lamps running at 1.1 amperes) to encourage plant growth. No fertilization or any other product is added to the soil or seed. Seeds are all bought and are all feminized seeds. Feminized seeds have about 90% germination rate. The producer has never observed male plants although a 2% chance of male seeds is common. For each plant ultimately used in production, three seeds were used as plants selected for transplanting and replenishment of plants showing undesirable characteristics that are culled. No specific pest management technique is required for indoor seedling production.

Figure 2.2. On farm picture of a 2-week-old seedling to be transplanted into a 1-gallon pot.

The seedlings remain in these trays for about 2 weeks. The lights must be adjusted in height as the plants start to grow. One must also assure that the lights do not heat the plant too much, generally 74°F on the surface of the plant's leaves is the maximum temperature limit. During the first week the seedlings sprout. In the second week, they mostly develop their root system before vegetative growth starts. By the second week one can observe 2-4 true leaves. Once the roots keep the soil in its structure, as shown in *Figure 2.2*, the plant is ready to be transplanted into 1 gallon grow pots approximately 2 weeks after seeding. Grow pots remain indoors but not under artificial light. Selection criteria during this grow pot stage are set by the producer and based on phenotypical characteristics such as root development, leaf development, hemp variety or strain, and leaf colors. It is rare to keep the seedlings more than two weeks in the seedling trays as the root system otherwise begins to grow in a circular way which may complicate further root development. Seedlings are given reversed osmosis-treated well water every day through a backpack sprayer. Once transplanted into 1-gallon pots, fertilizer is added manually (see D.6 Post-Plant Fertilization, below). The seedlings remain 2 weeks in the 1-gallon pots and are then transferred into the soil or bags where they will develop until harvest. During the development of the seedlings, land preparation is being conducted if necessary.

3. Land Preparation

Plants can be grown directly in soil or in bags, indoors and out, as may be observed in the marijuana industry (Rosenthal et al., 2021). Cover crops may be grown in both cases and are cut and integrated, or not, into the soil about 3 weeks before transplanting or seeding hemp. Soil testing before each growing season is recommended to adjust the soil pH, fertility, and characteristics. Jelliffe, Lopez, and Ghimire (2020, p.5) state that soil should be adjusted to *"[...] pH to around 6.5, to 15 PPM phosphorus (P), based on a modified Morgan test; potassium (K) within a range of 158-235 PPM; and Sulphur (S) availability to 10N:1S.*" If hemp is planted directly into the soil, a farmer may choose to work with plastic mulch to facilitate planting, moisture, temperature, and weed management. In bags, however, plastic mulch is not applied. Soil that is used to fill the bags must be carefully chosen or adapted after soil tests have been conducted. As a producer can choose among a wide variety of cultivars one must pay attention to which cultivars are best adapted to which type of soil. This information is often provided by the seed producers or found online. Indoor production methods are extremely diverse and will not be discussed in detail here as these entail many different possibilities such as hydroponics, vertical gardens, and aquaponics.

Compared to what is generally done on hemp farms, the case farm manages land preparation slightly differently. During the winter months (December to March), green leafy plants are produced in the high tunnel such as arugula, spinach, and cilantro which are directly seeded around the month of October. Two to four weeks before planting hemp, cover crops are harvested for self-consumption, but most are added to a compost pile. The cover crops' roots are simply removed from the soil and left to dry and decompose. Outdoors, nothing is used as cover crop, hence, hemp stems and roots are left in the soil during winter to conserve soil structure and let roots disintegrate and transform into minerals and organic matter.

Soil samples are taken and analyzed during the first week of March or about 8 weeks before transplanting. Soil is sampled from 1/3 of the bags placed outside on gravel, 1/3 of the indoor bags, and 1/3 of outdoor growing holes. The sampled locations are randomly selected by making sure that soil samples include soil from corner spots and more central locations. Soil is withdrawn with a spoon or by hand, at the 6–8-inch depth in the root zone. The amount of soil taken varies from bag to bag, is collected in a 5-gallon bucket where the soil is mixed and a 1-gallon Ziplock bag is then filled halfway and sealed until the soil samples reach a third-party lab for analyses. If any specific issue in a specific bag or grow hole is observed during the previous growing season, single soil samples are taken from these areas and analyzed apart from the other samples. Compost and potting soil that is not acquired through a commercial third-party is also analyzed. Analyses are mainly done to account for pH levels, micro- and macro-nutrients as well as minerals. Heavy metals are only analyzed in potting soil or given by the retailer if bought, as the farmer does not use any products that could possibly alter the number of heavy metals. Water from the well is also tested, especially to account for any diseases, pests, and pollutants. Fertilization is adapted yearly, based on all these results. Any soil improvements whether physical or chemical are done a minimum of two weeks before transplanting to allow time for the soil to adapt. Additionally, the producer regularly uses the application of biochar and worm castings.

Four to eight weeks before planting, gravel is added where hemp is grown in bags, spacing is verified, and gravel is used to level bags so that they do not tilt one way or another. The irrigation system remains drained and maintained throughout the winter as PVC pipes might burst or sprinklers might crack. Maintenance costs are only minimal as the irrigation system is fully drained and sanitized with bleach after the growing season each fall.

Weeding is mostly done manually. To protect plants especially from larger animals and to support the plants once they grow taller, supportive circular cages are put into place in every bag and grow hole. The cages are open at the bottom and the top and are inserted in the soil to stand straight. Cages are made from concrete reinforced wire and are painted to prevent rust and cost about $8 per cage. They are about 5 feet tall and have a diameter of about 1.5-2 feet. The cages are removed after each harvest to allow for easy clean-up, cover crop growth, and to avoid degradation induced by the environmental condition during the winter.

Additionally, during the month of May and early-June, the producer goes over the entire farm to rule out and take remove any pest hiding spots, such as stacked pots, tools, irrigation lines, materials, etc. Equipment, which is cleaned, is also checked for any traces of pests, and if needed destroyed and replaced. Specific durations for land preparation activities, which drive labor costs, were observed and measured and will be shown in the results (**Table 2.1** in section F.1 Labor Cost, below).

4. Transplanting

If applicable, transplanting is done by hand or by tractor where the latter requires less labor. The latter is also faster and likely required if hemp is grown on more than 5 acres. If plants are transplanted from the inside to outdoors, plants need to be acclimated to the increased sunlight to avoid plant damage and stress.

On the studied farm, as seedlings reach a height of approximately 8 inches, they are shortened by half their height to trigger increased root production. Transplanting is done manually, without external labor force at a rate of approximately 13 plants per hour and per person, or 4.6 minutes per plant. Replacement planting is made possible by having backup seedlings available for transplanting.

5. Post-Plant Irrigation

Irrigation is of utmost importance in the first month after planting. Moisture content and temperature in soil, or humidity and temperature in the greenhouse must be monitored to be able to irrigate at the right time. Some farmers will decide to remove irrigation after this phase (Jelliffe, Lopez, and Ghimire, 2020). However, others leave the irrigation system and irrigate every other day especially in warmer and drier climates. Irrigation pumps and system are installed as well as drip tape or micro-sprinklers. Based on literature, water demand ranges between 10 – 16 acre-inches (250 – 400 mm) per growing season (Ranalli and Venturi, 2004). Based on the data from Jelliffe, Lopez, and Ghimire (2020), irrigation on a 1-acre hemp farm in Connecticut costs around $61,500 in material cost including a 75hp well pump, sprinkler pipes, and lateral lines, and $485 in yearly labor cost. In contrast to this, Lamont et al., (2012) estimated the cost for a 1-acre plastic mulch drip irrigation system on a vegetable farm to be approximately $9,850 including a 5.5hp engine and pump, which might be more realistic in terms of expected irrigation material costs.

On the Arkansans case farm, the producer estimates the water needs of 2-3 gallons per plant per day. A 450-ft deep well is present on the farm and provides all necessary water which amounts to 860-1,290 gallons of water a day for 430 plants for the entire growing season which in 2021 went from April 8^{th} to September 30^{th} and includes the time for seedling production. This amounts to approximately 150,000-230,000 gallons of water per growing season for 430 plants. These are estimates, as water needs outdoors depend on the amount of rain that the plants receive and as water needs during the time of seedling production can vary. Plants in grow bags are generally consistently irrigated every day whereas plants in soil are often irrigated every 2^{nd} to 3^{rd} day depending on their needs. Irrigation water taken from the well and pumped to the surface may be adjusted in pH as the well water in the area often has a pH of 8. As hemp plants prefer a pH environment of 6.5-7, sulfuric acid is added if necessary to bring down the pH level. Moisture is monitored as the farm does not want to encourage mold development and air flow is managed indoors if needed by using rotating ventilators.

Irrigation is done using 2 micro-sprinklers per plant in bags and growing holes. The irrigation system with pH control is used for plants in bags indoors and out, whereas the plants in the growing holes outdoors are irrigated exclusively by well water that can be shut off when rain feeds those plants. Water needs of plants is mainly observed by the condition of the leaves, if the leaves start to show signs of flaccidity (curling leaves) water is given. The irrigation system functions based on duration of water supply. All micro sprinklers have the same amount of water pressure and thereby release the same amount of water over a given period and are calibrated before every growing season by measuring the time several micro sprinklers require to fill a 5-gallon bucket, the amount needed to soak the 45-gallon grow bags. On the case farm, sufficient water for a day is available in approximately 20 minutes. The entire irrigation system is connected to the well pump delivering water to each row using PVC pipe for bagged production. The well delivers 13-15 gallons of water per minute using an electric 3 horsepower water pump.

6. Post-Plant Fertilization

Fertilization always depends on the plants' needs. A farmer must regularly assess the potential need for fertilizer. For the case farm, fertigation (delivering liquid fertilizer blended with irrigation water) is continuously used to provide plants with the needed nutrients, amendments, microbials, and bacteria, for all plants grown in bags. The remaining outdoor plants are fertilized by the same concentrate as the plants in bags, however, the amount those plants receive varies as this is done manually. Fertilization is provided all along the growing season once the seedlings are transplanted into the 1-gallon pots. The specific fertigation method used on the farm is shown in Appendix C – On-Farm Specific Fertigation Technique.

7. Roguing

Roguing describes the removal technique of male plants, if necessary, from the production. This must be done before male plants emit pollen (Appendix D – Roguing Techniques).

8. Post-Plant Pruning

The size of the plants grown depends on many factors such as the pruning method, plant spacing, soil characteristics, and accessible area for root development. The height of hemp plants, when producing hemp for flowers only, commonly ranges from 20 to 79 inches whereas widths can reach 8 to 40 inches, both of which can be modified with pruning. Different pruning methods can be applied to hemp plants, but most rely on techniques used in the marijuana industry. On the studied farm, three different times pruning keep plants at a maximum height of approximately 60 inches which facilitates manual harvest and facilitates horizontal rather than vertical plant development (Appendix E – On-Farm Pruning Methods). Additionally, although not considered pruning as such, primarily dead or yellowing leaves are regularly removed. These leaves might be diseased, in decomposition, or healthy. Healthy leaves are detached to enhance air flow and sunlight exposure within the plant and on its flowers.

9. Pest Management

In hemp production it is difficult to combat pests and diseases as there are no labelled pesticides for weed, insect, or pathogen management for hemp in the U.S. (Crini and Lichtfouse, 2020). Literature mainly refers to Integrated Pest Management (IPM) for effective and safe pest management in the hemp and marijuana industry (Rosenthal et al., 2021). Management of weeds, vertebrates, insects, and diseases, mainly affect labor costs. Specific on-farm pest management techniques are described in Appendix F – On-Farm Pest Management.

10. Harvest

Harvest time differs by maturity of the hemp flower variety grown. Crini and Lichtfouse, (2020) report the usual length of growing season from planting to flower harvest within 50 to 60 days for northern *Cannabis* varieties, and 140 to 160 days for southern varieties. On the case farm, 109 to 123 days were observed between transplanting to beginning of harvest. Outdoor grown plants are observed to take about 5 to 6 weeks between the start of the flowering stage until the beginning of harvest, whereas indoor plants are observed to need 7 to 8 weeks. The difference is expected to be a function of sunlight exposure, farm location, variety, and variety origin. The origin of the seeds and the variety is important as each variety can have specific cumulative growing degree day requirements (avg. temperature above 51°F). Northern varieties require cumulative growing degree days to total 1,472 to 1,652°F, whereas southern varieties require a total of 6,332 to 7,232°F. This helps a small-scale farm to manage its harvest as all plants must not be harvested simultaneously. Harvest is the most time-consuming activity and the most labor intensive (Jelliffe, Lopez, and Ghimire, 2020). The timing of harvest is also one of the most crucial steps as total THC content in the flowers increase with maturity of the flowers. Thus, hemp producers must be extremely cautious when timing the harvest to remain within legal limits.

Rather than harvesting the whole plants, the studied farm high-grades its harvests. There are two distinct harvest times on each plant. The partial harvesting allows the farm to harvest the matured flower buds first and gives the remaining flowers increased light and air flow for an additional 2 weeks for them to develop for more yield. Nevertheless, this adds to the labor and time intensity of the harvesting. This is considered infeasible at larger scale (above 1 acre). High-grade harvesting 420 plants takes about 1 to 1.5 months for a full-time worker. More precise timing will be assessed in the result section as time was measured for each harvest activity throughout the months of August, September, and October in 2021 (F.1 Labor Cost).

Further, other aspects must be considering before, during, and after harvest which are -pre-harvest testing of flowers, defoliation during harvest, and drying, debudding, and curing after harvest.

i. Pre-Harvest Testing

State rules require that hemp plant material is tested for total THC content prior to harvest. Each state has its own specific rules. A common rule is that THC content cannot be above 0.3% total THC. Flowers to be tested are mostly sampled by cutting off 8-inch-long apical branches as THC levels tend to be highest in the flowers growing at the furthest extremities (Namdar et al., 2018). This research, on the other hand, seems to be refuted by the statements made by the local hemp farmer which uses pruning methods on the plants and whose laboratory results show that

THC levels were consistent in all the flowers along the stems and that CBD was in higher concentrations in bottom growing flowers.

Sampling is done by state authorities and the material is tested by third-party laboratories. Testing costs must be paid by the producer and testing must be done on each of the varieties produced on the farm. Harvest timing must therefore be very exact and must not be done too late in the growing season as THC content increases daily. If plant material is not compliant with the regulations, tests are repeated, or plant material is destroyed if THC levels are above 0.5%.

If compliant with the regulations on total THC levels, the farmer is free to proceed with the harvesting and processing of their plant material. After testing, the producer has 15 days to harvest the flowers (Arkansas Department of Agriculture, 2020). In the state of Arkansas, the testing fee is $100 per variety and the producer receives a single pass or fail result. The state does not provide the producer with complete laboratory result of the cannabinoid and terpene profile of the flowers. Hence, if the producer wants complete laboratory analyses, additional laboratory testing must be done through another third-party laboratory at an average cost of $50 per variety.

As it is crucial to harvest at the right time, the producer must initiate state testing at the right time. This decision is made based on the appearance of the trichomes on the hemp flowers. As trichomes and their content mature, their colors change from a rather translucid state where they are still developing, to a milky white state that indicate that the flowers are ready to be harvested. Amber coloration indicates a final mature state at which THC levels are often above legal limits. The farmer chooses to initiate state required testing when flowers show 20 to 50% of trichomes at a milky white state. Sampling and testing are done, and within 7 to 14 days, all trichomes of the plant will be in a milky white state which is when the producer starts the harvest.

For the industry in general, hemp is harvested by cutting the entire plant as this method is quick and easy. On the case farm, only flowers are harvested. Some might use mechanization to harvest if the farm is considered large-scale (above 5 acres). Since CBD flower production is mainly performed on small-scale farms, such as the case farm, manual labor is required for the harvest (Crini and Lichtfouse, 2020) with duration for harvesting activities presented in the results (F.1 Labor Cost).

ii. Defoliation

Flowers are trimmed and defoliated to allow for consistent drying and as the rest of the plant is usually not used for crude hemp oil extraction. Harvested plant material must be transported to the drying facility or room. This can be done by truck or manually if the drying room is not far from the growing area.

At the case farm, defoliation is a continuous part of the production as some leaves are eliminated during growing to allow for better air flow. Once harvest starts, harvested fresh hemp flower with stems and some leaves are brought into the drying/processing room and is first superficially defoliated. Leaves are collected on a pile to decompose on ground. After defoliation, the plant material is hung upside down on clothes hangers to dry or is spread out on a flat mesh bed to dry if too small to hang. Prepping plant material to hang also requires having a careful look at the flowers to eliminate any development of mold, insects, etc. Duration of harvesting, defoliating, and preparation for hanging were collected in 2021 for estimation of labor charges.

iii. Drying

Fresh hemp contains about 80% water on a wet basis (w.b.). Thus, drying is a crucial step in the CBD oil supply chain between harvest and extraction. It is typically time consuming, energy intensive, and prone to mold issues (Lazarjani et al., 2021). Drying also allows long term storage of hemp while conserving potency, taste, and medicinal properties (Lazarjani et al., 2021). Drying methods range from traditional air-drying on small-scale operations to forced heated air-drying using natural gas on larger-scale operations. More sophisticated methods involve freeze-drying (FR) or drying with infrared radiation (IR) as discussed further in detail as follows:

Air-Drying or slow air-drying is the oldest hemp drying method (Lazarjani et al., 2021). The flowers are dried to 8-10% moisture content (w.b.) for 10 to 14 days. This is done by hang- or laid out-drying of defoliated hemp flowers. The drying environment is characterized by temperatures between 65 and 70°F and relative ambient air humidity levels between 45 and 60% (Lazarjani et al., 2021). Uneven drying is a major issue in this method which can lead to mold. Nonetheless, literature shows that it remains the "[…] *most convenient way to reduce the prevalence of mold and bacteria during storage before extraction*" (Lazarjani et al., 2021, p. 14). It is unclear whether and how much mold remains in crude hemp oil after oil-extraction.

Infrared Radiation Drying (IR) uses radiant heat to dry hemp flower. The method is in the experimental stage and still requires further research and development (Mujumdar, 2006). Results to date have shown that IR is most efficient for dehydrating foods such as seaweed, vegetables, and bacon (Mujumdar, 2006) as it requires simple equipment, is not energy intensive and comparatively fast (24 hours with much of that time used to temper the product). Experiments conducted using case farm hemp flower were conducted with results reported and discussed below. Much less room for equipment and energy use are expected with this method in comparison to air-drying. A comparative cost analysis is presented in the results.

Freeze-drying (FR) hemp material has recently increased in demand especially for medicinal *Cannabis* (Lazarjani et al., 2021). This method consists of removing water from hemp flowers by freezing the material below its solidification temperature, followed by two drying stages i.e., primary, and secondary (Mujumdar, 2006). Drying is done under vacuum and by heating the material such that water is instantly evaporated without thawing the plant material (Mujumdar, 2006). Although this method allows a producer to dry hemp flowers while preserving almost every biological component of the flowers (Cannabinoids, Terpenes, and Flavonoids) and hence, it's quality (Lazarjani et al., 2021), it is high in cost due to its long drying times and its intensive energy needs (Tambunan et al., 2013).

Currently, "Botanique Preservation Equipment, Inc." (Cannafreeze.net) is entering the market with freeze driers specifically designed for marijuana and hemp flowers. Prices range from $32,000 to $900,000 (plus additional delivery fees) depending on the drying time and capacity a producer is looking for. The cheapest option processes 20 pounds of fresh hemp flower in 3 to 5 days using 12.9 sq. ft. trays. The most expensive option dries 785 pounds in 24 to 36 hours on trays summing to an area of 549 sq. ft.

Scientific literature on freeze-drying hemp is almost non-existent. As such, one must rely on manufacturer statements for now. Advantages are stated to be good preservation of hemp flower chemical profiles, no degradation of terpenes, an average 3 to 4% increase in total cannabinoids in the dried flowers compared to the fresh flowers, no flower shrinkage, 1-year shelf life of dried flowers if stored in airtight containers, and sanitary advantages. Further assessment of costs involved in freeze-drying will be presented in the results.

iv. Debudding

Dried flowers are taken off their stems manually (small-scale) or with mechanized tools (large-scale). This is a quick and easy step as flowers come off their stems very spontaneously when dry. Stems are not conserved for post-harvest extraction as they are often not dry enough, do not add much in terms of CBD content, and add wax to the crude oil that must be extracted to conserve fluidity and crude CBD oil quality. After drying, flowers are conserved in sealed boxes, and stored away from light and sources of humidity. Alternatively, flower can be sealed in vacuum or nitrogen filled bags for longer conservation which adds materials and processing costs but affords greater marketing flexibility as flowers can be sold as much as three years after harvest.

On the case farm, once the flowers are dried, they are separated from their stems and put into buckets with lids to cure as discussed in Appendix G – Hemp Flower Curing.

11. Post-Harvest

i. Post-Harvest Clean-Up

Post-harvest clean-up is very different from farm to farm. Did the farm use plastic mulch? How well established are certain weeds? Is there any specific clean-up to do? These are all questions that might make clean-up tasks very diverse. At the case farm hemp roots and the trunk of the plant cut to 2 to 3 inches above the soil surface remain in the field. Other plant material is composted. Circular plant cages are removed, and weeds are taken out. In October, winter and cover crops are planted in the bags indoors and covered with a thin mesh to conserve heat and moisture. The bottom 4 to 5 inches of the growing bags are sprayed and cleaned with bleach as these are humid spots where algae and moss tend to grow on the surface reducing the 5-year useful life of bags. Treatment with bleach does not impact next year's production. In November, the high tunnel is also sealed with an extra layer of plastic on its side walls to minimize cold air flow to protect contents.

ii. Extraction

The choice of method used for cannabinoid extraction depends on the plant variety, flower density, moisture content of the flowers, and on the desired final product. Many different oil extraction methods can be used. However, one can generally distinguish between solventless, solvent-based, conventional, and innovative extraction methods (Lazarjani et al., 2021; Ramirez, Fanovich, and Churio, 2019).

Currently, the most common methods are the extraction of cannabinoids and oil using solvents such as ethanol or using carbon dioxide (CO_2) as a solvent under supercritical conditions (high pressure) (Ramirez, Fanovich, and Churio, 2019). Ethanol extraction is the easiest and cost effective, however, solvent residue in the final product is common even with distillation. Since some of these steps involve high temperatures, the chemical composition in the crude CBD oil is affected throughout the process as most cannabinoids are thermosensitive compounds (Lazarjani et al., 2021; Ramirez, Fanovich, and Churio, 2019). *Figure 2.3* shows the most common cannabinoids and their pathways of transformation when heated (decarboxylation) and aged (synthase and oxidative degradation).

Using supercritical CO_2, specific components to be extracted from plant material can be targeted leaving not much, if any, residue in the final product. The chemical composition of the extracted plant material is also not changed (Lazarjani et al., 2021) as low critical temperatures and pressures are required. Further, CO_2 is non-flammable, relatively inert, abundant, and cost-effective (Ramirez, Fanovich, and Churio, 2019) with a supercritical state at 88°F and pressure of 73.83 bar as depicted in *Figure 2.4* (Lazarjani et al., 2021). In this state, liquid and gas phases do not exist and CO_2 behaves like a non-polar solvent capable of extracting non-polar cannabinoids such as CBD and THC (Lazarjani et al., 2021). Different cannabinoids and terpenes, described later, become solvent at different pressures and temperatures such that extraction can be targeted at desired compounds. Composition of the raw hemp flower nonetheless still plays a role.

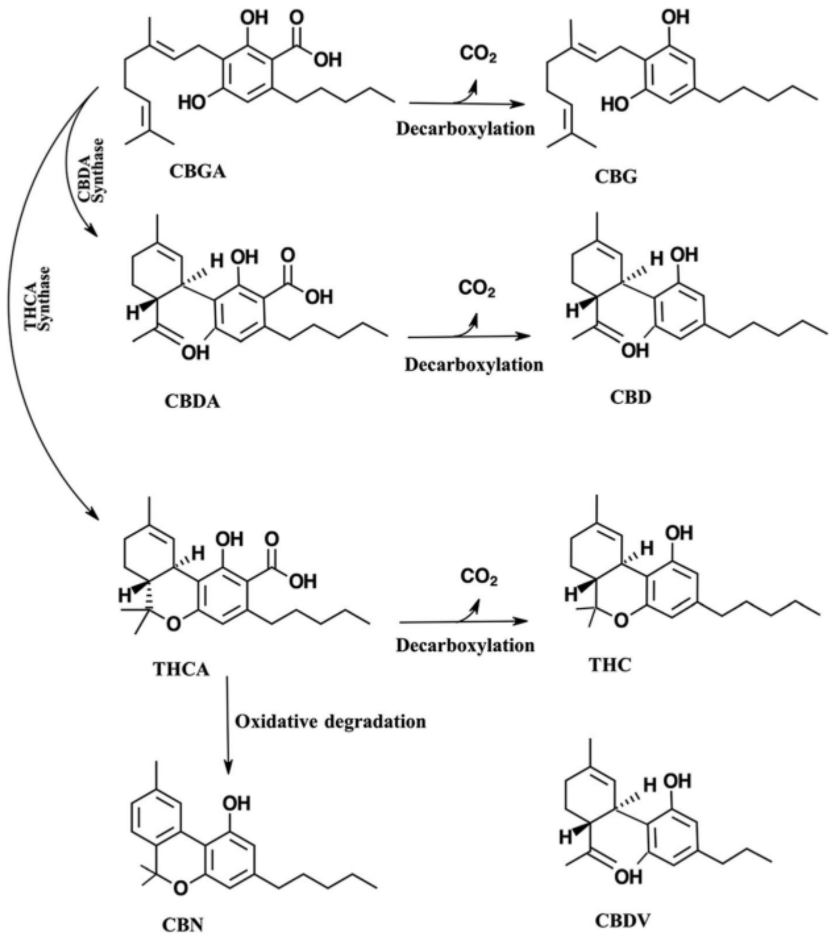


Figure 2.3. Common cannabinoids and their conversion pathway by decarboxylation because of heat or aging.
CBGA can convert to CBDA and THCA by CBDA synthase and THCA synthase, respectively. CBGA: cannabigerolic acid, CBG: cannabigerol, CBDA: cannabidiolic acid, CBD: cannabidiol, THCA: tetrahydrocannabinolic acid, THC: tetrahyrocannabinol, CBN: cannabinol. (Lazarjani et al., 2020).

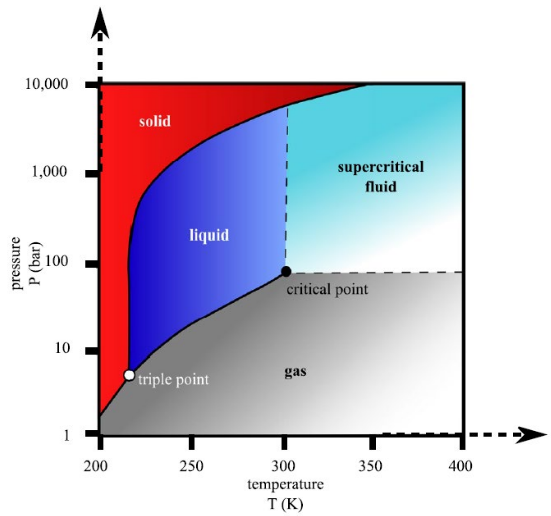


Figure 2.4. CO_2 pressure–temperature phase diagram.
The critical temperature is 304.13 K or 31.0 °C or 87.8°F, and the critical pressure is 7.3773 MPa or 72.8 atm or 1070 psi or 73.8 bar. (Lazarjani et al., 2020).

Ramirez, Fanovich, and Churio (2019, p.151) described the general sequence of oil and cannabinoid extraction from dried hemp flowers as follows "[…] *(1) a heating step to decarboxylate the acid forms of the cannabinoids* (e.g. THCA, CBDA) *until neutral species are obtained* (e.g. THC, CBD) *at 100–150°C; (2) a CO2 extraction step from a packed coarse powder at 600bar and 35°C (4 h)—although other combinations of T and P, between 10–35°C and 60–600bar, could be used; (3) a final step* (if needed) *that involves ethanolic precipitation at -20°C for 24h and removal of waxy material by filtration*". Decarboxylation is used because cannabinoids in their acid forms are not bioavailable to the human body based on today's research and knowledge. Decarboxylation leads to the transformation of the acid forms of cannabinoids into their assimilable forms e.g., CBGA to CBG as shown in *Figure 2.3* above. Ramirez, Fanovich, and Churio (2019, p.148) also state that there is no specific research done yet on optimized moisture content of dried hemp flowers and that "*Since cannabinoids are concentrated in the trichomes, the cutting, grinding, or crushing of Cannabis herb is not beneficial because these processes can enhance the dissolution of non-desired substances*".

In practice, producers, and processors: i) target a moisture content of 10% in dried hemp flowers; and ii) opt for a cutting or grinding step prior to pre-extraction decarboxylation (heating) to enhance cannabinoid yield. Grinding the material exposes it to ambient air where it will lose about 2% moisture content with an additional 2 to 3% moisture content loss during decarboxylation. Thus, if the plant material is too dry to begin with it is more complicated to manage. Optimal plant particle sizes for extraction and oxidation stability of cannabinoids range from 0.028 to 0.033 inches based on Ramirez, Fanovich, and Churio (2019) or 0.08 inches based on Roggen's (2019) extensive research on *Cannabis* Curing and Extraction.

After the grinding step, processors may also opt to extract terpenes under either subcritical or supercritical CO_2 conditions as these are extracted at lower pressures compared to cannabinoids. This step is added to the sequence before decarboxylation (heating) which would otherwise destroy 90% of terpenes. Extracting terpenes beforehand allows reintroduction to the final product for quality, flavors, and medicinal properties. Further specifics about the oil extraction process from the case farm's hemp flowers are described in Appendix H – Specificities on the Case Farm's Hemp oil extraction Process.

In general, the greater the flower to leaf and stem ratio in the plant material to be extracted, the better. For the case farm, the crude hemp oil yield from the 2021 harvest was approximately 9.6 lbs. dried hemp flower per lb. of crude oil, or 0.09 lbs. of crude hemp oil per pound of dried hemp flower at 10% moisture content (w.b.) The industry average is closer to a 12 to 1 ratio or 0.083 pounds of crude hemp oil per pound of dried hemp flower, suggesting that the case farms' production methods are higher yielding.

The crude oil is relatively thick in consistency. Hence blending with a carrier oil, like Medium-chain triglyceride (MCT) oil, aids consumption and allows for THC level compliance.

CBD or other cannabinoid concentration in the final product therefore mainly depends on the THC content of the oil and on a producer's or seller's interest on what CBD concentration of oil to sell to its consumers. Also, it is often better for a processor to have an oil that has less total THC and more overall cannabinoids as it is easier to add and concentrate cannabinoids to reach higher potency, whereas if THC levels are high, one must dilute and cannot work on increasing the oil's other-than-THC cannabinoid potency. Some processors use t-remediation which is a process that extracts THC from crude oil. However, the final product then cannot be sold as a full spectrum oil but rather as a broad spectrum or isolate which is anticipated to lower its value. Also, the process entails added expenditures for the producers.

Cost of extraction, dilution with MCT oil, and oil testing vary between processors, but one can assume a cost of approximately $8 to $20 per pound of dried hemp flower or plant material depending on the process steps and the extractor. For the case farm these costs ranged between $8 and $12 per pound of dried hemp flower.

Coagulation can happen between MCT and CBD oil. While crude hemp or CBD oil can last as long as 30 years, once blended with MCT, the shelf life is reduced to approximately 2 years as long as bottles remain sealed. With each exposure to ambient air, one promotes degradation of the oil. Labor time and costs for bottling are accounted for in the result section.

Assessing the risk of fungus and bacteria on hemp flowers to transfer to the final product is of interest. Laboratory tests are presented to assess these concerns based on different drying methods. However, no test has been conducted on the final oil product as quantities processed for drying were insufficient to warrant extraction. Alternatively, the issue was discussed with the extractor who stated that it is most important not to have any mold in its pluming stage of releasing spores when the material is brought into the extraction facility as most molds and fungi are not toxic in their early stages and are mainly destroyed during decarboxylation and dissipated through the ventilation. On the other hand, even if some of these organisms survive, every oil batch must be analyzed by a third-party laboratory for fungal and bacterial count as required by food safety legislations. Thus, certain threshold must be respected to assure the safety of the final product. These results were not available as the processor received results on a pass or fail basis without stating specific results. Detailed thresholds for contaminants, pesticides and other food safety standards can be found through the Arkansas state board of health, department of health, through its rules and regulations governing medical marijuana registration, testing, and labeling in Arkansas promulgated under the authority of amendment no. 98 of the constitution of the state of Arkansas of 1874 and the medical marijuana amendment of 2016 (Arkansas Department of Health, 2016). The same regulations apply to hemp derived products.

12. Yields

Average yields per acre vary across farming methods and *Cannabis* varieties or cultivars used. Jelliffe, Lopez, and Ghimire (2020) observed yields of approximately 2,500 lbs. per acre of dried flower at a moisture content of 8% (w.b.) As the number of plants per acre can vary to a great extent among farms, acre-based yields are not considered very indicative. Although yields depend on specific plant varieties, literature shows yields of 0.5 to 1 lb. of dried hemp flowers per plant in Minnesotan hemp farms (Minnesota Department of Agriculture, 2020). In the start-up year on the case farm that yield per plant was similar, but in 2021 yields ranged between 1.9 to 2 lbs. of dried hemp flower per plant no matter if those were produced indoors or outdoors. As often observed in agriculture, the soil needs time to adapt and first year production is often lower than for subsequent years. Expectations are that third year yield might be slightly higher than the second-year yield and will set the standard for years to follow.

Given 2021 data on yield expectations of 2 lbs. of dried hemp flower per plant and a ratio of 9.6 lbs. dried hemp flower per lb. of crude oil, the case farm produced 9,912 CBD oil bottles at a 3,300 mg CBD concentration per ounce which converts to approximately 27,425 - 1 oz. bottles of CBD oil at 3,300 mg per acre of production.

13. Revenue Projections

Price per pound of dried flower is rather low at $1.50 per percentage point of CBD ($ / % CBD / lb.) (Jelliffe, Lopez, and Ghimire, 2020). As such, most producers will opt to produce CBD oil. The processing (oil extraction, dilution, and testing) costs which vary between $8 to $20 are assumed at $8 per pound of dried flower for the sake of facilitating the analyses and because this was the amount paid by the case farm. The price for final CBD oil depends on the CBD concentration. For the value of the final product used in the economic analysis, this study considered the case farm's 1 ounce 3,300 mg CBD oil bottles sold at a wholesale and retail price of $80 and $160, respectively.

To assess profitability of CBD oil production there are other aspects to consider. Generally, a hemp producer must account for labor, building and equipment (e.g., tools, buildings, transportation, irrigation systems, etc.) ownership charges including depreciation, interest, property taxes, rent and insurance, office supplies, licensing and fees, marketing, processing, and packaging costs. Insurance costs are different based on which insurance a hemp producer uses and whether crop insurance is used or not. Hemp licensing and fees also vary between states as well as their specific regulations but will always be part of hemp production expenses as well as land rent if land is not owned. In literature, sales and marketing charges are often assumed 5% of gross revenue (Jelliffe, Lopez, and Ghimire, 2020).

As hemp is a newly emerging industry, many risks are also involved in its production. Unexpected pests and environmental pressures, crop losses, market collapses, and legislative changes or concerns are common. Additionally, as prices for CBD oil products vary significantly by CBD concentration but are also impacted by other characteristics (country of origin, organic/natural production, and advertised medicinal properties), focusing on cost of production to determine a breakeven price makes more sense.

E. Materials and Methods

On-farm production methods, data on costs of production, and hemp flower samples were collected from the experienced small-scale hemp producer in Arkansas. On farm data has been continuously collected starting in late August 2021 until March 2022 to collect data during the times of pre-harvest, harvest, post-harvest, winter season, and start of the growing season. Data was collected on labor, overall production costs, drying methods, and oil extraction and investment needs as explained hereafter.

1. Economic Analysis

i. Labor Time and Costs Estimates

Data collection on labor cost was done by measuring duration and timing of specific on-farm activities with a stopwatch to estimate labor hours. Documented also are certain discussions and communications with the farmer and hemp oil extractors.

Labor time and cost from 2021 was used to determine expected yearly values which were further extrapolated to a 1-acre production area using assumptions and a 2.7 multiplier (1 divided by 0.37 acres in production on the case farm). Further, costs were differentiated between indoor and outdoor production. Labor time spent and periods for cleaning, weeding, preparing the land, seedling production, fertigation, transplanting, daily check-up, leaf plucking, pruning, and irrigation were estimated via the farmer's statements.

ii. Production Costs

The financial data was collected by discussing financials with the farmer, the accountant, but also by analyzing the farm's balance sheets, income statements, and yearly receipts. Production costs were collected for 2020 and 2021.

Capital investment expenditures for building costs, equipment rental for buildings, building labor, the irrigation system, the high tunnel plastic roof - and side covers, as well as the 243 growing fabric bags, had to be accounted for. These capital investments for these categories have been estimated by deducting the amount of 2021 expenses in each targeted category from the 2020 expense in the respective category to differentiate between capital investment costs and recurring yearly costs in these same categories. Capital investment costs were depreciated over time assuming straight-line depreciation involving purchase price, salvage value and years of useful life. Salvage value for buildings were set at $20,000 and zero for equipment, respectively. Useful life for the plastic covers and the growing bags were 5 years given supplier information, whereas other equipment was assumed to last 15 years.

Shipping costs in 2020 and 2021 did not reflect the expected yearly costs given that shipping and sales expenses only showed the expenses on CBD products that were sold in that timeframe. The costs vary based on the number of CBD bottles that are shipped at a time, different delivery companies, and whether shipping is done locally, within the state, country or internationally. An overall, average cost of shipping and sales for one CBD oil bottle was estimated at $3 given the producer's experience regarding shipping costs, potential customs expenses, and other sales related expenses to date. This cost estimate does not include fuel used to visit retailers and other business partners as well as trip costs for oil extraction that were added as part of marketing expenses amounting to 5% of gross revenue as mentioned earlier.

iii. Conversion to Per Acre Cost and Revenue Expectations

Simple scaling of cost to account for the difference in production area, for the case of the study farm, assumes that the ratio of indoor and outdoor production methods is held constant. Producing on 1 acre thus involves 0.81 acres of outdoor and 0.19 acres of indoor production involving 1,162 plants (assuming no plant is lost due to diseases or other factors). Based on 2021, where 88 plants are grown indoors and 342 were outdoors, 238 plants would be grown indoors and 924 outdoors on one acre. Assuming an average of 8.94 lbs. of fresh hemp flower is produced per plant whether outdoor or indoor grown, a fresh flower harvest weight of 2,128 lbs. indoors and of 8,260 lbs. outdoors is assumed. Knowing the time, it takes to harvest 1 lb. of fresh flower indoor and outdoor, it was possible to assess labor time and costs for harvesting one acre of hemp flowers (if current production and harvesting methods remain unchanged). To assess processing losses, weights of harvest were taken on farm at harvest and once the flowers were dried and collected to a precision of ± 0.1 lb. Also, knowing that hemp flowers lose approximately 78% of their weight during drying, it was possible to assess that per acre hemp flower production, based on the current farm management, could produce 2,285 lbs. of dried hemp flower ultimately leading to 27,425 bottles of 1-oz. CBD oil bottles with a wholesale value of $80 per bottle at a concentration of 3,300 mg of CBD per bottle.

When assessing per acre costs without a constant indoor and outdoor production ratio but rather with a complete indoor or outdoor production acreage, modifying the ratio of indoor to outdoor production critically impacts investment in high tunnels as well as harvest labor charges. Harvesting took 1 minute longer for indoor production compared to outdoor production. High tunnels, which have been identified as cheaper compared to greenhouses have the disadvantage that they are limited in square footage. Based on Adams and Todd (2015), a high tunnel can commonly measure up to 30x150 feet (width x length) or 4,500 square feet. As such approximately 10 high tunnel structures would occupy 1 acre. Based on Gu, Masabni, and Wallace (2019) and Robbins and Gu (2009) building costs for high tunnels range from \$2.25 to \$5.00 per square foot. On a 1-acre basis this would mean building costs ranging from \$98,010 to \$217,800. Picking a simple average, high tunnel building cost of \$157,905 are used to scale to 1 complete indoor production acre.

Further, on a 1-acre production basis, costs of a drying room of at least 4,875 sq. ft. assumed at an 8.5 ft. internal height sectioned into approximately fourteen 26 ft. long rows of wires to support clot hangers for drying hemp flower with rows spaced 5 ft. apart. Room requirements also include an air-conditioning unit, as well as thermostats and a dehumidifier. Assuming a cost per square foot of \$8.70 for an industrial building, the drying room for a 1-acre hemp flower production would cost approximately \$42,413. On the one-acre production basis it was assumed that all plants are grown in bags at \$13 per bag.

2. Drying Methods

To assess differences in dried hemp flower quality attributes by drying method, hemp flowers were collected and dried using both conventional air-drying and IR-drying. Drying hemp flowers using freeze-drying has not been tested firsthand and its analysis therefore relies solely on literature review. Described hereafter are different drying methods that incur different expenses which will be estimated as described in section F.5 Estimated costs of drying.

Samples of hemp flowers were collected during the harvest months from September to October 2021, and dried both on farm using air-drying, and in laboratory, using IR-drying. Samples were collected both, in-doors and out, and from two different hemp varieties – BK and W. For the sake of consistency, flowers on their stems that were dried on farm and in the lab were collected from the same plant, at same stage of maturity, and growing at approximately the same height on the plant. This was important as cannabinoid and terpene profiles are expected to vary between inflorescences at the bottom of the plant compared to the ones at the extremities near the top of the plant as discussed above. Samples did not come from the same branches. Flowers were collected with their stems and dried on their stems as it is usually done on a farm with air-drying. For IR-drying experiments a different approach was required as described below.

Infrared radiation experiments were conducted by using a laboratory infrared radiation oven where hemp material was dispersed on a flat surface. Samples of hemp flower varied between 0.38 and 0.44 lbs. and were positioned 10.8 inches from the heat source set to an intensity of 2.51 kW per square meter. Required duration of drying was unknown, and experiments mainly focused on drying the hemp material until the weight of the samples remained constant. This indicates that most of the free water has been extracted from a material. Going beyond the extraction of free water potentially impacts the dried material's quality and often resulted in burned samples as bound water was extracted. Three main trials were conducted and only the third trial was considered successful.

The method consisted of drying two samples of W hemp flower and three samples of the BK hemp flower. Only two trials with the W variety were conducted given insufficient available plant material for both drying and control samples needed for laboratory analyses. The hemp flowers were dried without their stems and were cut into more or less uniform chunks of approximately 0.4 to 0.8 inch in dimension with a regular kitchen knife instead of using high-speed blenders to conserve quality. The cut flowers were then dispersed onto the metal plate covered with a metal mesh to avoid direct contact between hemp material and the metal plate. The metal mesh held the plant material about 0.4 inches above the metal plate. The plate was introduced to the pre-heated IR-drying oven. The samples were weighed and turned every 2 minutes. After 9 minutes of drying the samples were moved to two sealed Ziplock bags and stored inside a sealed container in an environmental chamber at 68°F and 12% relative humidity for a duration of 46-47 hours to allow samples to temper by absorb some humidity such that the entire sample would take on a similar moisture content. After, this stage, samples were once again infrared irradiated using the same approach until reaching a constant weight (moisture content of approximately 10% w.b.) with an additional approximate 4 minutes of drying.

To inform about changes in cannabinoid, terpene, fungal and bacterial count changes as a function of drying method, laboratory analyses of plant materials were conducted on both varieties as (1) fresh flowers with stems before drying; (2) on-farm air-dried flowers; and (3) in-lab dried flowers by infrared-radiated-drying. Three replicates per group and hence, a total of 18 samples were analyzed as described further below.

3. Dried Hemp Samples Analysis

Hemp flower samples were analyzed in the laboratory. Moisture content of the samples were measured using the oven method where hemp samples were weighted, placed into an oven for 24 hours at approximately 122 to 140°F before being weighted again to assess the weight loss to determine initial moisture content. The samples had their i) cannabinoids extracted and analyzed by the HPLC method; ii) terpenes and volatile compounds extracted and analyzed by the GC-MS-FID method; and their iii) presence of fungi and bacteria manually quantified assessing the number of colonies per one gram of sample. Details regarding laboratory methodology are provided in Appendix I – Laboratory Methodology for Analyses on Fresh and Dried Hemp Flower.

Sample concentrations of eleven cannabinoids included: Cannabidivarinic acid (CBDVA), Cannabidiolic acid (CBDA), Cannabigerol (CBG), Δ9-Tetrahydrocannabivarin (THCV), Cannabigerolic acid (CBGA), Tetrahydrocannabivarin Acid (THCVA), Cannabinol (CBN), Δ9-Tetrahydrocannabinol (Delta-9), Δ8-Tetrahydrocannabinol (Delta-8), Cannabichromene (CBC), Δ9-Tetrahydrocannabinolic acid (THCA), Cannabichromenic acid (CBCA), Cannabidivarin (CBDV), and Cannabidiol (CBD). Of interest in this study were CBDA, CBG, CBGA, CBN, Delta-9 (THC), THCA, and CBD to assess whether hemp flower samples were within legal limits. Total THC percentage was calculated based on the approach from Steep Hill Labs, Inc. using:

$$(0.75 \cdot 0.88 \cdot \text{Delta-9}) + \text{THCA}, \tag{1}$$

where Delta-9 and THCA are expressed as percentages on dry matter basis.

Also, total percent CBD (TCBD) was calculated based on the formula used by Chen et al. (2021) where:

$$\text{TCBD} = \text{CBD} + \text{CBDA} \cdot 0.877 \tag{2}$$

and CBD and CBDA are again expressed as percentage concentrations on a dry matter basis.

The laboratory analyses also profiled 158 different volatiles among which most can be qualified as terpenes. To make results easier to read and understand, these volatiles were grouped into thirty-nine groups. Subsequently, terpene results are reported as averages across replicates and reported for six main groups: alpha.-Pinene, beta.-Myrcene, D-Limonene, Linalool, Caryophyllene, and Humulene. The selection of these groups was based on the findings of Sommano et al. (2020) and Baron (2018) who identified these primary groups to have many beneficial health related properties ranging from analgesic, anti-inflammatory, anesthetic, anti-oxidative, and anti-cancer effects while also having insect and bacteria repellent effects.

Bacteria and fungi or mycotoxin counts were based on the overall count for each organism, but do not specify which specific type of bacteria or mycotoxin is being accounted for. Results are presented as the logarithm of the colony forming units per gram of sample. While specific units are not of interest, replicate averages and their standard deviation are compared across drying method and variety to gain appreciation for changes in counts across drying method.

4. Expected Oil Extraction Impacts on Hemp Flower Profiles

Hemp material is decarboxylated (heated) before oil extraction and is exposed to additional heat during oil extraction which modifies the chemical profiles of the hemp flowers. While the above preliminary work did allow for assessing differences between air-drying and IR, extraction also contributes to changes in the ultimate make up of crude CBD oil.

The impact of the oil extraction process on the flowers' profiles was assessed by collecting laboratory results of marijuana samples given by an Arkansan oil extractor where flowers' chemical profiles were examined before and after oil extraction. Several certificates of analyses (COA) from the processor were requested to compare the chemical profiles of dried hemp flowers and of the supercritical-CO_2 oil extracted from those flowers. However, only one COA was ultimately delivered. That oil extraction batch used high THC content hemp flowers that were converted to oil. As one sample, with the wrong target cannabinoid (THC vs. CBD) is not representative of what kind of results to expect for CBD using CO_2 extraction, results are presented to suggest that the impact of the oil extraction must be evaluated by hemp producers and processors when deciding on which final products to produce.

5. Costs of Drying

As different drying methods use different equipment and have different drying times and building space needs, both fixed and operating costs will vary across methods (Sztabert and Kudra, 2006). Sztabert and Kudra accounted for the fixed costs of the dryer itself (if necessary), pre- and post-drying equipment and buildings by capturing depreciation, insurance & maintenance charges, as well as variable costs of energy, utilities, and labor. To assess cost differences across drying method, measurements from the studied air-drying process were used to inform about labor and energy needs per unit of material processed. At the same time the lab work provided benchmark values for labor and energy needs whereas freeze-drying information came from manufacturer information. A summary of that work is provided in Appendix J – General and Specific Assumptions for Differences in Cost by Drying Method.

F. Results

1. Labor Cost

Yearly expected labor time and associated expenses per hemp plant are shown in **Table 2.1** and **Table 2.2**. At a wage rate of $15 per hour, differences in yield and harvesting time requirements between indoor and outdoor production are reported.

Table 2.1. On-Farm Expected Labor Time (Harvest Excluded).

Activity	**Period ((X) hours per day)**	**Hours per plant[1]**
Cleaning	Jan-Apr & Sep-Dec (2) - May-Aug (1)	1.01
Weeding	Jun (1) - Jul-Oct (0.5)	0.15
Prepping Land	Mar-May (3) - Nov (2)	0.56
Seedling production	Apr (2)	0.10
Fertigation & Fertilization (Manual)	May-Aug (4 hours per week) (17 weeks)	0.16
Transplanting	May (33 hours for 430 plants)	0.08
Daily check-up	Apr-Oct (1)	0.36
Leaf plucking	Jul-Aug (1)	0.10
Pruning	0.17 hours per pruning (3 pruning per plant)	0.50
Irrigation	May-Oct (1)	0.30
Bottling[2]		0.32
Non-harvest total hours		**3.64**
Harvesting	Aug-Oct (8)	See Table 2.2

[1]All duration of activities, besides transplanting, pruning, bottling, and harvesting, are based on average hours spend on each activity in 2020 and 2021. The duration of the other activities is based on the data from 2021 as future expected yearly hemp flower yields and labor expenses are assumed to coincide with labor costs in 2021 for these specific activities.
[2]Given 9,912 bottles from planting 430 plants and harvesting 420 plants at 50 seconds per bottle (2021).

Using a pre-harvest total of 3.64 hours per plant of labor that can be extrapolated to fewer or more plants grown within reason, the information provided in **Table 2.1** and **Table 2.2** suggest that labor charges valued at \$15 per hour, amount to \$54.60 for non-harvest activities (3.64 hrs/plant · \$15/plant) with an additional 0.44 to 0.64 hours per plant for harvesting, where more expeditious harvesting on outdoor plants leads to lower harvest labor charges per plant. As such, total labor charges per plant as estimated for the case farm, with a given ratio of indoor and outdoor production, amounted to (3.64 + 0.48) hours per plant or \$61.80 per plant.

Table 2.2. On-Farm Expected Harvest Time and Subsequent Labor Costs.

Activity	**Hours per plant**	
	Indoor	**Outdoor**
Harvesting (Based on 2021 data collection on 0.37 acres)		
Avg. time per lb. of fresh hemp flower[1] (minutes:seconds)	3:13	2:13
Lbs. of fresh flower per plant	8.94	8.94
Number of plants harvested (lost 10 outdoors)	88	332
Total lbs. harvested	787	2,968
Total harvest hours	42	110
Number of harvest days[2]	26	
Number of hours per plant given indoor/outdoor ratio	**0.48**	
Harvesting 1 acre[3] of hypothetical indoor or outdoor production		
Number of plants harvested[4]	1,162	1,135
Total hours 100% indoor vs. outdoor	557	375
Number of harvest days	93	63
Number of hours per plant 100% indoor/outdoor	**0.64**	**0.44**

[1]Data was estimated from tracking time required to handle 6 batches of hemp flower from indoor production with an average e weight of 14 lbs. per batch and 11 batches of hemp flower from outdoor production at an average weight of 23 lbs. per batch.
[2]Since 2 hours are required daily for workspace preparation during harvesting, 6 hours per day were available for harvesting.
[3]A 2.7 multiplier was used to calculate the hours spent on a 1-acre production area.
[4]Using the 2.7 multiplier a loss of 27 plants is assumed when producing hemp outdoors.

Using only indoor production would result in \$64.20 labor charges per plant and only outdoor production would lead to \$61.20 labor charges per plant. At the same time, outdoor production is expected to yield fewer plants and thereby associated revenue losses.

2. Financial Analysis & Estimated Potential Returns

Table 2.3 and **Table 2.4** show results of the financial analysis by adding non-labor related charges using financial records from 2020 and 2021. **Table 2.3** shows the expected capital investment expenditures of approximately \$110,000 on a 0.37-acre basis and included building material costs, equipment rental needed to construct the buildings, building labor, the irrigation system, the high tunnel plastic roof - and side covers, as well as the 243 growing fabric bags. Annual depreciation for these capital investments summed to approximately \$6,500. On a 1-acre basis this capital investment is expected to increase to approximately \$290,000 with annual depreciation of approximately \$20,000. However, these values might be different in reality as another well and well pump might be required to have sufficient water for the plants. Also building labor equipment and materials may not scale as efficiencies and/or alternative technology may be employed when increasing the acreage.

Table 2.3. Expected Investment Needs on 0.37 Acres, Per Plant, and on a 1-Acre Basis.

Budget Items	Value (\$/0.37 acres)	Value (\$/acre)
Depreciated over 15 years		
Building[1]	\$ 53,581	\$ 144,812[2]
Equipment Rental	\$ 836	\$ 2,259
Building Labor	\$ 43,848	\$ 118,508
Irrigation System	\$ 3,096	\$ 8,368
Building on 1-acre indoor production[3]		\$ 200,318
Building on 1-acre outdoor production[4]		\$ 42,413
Depreciated over 5 years		
High-Tunnel plastic covers & Growing bags	\$ 5,359	\$ 14,484

[1]Total building costs as reported in the farm's financial statements. \$19,700 of these expenses are expenses specific to the high-tunnel structure on 0.37 acres.
[2]The building expense on 1-acre is scaled using the 0.37-acre information assuming the same ratio of outdoor and indoor hemp production practiced on the case farm.
[3]The building expense on 1-acre indoor production is \$157,905 for the high-tunnels and \$42,413 for the drying room.
[4]The building expense on 1-acre outdoor production is \$42,413 for the drying room.

Table 2.4. Annual Expected Costs and Returns on 0.37 Acres, Per Plant, and on a 1-Acre Basis.

Budget Items	**Value[1] ($/0.37 acres)**	**Value ($/plant)[2]**	**Value[1] ($/acre)[2]**
Value of Production (Wholesale)			
1 oz CBD oil bottles at 3,300 mg CBD/oz	**$ 523,200**	**$ 1,216.74**	**$ 1,414,054**
Variable Inputs			
Administrative Fees	$ 5,778	$ 13.44	$ 15,616
Compost, & Soil Amendments	$ 9,235	$ 21.48	$ 24,961
Cover Crop	$ 98	$ 0.23	$ 264
Drying room & Storage supplies	$ 1,154	$ 2.68	$ 3,120
Farm supplies	$ 11,633	$ 27.05	$ 31,441
Fuel	$ 56	$ 0.13	$ 151
High Tunnel supplies	$ 128	$ 0.30	$ 345
Interest	$ 1,843	$ 4.29	$ 4,981
Irrigation	$ 1,218	$ 2.83	$ 3,292
Lab Analyses	$ 1,807	$ 4.20	$ 4,882
Miscellaneous Labor	$ 729	$ 1.69	$ 1,970
Marketing & Advertisement	$ 5,929	$ 13.79	$ 16,024
Miscellaneous[3]	$ 6,893	$ 16.03	$ 18,630
Office supplies	$ 3,049	$ 7.09	$ 8,240
Oil Extraction	$ 6,608	$ 15.37	$ 18,282
Pest Management	$ 874	$ 2.03	$ 2,362
Repairs and Maintenance	$ 667	$ 1.55	$ 1,804
Sales, Shipping, & Supplies[4]	$ 29,736	$ 69.15	$ 82,270
Seeds[5]	$ 1,290	$ 3.00	$ 3,486
Soil & Mulch	$ 4,115	$ 9.57	$ 11,122
Licensing & Fees	$ 2,165	$ 5.03	$ 5,850
Building Supplies	$ 937	$ 2.18	$ 2,532
Total Labor (Miscellaneous included) [6]	$ 27,253	$ 63.38	$ 73,252
Total Variable Costs	**$ 122,465**	**$ 284.80**	**$ 332,907**
Fixed Inputs			
Total annual depreciation[7]	$ 6,496	$ 15.11	$ 19,827
Electricity	$ 2,251	$ 5.24	$ 6,085
Rent[8]	$ 150	$ 0.35	$ 150
Security	$ 939	$ 2.18	$ 2,537
Total Fixed Costs	$ 9,836	$ 22.87	$ 28,598
Total Costs	**$ 132,301**	**$ 307.68**	**$ 361,505**
Net Returns			
Returns above Variable Costs	$ 400,661	$ 931.94	$ 1,078,646
Returns above Total Costs	**$ 390,899**	**$ 909.07**	**$ 1,052,549**

[1]Total of 0.37 acres (0.3 outdoors and 0.07 indoors). On 1 acre, 0.81 acres outdoors and 0.19 acres indoors.
[2]Per plant values were calculated by dividing expected values by 430 (2021 number of plants). Per acre values see methodology.
[3]Miscellaneous = Non-categorizable, Internet & TV, Trash, Travel & Business Meetings, Subscriptions, Parking.
[4]Shipping and sales related costs of one CBD oil bottle was assumed at $3 per bottle.
[5]Yearly expected seed costs are assumed at $1,290 at $1 per seed and at $3,486 on a one-acre basis.
[6]Please refer to Table 2.1 and Table 2.2
[7]Please refer to Table 2.3
[8]The price of the rent on the studied farm is for 1 acre of land.

As in **Table 2.1** and **Table 2.2**, yearly expense values in **Table 2.4** are reported for the case farm, on a per plant basis and extrapolated to a per-acre basis. **Table 2.4** shows a total expected yearly expense of $132,301 at a total expected yearly return to labor, management and capital of $390,899 and was scaled to $361,505 and $1,052,549, respectively, on a 1-acre basis. On a per plant basis, the yearly costs are $307.68, and yearly net returns are $909.07. Producing 9,912 bottles of CBD with total annual production costs of $132,301, the farm needs to sell its 3,300 mg CBD oil 1-ounce bottles at a minimum price of $13.35 to break even. At the same time, given the wholesale price of $80 per bottle, the producer needs to sell 1,655 bottles.

It is expected, however, that costs and returns may vary in reality in the sense that oil processing costs might increase or decrease at different CBD oil concentrations than the 3,300 mg per bottle chosen by the producer. Also, shipping costs are not accounted for in this financial analysis and other overall fees such as administrative fees, fertilizer, fuel, supplies and equipment costs, marketing fees, licensing expenses, and others may change with scale of operation.

For example, labor costs make up the largest share of variable cost for producing hemp flowers. On a 1-acre basis, this expense might decrease using mechanized harvesting and farm tools which would be depreciated over several years.

To compare indoor and outdoor production, **Table 2.5**. presents per/acre information using assumptions provided in section E.1.iii Conversion to per acre cost and revenue expectations.

Indoor vs. outdoor net return differences are estimated to vary by $33,142. However, outdoor production with greater pest pressure is considered riskier and as such net return differences may be larger or smaller. At the same time, capital investments are smaller with outdoor production and as such financially less risky. Nonetheless, once the main structure of the high tunnel is paid off, a producer producing indoor hemp flower only, will face better cash flow projections lowering their short-run break even price.

Table 2.5. Estimated Per-Acre Annual Cost and Returns for Indoor vs. Outdoor Production.

<table>
<tr><th>Budget Item</th><th>Indoor ($/acre)[1]</th><th>Outdoor ($/acre)[2]</th></tr>
<tr><td>Value of Production (Wholesale)</td><td></td><td></td></tr>
<tr><td>1 oz CBD oil bottles at 3,300 mg CBD/oz[3]</td><td>$ 2,194,005</td><td>$ 2,143,025</td></tr>
<tr><td>Variable Inputs</td><td></td><td></td></tr>
<tr><td>Administrative Fees</td><td colspan="2">$ 15,616</td></tr>
<tr><td>Compost, & Soil Amendments</td><td colspan="2">$ 24,961</td></tr>
<tr><td>Cover Crop</td><td colspan="2">$ 264</td></tr>
<tr><td>Drying room & Storage supplies</td><td colspan="2">$ 3,120</td></tr>
<tr><td>Farm supplies</td><td colspan="2">$ 31,441</td></tr>
<tr><td>Fuel</td><td colspan="2">$ 151</td></tr>
<tr><td>High Tunnel supplies</td><td>$ 1,815</td><td>$ 0</td></tr>
<tr><td>Interest</td><td colspan="2">$ 4,981</td></tr>
<tr><td>Irrigation</td><td colspan="2">$ 3,292</td></tr>
<tr><td>Lab Analyses</td><td colspan="2">$ 4,882</td></tr>
<tr><td>Miscellaneous Labor</td><td colspan="2">$ 1,970</td></tr>
<tr><td>Marketing & Advertisement</td><td colspan="2">$ 16,024</td></tr>
<tr><td>Miscellaneous[4]</td><td colspan="2">$ 18,630</td></tr>
<tr><td>Office supplies</td><td colspan="2">$ 8,240</td></tr>
<tr><td>Oil Extraction[5]</td><td>$ 18,283</td><td>$ 17,859</td></tr>
<tr><td>Pest Management</td><td colspan="2">$ 2,362</td></tr>
<tr><td>Repairs and Maintenance</td><td colspan="2">$ 1,804</td></tr>
<tr><td>Sales, Shipping, & Supplies</td><td colspan="2">$ 82,275</td></tr>
<tr><td>Seeds[6]</td><td colspan="2">$ 3,486</td></tr>
<tr><td>Soil & Mulch</td><td colspan="2">$ 11,122</td></tr>
<tr><td>Licensing & Fees</td><td colspan="2">$ 5,850</td></tr>
<tr><td>Building Supplies</td><td colspan="2">$ 2,532</td></tr>
<tr><td>Total Labor (Miscellaneous included) [7]</td><td>$ 76,572</td><td>$ 71,501</td></tr>
<tr><td>Total Variable Costs</td><td>$ 337,704</td><td>$ 330,393</td></tr>
<tr><td>Fixed Inputs</td><td></td><td></td></tr>
<tr><td>Annual depreciation[8]</td><td>$ 15,600</td><td>$ 5,073</td></tr>
<tr><td>Electricity</td><td>$ 6,085</td><td>$ 6,085</td></tr>
<tr><td>Rent</td><td>$ 150</td><td>$ 150</td></tr>
<tr><td>Security</td><td>$ 2,537</td><td>$ 2,537</td></tr>
<tr><td>Total Fixed Costs</td><td>$ 24,372</td><td>$ 13,845</td></tr>
<tr><td>Total Costs</td><td>$ 362,076</td><td>$ 344,238</td></tr>
<tr><td>Net Returns</td><td></td><td></td></tr>
<tr><td>Returns above Variable Costs</td><td>$ 1,856,301</td><td>$ 1,812,632</td></tr>
<tr><td>Returns above Total Costs</td><td>$ 1,831,929</td><td>$ 1,798,787</td></tr>
</table>

[1]Assuming only indoor production.
[2]Assuming only outdoor production.
[3]Output due to plant losses with outdoor production changes from 27,425 bottles with indoor production to 26,788 1ounce 3,300 mg CBD oil bottle. Please refer to Table 2.2 for additional detail.
[4]Please refer to Table 2.4
[5]Oil extraction costs are based on a fresh flower yield of 10,388 lbs. using indoor production resulting in 2,285 lbs. of dried hemp flower. A yield of 10,147 lbs. of fresh flower was assumed for outdoor production resulting in 2,232 lbs. of dried hemp flower. Oil extraction costs of $8 per pound were applied to dried flower yields.
[6]Seed cost was charged at $1 per seed. Since 3 seeds are grown per plant grown, this adds up to 3,486 seeds or $3,486.
[7]Please refer to Table 2.1 and Table 2.2
[8]Please refer to Table 2.3

3. *Drying Methods and Effects on Yields, Cannabinoids, Terpenes, Bacteria and Fungus*

Results in terms of flower profile on air-dried samples are shown in tables **Table 2.6**, **Table 2.7**, and **Table 2.8** and are labeled as *BK Air* and *W Air*, IR-dried samples are labeled as *BK IR* and *W IR*, and fresh samples are labeled as *BK Fresh* and *W Fresh*. As this study only accounts for cannabinoids of interest and for six major volatile groups, the complete analyses on cannabinoids and terpenes are provided in Appendix K – Detailed Laboratory Results on Cannabinoids and Terpenes.

i. Cannabinoids, Terpenes, Bacteria Count and Fungal Count

In terms of cannabinoids, results in **Table 2.6** suggest that total average amounts of cannabinoids are generally higher when air-drying is used compared to IR-drying. This is probably due to the effect of heat when IR-drying is used.

Compared to the fresh samples when drying the BK variety by IR and air, most cannabinoids decreased except CBG and Delta-9 which increased. The result of higher Delta-9 with air-drying is puzzling as synthesis requires heat (D.11.ii Extraction). On average Delta-9 with air-drying increases only marginally compared to the fresh sample, whereas IR-drying increased CBG and Delta-9 more than air-drying – likely as a function of heat. At the same time, air-drying decreased the remaining cannabinoids to a lesser extend compared to IR-drying. Thus, drying method selection impacts final cannabinoid profile.

Further, when drying the W variety by IR, CBN and Delta-9 increased. When using air-drying, most cannabinoids increased except CBDA which decreased. IR-drying increased Delta-9 more than air-drying. As such, drying method not only impacts cannabinoid profiles, but does so differently by variety. This will be further discussed in section G Discussions.

Finally, CBD content, which is expected to impact CBD oil prices, was higher in the BK compared to the W variety when using IR-drying. At the same time, air-drying BK led to the highest CBD concentration. Regardless of drying method, section F.4 Oil extraction processing impacts on hemp flower profile, highlights that oil-extraction will further modify cannabinoid concentrations in the crude hemp oil with implications discussed in section G Discussions.

Total THC content played a larger role for the BK variety, but not in the W variety where total THC is close to zero.

Table 2.6. Average and Standard Deviation of Cannabinoid Concentrations by Variety and Drying Method in Comparison to Fresh Flowers on a Dry Matter Basis.

	Hemp varieties, Drying Method, and number of Cannabinoids (mg/g)[1]					
Cannabinoids	**BK Fresh**	**BK IR**	**BK Air**	**W Fresh**	**W IR**	**W Air**
CBDA	13.73 ± 2.68	6.51 ± 0.96	12.11 ± 0.83	6.95 ± 0.97	2.47 ± 0.63	1.51 ± 0.46
CBG	n.a.[2]	5.96 ± 0.46	0.03 ± 0.00	n.a.	n.a.	0.05 ± 0.02
CBGA	7.68 ± 0.28	1.61 ± 0.54	2.39 ± 0.54	22.18 ± 4.27	18.63 ± 1.07	31.13 ± 5.00
CBN	0.56 ± 0.18	0.38 ± 0.05	0.41 ± 0.13	0.55 ± 0.09	0.71 ± 0.23	0.71 ± 0.52
DELTA 9	n.a.	2.09 ± 0.26	0.24 ± 0.05	0.30 ± 0.26	0.53 ± 0.09	0.40 ± 0.01
THCA	7.72 ± 1.54	0.33 ± 0.06	1.48 ± 0.29	n.a.	n.a.	n.a.
CBD	3.12 ± 0.45	2.51 ± 0.19	0.09 ± 0.02	n.a.	n.a.	0.21 ± 0.08
Tot. Avg. Cannabinoids[3]	**36.84 ± 4.92**	**23.37 ± 1.93**	**35.25 ± 3.15**	**48.32 ± 6.00**	**33.25 ± 2.12**	**38.61 ± 5.80**
Tot. THC (%)[4,5]	**0.77 ± 0.15**	**0.17 ± 0.02**	**0.16 ± 0.03**	**0.02 ± 0.02**	**0.04 ± 0.01**	**0.03 ± 0.00**
Tot. CBD (%)[4,6]	**1.52 ± 0.21**	**0.82 ± 0.09**	**1.07 ± 0.07**	**0.61 ± 0.09**	**0.22 ± 0.05**	**0.15 ± 0.05**

Cannabinoids are as follows: Cannabidiolic acid (CBDA), Cannabigerol (CBG), Cannabigerolic acid (CBGA), Cannabinol (CBN), Δ9-Tetrahydrocannabinol (Delta-9), Δ9-Tetrahydrocannabinolic acid (THCA), and Cannabidiol (CBD).
[1]Varieties: Bubba Kush (BK) and White (W); Fresh flowers (Fresh), Infrared Radiated dried (IR), and Air-dried (Air).
[2]n.a. stands for non-measurable amounts, hence zero value is assumed in further calculations.
[3]Total average cannabinoids given by the laboratory results, hence including cannabinoids not shown in this table.
[4]As, mg/g is parts per thousand, divided by ten calculates parts per hundred (also known as percent).
[5]Total THC percentage is calculated based on Eq. (1). For BK IR, for example, $[(0.75 \cdot 0.88 \cdot (2.09/10)) + (0.33/10)]$
[6]Total CBD percentage is calculate based on Eq. (2). For BK IR, for example, $[(2.51/10) + (6.51/10) \cdot 0.877]$

In terms of terpenes, results in **Table 2.7** indicate that total terpenes are generally higher when air-drying is used compared to IR-drying. Especially when IR-drying is used, overall terpenes are lost compared to the fresh samples.

Regarding the six major groups of terpenes of interest in this study, results show that IR-dried samples are all lower in amounts of major terpenes compared to the samples dried by air. The heating component and the fast-drying time in IR-drying negatively affected the number of major terpenes. Further discussion is reserved for section G Discussions.

Table 2.7. Average and Standard Deviation of Volatile and Terpene Concentrations by Variety and Drying Method in Comparison to Fresh Flowers on a Dry Matter Basis.

Volatile Group	Hemp varieties, Drying Method, and number of volatiles & Terpenes (µg/g)[1]					
	Fresh BK	**BK IR**	**BK Air**	**Fresh W**	**W IR**	**W Air**
.alpha.-Pinene	102.93 ± 63.97	n.a.[2]	30.55 ± 8.93	52.30 ± 11.07	n.a.	16.61 ± 4.54
.beta.-Myrcene	12.15 ± 4.83	0.93 ± 0.13	11.63 ± 1.63	49.11 ± 4.87	1.02 ± 0.26	17.43 ± 4.89
D-Limonene	183.96 ± 82.24	9.68 ± 2.03	158.57 ± 32.95	255.00 ± 35.92	10.74 ± 3.96	115.94 ± 41.79
Linalool	12.87 ± 3.52	6.35 ± 0.94	18.17 ± 5.04	3.50 ± 0.44	3.27 ± 1.21	19.83 ± 5.96
Caryophyllene	2,629.01 ± 371.30	1,587.51 ± 146.77	2,641.73 ± 526.21	3,209.63 ± 240.08	447.64 ± 62.73	950.26 ± 150.56
Humulene	335.45 ± 17.95	169.85 ± 17.66	300.13 ± 64.97	671.15 ± 26.46	85.10 ± 9.82	196.82 ± 32.96
Total Avg. Volatiles[3]	**5,144.00** ± 498.83	**2,614.90** ± 248.85	**4,157.98** ± 1,029.34	**7,143.59** ± 716.47	**1,150.73** ± 212.89	**8,178.31** ± 1,104.83

[1]Varieties: Bubba Kush (BK) and White (W); Fresh flowers (Fresh), Infrared Radiated dried (IR), and Air-dried (Air)
[2]n.a. stands for non-measurable amounts.
[3]Total average volatiles given by the laboratory results, hence including volatiles not shown in this table. Please refer to Appendix K – Detailed Laboratory Results on Cannabinoids and Terpenes.

In terms of bacterial and fungal count, results in **Table 2.8** show that the bacterial and fungal count decreased with both drying methods and is the lowest when hemp flowers are dried by IR compared to air-dried and fresh samples. This suggests that IR-drying is better than air-drying if one wants to maximize the elimination of bacteria and fungi on hemp flowers.

Table 2.8. Average and Standard Deviation of Bacterial and Fungal Counts per Gram of Sample on a Dry Matter Basis.

Tot. Count	Hemp varieties, Drying Method, and number of bacterial and fungal counts (cfu/g)[1]					
	Fresh BK	**BK IR**	**BK Air**	**Fresh W**	**W IR**	**W Air**
Bacterial (log cfu/g)	26.50 ± 0.67	4.24 ± 0.02	8.67 ± 0.01	29.91 ± 3.97	2.12 ± 3.00	8.98 ± 0.12
Fungal (log cfu/g)	31.48 ± 0.46	2.31 ± 0.28	5.93 ± 0.08	32.38 ± 0.21	0.00 ± 0.00	6.85 ± 0.08

[1]Varieties: Bubba Kush (BK) and White (W); Fresh flowers (Fresh), Infrared Radiated dried (IR), and Air-dried (Air)

ii. In Laboratory Infrared Radiation Drying

Three main trials were conducted to measure effects of IR-drying on hemp flower. The third trial led to the most satisfactory results in terms of moisture content and the amount of burned flowers. Samples dried during the third trials were the ones analyzed in the prior section. Samples and results from the other trials were rejected and *Figure 2.5* shows the effect of different drying times on the moisture content of the hemp flowers.

These experiments indicate that hemp flower samples ranging from 0.37 to 0.44 lbs. need approximately 11 to 12 minutes to dry to a moisture content of approximately 11%. Adding 46 to 47 hours rest time in the environmental chamber for tempering, drying fresh hemp flower samples, cut to particle size of ≤ 0.5 inch, needs approximately 46 to 48 hours with IR-drying in comparison to 10 to 14 days expected with air-drying.

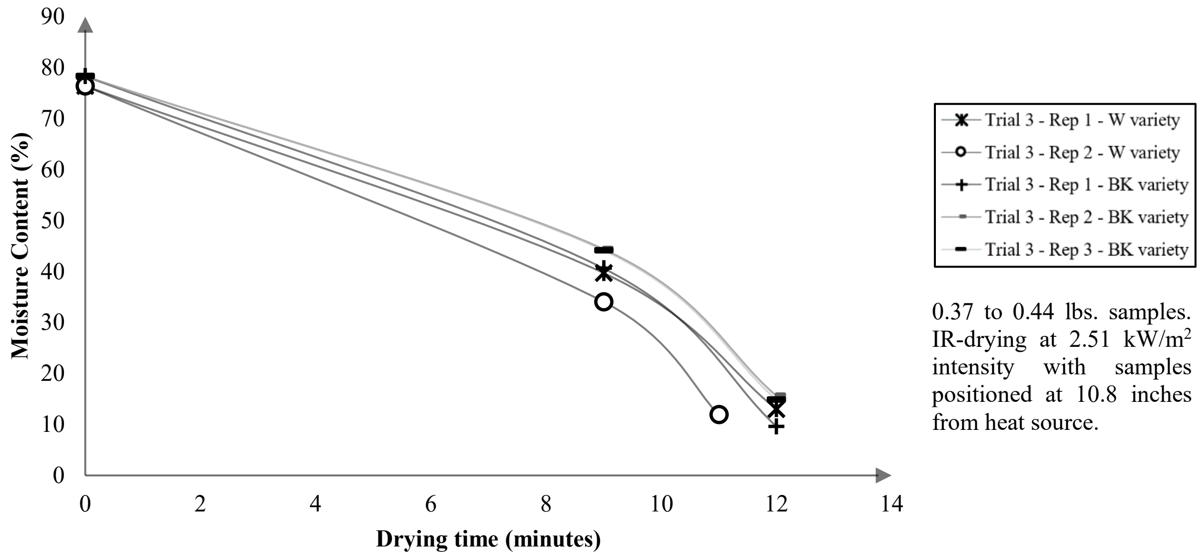


Figure 2.5. Moisture content in hemp flower samples dried by infrared radiation over time.

iii. Drying by Lyophilization (Literature Review Based)

Drying hemp flowers by lyophilization or freeze-drying has been explained in section D.10.iii. Chen et al. (2021), Challa, Misra, and Martynenko (2020), and Lazarjani et al. (2021) state that freeze-drying leads to significantly less losses in terpenes and cannabinoids during drying compared to other drying methods. Also, the authors state that drying by lyophilization leads to higher retentions of phenolic and antioxidant properties of the hemp flowers' compounds. Hence, one can assume that if freeze-drying is tested on hemp flowers, the flowers' profiles should be almost identical to the profile of the fresh hemp flowers. Whether this is of interest to a producer remains to be assessed. However, as CBD oil producers target higher concentrations in cannabinoids, freeze-drying might not be a very suitable option for this specific industry as concentrations of CBD increased with IR- and air-drying as shown above. Also, Chen and Pan (2021) state that freeze-drying, among other innovative hemp flower drying technologies, IR-drying included, need further research especially on terpene and cannabinoid retention as well as microbial and fungal development.

This does not allow for much further development as no firsthand experiments were conducted on freeze-drying hemp flowers in this study. Nonetheless, as the technique is gaining in interest within the hemp industry this study discussed costs involved with this drying method. Chen et al. (2021), Challa, Misra, and Martynenko (2020), and Lazarjani et al. (2021), as well as Tambunan et al. (2013) and Mujumdar (2006), state that the costs involved in freeze-drying are much higher compared to other commonly used drying methods as it is time consuming and energy intensive.

4. Oil Extraction Processing Impacts on Hemp Flower Profile

Table 2.9 shows the summarized results of the oil extraction processing impacts on the cannabinoids profile of dried hemp flowers that are processed into oil. As noted above, these results pertain to an oil extraction process using high THC flowers, targeting a high THC product and thereby will not inform about what to expect when extracting for CBD oil. Nonetheless, it can serve to assess what impacts the processing has on a cannabinoid profile of hemp flowers.

The results in **Table 2.9** indicate that some cannabinoids are lost during the process especially the acid forms of cannabinoids CBDA, CBGA and THCA which are transformed into their stable forms CBD, CBG and THC (Delta-9).

Table 2.9. Hemp Flower Supercritical-CO2 Oil Extraction Impacts on Dried Hemp Flower and Hemp Oil Cannabinoid Profiles on a Dry Matter Basis.

Cannabinoid	Dried Hemp Flower (mg/g)	Extracted Oil (mg/g)
CBDA	125.33	88.91
CBG	0.00	11.04
CBGA	5.11	0.00
CBN	0.00	0.60
Delta-9	0.78	21.37
THCA	5.56	0.90
CBD	5.22	736.68
Total	142.44	886.50
Total THC	6.07	15.01
Total CBD	115.14	814.65

5. Estimated Costs of Drying

Results for the estimation of incurred drying expenses based on different drying methods are shown in **Table 2.10**. Specific equipment and costs for each drying method are described in the footnotes. Based on these estimations and on the estimated annual costs spread over the total drying time, it appears that the cheapest method to dry hemp flowers is drying the flowers at two distinct and consecutive periods in one smaller building. This can, however, be an inconvenience for a hemp farmer or processor if flowers are at maturity at the same time.

The second-best option in terms of least cost/lb. is air-drying the flowers using only one drying room and drying all flowers in one run. Compared least-cost air-drying using two consecutive drying periods with lesser building requirements it is faster. Using multiple smaller stationary or batch IR-drying systems appear manageable from an investment cost perspective but are more expensive in terms of cost/lb. The large-scale IR-drying option using one larger continuous IR-drying oven entails more costs, but cuts drying times significantly.

Table 2.10. Comparison of Estimated Cost of Air-, Infrared Radiation (IR-), and Freeze-Drying Hemp.

	Air (1 run)[1]	Air (2 runs)[2]	IR (Small)[3]	IR (Large)[4]	Freeze (Medium-Slow)[5]	Freeze (Medium-Fast)[6]	Freeze (Large)[7]
Fresh flower (lbs.)	10,388.28						
# of drying units	1	1	4	1	4	2	1
Duration (hours)	336	672	1,233	269	1,133	973	397
Investment							
Equipment	$ 13,718	$ 8,637	$ 40,000	$ 100,000	$ 430,180	$ 559,400	$ 946,600
Buildings	$ 42,413	$ 21,206	$ 6,614	$ 4,060	$ 4,226	$ 2,821	$ 2,126
Annual Fixed Cost							
Depreciation	$ 4,200	$ 1,581	$ 441	$ 2,271	$ 13,288	$ 17,501	$ 30,362
Insurance	$ 6,713	$ 3,445	$ 5,594	$ 12,487	$ 52,129	$ 67,467	$ 113,847
Maintenance	$ 1,107	$ 583	$ 1,688	$ 4,054	$ 5,792	$ 7,496	$ 12,650
Annual Variable Cost							
Utilities	$ 328	$ 356	$ 303	$ 145	$ 1,249	$ 6,084	$ 9,240
Labor	$ 2,164	$ 2,164	$ 18,498	$ 8,076	$ 8,055	$ 2,630	$ 3,258
Total Cost	$ 14,580	$ 8,537	$ 26,524	$ 27,034	$ 80,513	$ 101,178	$ 169,357
Cost in $/hr.	**$ 43.39**	**$ 12.70**	**$ 21.43**	**$ 100.42**	**$ 71.05**	**$ 103.89**	**$ 426.59**
Cost in $/lb.	**$ 1.40**	**$ 0.82**	**$ 2.55**	**$ 2.60**	**$ 7.75**	**$ 9.74**	**$ 16.30**

Note: Further details on the analysis are given in Appendix J – General and Specific Assumptions for Differences in Cost by Drying Method.

[1]The entire harvest is dried at once in one single building. 1 pound of fresh flower to dry per hanger at $0.2 per hanger. Building at 14 rows of 26 feet length each with three levels of wire to hang the hangers at a total cost of $240. Drying room is 4,875 sq. ft. at $8.70 per sq. ft. Additionally, $1,390 for a 125-pint dehumidifier (0.84 kWh) and $4,501.98 per 3-ton AC unit (4.56 kWh). These prices and the following ones were all based on local supplier costs at the time of research.

[2]The entire harvest is dried at two distinct consecutive periods in one single building. Based on the previous footnote, one needs 5,194 hangers, 7 rows of 26 feet length, a drying room of 2,437.5 square feet, a $1,439 50-pint dehumidifier, and a $5,000 3-ton AC unit.

[3]The entire harvest is dried using four stationary IR-drying systems to dry the flowers in 62 days. The price of one batch IR system is $10,000, requires 190.07 sq. ft. per unit (workspace included) and consumes 2.51 kWh per unit. For labor, one stationary unit requires 1 worker per drying unit during the entire time of drying.

[4]The entire harvest is dried using one large continuous IR-drying system at $100,000. 24 minutes are needed to dry 15.4 lbs. of fresh flower. This system requires 466.67 sq. ft. (workspace included), consumes 5.5 kWh and necessitates 2 workers during the entire time of drying.

[5]The entire harvest is dried using four medium-sized, slow-freeze driers to dry in 62 days. The system requires four days to dry 220 lbs. of fresh hemp flower on 108 trays at a time, costs $107,545 per unit, uses 121.45 sq. ft. per unit (workspace included), and consumes 11.25 kWh per unit. Labor time estimates are based on, 6 minutes per tray for loading and unloading. Further, cleaning is expected to require approximately 15 minutes per tray.

[6]The entire harvest is dried using two medium-sized fast-freeze driers. This system requires 30 hours to dry 160 lbs. of fresh hemp flower on 26 trays at a time, costs $279,700 per unit, uses 162.13 sq. ft. per unit (workspace included), and consumes 60.75 kWh per unit (chiller included) with similar load, unload, and cleaning times per tray as in the prior footnote.

[7]The entire harvest is dried using one large freeze drier. This system requires 30 hours to dry 785 lbs. of fresh hemp flower on 138 trays at a time, costs $946,600 per unit, uses 244.33 sq. ft. per unit (workspace included), and consumes 237.5 kWh per unit (chiller included). See prior note for load, unload, and cleaning times per tray.

G. Discussions

Assuming current production methods at the studied farm it can be said that a hemp flower producer can produce about $523,200 worth of CBD oil bottles at a concentration of 3,300 mg per ounce of CBD oil on a 0.37-acre farm. Total annual net returns on such a farm were estimated at

$390,825. Thus, a hemp flower producer can be profitable on 0.37 acres assuming that all products are sold in a timely manner which, given the current market is difficult.

The scaled results, modeling production on a per acre production basis holding production practices constant, show that whether the producer grows indoor or outdoor does not make much difference. As yields indoor and outdoor are similar, both scenarios show CBD oil valued at approximately $2,194,000 assuming a constant yield of about 2 pounds of dried hemp flower per plant. Results show that using only indoor production might be better for hemp flower producers despite greater labor cost and building investment as yields are slightly higher and exposure to weather and pest related production risk is lowered. Further, it remains true that selling all the products may be complicated. Especially at larger scale, a farmer might decide to sell at lower prices and to diversify its end-products to accommodate different customers' needs and wants.

In all the above-mentioned scenarios it is expected that costs might slightly vary in practice especially the variable costs as well as costs on irrigation systems, rent, and security. It was also assumed that on a 1-acre production basis, production methods would remain unchanged and that all plants would be produced in growing bags. In practice, production methods on 1 acre may become more mechanized to lower potential costs and that instead of growing hemp in bags a producer might decide to produce in soil using plastic mulch.

Further research investigating different production methods and alternative scales of production is required. Further research is also needed on the differences in hemp flower chemical profiles between indoor and outdoor grown hemp flower such as the research from Garcia-Tejreo et al. (2019) which showed significant differences in cannabinoids in hemp flowers grown indoors and outdoors in a Mediterranean environment. This present study has not been able to assess the impact of indoor or outdoor contexts on these profiles as indoor grown varieties were different than the ones grown outdoors.

Nonetheless, results show that the production of hemp flowers for CBD oil at the assumed selling price is profitable, and hence, that the industry is attractive for farmers. The main difficulty appears to be to find the right channels of distribution for the products and to stay ahead of trends to capture the right markets at the right time. Additional insights on the latter will be provided in Chapter III. Marketing CBD oil.

Additionally, results have shown that different methods to dry hemp flowers have different impacts on flower profiles and thereby on the end-product. It was assessed that freeze-drying keeps flower profiles steady from the moment flowers are being harvested until they are processed into oil. However, as this study could not conduct its own experiments, drying by lyophilization remains a subject of further study. Air-drying compared to IR-drying, however, showed that air-drying is overall more attractive to a hemp flower producer assuming that the goal is to have flowers high in total cannabinoids and terpenes. The main difference between both drying methods is the action of heat which leads to different processes within the hemp flowers.

The study expected to be able to draw definitive conclusions on which drying method to use. Chen et al. (2021), show that the IR-drying method can negatively impact the CBD content of dried hemp flowers especially at high temperatures while increasing CBN content, while other research e.g., internal research at the university of Arkansas, showed that it can increase CBD content and that different drying methods have different impacts on hemp flower cannabinoid profiles depending on the hemp variety used. The results have shown that, for both hemp varieties BK and W, IR-drying increases or synthetizes more Delta-9 cannabinoids compared to air-drying. At the same time air-drying results in higher amounts of CBGA and total average cannabinoids compared to when IR-drying is used. Thus, if a hemp producer or a CBD oil processor is seeking to have a final product, given one of these two hemp varieties, with increased amounts of either of the aforementioned cannabinoids, these results can assist in the decision on which drying method to use. For the remaining cannabinoids, however, no conclusive decision can be proposed as the drying impacts on these cannabinoids are opposite from each other for both hemp varieties, e.g., using the W variety CBD is higher when using IR-drying, but for the BK CBD is higher when using air-drying. No explanation for this has been found and further research is necessary. It is expected that this is probably due to underlying differences in cannabinoid profiles between both hemp varieties.

Additionally, hemp producers and processors must expect that the supercritical-CO_2 extraction of oil from dried hemp flowers will impact the final product. The results of the impact on cannabinoids from the oil extraction process must be taken as preliminary results and seem to indicate that during the oil extraction cannabinoids in their acid forms are mostly transformed into their stable form e.g., CBGA into CBG. Nonetheless, CBDA seems to slightly resist this process, whereas CBGA and THCA are almost entirely transformed into CBG and Delta-9. These conversions inevitably lead to high increases in Delta-9 and CBG concentrations; however, the results show that the total number of cannabinoids is also increased during the oil extraction, which is possibly a result of cannabinoids not captured within regular laboratory analyses that are transformed into compounds such as Delta-9 and CBG.

Thus, it must be expected that supercritical-CO_2 oil extraction will decrease cannabinoids in their acid forms and result in major increases in total cannabinoids as well as in CBG, Delta-9 and CBD cannabinoids as shown in the results. Although one might expect the same impacts from the oil extraction on cannabinoid profiles of hemp flowers dried by any given method, it can be stipulated that as IR-drying already uses the effect of heat on hemp flowers an additional decarboxylation stage might not be necessary for IR-dried hemp flowers when starting the oil-extraction. If this is the case, the hemp flower profile of IR-dried flowers might be less impacted by the oil extraction compared to hemp flowers that were air-dried. To draw definitive conclusions on this matter, however, more research is needed to assess every change in hemp flower profiles between every stage of the hemp oil extraction. Problematic for this type of research is the batch size required for oil-extraction as the case producer processed 230 lbs. of dried flower at a time.

In terms of bacterial and fungal development on flowers, IR-drying is more interesting as the flowers are exposed to radiant heat and are therefore dried quicker and do not provide sufficient time for the development of bacteria or fungi. It must be noted that bacteria and fungi development do not only depend on the drying method but, also on the initial presence of those organisms on the fresh flowers. Nonetheless, a producer targeting hemp flowers with low amounts of bacteria and fungus may be more interested in using IR-drying, compared to air-drying. IR-drying is also expected to become more attractive in case a farm grows in scale as it is faster compared to drying hemp flowers by air-drying. The drying costs estimates support the latter as these showed that the fastest method to dry hemp flowers is using a large continuous IR-drying unit. However, the different impacts of drying methods on flower profiles have not been accounted for in these estimations as it is not clear how to value the different impacts. Further research will be needed on the monetary valuation of these impacts which are also expected to further drive the decision on drying methods as hemp producers and processors that target high quality products, in comparison to those who target industrialized products, are not expected to only account for yearly expenses, but also for product characteristics and associated cost, yield, and quality tradeoffs.

The decision-making process involving how to produce and process hemp flowers into CBD rich hemp oil is complex and highly depends on what a hemp producer and processor is targeting. **Table 2.11** attempts to summarize the findings of this chapter to facilitate the comprehension and decision-making process.

Table 2.11. Summarized Study Findings.

<table>
<tr><th colspan="6">Profitability</th></tr>
<tr><td>Non-mechanized Indoor Production</td><td colspan="5">Profitable and higher returns (optimistic scenario).
Increased labor and initial investment costs.
Increased protection from external factors.
Production possible all year around (expected increase in net returns and higher costs on equipment).</td></tr>
<tr><td>Non-mechanized Outdoor Production</td><td colspan="5">Profitable.
Lower labor and initial investment costs.
More precise monitoring needed.
Fewer equipment and building costs.
More exposure to external factors such as weather fluctuations or pests.</td></tr>
<tr><th colspan="6">Drying and Extraction Methods</th></tr>
<tr><td></td><td>Cannabinoids</td><td>Terpenes</td><td>Bacteria</td><td>Fungus</td><td>Costs</td></tr>
<tr><td>Air-Drying</td><td>Increases Total Cannabinoids and CBGA & higher CBD in BK variety.</td><td>Higher in total terpenes.</td><td>Favors bacterial growth.</td><td>Does not favor nor eliminate fungus and fungal development.</td><td>Low</td></tr>
<tr><td>IR-Drying</td><td>Increases Delta-9 & higher CBD in W variety.</td><td>Lower total terpenes.</td><td>Eliminates bacteria.</td><td>Eliminates Fungus.</td><td>Mid</td></tr>
<tr><td>Freeze-Drying</td><td>Assumed unchanged in short term and if kept away from oxygen.</td><td>Assumed unchanged.</td><td>Assumed unchanged.</td><td>Assumed unchanged.</td><td>High</td></tr>
<tr><td>Supercritical-CO_2 Oil Extraction</td><td colspan="5">Transforms cannabinoids from their acid form to their stable form thus increases Delta-9 THC, CBD, CBG, and total cannabinoids depending on temperatures and pressures used. As air-drying results in more cannabinoids in their acid forms this must be considered.</td></tr>
<tr><th colspan="6">Further Research Areas</th></tr>
<tr><td>Further Research is needed on:</td><td colspan="5">CBD oil markets and distribution channels.
Mechanized hemp production.
Further research in different states and contexts especially given different climates and soils.
Different chemical compounds and profiles of hemp flowers whether indoor or outdoor grown with or without artificial light, grown in a greenhouse or high tunnel or using different construction materials.
Freeze-drying hemp flowers needs further assessment.</td></tr>
</table>

H. Conclusions

This chapter discussed typical and small-scale farm specific hemp production methods. The research shows that a hemp farm growing hemp on less than 1 acre can be profitable at break-even points of approximately $13.35 per unit of 1-ounce 3,300 mg CBD oil bottles, considering the assumptions made. It also compared indoor and outdoor production and pointed out that almost every decision depends on many varying factors such as the farm location, weather patterns in that location, and producer's preferences and desired end-product characteristics. As an example, indoor production lowered production risk stemming from weather and pest pressure as well as ease of farm management. However, compared to outdoor production, costs were higher, and harvesting was more labor intensive. Hence, decisions must be adapted based on a farm's context. In Northwest Arkansas, highest net returns were estimated using indoor production. Especially as a farm grows, indoor production was considered more attractive as pest management becomes increasingly difficult to manage outdoors.

Pointed out as the most important factor is a producer's preferences and objectives. This is especially true when a producer must make decisions on how to harvest, process, and sell his or her hemp flowers and final products. A producer must carefully choose the hemp variety used and how to manage that variety depending on the characteristics of the final product. The choice of the variety must coincide with the choice of the drying method used as different methods have different impacts on final product attributes. Is a producer looking for more total average cannabinoids and terpenes, then air-drying is the best choice. However, if a producer is targeting a product with a higher THC and/or Delta-9 content, among others, then IR-drying is more interesting which also comes at a low cost, is much faster, and eliminates more bacteria and fungus from flowers compared to air- or freeze-drying. Freeze-drying requires further research and was shown to be an expensive drying method which does not seem to be beneficial for small-scale farmers. Thus, it is crucial that a hemp farmer evaluates his needs and wants very accurately before starting his or her hemp production to minimize potential risks of failure.

I. References

Adams, S.A. and Todd, K.A. 2015. "High Tunnel Design, Site Development, and Construction". University of Nebraska-Lincoln Institute of Agricultural and Natural Resources EC308. Retrieved March 25th, 2022, from https://extensionpublications.unl.edu/assets/pdf/ec308.pdf

Arkansas Department of Health. 2016. *Rules And Regulations Governing Medical Marijuana Registration, Testing, And Labeling in Arkansas*. Arkansas: Arkansas State Board of Health, Department of Health. Retrieved March 10th, 2022, from https://www.healthy.arkansas.gov/images/uploads/pdf/MMJ_Rules_and_Regs_2.pdf

Ames, G.K. 2016. *High Tunnel Tree Fruit and Grape Production for Eastern Growers*. Montana: National Center for Appropriate Technology, Horticulture. Retrieved on January 25th, 2022, from: https://www.uaex.uada.edu/farm-ranch/crops-commercial-horticulture/horticulture/commercial-fruit-production/High%20Tunnel%20Tree%20Fruit%20and%20Grape%20Production%20for%20Eastern%20Growers.pdf

Arkansas Department of Agriculture. 2020. *Hemp Grower Orientation 2020 Growing Season*. Arkansas: Arkansas Department of Agriculture For Hemp Research Program. Retrieved February 22nd, 2022, from https://www.agriculture.arkansas.gov/wp-content/uploads/2020/06/11b-2020_Hemp_Grower_Orientation_PPT.pdf

Baron, E. P. 2018. "Medicinal Properties of Cannabinoids, Terpenes, and Flavonoids in Cannabis, and Benefits in Migraine, Headache, and Pain: An Update on Current Evidence and Cannabis Science". *Headache: The Journal of Head and Face Pain*, 58(7):1139–1186. https://doi.org/10.1111/head.13345

Challa, S. K. R., Misra, N. N., and Martynenko, A. 2020. "Drying of cannabis—state of the practices and future needs". *Drying Technology*, 39(14):2055–2064. https://doi.org/10.1080/07373937.2020.1752230

Chen, C., and Pan, Z. 2021. "Cannabidiol and terpenes from hemp – ingredients for future foods and processing technologies". *Journal of Future Foods*, 1(2):113–127. https://doi.org/10.1016/j.jfutfo.2022.01.001

Chen, C., Wongso, I., Putnam, D., Khir, R., and Pan, Z. 2021. "Effect of hot air and infrared drying on the retention of cannabidiol and terpenes in industrial hemp (Cannabis sativa L.)". *Industrial Crops and Products*, 172, 114051. https://doi.org/10.1016/j.indcrop.2021.114051

Crini, G., and Lichtfouse, E. 2020. *Sustainable Agriculture Reviews 42: Hemp Production and Applications,* 1st. ed. [E-book]. Switzerland: Springer. https://doi.org/10.1007/978-3-030-41384-2

Freeman, L., Dickey, D., McAfee J. and Rom, C. 2015. *Basics of High Tunnel Caneberry Production*. University of Arkansas Division of Agriculture Research and Extension. Retrieved on January 25th, 2022, from: https://agcomm.uark.edu/cars/crop/High-Tunnel-Construction_Freeman-2015.pdf

Gould, J. 2015. "Cannabis: 4 big questions". *Nature*, 525(7570), S18. https://doi.org/10.1038/525s18a

Gu, M., Masabni, J. and Wallace, R. 2019. *Costs to Build a Metal-Hoop High Tunnel*. Texas A&M Agrilife Extension. Retrieved March 25th, 2022, from http://counties.agrilife.org/collin/files/2019/03/EHT-105-Costs-to-Build-a-Metal-Hoop-High-Tunnel.pdf

Jelliffe, J., Lopez, R.A. and Ghimire, S. 2020. "CBD Hemp Production Costs and Returns for Connecticut Farmers in 2020". University of Connecticut Department of Agricultural and Resource Economics Zwick Center for Food and Resource Policy Outreach Report No. 66. Retrieved November 1st. 2021, from https://are.uconn.edu/wp-content/uploads/sites/2327/2020/02/ZwickOR66_Feb25.pdf

Sztabert, Z. and Kudra, T. 2006. "Cost-Estimation Methods for Drying". In A. Mujumdar, ed. *Handbook of Industrial Drying*, 3rd. ed. UK: Taylor and Francis Group, pp. 1266-1278 https://doi.org/10.1201/9781420017618.ch53

Lamont, W.J.Jr., Orzolek, M.D., Harper, J.K., Kime, L.F. and Jarrett, A.R. 2012. "Drip Irrigation for Vegetable Production". Agricultural alternatives Penn State Cooperative Extension College of Agricultural Sciences, Pennsylvania State University. Retrieved March 23rd, 2022, from https://extension.psu.edu/drip-irrigation-for-vegetable-production

Lazarjani, M.P., Young, O., Kebede, L. and Seyfoddin A. 2021. "Processing and Extraction Methods of Medicinal Cannabis: A Narrative Review". *Journal of Cannabis Research*, vol. 3, no. 1, 2021. https://doi.org/10.1186/s42238-021-00087-9

Minnesota Department of Agriculture. 2020. *Hemp Pilot Program*. Minnesota Department of Agriculture For Plant Protection Division. Retrieved February 24th, 2022, from https://www.mda.state.mn.us/sites/default/files/2020-02/hempprogramannualreport2019.pdf

Merriam-Webster. 2022. "Definition of marijuana". Massachusetts: *Merriam-Webster*. Retrieved February 2nd, 2022, from https://www.merriam-webster.com/dictionary/marijuana

Mujumdar, A. 2006. *Handbook of Industrial Drying*, 3rd. ed. UK: Taylor and Francis Group, CRC Press. ISBN 1574446681

Namdar, D., Mazuz, M., Ion, A., and Koltai, H. 2018. "Variation in the compositions of cannabinoid and terpenoids in Cannabis sativa derived from inflorescence position along the stem and extraction methods". *Industrial Crops and Products*, 113: 376–382. https://doi.org/10.1016/j.indcrop.2018.01.060

Lazarjani, P.M., Torres, S., Hooker, T., Fowlie, C., Young, O., and Seyfoddin, A. 2020. "Methods for quantification of cannabinoids: a narrative review". *Journal of Cannabis Research*, 2(1). https://doi.org/10.1186/s42238-020-00040-2

Ramirez, C. L., Fanovich, M. A., and Churio, M. S. 2019. "Cannabinoids: Extraction Methods, Analysis, and Physicochemical Characterization". *Studies in Natural Products Chemistry*, 143–173. https://doi.org/10.1016/b978-0-444-64183-0.00004-x

Ranalli, P. and Venturi, G. 2004. "Hemp as a raw material for industrial applications". *Euphytica*, 140(1–2): 1–6. https://doi.org/10.1007/s10681-004-4749-8

Robbins, J.A. and Gu, M. 2009. *Cost of Constructing a Metal Hoop High Tunnel. Agriculture and Natural resources*. University of Arkansas Division of Agriculture Research and Extension. Retrieved March 25th, 2022, from https://www.uaex.uada.edu/publications/PDF/FSA-6147.pdf

Roggen, M. 2019. *Controlling Terpenes and Cannabinoids in Flower and Extract*. LabRoots - Cannabis Sciences Virtual Event 2019. Retrieved January 20th, 2022, from https://www.youtube.com/watch?v=y1n4OJTW0Lw

Rosenthal, E., Flannery, R., Bacca, A., and Chong, T. 2021. *Cannabis Grower's Handbook: The Complete Guide to Marijuana and Hemp Cultivation*. California: Quick American Publishing. ISBN: 9781936807543

Schreiber, B.A. 2022. "Cannabis". *Encyclopaedia Britannica*. Retrieved February 2nd, 2022, from https://www.britannica.com/plant/cannabis-plant

Sommano, S. R., Chittasupho, C., Ruksiriwanich, W., and Jantrawut, P. 2020. "The Cannabis Terpenes". *Molecules*, 25(24): 5792. https://doi.org/10.3390/molecules25245792

Tambunan, A. H., Yudistira, Kisdiyani and Hernani. 2013. *Freeze-drying Characteristics of Medicinal Herbs*. Drying Technology, vol. 19, no. 2, 2001, pp. 325–31. https://doi.org/10.1081/drt-100102907.

Tyler, M., Shepherd, J., Olson, D., Snell, W., Proper, S., and Thornsbury, S. 2020. *Economic Viability of Industrial Hemp in the United States: A Review of State Pilot Programs,* EIB-217. Washington DC: U.S. Department of Agriculture, Economic Research Service. Retrieved January 25th, 2022, from https://www.ers.usda.gov/publications/pub-details/?pubid=95929

US Climate Data. 2022. *Monthly Climate Fayetteville – Arkansas*. US Climate Data Website. Retrieved February 25th, 2022, from https://www.usclimatedata.com/climate/fayetteville/arkansas/united-states/usar0189

Yerbasi, S. 2016. *How to prune cannabis plants*. SantYerbasi Grow Shop – Blog. Retrieved March 3rd, 2022, from https://www.santyerbasi.com/en/blog/prune-cannabis-plants/

Chapter III. Marketing CBD Oil

A. Introduction

The recent decriminalization of hemp (*Cannabis sativa* and *indica*) through the 2018 Farm Bill in the USA (Hudak, 2018) has significantly increased the cultivation of hemp in the country (Olson, Thornsbury, and Scott, 2020). Hemp can be used for a variety of purposes e.g., seed production, fiber industry, oil, etc. (Ronde, 2013). As dried hemp flower high in the cannabinoid cannabidiol (CBD) can be processed into CBD products (oil, salves, chews, etc.) and their market potential is promising in Europe and the U.S. (Tyler et al., 2020; Crini and Lichtfouse, 2020; Mordor Intelligence, 2020), this chapter focused on the market of hemp processed into CBD oil.

With this market in its infancy, pricing for CBD oil products does not seem to be standardized. Further, little scientific and peer-reviewed research on the parameters that affect the price of CBD oil exists at the time of this writing. Given this lack of market analyses, producers targeting this specific market face difficulties with setting a price, and further, which of a myriad of different production practices that affect cannabinoid properties in dried hemp flower from which CBD oil is derived, to pursue. Questions arise about whether or not to: i) promote organic, local, small-scale production; ii) use a more controllable indoor vs. less-controlled outdoor production environment; iii) investigate alternative drying methods prior to a choice of different oil extract methods; and, finally, iv) at what CBD concentration to sell CBD oil as extracted crude CBD oil is blended with a carrier oil to meet psychoactive, tetrahydrocannabinol (THC) standards and make the end product more palatable while also altering cost and thereby retail price.

In Chapter II, where the cost of production and processing of hemp flowers into CBD oil was discussed in detail, results have shown that to break even, CBD oil with a concentration of

3,300 mg per 1-oz. bottle, needs to sell at a minimum price of approximately $13.35. As the producer currently sells at a price of $80 the current high margin allows the possibility to lower price to potentially increase sales.

Therefore, this chapter delved into on-line CBD oil offerings in the U.S. to assess what different variables drive current prices. Given that background, an on-line choice experiment was conducted to estimate consumer willingness to pay (WTP) for CBD oil attributes. Results are expected to assist CBD oil producers and retailers with making production and marketing choices.

B. Market Potential for CBD Oil

Cannabinoids are believed to have a variety of beneficial effects on the human body. Tetrahydrocannabinol (THC) has been identified as having an analgesic and anti-depressant effect. Another cannabinoid, CBD, is expected to help with depression and/or sleep disorders. Other cannabinoids, such as cannabigerol (CBG) and cannabinol (CBN), are also believed to have medicinal and/or curative properties to which individual react differently, adding uncertainty to target marketing efforts (Crini and Lichtfouse, 2020).

Although the legislature is steadily evolving, compared to all other hemp derived products, CBD oil currently is the most attractive as its demand from producers, investors, and consumers is steadily increasing (Tyler et al., 2020; Statista, 2022). As Tyler et al. (2020, p.23) state "[…] *information on economic returns remains difficult to ascertain* […]"; hence, the market needs evolving and continuous objective research. For example, the academic research from the University of Kentucky and the University of Tennessee shows that CBD oil has high profit potential on a per acre basis compared to other hemp-derived products (Tyler et al., 2020).

One can make assumptions on how the industrial hemp market is going to develop. Hemp for CBD production is experiencing declining prices as the industry continues to develop and it remains to be seen how potential imports, legislation, and research is going to develop (Jelliffe, Lopez, and Ghimire, 2020). Nevertheless, the Canadian industrial hemp industry may serve as a good example in the sense that the market expanded fast until market prices dropped with excess supply leading to a volatile market. With the U.S. importing most of its hemp oil through Canada, substitution with U.S. national production could create greater volatility for Canadian producers still (Tyler et al., 2020) who are currently investing or acquiring U.S. hemp companies (GlobeNewswire, 2022).

Tyler et al. (2020, p.21) argued that: "[…] *in the longer term, competition for investment capital and acreage between hemp and marijuana may ultimately be more of an issue* […]". Hence, both producers and consumers are getting more knowledgeable about cannabinoids, terpenes, and flavonoids and their interaction, which is commonly referred to as the entourage effect described by Rosenthal et al. (2021) and Sommano et al. (2020). The interaction between botanical secondary metabolites creates health supporting properties that are superior compared to those from single molecules. Hence hemp and marijuana producers and processors are finding a common ground on supplying products for the market that are not only high in concentration of one sole cannabinoid, but rather offer the customer products that are rich in many types of cannabinoids making the blend of cannabinoids in oil products a significant marketing and production decision that is the focus of the remainder of this chapter.

C. Materials and Methods

Because market-level data in the U.S. on CBD oil prices, consumers, and consumer's preferences is rare if not non-existent, the collection of primary data was deemed necessary. For the collection of data, two methods were used. First, an on-line study was conducted to assess current market prices of CBD oils in the U.S. Second, an online choice experiment was performed to assess consumers' preferences and WTP for CBD oil.

1. Regression Analysis: 2021 U.S. Market Prices on CBD Oil

During the fall of 2021, market prices for 1-oz. CBD oil bottles with varying labeled CBD concentrations, using different production methods and country of origin were collected using an exhaustive search to collect information from as many U.S. retailers as searchable using the Google search engine and the Amazon retailer platform. Information was collected on thirteen different variables: i) price per 1-ounce CBD oil bottle (*P*); ii) content of CBD in mg per bottle (*CONT*) in linear and quadratic functional form, iii) country of origin (U.S. = 1, others = 0) (*US*); iv) a binary variable for natural =1 vs. not = 0 (*NATURAL*); v) organic (certified and/or stated) =1 vs. not = 0 (*ORGANIC*); vi) whether the oil was extracted by CO_2 extraction (1) or not (0) (CO_2); vii-ix) if primary health benefits were to fight pain (1) or not (0) (*PAIN*), anxiety (1) or not (0) (*ANXIETY*) or insomnia (1) or not (0) (*SLEEP*); x-xi) whether the hemp flowers were dried by air (1) or not (0) (*AIR*) or using heated air-drying (1) or not (0) (*HEAT*); xii) the average customer star rating of the product (*RATE*); and xiii) the number of ratings available from customers (*NRATE*).

To assess the quantitative effect of the explanatory variables on *P*, the dependent variable, three ordinary least squares regression analyses were conducted to avoid misspecification bias, to correct for heteroskedasticity, and to remove outliers. The first regression (A) used all explanatory variables but only considered observations where a rating was available which reduced the sample size from 206 to 175. The second regression (B) removed observations with a CBD price below $0.016 per milligram of CBD as those were considered unreliable, further reducing the sample to 124 observations. The third regression (C) excluded *US, NATURAL, ORGANIC, ANXIETY, AIR* and *NRATE* as the absolute value of their t-statistics were less than 1. Goodness of fit was judged by sign and size of coefficient estimates and adj. R^2. Multicollinearity among explanatory variables was not significant, however, heteroskedasticity was an issue using the Breusch Pagan test ($p < 0.0001$). To correct for heteroskedasticity, the Huber-White standard error correction option in Eviews 9.5 was applied. Results from these regression analyses, reported and discussed below, justified CBD concentration, target remedy, and drying method to be variables to consider for the online choice experiment discussed next.

2. Survey: Consumer Attitudes and WTP

To collect a comprehensive set of data from hemp and CBD oil consumers with a broad range of demographics within the U.S., a survey assessing consumer knowledge on CBD, attitudes towards hemp and CBD oil, and their WTP for CBD oil bottles, was developed. The survey contained 73 questions (Appendix L – Survey Questions) and was implemented through the University of Georgia in collaboration with Auburn University, the University of Delaware, and the University of Kentucky within the project sponsored by the United States Department of Agriculture entitled "*Hemp Marketing: Measuring Stated Demand and Preferences in an Emerging Market*." Using Qualtrics the online survey was administered nationally by Toluna Inc. (*Reference*) until approximately one thousand complete responses from a nationally representative sample of respondents (by age, gender, income, and education) was obtained. Response data collection commenced on April 1, 2022 and was concluded by April 20, 2022.

Using conjoint analysis in the form of a Multinomial Discrete Choice Experiment (CE) consumers were repeatedly (9 times) presented with purchasing scenarios with three attribute variables modified. In this case, CBD oils, varying in price, by drying method and CBD content. Using repeated bidding, respondents make trade-offs between the different attributes of the product and cost to maximize their utility from the attributes of the oil rather than from the oil itself as described by Lusk et al. (2003). Further, the trade-off with cost (*P*) allowed the assessment of a consumer's WTP for these different attributes in a product and how WTP changes by respondent demographics and attitudes.

The respondents were asked to make a choice between three 1-ounce CBD bottles, each described by three randomized variables (three different hemp flower drying methods, three different CBD concentrations in the oil, and three different prices) and a no-purchase option. An information treatment about the different drying method was also randomly administered to approximately half of the respondents to elicit an information effect that would assist marketers about whether or not providing information about drying methods would add or subtract from WTP.

All three variables describing attributes of CBD oil were randomized for each respondent and each of the nine purchasing scenarios varying among three levels for each attribute. The CE design was computer-generated within Qualtrics and considered the main effects for all attributes and a two-way interaction within alternatives X_1*X_3, X_2*X_3 (see **Table 3.1**). The resulting 27 choice sets (full factorial) were selected using the Statistical Analysis System (SAS) macros for experimental design and choice modeling (SAS Institute Inc., n.d.). The possible price range as well as the possible range of CBD concentrations were drawn from the previous market assessment described in the prior section. The three types of drying were chosen based on the drying methods studied in Chapter II. Industrial Hemp & Farm Management. A sample CE question and a description of attribute levels is shown in *Figure 3.1* and **Table 3.1**.

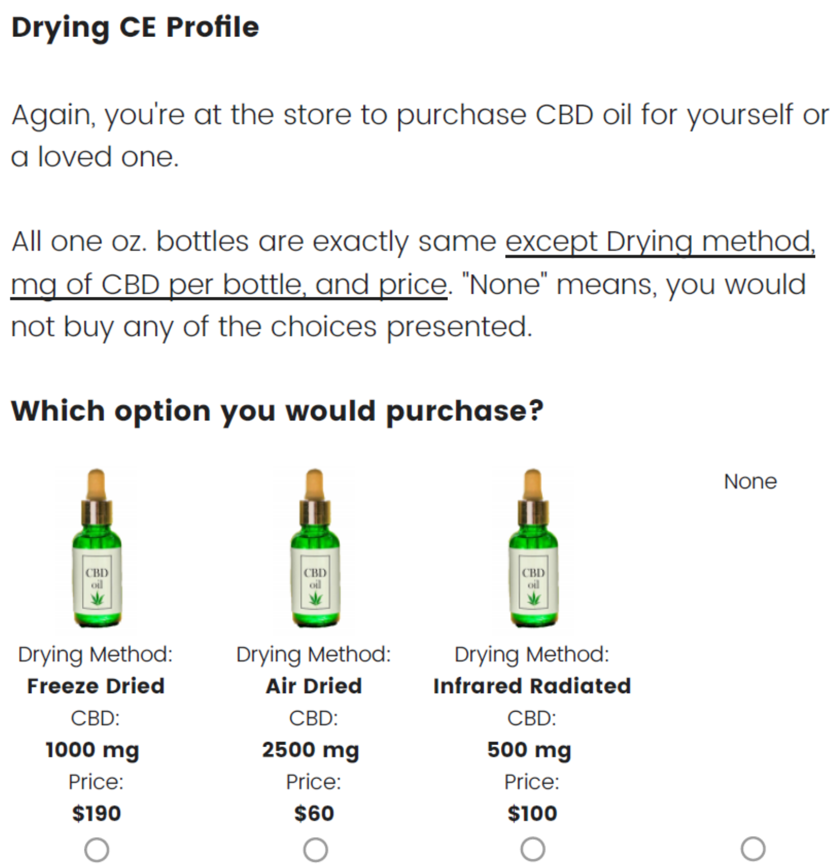


Figure 3.1. Sample choice experiment question.

Table 3.1. 1-Oz. CBD Oil Attributes and Attributes Levels in the CE Survey.

CBD oil Attribute	Factor	Attribute Levels
Drying Method	X_1	Air-Dried Infrared Irradiated (IR) Freeze Dried (FR)
CBD Concentration in milligrams (mg)	X_2	500 mg 1,000 mg 2,500 mg
Price	X_3	$ 60 $ 100 $ 190

The statistical analysis relied on a conditional logit model that describes how consumers choose among a discrete set of unordered scenarios. This was possible as the Multinomial Discrete Choice (MDC) procedure supports conditional logit models (SAS Institute Inc., 2014). In the survey, consumers i = 1, 2,…N, were faced with 27 discrete choices between three CBD oils described by a chosen set of CBD oil attributes. As shown by McFadden (1973), a random utility function may be defined by a deterministic (V_{ij}) and a stochastic (ε_{ij}) component as defined in Eq. (1) where U_{ij} is the ith consumer's utility of choosing option j, V_{ij} is the systematic portion of the utility function determined by the CBD oil attributes and their values (**Table 3.1**) for alternative j, and ε_{ij} is a stochastic element that varies randomly to account for the random effects on U_{ij} of unobserved attributes of the alternative j and individual i.

(1) $$U_{ij} = V_{ij} + \varepsilon_i$$

Thus, the random utility model assesses the probability at which each alternative is chosen. Considering an individual i who chooses among j alternatives in question k and accounting for the factors in **Table 3.1**, the Eq. (2) can be used as the utility function to explain the effects of hemp flower drying method and CBD concentration on the willingness to pay for these specific attributes. In the following equation α is the constant coefficient that has a significance of the p-value associated to it and which gives the degree of change in the independent variable X (see factors in **Table 3.1**) for every 1-unit of change in the dependent variable.

(2) $$U_{ijk} = \alpha X_{ijk} + \varepsilon_{ijk}$$

When integrating the respective factors into the function, the utility function U_{ijk} is the ith individual's utility of choosing option j in question k and becomes Eq. (3):

(3) $$U_{ijk} = \alpha_1 IR_{ijk} + \alpha_2 FR_{ijk} + \alpha_3 500MG_{ijk} + \alpha_4 2500MG_{ijk} + \alpha_5 Price_{ijk} + \varepsilon_{ijk}$$

where $IR_{ijk}, FR_{ijk}, 500MG_{ijk}$ and $2500MG_{ijk}$ are binary variables indicating whether the respective hemp flower product chosen was infrared radiated (IR) or not, freeze-dried (FR) or not, whether the CBD oil has 500 mg of CBD per ounce of oil or not, and if it has 2,500 mg of CBD per ounce of oil or not, respectively. The air-dried hemp flower derived CBD oil as well as the CBD oil having 1,000 mg per ounce of oil was chosen as the baseline. The price variable $Price_{ijk}$ varied as indicated in **Table 3.1** for a one-ounce bottle of CBD, and ε_{ijk} is the extreme value error term that is independently and identically distributed.

A negative coefficient of the price (α_5) is expected as well as a negative coefficient for IR-drying (α_1) given the negative connotations of the term "radiation". Freeze-drying is expected to have no impact in the sense that "freezing" a product is expected to have a more or less neutral impact on product quality perception for most people given the common household practices of freezing products for conservation. The coefficients on CBD concentration of 500 mg (α_3) and 2,500 mg (α_4) are expected to bear negative and positive coefficients, respectively, given that less and more CBD than the baseline is provided.

The Willingness to Pay (WTP) for CBD oil derived from IR (Eq. (4)) and FR (Eq. (5)) dried flowers and CBD oils with 500 mg (Eq. (6)) or 2,500 mg (Eq. (7)) of CBD, relative to the 1,000 mg CBD air-dried product, all other attributes remaining the same, is then estimated as follows and result in binary attribute estimates:

(4) $$WTP_{IR} = (\alpha_1)/-(\alpha_5)$$

(5) $$WTP_{FR} = (\alpha_2)/-(\alpha_5)$$

(6) $$WTP_{500MG} = (\alpha_3)/-(\alpha_5)$$

(7) $$WTP_{2500MG} = (\alpha_4)/-(\alpha_5)$$

Based on these attribute estimates one could approximate the effects of a one milligram decrease in CBD concentration relative to the baseline product of 1,000 mg. Nonetheless, as the utility function has three price levels and a strictly linear utility curve between price points cannot be assumed, one can only assess the WTP for the given concentrations of 500 and 2,500 mg.

This study will only look at the coefficient estimates that are statistically significant at p-values below 0.1, 0.05, or 0.01 indicating significance at the 90%, 95%, and 99% level, respectively.

To assess the statistical significance of the estimated WTP values, due to the non-linearity of the formula from (4) to (7), a Monte-Carlo simulation procedure is used to resample or simulate based on the different coefficient attributes. Resampling a thousand times using ten thousand Monte Carlo simulated samples, following a normal distribution, WTP values were estimated. Using average and standard deviations of these model runs, a t-test was performed to assess whether WTP estimates were statistically significantly different from the baseline WTP by calculating the respective two-tailed p-value.

Furthermore, the study assesses the effect on consumers' WTP from the information treatment as well as the effects of different consumer demographics such as age, gender, education, and other consumer attributes such as the level of concern over CBD oil quality, and typical expenditure level on CBD oil. These effects can be assessed by including them as binary variables in the utility function (Eq. (8)). The intent is to estimate the effect of the information treatment (*T*), for example. The variable T takes on a binary value of 1 or 0 based on whether the respective respondent i had received an information treatment or not. Multiplying T by the i^{th} respondent's value for each respective baseline variable, U_{ijk} remains the i^{th} individual's utility of choosing option j in question k, which is now modified additively with the interaction. As such, the previous α coefficients are now denoted as β and the error term becomes μ_{ijk}.

(8) $U_{ijk} = \beta_1 IR_{ijk} + \beta_2 FR_{ijk} + \beta_3 500MG_{ijk} + \beta_4 2500MG_{ijk} + \beta_5 Price_{ijk} + \beta_6 TIR_{ijk} + \beta_7 TFR_{ijk} + \beta_8 T500MG_{ijk} + \beta_9 T2500MG_{ijk} + \beta_{10} TPrice_{ijk} + \mu_{ijk}$

The WTP must be assessed differently between different consumer segments e.g., consumers that have received an information treatment and other that have not. Alternative interactions could also be performed by age, income, education, or others respondent category. The WTP for CBD oil derived from IR-dried (Eq. (9) and (13)) or FR-dried ((10) and (14)) flowers and CBD oils with 500 mg ((11) and (15)) or 2,500 mg ((12) and (16)) of CBD, relative to the 1,000 mg CBD air-dried product, all other attributes remaining the same, is then estimated as follows (where *T* is an example and is referring to an information treatment effect, hence *T* could also be *A* for Age effect, among others) and result in binary attribute estimates:

(9) $WTP_{IR} = (\beta_1)/-(\beta_5)$

(10) $WTP_{FR} = (\beta_2)/-(\beta_5)$

(11) $WTP_{500MG} = (\beta_3)/-(\beta_5)$

(12) $WTP_{2500MG} = (\beta_4)/-(\beta_5)$

(13) $WTP_{TIR} = {(\beta_1 + \beta_6)}\big/{-(\beta_5 + \beta_{10})}$

(14) $WTP_{TFR} = {(\beta_2 + \beta_7)}\big/{-(\beta_5 + \beta_{10})}$

(15) $WTP_{T500MG} = {(\beta_3 + \beta_8)}\big/{-(\beta_5 + \beta_{10})}$

(16) $WTP_{T2500MG} = {(\beta_4 + \beta_9)}\big/{-(\beta_5 + \beta_{10})}$

The difference in the WTP, for CBD oil derived from IR (Eq. (17)) or FR (Eq. (18)) dried flowers and CBD oils with 500 mg (Eq. (19)(15)) or 2,500 mg (Eq. (20)) of CBD, between consumer segments e.g., consumers that have received an information treatment and other that have not, relative to the 1,000 mg CBD air-dried product, all other attributes remaining the same, is then estimated as follows:

(17) $WTP\ difference_{IR-TIR} = (9) - (13)$

(18) $WTP\ difference_{FR-TFR} = (10) - (14)$

(19) $WTP\ difference_{FR-TFR} = (11) - (15)$

(20) $WTP\ difference_{2500MG-T2500MG} = (12) - (16)$

To assess the statistical significance of these WTP values, the identical Monte-Carlo simulation and p-value assessment method is used as previously described and applied to the values of the WTP differences to assess the statistical significance of the difference between the respective consumer segments as explained above. The null hypothesis in this case, taking the information treatment effect as an example, is that consumers that have received prior information about drying methods are willing to pay the same for 1,000 mg air-dried CBD oil compared to IR or freeze-dried hemp oil at 500 or 2,500 mg depending on the question at hand. The alternative hypothesis then being that consumers are not willing to pay the same, hence that the difference between these consumer segments is statistically significant which would mean that giving consumers information about hemp flower drying methods impacts their WTP either decreasing or increasing it depending on the coefficient estimates. Whether the estimated WTP difference is statistically significantly different from zero (p-value below 0.1) or not then informs about whether a particular drying method statistically significantly modifies WTP or not.

D. Results

The results will be presented as outlined in the previous sections by presenting market information as sourced in the fall of 2021 from U.S. retailers followed by results from the online U.S. choice experiment conducted in the spring of 2022. Respondent demographics for the choice experiment are also presented.

1. 2021 U.S: Market Prices on CBD Oil

Summary statistics and variable definitions of the collected samples are shown in **Table 3.2** and are adapted to the number of observations kept.

Table 3.2. Summary Statistics and Variable Definitions.

Variable	Definition	Mean		
P	USD per 1-ounce CBD bottle	70.14 (61.21)[1]	70.97 (64.29)	92.29 (64.78)
CONT	CBD concentration in mg of CBD per ounce of oil	1,631,330.87 (17,175,578.76)	1,920,044.05 (18,627,955.64)	1,489.59 (1,763.97)
US	1 = U.S. Hemp; 0 otherwise	0.80 (0.40)	0.78 (0.41)	0.91 (0.29)
NATURAL	1= Natural; 0 otherwise	0.35 (0.48)	0.35 (0.48)	0.27 (0.45)
ORGANIC	1 = Organic; 0 otherwise	0.61 (0.49)	0.63 (0.48)	0.60 (0.49)
CO_2	1= CO_2 extracted oil; 0 otherwise	0.44 (0.50)	0.41 (0.49)	0.47 (0.50)
PAIN	1 = Sold for pain relief; 0 otherwise	0.49 (0.50)	0.54 (0.50)	0.47 (0.50)
ANXIETY	1 = Sold to fight anxiety, 0 otherwise	0.50 (0.50)	0.55 (0.50)	0.52 (0.50)
SLEEP	1 = Sold for sleep; 0 otherwise	0.51 (0.50)	0.55 (0.50)	0.48 (0.50)
AIR	1 = Air-dried hemp; 0 otherwise	0.05 (0.22)	0.03 (0.17)	0.04 (0.20)
HEAT	1 = Heat dried hemp; 0 otherwise	0.01 (0.12)	0.02 (0.13)	0.02 (0.15)
RATE	Customer star rating	3.86 (1.67)	4.55 (0.38)	4.73 (0.28)
NRATE	Number of ratings	491.99 (1,475.04)	579.14 (1,585.12)	390.50 (654.55)
Number of observations		206	175	124

[1]Numbers in parentheses are standard deviations

Table 3.3 shows the three regression outputs which were based on the market data collected in 2021 on the U.S. CBD oil as explained in the methodology.

Table 3.3. Determinants of Price for 1-Oz. CBD Oil, U.S. Online Retail Offerings, 2021.

	Alternative Model Specifications		
Explanatory Variables[a]	**A**	**B**	**C**
Constant	-246 (45 [b]) ***	-165 (79) **	-189 (67) ***
CONT	$1x10^{-7}$ ($3x10^{-7}$)	$4x10^{-2}$ ($6x10^{-3}$) ***	$4x10^{-2}$ ($6x10^{-3}$) ***
$CONT^2$	$-2x10^{-16}$ ($1x10^{-15}$)	$-9x10^{-7}$ ($6x10^{-7}$)	$-9x10^{-7}$ ($6x10^{-7}$)
US	15 (8) *	-10 (15)	
NATURAL	-3 (8)	2 (9)	
ORGANIC	-30 (8) ***	-10 (8)	
CO_2	17 (10) *	14 (9)	8 (8)
PAIN	6 (15)	12 (10)	17 (8) **
ANXIETY	-4 (13)	2 (10)	
SLEEP	1 (10)	12 (8)	14 (9)
AIR	64 (41)	61 (32) *	54 (30) *
HEAT	-25 (20)	13 (13)	
RATE	70 (10) ***	43 (16) ***	45 (14) ***
NRATE	$-2x10^{-3}$ ($2x10^{-3}$)	$-1x10^{-3}$ ($5x10^{-3}$)	
R-square	30.06%	66.50%	65.55%
Adjusted R-square	24.41%	62.54%	63.47%
No. observations	175	124	124

[a] Content of CBD in mg per bottle in linear (*CONT*) and quadratic ($CONT^2$) functional form; (*US*) country of origin (U.S. = 1, others = 0); (*NATURAL*) a binary variable for natural =1 vs. not = 0; (*ORGANIC*) organic (certified and/or stated) =1 vs. not = 0; (*CO_2*) whether the oil was extracted by CO_2 extraction (1) or not (0); if primary health benefits were to fight pain (1) or not (0) (*PAIN*), anxiety (1) or not (0) (*ANXIETY*) or insomnia (1) or not (0) (*SLEEP*); whether the hemp flowers were dried by air (1) or not (0) (*AIR*) or using heated air-drying (1) or not (0) (*HEAT*); (*RATE*) the average customer star rating of the product; and (*NRATE*) the number of ratings available from customers.
[b] Standard errors are reported in parentheses.
*, **, *** indicates significance at the 90%, 95%, and 99% level, respectively.

With the successive refinement in model specifications from the initial model (A) to the final functional form chosen (C) adj. R^2 increased as did the number of significant variables. Most coefficient estimates bear the expected sign in the sense that more CBD content increased the price, for example. Using these coefficient estimates, *Figure 3.2*, demonstrates that higher CBD content diminishingly adds to price at higher CBD content. This seems appropriate since consumers using CBD oil cannot reduce droplet size beyond a certain point and further because oil quality deteriorates with successive openings of the storage container. That is, most users will want to consume the contents of a bottle in a month or two. If dosage needed to be reduced to less than 1 drop to obtain the desired amount of CBD, the bottle would last much longer than two months with attendant quality deterioration.

The results from regression (C) showed that each mg of CBD in CBD oil adds $0.04 to the CBD oil price of a one-ounce bottle and that hemp flowers dried by air, the CBD use for pain, and the consumer rating, statistically significantly impacted the price positively. The statistically significant results on CBD concentration and drying method motivated the choice of using these two factors in the choice experiment. Since the data collection method for this market assessment did not allow for collection of explanatory variables that may vary by the individual consuming the product, the following choice experiment results are expected to add further insight.

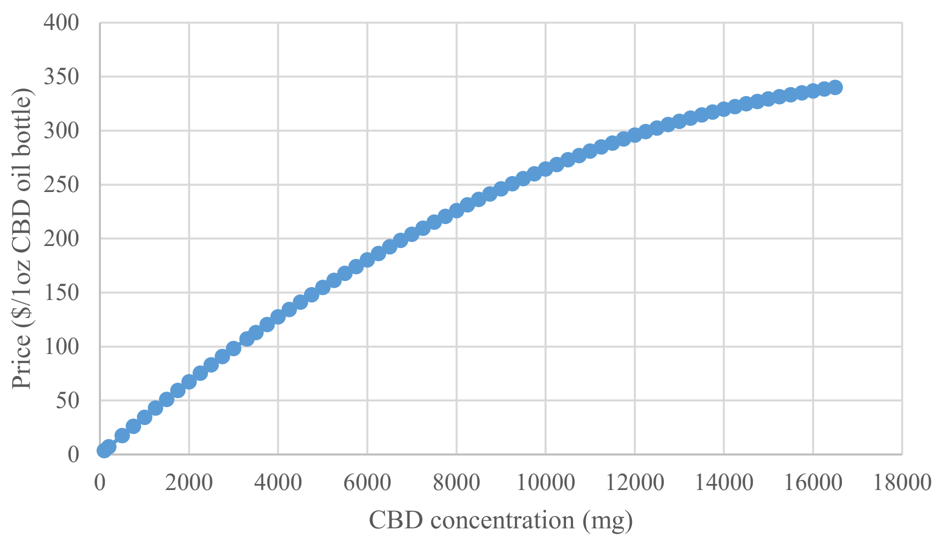


Figure 3.2. Prices observed as a function of CBD concentration.

2. *Summary and Analysis of the Consumer Survey*

The survey was completed on average in 20.08 minutes with a median duration of 14.4 minutes. Participants below the age of eighteen years old were not allowed to take the survey. Approximately 1,004 eligible respondents participated and completed the survey. Of this sample, 549 were excluded from the final analysis as they had never tried any products containing CBD. Of the 455 respondents left, 40% (184 respondents) had tried or regularly consume CBD in the form of oil, 30% were between 18 and 25 years old, 52% between 25 and 54 years old, and 18% were over 54 years old. Summary statistics and variable definitions of usable responses are shown in **Table 3.4**.

A little more men answered the survey (54%) as compared to women and other genders. The average age of the respondents was 38 years old, and most respondents (77%) had a college degree or higher. About half the respondents were using CBD for medical conditions or pain relief. The importance of the hemp flower drying method, as well as the no mold guarantee, could not be discussed (although evaluated) as too few observations highlighted these characteristics to be among the top three. Nonetheless, the respondents indicated that they were slightly (about 50%) concerned about the quality and the contaminants (such as mold) in CBD products which corresponds to the study's initial perception. About seventy percent of the respondents said they are spending up to $100 per month on CBD products; others said they would spend more, but again the latter did not seem to follow a normal distribution. Further, among the 455 respondents with CBD experience, 49% received the drying method information treatment prior to completing the choice experiment; hence, the randomization performed as expected.

Sample selection bias may exist because of the selection of CBD consumers only. Nonetheless, compared to U.S. census data the surveyed sample appears to be well balanced.

Table 3.4. Summary Statistics and Variable Definitions.

Variable	Definition	Mean		
		CBD Users	Non-Users	All
Gender[1]	1 = male; 0 = female & other	0.547[3] (0.498)[2]	0.406[4] (0.492)	0.470 (0.500)
Age	Age in years	37.5[3] (15.7)	48.5[4] (20.6)	43.5 (19.3)
Child	Children per household	1.00[3] (1.12)	0.54[4] (1.02)	0.75 (1.09)
Education	1 = College and higher; 0 otherwise	0.77[3] (0.42)	0.71[4] (0.46)	0.74 (0.44)
Annual household income	Annual household income in USD	87,098.9 (55,965.1)	68,433.5[4] (52,292.5)	76,892.4 (73,892.4)
Information treatment	1 = received; 0 otherwise	0.490 (0.500)		
CBD Quality	Percentage concern for CBD quality	0.557 (0.330)		
CBD Contaminants	Percentage concern for CBD contaminant	0.482 (0.335)		
CBD concentration	CBD oil concentration (in mg) typically purchased	1,657 (765)		
Medical	1 = CBD use for medical condition; 0 otherwise	0.468 (0.499)		
Pain	1 = CBD use for pain relief; 0 otherwise	0.563 (0.497)		
Purchased CBD last year	1 = yes; 0 otherwise	0.820 (0.385)		
Among top 3 important factors (1 = Among top three; 0 otherwise)	Total amount of CBD in product	0.312 (0.464)		
	Local product	0.154 (0.361)		
	Lab results	0.229 (0.420)		
	Organic product	0.211 (0.408)		
	Drying Method	0.132 (0.339)		
	No mold guarantee	0.134 (0.341)		
Monthly spending on CBD	Up to $100; 1 = yes; 0 otherwise	0.697 (0.460)		
	Over $100; 1 = yes; 0 otherwise	0.182 (0.387)		
"None" responses	Cumulative percentage of "none" responses in the 9 choice experiment questions	0.107 (0.310)		
Number of observations		455[5]	549	1,004

[1]Five respondents answered "Other Gender"

[2]Numbers in parentheses are standard deviations

[3]U.S. mean (U.S. Census Bureau) of i) males in 2019 was 49.2 %; ii) age in 2019 was 38.5 years old; iii) 1.93 children under 18 years old in 2020; and iv) people that had graduated from college, or another higher education was 37.5 percent.

[4]The differences between CBD users and non-users were statistically significant at the 99% level for gender, age, number of children, education level, and annual income which was measured using two-sample t-test analyses assuming unequal variances.

[5]The most represented states among the 455 respondents were California (14 %), Florida (9), New York (9), and Texas (8).

The summary statistics in **Table 3.4** also show that on average CBD product users or consumers, compared to non-users, are statistically significantly more likely to be male, younger, have more kids, are slightly more educated, and have a higher annual household income.

The number of observations as well as the percentage of response for the choice experiment are based on 4,095 observations as there are nine choice experiment questions for each of the 455 respondents. The discrete response profile in percentage terms for choices one, two, three, and four ("none") as shown in *Figure 3.1* was 31.77%. 30.65%, 26.72%, and 10.87% throughout the study, respectively.

Firstly, the study focused on assessing the WTP for IR-dried, Freeze-dried, 500 mg CBD, and 2,500 mg CBD, CBD oil bottles setting an air-dried CBD bottle of 1,000 mg CBD as the baseline. Without analyzing how the WTP varies between respondents that had received an information treatment nor comparing respondents from different demographic categories. These results tell us whether the regression estimates are statistically significant (**Table 3.5**) and whether the calculated WTP for these different attributes is significant or not (**Table 3.6**).

Table 3.5. Estimates of Conditional Logit Model.

Attribute	Estimate	Log likelihood	Schwarz Criterion	McFadden's LRI
Infrared Radiation Drying	-0.0315 (0.0427[a])			
Freeze-drying	0.0520 (0.0415)			
500 mg CBD	0.2167*** (0.0436)	-5,563	11,167	0.0201
2,500 mg CBD	0.4832*** (0.0401)			
Price	0.0008*** (0.0003)			

[a] Standard errors are reported in parentheses.

*, **, *** indicates significance at the 90%, 95%, and 99% level, respectively.

Table 3.6. Estimates of Simulated WTP for Baseline Model.

Attribute	Estimated WTP (simulated)
Infrared Radiation Drying	$37.21
Freeze-drying	- $85.30
500 mg CBD	- $329.18
2,500 mg CBD	- $719.18

*, **, *** would indicate significance at the 90%, 95%, and 99% level, respectively.

The WTP results for the baseline model show that, compared to an air-dried hemp flower derived CBD oil at 1,000 mg concentration, IR-drying increases the WTP, whereas freeze-drying, as well as decreasing and increasing the CBD concentration, decreases the WTP. However, as WTP values are all not statistically significantly different from zero these statements cannot be accepted as such. The price coefficient being positive is problematic. Respondents, on average, regard CBD oil as Giffen goods, which is a product that consumers purchase more of as the price rises. To address respondents' different aspect of price coefficient, the study must utilize a mixed logit model or Bayesian hierarchical model that allow respondents' specific parameter estimates. However, this study only considers preferences and WTP of average respondents using a conditional logit model. Statistical significance is also observed in the coefficients on the CBD concentration, both positive, which means that a 500 and 2,500 mg CBD oil increases a consumer's utility. Compared to a 1,000 mg CBD oil bottle, consumers derive slightly more utility from a bottle with 500 mg and much more utility from a 2,500 mg CBD oil.

Secondly, the study focused on assessing the WTP for the same attributes as before, compared to the same baseline product, but also the difference of the WTP between respondents that had received an information treatment and others that did not, and between respondents from different demographic categories. The analysis focused on assessing the differences in WTP between respondents from the categories summarized in **Table 3.7** where respondents could either possess category characteristics (1) or not (0) using Eq. (8).

Table 3.7. Summary Statistics and Variable Definitions for Respondent Categories.

Variable	Definition	Mean
1) Information treatment or not	1 = received; 0 otherwise	0.490 (0.500)[1]
2) Age category 18-24	1 = 18 to 24 years old; 0 otherwise	0.303 (0.460)[2]
3) Age category 25-54	1 = 25 to 54 years old; 0 otherwise	0.516 (0.500)
4) Age category over 54	1 = over 54 years old; 0 otherwise	0.180 (0.385)
5) Gender male	1 = male; 0 = female & other	0.547 (0.498)[2]
6) Education college, masters, & PhD	1 = College and higher; 0 = high-school and below	0.771 (0.420)[2]
7) Quality concern <49%	1= % concern for CBD quality over 49%; 0 otherwise	0.473 (0.500)
8) Contaminants concern <49%	1= % contaminants concern over 49%; 0 otherwise	0.536 (0.499)
9) Daily usage of CBD	1 = Daily use of CBD; 0 otherwise	0.240 (0.427)
10) Weekly or monthly usage of CBD	1 = weekly or monthly use of CBD; 0 otherwise	0.576 (0.495)
11) CBD dose below 10 mg	1 = Typical CBD dose below 10 mg; 0 otherwise	0.215 (0.412)
12) CBD dose 10-30 mg	1 = Typical CBD dose 10 to 30 mg; 0 otherwise	0.248 (0.433)
13) CBD dose 30-50 mg	1 = Typical CBD dose 3; to 50 mg; 0 otherwise	0.220 (0.415)
14) Local CBD important	1 = Among top three; 0 otherwise	0.154 (0.361)
15) Laboratory tests important	1 = Among top three; 0 otherwise	0.229 (0.420)
16) Drying method important	1 = Among top three; 0 otherwise	0.132 (0.339)
17) Mold in the product important	1 = Among top three; 0 otherwise	0.134 (0.341)
18) Typical expenses on CBD < $49/month	1 = Monthly spending on CBD below $49; 0 otherwise	0.534 (0.499)
19) Typical expense $50-$100/month	1 = Month. spending on CBD $50 to $100; 0 otherwise	0.284 (0.451)
20) Typical expense > $100/month	1 = Month. spending on CBD above $100; 0 otherwise	0.182 (0.387)
21) Respondent from a rural area or not	1 = From a rural area; 0 otherwise	0.160 (0.367)
22) Medical or pain relief CBD use	1 = CBD use for medicine or pain; 0 otherwise	0.754 (0.431)
23) Low income tier	1 = Household Income (Inc.) below $30k; 0 otherwise	0.209 (0.407)[2]
24) Middle income tier	1 = Inc. above $30k and below $80k; 0 otherwise	0.360 (0.481)[2]
25) Upper income tier	1 = Inc. above $80k and below $190k; 0 otherwise	0.382 (0.487)[2]
26) High income tier	1 = Inc. above $190k; 0 otherwise	0.048 (0.215)[2]
27) THC legal recreationally	1 = THC legal in state for recreational use; 0 otherwise	0.479 (0.500)
28) THC legal medically	1 = THC legal in state for medical use; 0 otherwise	0.741 (0.439)
29) THC illegal (CBD legal)	1 = THC illegal in state (CBD legal); 0 otherwise	0.259 (0.439)
30) THC legal recreationally and medically	1 = THC legal in state for recreational and medical use; 0 otherwise	0.741 (0.439)
31) Duration of survey completion: Short	1 = duration below 776 seconds; 0 otherwise[3]	0.422 (0.494)
32) Duration of survey completion: Medium	1 = duration between 776 and 1,552 s.; 0 otherwise[3]	0.448 (0.498)
33) Duration of survey completion: Long	1 = duration above 1,552 s.; 0 otherwise[3]	0.130 (0.336)
Number of observations		455

[1]Numbers in parentheses are standard deviations

[2]U.S. mean (U.S. Census Bureau) of i) persons between 18 and 24 years old in 2020 was 12 percent (data on the other age categories was not available); ii) males and people that had graduated from college, or another higher education level are stated in Table 3.4.; and iii) persons in the low, middle, upper, and high income tiers (as defined in study) in 2020 was 22, 35, 31, and 11 percent, respectively.

[3]The choice of 776 seconds is based on the mode (most observed) of the duration of survey completion, 1,552 seconds being two times the mode.

Unfortunately, few statistical significances could be identified in the simulated WTP values nor in the difference in WTP values. Statistically significant WTP values were solely found for attribute categories (4), (5), and (18) shown in **Table 3.8**.

The results indicate that there are statistically significant differences in the WTP, compared to air-dried 1,000 mg CBD oil, for Freeze dried hemp flower derived CBD oil as well as for 500 mg and 2,500 mg CBD oil between consumers above the age of 54 years old and those below 54 years old, between male and female consumers, between consumers that spend less and over $49 per month on CBD products, and between consumers with lower and higher household incomes.

Table 3.8 shows the WTP values for these different consumers and indicates that, compared to air-dried 1,000 mg CBD oil:

- **Consumers below 54 years** old are willing to pay significantly less for 500 mg (-$137) and 2,500 mg (-$234) CBD oil, and that consumers above 54 years old tend to be willing to pay significantly more for freeze dried ($37) as well as 2,500 mg ($99) CBD oils;
- **Male consumers** are willing to pay significantly less for 500 mg (-$167) and 2,500 mg (-$286) CBD oil;
- **Consumers that typically spend more than $49 per month** on CBD products are willing to pay significantly less for freeze dried (-$45), 500 mg (-$121) and 2,500 mg (-$191) CBD oils; and that,
- **Consumers that have over $30,000 in annual household income** are willing to pay significantly less for 500 mg (-$164) and 2,500 mg (-$368) CBD oils.

However, these results do not coincide with the results in **Table 3.6** as these indicate that, compared to air-dried 1,000 CBD oil, consumers are willing to pay less the higher the CBD concentration, except for consumers above 54 years old. Thus, it can be said that although consumers derive an increasing utility the higher the CBD concentration, most consumers are not willing to pay a higher price that comes with the increased CBD concentration.

Table 3.8. Estimates of Simulated WTP Values for Different Categories.

Attribute	Estimated WTP	p-value	Estimated WTP	p-value
Category (4) – Age category over 54 years old				
	Below 54 years old		Over 54 years old	
IR-Drying	$2.95 (22.78)[1]	0.8968	- $15.80 (19.51)	0.4180
FR-Drying	- $22.49 (23.82)	0.3451	$36.66** (16.71)	0.0283
500 mg	- $137.05*** (37.12)	<0.001	- $24.72 (20.83)	0.2354
2,500 mg	- $234.06*** (48.09)	<0.001	$98.59*** (16.38)	<0.001
Category (5) – Gender Male				
	Female		Male	
IR-Drying	n.a.[2]	0.9968	- $57.65 (49.20)	0.2413
FR-Drying	n.a.	0.9996	- $60.02 (49.53)	0.2256
500 mg	n.a.	0.9972	- $167.04** (79.88)	0.0365
2,500 mg	n.a.	0.9967	- $285.55*** (110.45)	0.0097
Category (18) – Typical Expenses on CBD < $49/month				
	Expense > $49/month		Expense < $49/month	
IR-Drying	- $20.85 (25.30)	0.4098	n.a.	0.9922
FR-Drying	- $45.35* (26.76)	0.0901	n.a.	0.9994
500 mg	- $121.01*** (36.34)	0.0009	n.a.	0.9878
2,500 mg	- $190.62*** (43.58)	<0.001	n.a.	0.9892
Category (23) – Low Income Tier				
	Inc.[3] > $30k		Inc. < $30k	
IR-Drying	- $4.75 (40.18)	0.9060	n.a.	0.9869
FR-Drying	- $72.78 (54.85)	0.1845	n.a.	0.9866
500 mg	- $163.91*** (81.16)	0.0434	n.a.	0.9718
2,500 mg	- $367.79*** (140.23)	0.0087	n.a.	0.9784

*, **, *** indicates significance at the 90%, 95%, and 99% level, respectively.
[1]Standard errors are reported in parentheses.
[2]n.a. indicates that the WTP and Standard errors were not justified as the p-values indicate.
[3]Inc. indicates Annual Household Income

E. Discussions

Based on the results of this chapter, the market analysis shows that the price of CBD oil is mainly driven by its CBD concentration and customer ratings when it comes to selling price set by CBD oil retailers in the U.S. The analysis on the WTP of consumers, however, does not entirely support the retailers' approach. The survey results suggest that CBD oil products are much less price sensitive than initially expected as very few consumer categories show significant impacts on differences in a respondent's WTP for CBD oil, and that it appears to be perceived as a Giffen good. It further suggests that the drying method used on hemp flowers for CBD oil production combined with the CBD concentration in a CBD oil does not significantly matter to CBD consumers.

This is different for consumers over 54 years old who are willing to pay more the higher the CBD concentration in the CBD oil and if flowers were dried using freeze-drying. Nonetheless, for all the other tested consumer categories, the results, although limited in their interpretation, show that hemp producers might choose to use the cheapest drying method to lower their production costs. It is expected that there are other factors that must be accounted for when setting the selling price of CBD products which suggests that further research is needed.

F. Conclusions

It can be concluded that the most attractive market for CBD products seems to be CBD oil according to literature review, but that retail prices must be standardized and lowered, and that distribution channels as well as peer-reviewed research must be increased. The market analysis shows that CBD oil retail prices are mainly driven by the CBD concentration in the oil, and that there is need for further research to determine which other factors might drive CBD oil prices. It was observed that each additional milligram of CBD in CBD oil increases the oil's price by about \$0.04. The consumer survey supports this expectation as consumers seem to derive an increasing utility the higher the CBD concentration, however, consumers, except for consumers over 54 years old, do not seem to be willing to pay a higher price for their increased utility which leads to CBD products being less price sensitive than initially expected. The survey also shows that most surveyed consumers do not pay much attention to the drying method that was used on the hemp flowers to produce the CBD oil this might however change in the future as one or another drying method may become contested. The survey also showed that on average people using CBD product, compared to non-users, are more likely to be male, younger, have more kids, are slightly more educated, and have a higher annual household income. This may help CBD producers or processors for selecting target marketing strategies for CBD consumers.

Further, the only consumers that showed significant values for their WTP for CBD oil are male consumers and consumers that spend below $49 per month on CBD products which both tend to be willing to pay less for 500 and 2,500 mg CBD oils (always compared to the baseline product). These findings suggest that there is a need to better inform consumers about why costs increase when the CBD concentration increases, that a producer or processor might choose the cheapest drying method to save on production costs although one or another drying method might become contested in the future, and that further research is needed to find other parameters that affect consumer utility that may impact CBD oil pricing decisions.

G. References

Crini, G., and Lichtfouse, E. 2020. *Sustainable Agriculture Reviews 42: Hemp Production and Applications,* 1st. ed. [E-book]. Switzerland: Springer. https://doi.org/10.1007/978-3-030-41384-2

GlobeNewswire. 2022. “Icanic Brands Announces Binding LOI to Acquire 100% of LEEF Holdings, California’s Premier Extraction Company”. In *GlobeNewswire*, Notified, Intrado. Retrieved January 28th, 2022, from https://www.globenewswire.com/news-release/2021/08/31/2289113/0/en/Icanic-Brands-Announces-Binding-LOI-to-Acquire-100-of-LEEF-Holdings-California-s-Premier-Extraction-Company.html

Hudak, J. 2018. “The Farm Bill, hemp legalization and the status of CBD: An explainer”. *The Brookings Institution*, December. Retrieved December 12th, 2021, from https://www.brookings.edu/

Jelliffe, J., Lopez, R.A. and Ghimire, S. 2020. “CBD Hemp Production Costs and Returns for Connecticut Farmers in 2020”. University of Connecticut Department of Agricultural and Resource Economics Zwick Center for Food and Resource Policy Outreach Report No. 66. Retrieved November 1st. 2021, from https://are.uconn.edu/wp-content/uploads/sites/2327/2020/02/ZwickOR66_Feb25.pdf

Lusk, J. L., Roosen, J., and Fox, J. A. 2003. “Demand for Beef from Cattle Administered Growth Hormones or Fed Genetically Modified Corn: A Comparison of Consumers in France, Germany, the United Kingdom, and the United States”. *American Journal of Agricultural Economics*, 85(1): 16–29. https://doi.org/10.1111/1467-8276.00100

McFadden, D. 1973. “Conditional logit analysis of qualitative choice behaviour”. In P. Zaremiibka (ed.), *Frontiers in Econometrics*. New York: Wiley, pp. 105-135. Retrieved April 28th, 2022, from https://eml.berkeley.edu/reprints/mcfadden/zarembka.pdf

Mordor Intelligence. 2020. “CBD Oil Market - Growth, Trends, Covid-19 Impact, And Forecasts (2021 - 2026)”. *Mordor Intelligence Private Limited*: in press. Retrieved December 12th, 2021, from https://www.mordorintelligence.com/

Olson, D. W., Thornsbury, S. D. and Scott, S. 2020. *Hope for Hemp: New Opportunities and Challenges for an Old Crop*. Washington DC: U.S. Department of Agriculture, Economic Research Service, June. Retrieved December 12th, 2021, from https://www.ers.usda.gov/

Ronde, S. M. 2013. “Industrial Hemp in the Netherlands: The effect of changes in policies and subsidy structures”. MS thesis, Ghent University. Retrieved December 12th, 2021, from https://libstore.ugent.be/

Rosenthal, E., Flannery, R., Bacca, A., and Chong, T. 2021. *Cannabis Grower’s Handbook: The Complete Guide to Marijuana and Hemp Cultivation*. California: Quick American Publishing. ISBN: 9781936807543

SAS Institute Inc. 2014. *SAS/ETS® 13.2 User’s Guide: The MDC Procedure*. Cary, NC: SAS Institute Inc. Retrieved April 13th, 2022, from https://support.sas.com/documentation/onlinedoc/ets/132/mdc.pdf

SAS Institute Inc. n.d. *The %ChoiceEff Macro*. Cary, NC: SAS Institute Inc. Retrieved April 28th, 2022, from https://support.sas.com/rnd/app/macros/ChoicEff/ChoicEff.pdf

Sommano, S. R., Chittasupho, C., Ruksiriwanich, W., and Jantrawut, P. 2020. “The Cannabis Terpenes”. *Molecules*, 25(24): 5792. https://doi.org/10.3390/molecules25245792

Statista. 2022. *Total U.S. cannabidiol (CBD) product sales from 2014 to 2022*. (in million U.S. dollars) [Graph]. In Statista. Retrieved January 25th, 2022, from https://www.statista.com/statistics/760498/total-us-cbd-sales/

Tyler, M., Shepherd, J., Olson, D., Snell, W., Proper, S., and Thornsbury, S. 2020. *Economic Viability of Industrial Hemp in the United States: A Review of State Pilot Programs,* EIB-217. Washington DC: U.S. Department of Agriculture, Economic Research Service. Retrieved January 25th, 2022, from https://www.ers.usda.gov/publications/pub-details/?pubid=95929

Chapter IV. Summary of Conclusions and Considerations for Future Research

A. Summary of Results and Conclusions

The study shows that small-scale hemp farming in Northwest Arkansas on 0.37 to 1 acre targeting CBD oil production can be profitable if properly managed. Break-even point at these scales starts at $13.35 per 1-ounce CBD oil bottle. Main challenges are making the right farm management decisions and deciding on which end products to produce and sell which inevitably translates into production and processing methods and costs. In that sense, decision making on hemp production has been shown to be highly dependent on the environmental context of any hemp farm. Deciding on which hemp varieties to grow and which drying method to use was shown to impact final product characteristics which in turn impact producer's target market. A producer can sell products high in specific cannabinoids, terpenes, with more or less bacterial and fungal populations, among other factors. It has also been shown that a producer must account for impacts on final product characteristics that emanate from the oil extraction process.

Furthermore, the 2021 U.S. CBD market assessment as well as the assessment on consumer needs and wants has shown that the main driver of the CBD oil price seems to be the CBD concentration and that consumers derive an increasing utility the higher the CBD content. The survey has shown that on average people using CBD product, compared to non-users, are more likely to be male, younger, have more kids, are slightly more educated, and have a higher annual household income. However, consumers do not seem to be willing to pay more for the increased utility which suggests that consumers perceive CBD oil prices to be too high and as a Giffen good. Inevitably the latter suggests that CBD oil producers, processors, and retailers may want to lower the price of their products to increase their sales which is feasible considering a break-even price of $13.35 per bottle. This, however, depends on the targeted consumers as the study has shown that consumers above the age of 54 years of age are willing to pay significantly more for 2,500 mg CBD oils compared to 1,000 mg CBD oil. The consumer survey has also shown that most consumers do not seem to value any specific hemp flower drying method, which means that a hemp producer could use any given drying method that lowers his or her production and processing costs.

Along those lines, the study results suggest using air-drying at two distinct and consecutive periods in one smaller drying room. If this is inconvenient for a producer as it prolongs drying times, using air-drying in one run remains cheaper than using any other drying method. For hemp producers that are seeking to shorten drying times, using multiple smaller stationary or batch IR-drying systems appear manageable from an investment cost perspective but are more expensive in terms of cost per pound of fresh flower to dry. The large-scale IR-drying option using one larger continuous IR-drying oven entails more costs, but cuts drying times significantly. Thus, deciding on which drying method to use remains a consideration to meet producer's and consumer's needs and wants as different drying methods, as well as hemp varieties, impact the characteristics of the final product. Total average amounts of cannabinoids are generally higher when air-drying is used compared to IR-drying. CBD content, which is expected to allow producers to price CBD oil pending its content, was higher in the BK compared to the W variety when using IR-drying. At the same time, air-drying BK led to the highest CBD concentration. Total terpenes are generally higher when air-drying is used compared to IR-drying. Only IR-drying decreases bacterial count whereas it is increased when samples are air-dried.

Lastly, the CBD oil market is a difficult one as it is still emerging. Further research is needed to make this industry more efficient in terms of sales.

B. Study Limitations and Future Research

The study was limited by a lack of existing peer-reviewed research, a lack of market data, time, location, and financial means and access. Further research in the CBD market is necessary on different aspects. Pharmacological properties of CBD oil must be further researched to better inform potential CBD users about the potential effects of CBD on their health. Infrared radiation as well as freeze-drying must also be researched as the technology is promising in terms of processing costs (IR), time and energy use (IR), and industrial potentials (IR and Freeze). For the IR-drying method, the study's third trials may be used as a starting point as it showed the best results in terms of dried hemp flowers.

Also, this study assessed the hemp production in a specific location in the U.S. and it has shown that the location and environmental context matters in the decision making of a hemp producer, hence further research is necessary focusing on other parts of the U.S. with different environmental conditions. Furthermore, the study has shown that different hemp varieties behave in different ways for the same drying methods. The study could not conclude on specific reasons for this, thus, the effect of different drying methods on different hemp varieties and their hemp flower profiles must be further assessed. These differences that occur also need further research in terms of monetary valuation e.g., what could be the monetary value of a loss in CBD or CBG, among others.

In terms of markets for CBD products, these are not yet sufficiently developed to allow for a standardized and transparent market for consumers which may require further research. Also, additional research will be required to assess which parameters affect CBD consumers' WTP, although this study tested varying variables, very few were statistically significant which bears the question of what else might be important to customers when choosing CBD products. The lack of statistical significance may be explained by many factors. For example, the survey was lengthy, although accounting for duration did not statistically significantly impact WTP. Also, the surveyed sample of people contained few CBD oil consumers, which are representative of current consumer behavior in the U.S. Outliers, based on age and length of time to complete the survey were not removed from the surveyed sample as a threshold cutoff for these outliers seemed arbitrary. The interpretation of the survey results were also limited by the positive price coefficient on the baseline model. To address this, future surveys might consider designing a choice experiment with a smaller range of price levels which might lead to better results in terms of statistical significance and ease of interpretation. Additionally, future surveys could use a latent class analysis to determine whether respondents are part of certain groups that were not accounted for within the survey. The latter allows for further categorization of consumer's to assist with target marketing population segments with greater WTP for CBD oil. The survey has also not been analyzed to identify consumer segments that spend more on CBD and/or are more frequent users.

Appendices

A. Appendix A - English to Metric Unit Conversion Table as a Reader Reference

Unit Conversions Table

acre	/	2.4711	=	hectare
(°F – 32)	x	(5/9)	=	°C
lbs.	/	2.2046	=	kg
kg	/	1,000	=	g
g	/	1,000	=	mg
gallon	x	3.785	=	liter
liter	/	1,000	=	ml
Oz.	x	29.574	=	ml
ft.	/	3.281	=	m
ft.	x	30.48	=	cm
Sq. ft.	/	10.764	=	Sq. m.
in.	x	2.54	=	cm
in.	x	25.4	=	mm
hp	/	1.341	=	kW

B. Appendix B – Northwest Arkansas Climate Data

The following climate data has been retrieved for Fayetteville, Arkansas, in 2022 from the *usclimatedata* website (US Climate Data, 2022). The average annual high temperature is around 68°F, the annual low 48°F, and the average annual precipitation is around 46 in. Average monthly temperatures rarely go below 26°F, the coldest months being December, January, and February which are also the months with the least precipitation. Highest precipitation is commonly experienced from March to June and from September to November where average monthly temperatures steadily increase and decrease, respectively. Lowest rainfall and highest average monthly temperatures are mostly recorded during the months of July and August when temperatures average 89°F and rainfall is limited to approximately 3 in. per month.

C. Appendix C – On-Farm Specific Fertigation Technique

Fertilization is conducted once a week or about every 3rd irrigation. The irrigation system (for plants grown in bags) includes a 100-gallon black PVC tub which contains several lines of perforated tubes at its bottom to provide air. When fertigation is conducted, water is diverted into the tub where the producer mixes a fertilization concentrate that is agitated through the air provided by the bottom tubes which creates a bubble-bath type of environment. The concentrate's base ingredients are fish emulsion, seaweed, and microbials. The exact ingredients and compositions will not be detailed in this study as it is considered proprietary knowledge. The 100-gallon concentrate suffices to fertigate or fertilize all the plants. The dilution of the concentrate is done automatically through the Dosatron unit that is included in the irrigation system. The Dosatron generates a dilution of around 600 ppm of fertilizer at pH 7 and at around 74°F. The diluted fertilizer is then conducted through the irrigation system to the micro sprinklers and to the plants. If pH levels are higher than 7, sulfuric acid is added automatically by the Dosatron unit to bring it down.

The fertilizer concentrate mostly remains the same throughout the growing season, but there are two distinct Nitrogen-Phosphorous-Potassium (NPK) ratios that are provided during the growing season. An NPK ratio of 8-2-4 is provided during the plants' vegetative state which takes about 4-8 weeks or longer depending on hemp varieties and whether hemp is grown indoors or out. Once the plant starts producing flowers, 5-8 weeks before harvest, the NPK ratio in the fertilizer is changed to 4-2-4 as plants need less nitrogen during flowering. Harvest occurs mid-July to mid-August on the case farm.

D. Appendix D – Roguing Techniques

Roguing describes the removal technique of male plants, if necessary, from the production. This must be done before male plants emit pollen. Male flower detecting is not easy, some farmers may know by experience on the form of the axillary bud whether it is pointier or not as shown in *Figure A.1*. It is easier to observe this one month into production, this requires observation and time as this must be done manually and patiently every 4-5 days during the first growing month (Jelliffe, Lopez, and Ghimire, 2020). Other techniques exist such as lab testing which, however, destroys the plant, or the technique of forcing a flowering stage which is done by putting the seedlings into a 12-hour light and dark cycle which triggers flower production where one can eliminate male plants. The female ones are put back into a normal outdoor light cycle of around 14 hours depending on the location where they will instantaneously go back to a vegetative growth stage.

Some plants can also become true hermaphrodites where male and female flowers will grow on the same plant, however, this is often caused by human and/or environmental stress. Human or environmentally induced stress has many effects on the plant in general, one of these effects is that stress triggers flowering. When the stress ceases, although the plant recovers slowly, it recovers and may continue growing before going into its flowering stage later in the season.

Figure A.1. Female young flowers to the left and male flowers to the right. (Grace Genetics, 2021).

On the farm investigated in this study roguing or the elimination of male plants is non-existent as the producer buys and grows feminized seeds. If the producer doubts certain seeds or plants, the technique of using 12-hour light cycles to trigger flowering is used.

E. Appendix E – On-Farm Pruning Methods

Different pruning methods can be applied to hemp plants, but most rely on techniques used in the marijuana industry. On the studied farm, three different times of pruning are conducted. The first pruning happens when the plant reached a height of about 8-inch at which point the central branch is cut at its apex at the 8-inch mark (*Figure A.2*). This triggers the subsequent axillary branches into growth. Once these branches reach a height of about 20 inch (main stem included) their apex is cut again and triggers the growth of subsequent axillary branches. The third pruning is conducted in the same way at a height of about 40 inches.

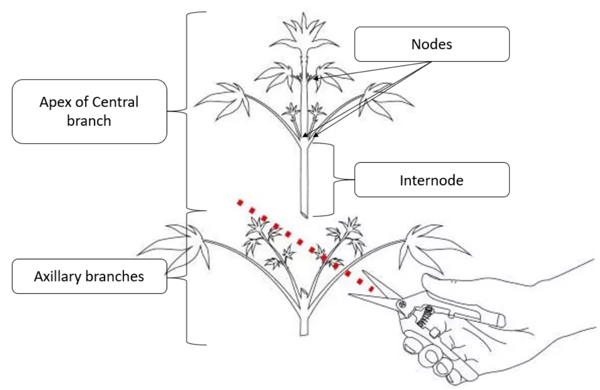


Figure A.2. Apical cut hemp pruning at 8, 20, and 40 inches. (Yerbasi, 2016).

Using this pruning method, it is important for a producer to keep an eye on the internodal lengths (*Figure A.2*). While the plant is in its vegetative state, internodal lengths remain almost identical. As soon as these internodal distances start to shorten it is a sign that the vegetative growth is slowing down and that the plant will soon start its flowering stage, which is the last moment a producer may, if needed, do an additional pruning. This pruning method induces about 64 tops or apical points where flowers are produced.

This is mainly the pruning method used on the case farm. This type of pruning also allows to keep plants at a maximum height of around 60 inches which facilitates manual harvest, and instead of triggering vertical growth of the central branch, the pruning method allows for a more horizontal plant development. The latter is why using plant support cages is important as the plants' stems need support to facilitate light exposure on flowers, to protect from vertebrates, and as plants are more subject to winds, although the producer states that by having more branches, the plant builds up in strength and resistance.

F. Appendix F – On-Farm Pest Management

i. Weeds

As hemp is a very good weed suppressor due to its fast growth, weed suppression is not considered a big issue in hemp production (Crini and Lichtfouse, 2020). However, a producer must continuously maintain (mow or weed) the areas between planting rows (Jelliffe, Lopez, and Ghimire, 2020), if no plastic mulch is used, to suppress weeds, to facilitate air flow, and to combat disease habitats. Weeds are manually eliminated from bags or growing holes before, during, and after the growing season. The farm does not have any consistent timing or period of doing this. Weeding is mostly done every other day, by the producer himself when walking through the production. Most weeds are encountered during the month of June.

On the case farm, continuous monitoring is done, manually, by the farmer, to ensure that no weeds are developing and negatively impacting the hemp production. The time to monitor is minimal and more important in early growing stages. Bags, and grow holes delimited by their circular plastic barrier, create an additional hurdle for weeds to develop which makes weeding easier. These barriers at the case farms were placed specifically to combat rhizomes from Bermuda grass (*Cynodon dactylon*) and are problematic for any plant production. No herbicide nor any weed suppressing substance is used, and weeds, if necessary, are eliminated manually every other day. Duration and labor costs for weeding will be accounted for in the results. As the farm grows the producer may start using mulch.

ii. Vertebrates

Most effective against vertebrates are electrical fences costing up to $2,500 per acre, signs, and video monitoring (Jelliffe, Lopez, and Ghimire, 2020; Crini and Lichtfouse, 2020). The Arkansan farm uses simple 2-line string fences, cages to protect plants, as well as camera surveillance overlooking the entire farm and signs that state that it is a hemp facility and not one where marijuana is grown to keep out potential burglars. The entire surveillance system is internal; hence, surveillance is done by the producer and came at a one-time lump-sum cost $800, whereas fences were already present before the hemp production to delimit the 1-acre farm, and cages cost about $8 per cage.

iii. Insects

There are many insects that can cause issues for hemp plants. They are also very dependent on the environmental context of the farm. Plants in early stages of growth are especially sensitive to insect pressure. Also, when flowers are produced caterpillars and mold can be important issues as they negatively affect yields. As hemp is mainly produced without insecticide, fungicide or other preventive and curative chemical methods, it makes it very difficult to manage pest under outdoor conditions. Indoor production, involving closed environments are easier to manage. However, monitoring is very important as pest may enter a closed environment and infest all plants very quickly as their natural predators are mostly absent. Although insects vary, common ones in hemp are: *"[…] aphids, corn ear worm, European corn borer, Japanese beetle, spotted cucumber beetle (aka Southern corn root worm), tarnished plant bugs, and Western black flea beetle*." (Jelliffe, Lopez, and Ghimire, 2020, p.6) as well as the hemp flea beetle (*Psylliodes attenuate*) (Crini and Lichtfouse, 2020). Insects and mites are best combatted through prevention, and if needed, action towards their eradication. The best common methods of prevention are to be taken from Integrated Pest Management (IPM) which are thoroughly described by Rosenthal et al. (2021).

For the case farm, insects are the main hurdle to maximum yield. As the farm minimizes its chemical applications, it mainly uses IPM methods to combat pests. The main problematic insects on the farm are various caterpillars, ants (Genus *Formica*), whiteflies (Genus *Aleyrodidae*), and spider mites (Genus *Tetranychidae*). Sticky traps and pheromone traps are used to attract and trap certain other insects. Caterpillars on the other hand must be removed manually which is labor intensive as it can be difficult to see them. Caterpillars are problematic as they often feed off botrytis, a fungus, found on leaves and other plant material. Subsequently, they nest in the hemp flowers where they eject the botrytis and become a vector for botrytis infestations in flowers causing mold and thereby yield losses.

Diatomaceous soil is used to cover the circular soil surface around the plants' stems to fight off ants which are believed to chew into the stems at the level of the nodes to obtain plant fluid which causes branches to break. By doing so, ants also become a vector for potential diseases that they carry and provide entry points to a plant's internal system for various diseases. Additionally, ants tend to grow aphids (Genus *Aphidoidea*) as ants feed off aphids' ejections. As aphids are a pest to hemp plants, and as ants favor the colonization of aphids on plants, it is important to combat them.

Indoors, IPM is even more important as there are no natural predators occurring in the sealed high tunnel. Thus, the farm does its best to keep all possible entries into the high tunnel sealed, but also works with natural predators such as ladybugs if the need occurs. While caterpillars occur less indoors, other insect can be problematic, and diseases must be monitored as they can thrive very rapidly in closed environments. It also appears that certain insects are more drawn to certain hemp varieties. There is no explanation for this yet, but it is being observed as certain plants are much more impacted than plants of different varieties in the same row.

White flies and spider mites are not subject to any IPM method on the farm. The producer states to have issues with these pests, which could be managed through different IPM methods such as soaps, alcohol, or plant covers, but also that losses due to these insects are minimal, part of the producing process, and not worth spending money on eliminating them. If mites get too problematic the producer uses an organic citric and lime mixture to repel and/or eliminate mites.

iv. Diseases

As with insects, diseases depend on where the farm is situated. Disease can, however, be prevented to a large extend through preventive measures such as climate control. Air flow between and within the plants is important, humidity and temperature must be monitored, and tools must be sanitized after each use. Jelliffe, Lopez, and Ghimire (2020) and Crini and Lichtfouse (2020) mention the following diseases as common and negative to hemp: seed rot and wilting, *Fusarium*, white mold also known as hemp canker, powdery mildew, Botrytis, stem cankers, downy mildew, root rot, charcoal rot, and a variety of different leaf spots which complicate photosynthesis. Botrytis (grey and brown mold) is described by Rosenthal et al. (2021) as the most common disease in *Cannabis* which appears to be the case for hemp as well. Botrytis issues are particularly problematic as they affect flowers specifically, hence they lead to important yield losses. Botrytis is best combated through IPM measures while competitive microorganisms and fungicides can help eradicate the fungus (Rosenthal et al., 2021). However, as the fungus often appears right before harvesting it is not recommended to use fungicides.

Observed and investigated on the case farm, diseases may appear on outdoor plants which may impact or lead to no yield from an affected plant. Specifically fungal diseases are common as temperatures and humidity are often optimal for fungal development and as air flow might not be as efficient for every plant outdoors compared to fan-controlled conditions in the high tunnel. Nevertheless, high tunnels may also become thriving environments for fungus as humidity and temperatures can increase rapidly. Thus, careful monitoring of these factors is non-negligible to keep plants healthy. IPM methods are very important such as cleaning every tool and equipment after each use with hydrogen peroxide to avoid introducing potential vectors. Further, minimizing animal traffic on the farm should reduce the potential for introducing diseases.

Diseases throughout the farm are the same and differ by intensity. The main pathogens on the farm are various *Pythium* and *Phytophthora* species in the soil, and *Botrytis* species above soil. The best results to combat in soil pathogens on farm (based on the producer's statements) were achieved by adding *Trichoderma* species fungal colonies to the soil which seem to effectively suppress the growth of certain plant pathogenic microorganisms. Nevertheless, the colonies are not introduced into soil before flowering and are only introduced if the situation with the pathogens becomes critical to yields. This decision is taken as *Trichoderma* species are dominant and suppress other beneficial microorganisms within the soil. Botrytis is problematic especially during and after harvest and is mainly infecting plants that carry caterpillars. During flowering and harvest, infested flowers are eliminated as well as caterpillars. Drying hemp flowers also dries out the Botrytis, however, the producer wants to avoid any hotspot on the harvested flowers and therefore, time is allocated to thoroughly inspect the flowers and eliminate any material showing accumulations of mold or caterpillars. The timing and labor cost needed for this activity is considered in the harvesting activities in the results of this study.

G. Appendix G – Hemp Flower Curing

Some producers might consider adding a curing step to their process. Curing hemp flowers is a technique derived from the marijuana and tobacco industry, where daily burping of sealed buckets, which consists of opening and closing the flower containing buckets regularly, is considered to mature the flowers. Oxygen and light deprivation at temperatures of 60 to 65°F and at humidity levels of 45 to 60% appear to be beneficial to the flowers and increase, alter, or mature their cannabinoids while inducing the breaking down of undesired compounds (Rosenthal et al., 2021; Lazarjani et al., 2021). In hemp, however, it is not yet clear if this step is worth the time as there is not enough research done yet to assess the legitimacy of this practice on CBD flowers specifically.

H. Appendix H – Specifics on the Case Farm's Hemp Oil Extraction Process

For the case farm, flowers are ground to 0.04 in. particle size. Grinding is performed immediately before extraction. Fifteen to thirty-five pounds of ground plant material is introduced in 25-micron mesh nylon bags. The weight of the material depends on many factors such as moisture of the plant material, cultivar density, how oily it is, and how it has been grown. The extractor used by the producer runs on full capacity when both extraction columns contain three 25-micron filled bags at a minimum and maximum total weight per column of 45 to 70 lbs., respectively. Each column has a capacity of 26.4 gallons and extraction is done one column at a time.

The hemp material produced on this farm is very rich in terpenes (based on the extractor's statements). Hence, the producer saves cost as terpenes must not be extracted first. Decarboxylation is performed for 105 to 120 minutes at 240°F depending on how dry the material is. After the decarboxylation stage, CO_2 extraction lasts approximately 90 minutes under pressures of 800 to 3,300 psi (5.5 to 22.8 MPa) and temperatures of 64 to 150°F. Pressures and temperatures vary based on the hemp cultivar and desired extract. For example, if a cultivar is high in CBG, extraction pressures will be less than for a cultivar high in CBD. As each cultivar reacts in a different way, extractors learn from trial and error to develop yield-maximizing pressure and temperature settings. Plant material from the case farm had most of its oil extracted at 1,700 psi and 107.6°F and thereby classifies as supercritical CO_2 extraction (*Figure 2.4*). Roggen (2019) reports 1,100 psi and 93.2°F for 5 hours for terpenes, and 1,900 psi and 140°F for 12 hours for cannabinoids.

In its supercritical state, CO_2 acts as a solvent, and the bags get compressed like bricks. Bags are needed for separation of the oil from the plant material particles. As the oil, terpenes remaining after decarboxylation, and cannabinoids are compressed from the plant material, the oil is infused with CO_2 resulting in the extraction. The extracted liquid flows into expansion chambers where pressures drop, and temperatures increase rapidly from 64.4 to 113°F which forces the CO_2 out of its supercritical stage into its gaseous form and is mostly recycled for extractions over the course of 24 hours. Minimal traces of CO_2 remain in the oil (Ramirez, Fanovich, and Churio, 2019) which is considered an advantage as CO_2 displaces oxygen which makes it act as a preservative for the oil.

I. Appendix I – Laboratory Methodology for Analyses on Fresh and Dried Hemp Flowers

Cannabinoid Mixture - Acids (C-218-1ML), *Cannabis* Terpene Mix A (CRM40755) and Cannabinoid Mixture -Neutrals (C-219-1ML) were obtained from Sigma-Aldrich, St. Louis, MO. Ethanol (Koptec, 190 proof, V1101), acetonitrile (Supelco, HPLC grade, AX0145-1) and formic acid (Millipore-Sigma, 98%, FX0440-6) were obtained from VWR, Radnor, PA.

i. Cannabinoid Extraction

Prior to extraction, dried hemp was ground into a powder using a coffee grinder from a local supermarket. Two hundred and fifty milligrams of the ground hemp flour were weighed in a 50ml centrifuge tube, and 10ml of ethanol was added. The slurry was stirred on a magnetic stir plate for 30 minutes, followed by sonication (VWR B2500A-MT sonicator) for 15 minutes. The slurry was then centrifuged at 10,000rcf for 5 minutes and the supernatant was decanted through Miracloth (Millipore-Sigma, St. Louis, MO) into a 25ml volumetric flask. To the remaining pellet, 10ml of ethanol was added and the stirring, sonicating, centrifuging, and filtering steps were repeated. The process was repeated a third time using 5ml ethanol for the final extraction. All the supernatants were pulled and assured of a final volume of 25ml. For the frozen hemp sample, 1g of hemp was homogenized (Ultra Turrax, T18 IKA Works Wilmington, NC) with 20ml ethanol, centrifuged at 10,000rcf, and filtered through Miracloth into a 100 ml volumetric flask. The remaining pellet was extracted 2 more times using this method and the supernatant was pooled and brought to a final volume of 100ml with ethanol.

ii. HPLC Analysis for the Cannabinoids

Samples (5 µL) were analyzed using a Waters UPLC Acuity H-Calss system equipped with a Quaternary Solvent Manager pump system, a Sample Manager FTN autosampler and PDA eλ photodiode array detector. Separation was carried out using a 4.6mm×100mm Kinetex® C18 column (Phenomenex, Torrance, CA, USA). The mobile phase began with a ratio of 50% using mobile phases of 0.1% formic acid (A) and 50% acetonitrile (B). A linear gradient followed from 50% B to 75% B for 10 min at 1.5 ml min−1. The system was equilibrated for 3 min at the initial gradient prior to each injection. Detection wavelengths was 215nm. Peaks were identified comparing retention times and UV spectra to that of the authentic standard. Calibration curves were performed for each cannabinoid standard 10-200 µg/g, and compounds concentrations were calculated from the linear regression lines.

iii. Terpene Extraction

Terpene extraction was performed using solid phase microextraction (SPME). The fiber used in this analysis was the 85µm, CAR/PDMS, Stableflex, 24 Ga, Manual Supelco (Bellefonte, PA). A 20ml headspace vial containing 5mg ground hemp was placed in a heat block on a stir plate with heating capability at 65°C and equilibrated at this temperature for 30min. The SPME fiber was inserted into the headspace above the sample and adsorbed for 20 min. For the fresh hemp sample 1 gram of frozen hemp was homogenized with 20 ml water, then 0.5ml was placed into a 20ml headspace vial and allowed to equilibrate at 65°C for 30 minutes and adsorbed for 20 minutes in the same matter as ground hemp. Samples were desorbed into the injection at 250°C for 3 minutes.

iv. GC-MS-FID Analysis of Aromatic Compounds

Gas chromatography analysis was performed using a Shimadzu GC-2010 Plus Gas Chromatograph equipped with a Flame Ionization Detector (GC-FID) and a GCMS-QP2010 SE Mass Spectrometer (GC-MS). Samples were analyzed by both GC-FID and GC-MS and separation was performed on each using a HP-5 (30 m × 0.25 mm inner diameter, 5% phenyl-methylpolysiloxane, 1.0 µm film thickness) capillary column (Agilent, Santa Clara, CA). For both GC-MS and GC-FID analysis, the injector temperature was 250°C. Helium was used as the carrier gas and column flow rate was 1.0mL/min. The oven temperature was programmed for a 45°C to 100°C at 2 °C/min, then from 100°C to 250°C at 5°C/min, and with a 5 min hold at 280°C. The GC-FID detector temperature was 300°C and the interface temperature for the GC-MS had an ion source temperature of 230°C and an interface temperature of 250°C. GC-MS was performed in full scan mode, with a scan range of 20-300 m/z. The volatiles were identified by comparison of their mass spectra with the National Institute of Standards and Technology NIST17 spectral library, literature data, and retention indices. The retention indices were performed after running alkane standards of 5 to 20 carbons and online searches of similar work with HP5 or comparable columns. Calibration curves were performed for several standards, and compounds concentrations were calculated from the linear regression lines from authentic standards or quantified as equivalents of related compounds where standard was not available.

J. Appendix J – General and Specific Assumptions for Differences in Cost by Drying Method.

General assumptions			
Fresh hemp flower weight (lbs.)	Assumed on a 1-acre basis based on previous results.		
# of drying units	The number of drying units was assessed so that the total drying time would not exceed 1488 hours.		
Equipment	Equipment costs were assessed for each drying method.		
Buildings	Building costs were assessed based on the square footage needed for each drying-method and equipment, for building costs \$8.70 per square foot of industrial building in Fayetteville Arkansas was assumed.		
Depreciation	Yearly on buildings were assessed on an assumed \$20,000 salvage value and a 15-year useful life.		
Insurance	The insurance expenses were assumed to be 1% of the equipment and building book values (per year).		
Maintenance	Maintenance costs were assumed at a 20% (0.2) repair factor based on values and useful life of equipment and building. Thus, maintenance costs were calculated by multiplying the repair factor by the equipment and building cost and dividing the output by the useful life of the equipment.		
Energy & Utilities	The electricity cost was assumed at \$0.098 per kWh for commercial usage. The price is based on the commercial use electricity price in Fayetteville, Arkansas provided by the Ozark electric cooperative in 2022. The energy consumption was based on the consumption of the equipment needed for drying. The consumption is specific to each method. Kilowatt consumption was based on specific example equipment used to assess the cost of drying which will be described in the results. When the kilowatt consumption as not available it was calculated using the multiplication of equipment amperes by their voltage. For the total energy consumption for drying the harvest the kW was multiplied by the hours of drying needed.		
Specific assumptions			
	Air-drying	Infrared Radiation drying	Freeze-drying
Drying Method	Assessment of drying all at once in one building or drying at two distinct periods using one smaller building.	Comparing IR—drying in a smaller stationary or batch system, and in a larger continuous system.	Comparing medium-slow, medium-fast, and large freeze-drying units from the manufacturer *Cannafreeze*.
Total Drying time	Based on study results.	Based on study results.	Based on manufacturer's indications.
Equipment	Specific prices and amount will be shown in the results as these depend on the scenario.		
	Equipment includes wires to hang the flowers, screws, poles, hangers, AC unit(s), and dehumidifier(s) (depending on the size of the building).	Equipment includes Infrared Radiation drying systems.	Equipment includes Freeze-drying systems.
Buildings		In addition to the floor area needed for the equipment 100 square feet are added to account for working area.	
	Depending on scenario: 4,875 square feet when drying all at once and 2,437.5 square feet when drying at two distinct moments.	Depending on scenario: 190.07 square feet for the stationary IR system and 466.67 square feet for the continuous IR system.	Depending on scenario: 121.45 square feet for the medium-slow freeze-drying unit, 164.13 for the medium-fast, and 244.33 for the large unit.
Yearly Depreciation	Equipment salvage value assumed at USD zero with 5 years useful life.		Equipment salvage value assumed at 50% of the book value with 15 years useful life.

Variable Labor	Based on study results. Labor cost assumed at $15 per hour.	Assumed at one or two persons for the stationary- and continuous-IR-drying system, respectively, and for the entire duration of drying at labor cost of $15 per hour.	Loading and unloading drying trays assumed at 6 minutes per tray. Cleaning trays and other activities after drying assumed at 15 minutes per tray. The number of trays depends on the scenario and will be detailed in the results. Labor cost assumed at $15 per hour.

K. Appendix K – Detailed Laboratory Results on Cannabinoids and Terpenes

Average and Standard Deviation of Cannabinoid Concentrations by Variety and Drying Method in Comparison to Fresh Flowers on a Dry Matter Basis.

	Hemp varieties, Drying Method, and number of Cannabinoids (mg/g)					
Cannabinoids	**BK Fresh[1]**	**BK IR**	**BK Air**	**W Fresh**	**W IR**	**W Air**
CBDVA	n.a.[2]	0.44 ± 0.12	n.a.	3.43 ± 0.14	n.a.	0.61 ± 0.19
CBDA	13.73 ± 2.68	6.51 ± 0.96	12.11 ± 0.83	6.95 ± 0.97	2.47 ± 0.63	1.51 ± 0.46
CBG	n.a.	5.96 ± 0.46	0.03 ± 0.00	n.a.	n.a.	0.05 ± 0.02
THCV	1.53 ± 0.28	0.46 ± 0.12	0.38 ± 0.16	2.86 ± 1.00	6.64 ± 0.53	1.38 ± 0.22
CBGA	7.68 ± 0.28	1.61 ± 0.54	2.39 ± 0.54	22.18 ± 4.27	18.63 ± 1.07	31.13 ± 5.00
THCVA	n.a.	n.a.	n.a.	0.79 ± 0.19	n.a.	n.a.
CBN	0.56 ± 0.18	0.38 ± 0.05	0.41 ± 0.13	0.55 ± 0.09	0.71 ± 0.23	0.71 ± 0.52
DELTA 9	n.a.	2.09 ± 0.26	0.24 ± 0.05	0.30 ± 0.26	0.53 ± 0.09	0.40 ± 0.01
DELTA 8	n.a.	n.a.	n.a.	n.a.	0.12 ± 0.01	0.07 ± 0.01
CBC	2.50 ± 0.87	2.70 ± 0.21	0.28 ± 0.39	2.65 ± 0.40	3.39 ± 0.21	1.72 ± 0.26
THCA	7.72 ± 1.54	0.33 ± 0.06	1.48 ± 0.29	n.a.	n.a.	n.a.
CBCA	n.a.	0.36 ± 0.10	17.84 ± 1.54	8.6 ± 0.83	0.76 ± 0.00	0.8 ± 0.07
CBD	3.12 ± 0.45	2.51 ± 0.19	0.09 ± 0.02	n.a.	n.a.	0.21 ± 0.08
Tot. Avg. Cannabinoids[3]	**36.84 ± 4.92**	**23.37 ± 1.93**	**35.25 ± 3.15**	**48.32 ± 6.00**	**33.25 ± 2.12**	**38.61 ± 5.80**
Tot. THC (%)[4]	**0.77 ± 0.15**	**0.17 ± 0.02**	**0.16 ± 0.03**	**0.02 ± 0.02**	**0.04 ± 0.01**	**0.03 ± 0.00**
Tot. CBD (%)[5]	**1.52 ± 0.21**	**0.82 ± 0.09**	**1.07 ± 0.07**	**0.61 ± 0.09**	**0.22 ± 0.05**	**0.15 ± 0.05**

Cannabinoids are as follows: Cannabidivarinic acid (CBDVA), Cannabidiolic acid (CBDA), Cannabigerol (CBG), Δ9-Tetrahydrocannabivarin (THCV), Cannabigerolic acid (CBGA), Tetrahydrocannabivarin Acid (THCVA), Cannabinol (CBN), Δ9-Tetrahydrocannabinol (Delta-9), Δ8-Tetrahydrocannabinol (Delta-8), Cannabichromene (CBC), Δ9-Tetrahydrocannabinolic acid (THCA), Cannabichromenic acid (CBCA), and Cannabidiol (CBD).

[1] Varieties: Bubba Kush (BK) and White (W); Fresh flowers (Fresh), Infrared Radiated dried (IR), and Air-dried (Air).

[2] n.a. stands for non-measurable amounts, hence zero value is assumed in further calculations.

[3] Total average cannabinoids given by the laboratory results, hence including cannabinoids not shown in this table.

[4] As, mg/g is parts per thousand, divided by ten calculates parts per hundred (also known as percent).

[5] Total THC percentage is calculated based on Eq. (1). For BK IR, for example, [(0.75 · 0.88 · (1.88/10)) + (0.29/10)]

[6] Total CBD percentage is calculate based on Eq. (2). For BK IR, for example, [(2.26/10) + (5.86/10) · 0.877]

Average and Standard Deviation of Volatile and Terpene Concentrations by Variety and Drying Method in Comparison to Fresh Flowers on a Dry Matter Basis.

Volatile Group	Hemp varieties, Drying Method, and number of volatiles & Terpenes (µg/g)					
	BK Fresh[1]	**BK IR**	**BK Air**	**W Fresh**	**W IR**	**W Air**
1-Hexanol	5.71 ± 2.26	10.12 ± 1.53	5.78 ± 1.47	1.29 ± 0.26	4.17 ± 0.91	20.61 ± 4.75
Hexanoic acid	n.a.[2]	n.a.	1.13 ± 1.50	n.a.	n.a.	1.83 ± 0.13
Hexanal	2.20 ± 0.79	0.54 ± 0.22	2.05 ± 0.39	1.62 ± 0.48	0.59 ± 0.02	0.70 ± 0.13
Heptanal	21.49 ± 8.23	2.80 ± 0.58	3.06 ± 1.30	20.81 ± 7.57	5.94 ± 1.10	7.99 ± 2.22
Ethyl hexanoate	4.81 ± 0.75	2.86 ± 0.71	0.42 ± 0.21	0.37 ± 0.04	0.14 ± 0.02	0.75 ± 0.43
2-Hexenal	12.03 ± 5.91	n.a.	3.16 ± 0.58	10.42 ± 0.88	n.a.	0.96 ± 0.26
.alpha.-Pinene	102.93 ± 63.97	n.a.	30.55 ± 8.93	52.30 ± 11.07	n.a.	16.61 ± 4.54
Camphene	n.a.	n.a.	5.21 ± 1.09	13.06 ± 2.16	n.a.	5.42 ± 1.37
Benzaldehyde	19.7 ± 16.02	0.58 ± 0.05	0.58 ± 0.22	24.66 ± 12.26	0.33 ± 0.03	0.47 ± 0.02
5-Hepten-2-one, 6-methyl	0.86 ± 0.32	0.98 ± 0.85	0.85 ± 0.26	n.a.	1.44 ± 0.08	1.16 ± 0.30
.beta.-Myrcene	12.15 ± 4.83	0.93 ± 0.13	11.63 ± 1.63	49.11 ± 4.87	1.02 ± 0.26	17.43 ± 4.89
3-Carene	4.37 ± 0.58	n.a.	2.16 ± 0.74	3.71 ± 1.23	n.a.	2.63 ± 0.99
Eucalyptol	2.89 ± 1.35	1.15 ± 0.33	3.75 ± 0.71	2.27 ± 0.29	1.11 ± 0.14	1.46 ± 0.12
.alpha.-Terpinene	0.72 ± 0.24	n.a.	0.83 ± 0.12	n.a.	0.27 ± 0.05	0.32 ± 0.10
p-Cymene	0.70 ± 0.13	0.38 ± 0.05	0.30 ± 0.05	n.a.	n.a.	n.a.
D-Limonene	183.96 ± 82.24	9.68 ± 2.03	158.57 ± 32.95	255.00 ± 35.92	10.74 ± 3.96	115.94 ± 41.79
beta.-Ocimene	1.57 ± 0.97	n.a.	1.89 ± 0.37	27.78 ± 0.68	1.23 ± 0.42	0.41 ± 0.03
gamma.-Terpinene	2.30 ± 0.27	n.a.	1.90 ± 0.20	n.a.	n.a.	n.a.
2-Heptanone	n.a.	1.03 ± 0.13	0.54 ± 0.09	n.a.	0.28 ± 0.25	n.a.
Terpinolene	1.57 ± 0.43	n.a.	n.a.	2.82 ± 0.24	n.a.	n.a.
Linalool	12.87 ± 3.52	6.35 ± 0.94	18.17 ± 5.04	3.50 ± 0.44	3.27 ± 1.21	19.83 ± 5.96
Phenylethyl Alcohol	0.71 ± 0.16	n.a.	0.47 ± 0.07	1.64 ± 0.33	n.a.	0.38 ± 0.13
Fenchol	27.95 ± 6.31	16.23 ± 2.42	40.75 ± 9.99	74.49 ± 9.88	14.5 ± 1.51	54.87 ± 16.18
Carvone	1.80 ± 0.22	1.23 ± 0.15	0.58 ± 0.10	3.12 ± 0.83	0.83 ± 0.06	0.68 ± 0.29
Borneol	5.04 ± 1.03	1.80 ± 0.26	3.93 ± 1.11	8.46 ± 1.80	1.01 ± 0.09	8.49 ± 2.12
Hexyl butanoate	n.a.	n.a.	0.39 ± 0.08	0.50 ± 0.15	0.27 ± 0.01	4.41 ± 2.08
Terpinen-4-ol	1.08 ± 0.06	0.42 ± 0.01	0.51 ± 0.08	0.38 ± 0.05	0.27 ± 0.09	0.16 ± 0.28
L-.alpha.-Terpineol	4.70 ± 0.78	3.91 ± 0.38	4.09 ± 0.85	7.54 ± 1.15	5.96 ± 0.46	8.61 ± 1.64
Citronellol	n.a.	1.43 ± 0.11	0.24 ± 0.21	5.22 ± 1.46	n.a.	n.a.
Carveol	1.63 ± 0.25	0.30 ± 0.03	n.a.	n.a.	0.21 ± 0.01	0.23 ± 0.03
Nerolidol	n.a.	n.a.	1.81 ± 0.27	n.a.	n.a.	1.50 ± 0.16
Perilla alcohol	n.a.	n.a.	0.24 ± 0.06	0.76 ± 0.13	0.22 ± 0.03	0.26 ± 0.09
.alpha.-Cedrene	3.97 ± 0.50	2.8 ± 0.37	2.28 ± 0.54	1.30 ± 0.28	0.21 ± 0.01	1.17 ± 0.18
Hexyl hexoate	0.70 ± 0.43	3.69 ± 0.28	5.00 ± 0.87	n.a.	1.92 ± 0.35	3.25 ± 1.29
Caryophyllene	2,629.01 ± 371.30	1,587.51 ± 146.77	2,641.73 ± 526.21	3,209.63 ± 240.08	447.64 ± 62.73	950.26 ± 150.56
(E)-.beta.-Famesene	371.83 ± 59.99	207.71 ± 3.41	451.14 ± 72.37	189.09 ± 11.63	35.66 ± 6.29	309.51 ± 52.32
Humulene	335.45 ± 17.95	169.85 ± 17.66	300.13 ± 64.97	671.15 ± 26.46	85.10 ± 9.82	196.82 ± 32.96
alpha.-Farnesene	63.45 ± 15.45	41.41 ± 2.15	83.09 ± 13.17	n.a.	n.a.	
alpha-Bisabolol	1,303.85 ± 356.02	539.23 ± 130.70	369.06 ± 330.98	2,501.58 ± 556.34	526.41 ± 268.75	6,423.17 ± 931.95
Total Avg. Volatiles[3]	**5,144.00** ± 498.83	**2,614.90** ± 248.85	**4,157.98** ± 1,029.34	**7,143.59** ± 716.47	**1,150.73** ± 212.89	**8,178.31** ± 1,104.83

[1]Varieties: Bubba Kush (BK) and White (W); Fresh flowers (Fresh), Infrared Radiated dried (IR), and Air-dried (Air)
[2]n.a. stands for non-measurable amounts.
[3]Total average volatiles given by the laboratory results.

L. Appendix L – Survey Questions

The appendix shows the survey questions and shows how those were asked for questions that were used within this study.

i. Introduction and Basic Demographics

1. Introduction and Confidentiality disclosures
2. Do you commit to providing your thoughtful and honest answers to the questions in this survey?
3. What is your age?

   What is your age?

   - <18 years of age
   - 18-24 years of age
   - 25-54 years of age
   - 55 years or older
4. What is your gender?

   What is your gender?

   - Male
   - Female
   - Non-binary / third gender / other
5. What is your annual household income?

1	Less than $10,000	14	$130,000 - $139,999
2	$10,000 - $19,999	15	$140,000 - $149,999
3	$20,000 - $29,999	16	$150,000 - $159,999
4	$30,000 - $39,999	17	$160,000 - $169,999
5	$40,000 - $49,999	18	$170,000 - $179,999
6	$50,000 - $59,999	19	$180,000 - $189,999
7	$60,000 - $69,999	20	$190,000 - $199,999
8	$70,000 - $79,999	21	$200,000 - $209,999
9	$80,000 - $89,999	22	$210,000 - $219,999
10	$90,000 - $99,999	23	$220,000 - $229,999
11	$100,000 - $109,999	24	$230,000 - $239,999
12	$110,000 - $119,999	25	$240,000 - $249,999
13	$120,000 - $129,999	26	$250,000 or more

6. What is the highest level of education you have completed?

What is the highest level of education you have completed?

- ○ Less than High School
- ○ High School/GED
- ○ Some College
- ○ 2-Year College Degree (Associates)
- ○ 4-Year College Degree (BA, BS)
- ○ Master's Degree
- ○ Professional Degree (Ph.D., J.D., M.D., etc.)

ii. Knowledge

7. Are you the primary purchaser of the following in your household?
8. Have you heard about the following items?
9. How often do you read or search for information about hemp?
10. Have you had conversations about CBD with others?
11. How would you describe your conversations about CBD?
12. How would you describe your feelings about CBD?
13. Please look at the following items below. How knowledgeable are you with the following items?
14. What percentage of people about your age in the United States know more than you about CBD products?

What percentage of people about your age in the United States know more than you about CBD products?

- ○ 100% (Everyone my age knows more about CBD products)
- ○ about 90%
- ○ about 80%
- ○ about 70%
- ○ about 60%
- ○ about 50%
- ○ about 40%
- ○ about 30%
- ○ about 20%
- ○ about 10%
- ○ 0% (No one my age knows more about CBD products than I do)

15. Do you associate CBD more with hemp or marijuana?
16. Does using CBD cause a user to feel high?
17. What is the current legal amount of THC in hemp?
18. To your knowledge, what and where are the following legal to grow? Please choose all that apply.

iii. Tried CBD: Introduction

19. To your knowledge, what and where are the following legal to purchase? Please choose all that apply.
20. Do you have a friend or family member who uses CBD?

21. What is your level of concern with the following aspects when thinking about using CBD?

What is your level of concern with the following aspects when thinking about using CBD?

	Not concerned	Somewhat concerned	Very concerned
	0	50	100
Legal status:	○		☐
Quality:	○		☐
Taste:	○		☐
Contaminants:	○		☐
Accuracy of dosing:	○		☐
Presence of THC:	○		☐

22. Has someone recommended CBD to you?
23. Have you recommended CBD to someone else?
24. Even if you have not tried CBD, would you feel comfortable purchasing CBD for yourself or a loved one?

iv. Tried CBD in one or another form

25. In the last year, have you tried CBD?
26. The CBD you tried, was it derived from hemp or marijuana?
27. When did you first use CBD?
28. How frequently do you use CBD?

How frequently do you use CBD?

- ○ At least once a day
- ○ Once to a few times per week
- ○ Once to a couple times per month
- ○ A few times per year or less
- ○ Only tried CBD once or twice

29. When you do use CBD, how much CBD do you use per day?

When you do use CBD, how much CBD do you use per day?

- ○ Less than 10mg
- ○ 10-29 mg
- ○ 30-49 mg
- ○ 50-99 mg
- ○ 100 mg +
- ○ Not sure

30. What form of CBD have you used? Check all that apply.

31. Below are questions about the CBD concentration of the oil you have purchased. Please check your label, if possible.

Q31 Below are questions about the CBD concentration of the oil you have purchased. Please check your label, if possible.

	mg per 1 oz bottle of CBD oil	Not sure
	500 1000 1500 2000 2500 3000 3500	
CBD concentration of typically purchased oil ()		
The highest CBD concentration you have purchased ()		
The lowest CBD concentration you have purchased ()		

32. Why do you use CBD? (Check all that apply)

Q32 Why do you use CBD? (Check all that apply)

- ☐ Medical (1)
- ☐ Pain (2)
- ☐ Unwinding (3)
- ☐ General Wellness (4)
- ☐ Other (please specify): (5)

33. Have you purchased CBD in the last year?

Q33 Have you purchased CBD in the last year?

- ○ Yes (1)
- ○ No (0)

34. Have you purchased CBD for a friend or family member in the last year?

35. When selecting CBD oil to purchase, what are the most important factors and the least important factors influencing your decision?

Q34 When selecting CBD oil to purchase, what are the most important factors and the least important factors influencing your decision?

Please drag up to 3 factors to the 'Most Important' box, and up to 3 factors to the 'Least important' box.

Most Important	Least Important
Price per bottle (1)	Price per bottle (1)
______ Amount of CBD per serving (2)	______ Amount of CBD per serving (2)
______ Total amount of CBD in product (3)	______ Total amount of CBD in product (3)
Whether the product is local (4)	Whether the product is local (4)
______ Brand (5)	______ Brand (5)
______ Design of label (6)	______ Design of label (6)
Lab testing results (7)	Lab testing results (7)
______ Whether the product is organic (8)	______ Whether the product is organic (8)
______ Reviews from other purchasers (9)	______ Reviews from other purchasers (9)
Mix of other cannabinoids (10)	Mix of other cannabinoids (10)
______ Presence of THC (11)	______ Presence of THC (11)
______ Hemp drying method (12)	______ Hemp drying method (12)
No mold guarantee (13)	No mold guarantee (13)
______ Price per unit of ingredient (14)	______ Price per unit of ingredient (14)

36. How likely are you to purchase CBD in the next month?
37. In a typical month, how many times do you purchase CBD?
38. In a typical month, what quantity of CBD (in milligrams) do you purchase?
39. In a typical month, how much do you spend on CBD?

Q38 In a typical month, how much do you spend on CBD?

- ○ $0 (1)
- ○ $1-$19 (2)
- ○ $20-$49 (3)
- ○ $50-$99 (4)
- ○ $100-$149 (5)
- ○ $150 or more (6)

v. Not tried CBD in any form

40. What are the reasons why you have not tried CBD? (Check all that apply)
41. What are the reasons why you would consider trying CBD? (Check all that apply)
42. What is your level of agreement with the following statement? "I am interested in learning more about CBD."
43. How would you describe your level of curiosity for trying CBD?
44. How likely are you to try CBD sometime in the next month?
45. Please imagine you had to purchase CBD, either for yourself or a loved one.

vi. Choice Experiment Partner University

46. → 53. Again, imagine you are at the store to purchase 1,000mg CBD oil for yourself or a loved one. The options you can select from in the store are presented below.

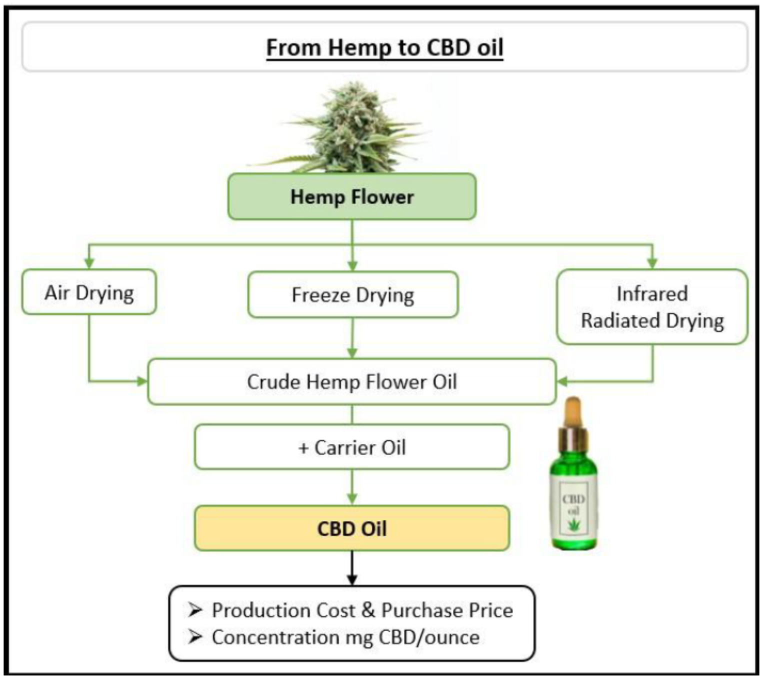
vii. Choice Experiment Willingness to Pay study

47. Information Treatment

The previous questions centered around labeling and content in CBD oil.

Now please consider that hemp produces flowers that need to be dried before processing into crude hemp oil which is mixed with a carrier oil to obtain the final product.

The steps shown below affect crude oil quality, production cost, and ultimately the price for the final product.



Q49

Fresh hemp contains about 80% water and thus drying is crucial before processing into CBD oil. Drying method affects the potential for mold but also impacts potency, taste, and medicinal properties. Literature on drying hemp flowers suggests the following.

1. Freeze drying involves first freezing the material and subsequently evaporating the water using heat under vacuum without thawing the flowers. The process preserves almost every biological component of the flowers (Cannabinoids, Terpenes, and Flavonoids) and hence, its quality. The cost is long drying time and high energy intensity.

2. Infrared radiation uses radiant heat that is considered efficient for dehydrating foods such as seaweed, vegetables, and bacon. Drying experiments on hemp flower show mixed results about improvement in cannabinoid concentration. Nonetheless, the equipment is not complex, simple to use, low in energy use and comparatively fast in relation to the other drying methods. More research is needed to avoid processing losses and to guarantee no mold contamination.

3. Air drying is the oldest hemp drying method and hence the conventional standard. The flowers are dried for about two weeks under controlled conditions (~68°F and humidity between 45 and 60%). Because of the long drying period, the potential for mold contamination is higher than with the other methods and thereby higher processing losses.

48. → 55. Again, you're at the store to purchase CBD oil for yourself or a loved one.

Again, you're at the store to purchase CBD oil for yourself or a loved one.

All one oz. bottles are exactly same except Drying method, mg of CBD per bottle, and price. "None" means, you would not buy any of the choices presented.

Which option you would purchase?

			None
Drying Method: **Freeze Dried**	Drying Method: **Air Dried**	Drying Method: **Infrared Radiated**	
CBD: **1000 mg**	CBD: **2500 mg**	CBD: **500 mg**	
Price: **$190**	Price: **$60**	Price: **$100**	
○	○	○	○

viii. Further Demographics

49. What year were you born?
50. What is your parental status?
51. How many children (younger than 18 yrs) live in your household?

Q68 How many children (younger than 18 yrs) live in your household?

▼ 0 (0) ... 10 or more (10)

52. How many adults (18 yrs or older) live in your household, including yourself?
53. Are you of Hispanic, Latino, or Spanish origin?
54. What is your race?
55. What is your five-digit postal (zip) code?
56. In what US state do you currently live?
57. Which best describes the area in which you live?

Q74 Which best describes the area in which you live?

○ Rural (1)

○ Suburban (2)

○ Urban (3)

○ Prefer not to answer (4)

58. What is your political party affiliation?
59. Please add other comments about CBD oil, if any, below.