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RESEARCH ARTICLE

CBD Oil Concentration and Hemp Flower Drying Preferences of U.S. Consumers

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Abstract: The method used to dry hemp flowers can impact the concentration of cannabidiol (CBD) and other quality characteristics like mold levels in CBD oil. Understanding consumer preferences is vital for hemp producers and processors because there is variation in drying time, energy use, and capital investment between potential drying methods. This research assesses willingness to pay (WTP) for CBD oil at varying CBD content (mg per 1-oz.(30 mL) bottle) and drying methods to better understand consumer preferences and how consumers make tradeoffs between CBD oil attributes. Specifically, the authors elicit preferences toward drying using: i) controlled ambient conditions (air-drying), ii) infrared radiation (IR), and iii) freeze-drying or lyophilization. Few statistically significant WTP differences between CBD oils, when marketed at average attribute levels, were found for higher or lower CBD concentration or drying method. An exception was respondents 55 years of age or older who had a higher WTP for CBD oil with greater CBD content (2,500 mg) and also preferred the freeze-dried product over the baseline of a conventionally air-dried product with 1,000 mg of CBD. The lack of distinct preferences among the majority of consumers suggests that producers and processors can choose alternative drying methods based on their cost, time, and energy constraints without risking a WTP penalty. The findings indicate that consumers do not have well-formed preferences for CBD oil as it is a relatively novel product. Yet, the results suggest that consumers may interpret higher prices to reflect higher quality/product safety, thereby offering perceived quality assurance.

Keywords: Cannabidiol (CBD); Hemp flower drying; CBD oil; CBD concentration; Choice experiment

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1. Introduction

The recent decriminalization of hemp (Cannabis sativa and indica) through the 2018 Farm Bill [1] has significantly increased the cultivation of hemp in the U.S. [2,3]. Hemp can be used for various purposes e.g., the production of seed, fiber, oil, and other value-added products [3,4]. Since, hemp varieties, targeting high concentrations of cannabinoid cannabidiol (CBD) in hemp flowers, can be processed into a host of CBD products (oil, salves, chews, etc.) and the potential for marketing products in the U.S. and Europe is promising [5–7], we focus on the market of hemp processed into CBD oil.

With this market in its infancy, pricing for CBD oil products is not standardized. Moreover, 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 the CBD market face difficulties with setting a price and identifying potential production practices to pursue in line with market preferences. Specifically, it is not clear to producers: i) what CBD concentration in CBD oil improves consumer satisfaction and profit margin; ii) whether price premiums for alternative drying methods of hemp flowers prior to oil extraction exist; iii) whether adding information about drying methods impacts consumer willingness to pay; and iv) what market segments to profitably target. Crude CBD oil, extracted from dried hemp flower, is blended with a carrier oil to make the consumer product more palatable while also altering cost and thereby breakeven retail price.

The costs associated with producing and processing hemp flower into CBD oil are discussed in detail by Jacobs [8], whereby a particular farm operation with indoor and outdoor production environments and two different varieties of hemp were analyzed. Results of that analysis revealed a breakeven price point at the farm gate for CBD oil with a concentration of 3,300 mg per 1-oz. (30mL) bottle to be near $15 leaving room for marketing margin to cover marketing expenses and producer compensation. Since that level of CBD concentration is a little more than twice the average CBD concentration in the market, the question of what CBD concentration to target for retail products is an important one.

Further, producers face a bottleneck with labor at harvest as they need to dry copious quantities of freshly harvested hemp flower from a moisture content of 60–70% (water as a percent of wet weight) to storage-safe levels (< 13%). With different drying methods affecting not only the cost of production but also CBD levels in dried hemp flower, the question of consumer acceptance toward different drying methods further compounds the complexity of making production and marketing decisions for hemp flower growers targeting the CBD oil market.

Therefore, this research began by analyzing online CBD oil offerings in the U.S. in the fall of 2021 to discern which product attributes influenced retail prices. Given that background, an online choice experiment was conducted in the spring of 2022 to estimate consumer willingness to pay (WTP) for CBD oil attributes. Results are expected to assist CBD oil producers and retailers make production and marketing decisions.

2. Background

Cannabinoids are believed to have various 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 individuals react differently, adding both opportunity and uncertainty to target marketing efforts [6].

Although legislation is steadily evolving, CBD oil currently stands out as the most attractive, compared to all other hemp-derived products, with farm-level hemp flower experiencing steadily increasing demand from processors, investors, and consumers [5,9]. As Mark et al. [5] state "*... information on economic returns remains difficult to ascertain ...*"; hence, the market needs evolving and continuous objective research. For example, research conducted at the University of Kentucky and the University of Tennessee showed that CBD oil had a high potential for profit on a per-acre basis compared to other hemp-derived products [5]. Nonetheless, expanding production usually leads to eventual price declines. Further, as the U.S. industry continues to grow, potential competition from imports may also be expected. At the same time, further legislation and market regulation may lead to foreign investment and compliance measures, that may result in greater standardization of product characteristics that could assist with marketing efforts [5,10,11].

Furthermore, Mark et al. [5] argued that: "*... in the longer term, competition for investment capital and acreage between hemp and marijuana may ultimately be more of an issue ...*" as both producers and consumers become more knowledgeable about cannabinoids,

terpenes, and flavonoids. Indeed, their interaction, commonly referred to as 'the Entourage Effect' [12,13], or 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 common ground in supplying products for the market that are not only high in concentration of one sole cannabinoid but also a combination of them. Therefore, the blending of cannabinoids is a significant marketing and production decision and the focus of the remainder of this analysis.

3. Materials and Methods

Because market-level data in the U.S. on CBD oil prices, consumers, and consumer's preferences are rare, if not non-existent, primary data collection on pricing and product attributes was necessary. Two data collection strategies were involved: a collection of current market prices of CBD oils marketed online and an online choice experiment to assess consumers' preferences and WTP for CBD oil.

3.1 Online Study

During the fall of 2021, U.S. market data were collected for the prices of 1-oz. (30 mL) CBD oils at varying concentrations, production methods, and country of origin to determine attribute levels of available retail products. Using the Google search engine and the Amazon retailer platform, information regarding pricing and CBD oil attributes are summarized in Table A1 to inform about the range of CBD concentrations in product offerings and associated pricing. Additional product attributes involved country of origin, labeled as naturally grown or certified organic, whether crude oil was extracted using CO_2 extraction, what health benefit was targeted (pain relief, anxiety management, sleep deprivation), how hemp flowers were dried, what the online consumer rating was as well as how many consumer ratings had been performed. The results of the online product information collection efforts were also helpful for picking price points for the online choice experiment described next.

Further, we regressed explanatory variables against the CBD price (*P*) per 1-oz. (30 mL) bottle to assess their quantitative or hedonic impact on CBD oil prices charged. To avoid misspecification bias, to correct for heteroskedasticity, and to remove outliers, observations with a CBD price below $0.016 per milligram of CBD were considered unreliable as were those without a consumer rating (initial sample size was 206 observations). A non-linear price response to CBD content (*CONT*) was expected and modeled using a choice of quadratic, logistic, and square root functional forms. Variables with coefficient estimates that had |t-stat| < 1 were excluded given their lack of explanatory power [14]. The goodness of model fit was judged by the sign and size of coefficient estimates, adj. R^2, and Akaike Information Criterion (AIC). Multicollinearity among explanatory variables was non-problematic (all bivariate Pearson correlation coefficients < 0.55). Huber-White standard error correction for robustness was performed based on the Breusch Pagan test ($p < 0.0001$). Results from these regression analyses were used to inform the inclusion of CBD concentration and drying method as variables in the online choice experiment discussed next.

3.2 Consumer Choice Experiment

A U.S. electronic survey assessing consumer knowledge of CBD, attitudes towards hemp and CBD oil, and their WTP for CBD oil bottles, was developed and targeted at hemp and CBD oil consumers with a broad range of demographics. The survey had a total of 73 questions as part of a USDA-sponsored project entitled "*Hemp Marketing: Measuring Stated Demand and Preferences in an Emerging Market*." (IRB ID: VERSION00001425 with DHHS Exempt 2(i) status at University of Georgia). Using Qualtrics the online survey was administered nationally by Toluna headquartered in Dallas for the U.S. (https://tolunacorporate.com) until ~1,000 complete responses from a nationally representative sample of respondents (by age, gender, income, and education) were obtained. Response data collection commenced and concluded in April 2022.

Using conjoint analysis in the form of a Multinomial Discrete Choice Experiment (CE), consumers were presented with repeated, random purchasing scenarios to analyze three attribute variables including price (*P*), drying method, and CBD content to maximize their utility from the attributes of the oil rather than from the oil itself as described by Lusk et al. [15]. This allowed assessment of a consumer's WTP for these different attributes and differentiation of WTP by respondent demographics and attitudes. Specifically, the respondents were asked to make nine repeated choices between three 1-oz. (30 mL) CBD bottles, each described by three randomized attributes (three different hemp flower drying methods, three different CBD concentrations in the oil, and three different prices). Respondents were also provided a no-purchase option (Figure 1).

Figure 1. Sample choice experiment question with an introductory statement of "You are at the store to purchase CPB oil for yourself or a loved one. All one oz. bottles are exactly the same except for drying method, mg of CBD per bottle, and price. 'None' means, you would not buy any of the choices."

The three main effects (Table 1) and their two-way interactions resulted in 27 choice sets (full factorial) that led to 9 bidding rounds that were selected using the Statistical Analysis System (SAS) macros for experimental design and choice modeling [16]. The three types of drying method were chosen based on earlier work by Jacobs [8]. A potential downside of non-binding choice experiments is hypothetical bias [17]; however, it is necessary to use a stated preference approach when there are no revealed preference data available for CBD products that are differentiated by drying method.

Table 1. CBD oil attribute levels per 1-oz. (30 mL) bottle selected for the choice experiment.

CBD oil attribute	Factor	Attribute levels
Drying method	X1	Air-dried Infrared irradiated (IR) Freeze dried (FR)
CBD concentration in milligrams (mg)	X2	500 mg (23rd percentile) 1,000 mg (47th percentile) 2,500 mg (81st percentile)
Price	X3	$60 (40th percentile) $100 (72nd percentile) $190 (91st percentile)

Note: Percentiles are based on information collected from the online study.

3.3 Drying Method Information Treatment

Since respondents were not necessarily expected to be well informed about crude oil extraction and drying methods of hemp flower, approximately half of them were provided with information about drying methods to see whether adding such information to product labeling could alter consumer preference and lead to an increased willingness to pay (WTP).

Since fresh hemp plants contain approximately 80% water, drying is crucial before processing hemp flowers into CBD oil to avoid spoilage. Further, the choice of drying method impacts the potential presence of mold as well as product potency, taste, and medicinal properties. Hence half of the respondents were prompted with the following information about drying methods as an information treatment (T):

1) Freeze drying involves 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), thereby preserving their 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 flowers 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 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 leads to higher processing losses. [8]

3.4 Willingness to Pay Estimation

The statistical analysis relied on a conditional logit model that described consumer choice among a discrete set of unordered scenarios. This was possible as the Multinomial Discrete Choice (MDC) procedure supports conditional logit models [18]. In the survey, consumers i = 1, 2,...N, were faced with 27 discrete choices over nine rounds of bidding for three CBD oils described by a chosen set of CBD oil attributes. As shown by McFadden [19], a random utility function may be defined by a deterministic (V_{ij}) and a stochastic (ε_{ij}) component as defined in Equation (1) where U_{ij} is the i^{th} consumer's utility of choosing option j, V_{ij} is the observable portion of the utility function determined by the CBD oil attributes and their values (Table A2) 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*.

$$U_{ij} = V_{ij} + \varepsilon_{ij} \tag{1}$$

Expanding V_{ij} using *k* rounds of bidding with j independent variables (*X*) allows estimation of utility impacts via coefficient estimates α as follows:

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

Replacing *X* with observable factors, the utility function U_{ijk} is the *i*th individual's utility of choosing option *j* in question *k* and becomes Equation (3):

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

where IR_{ijk}, FD_{ijk}, $500MG_{ijk}$, and $2500MG_{ijk}$ are binary variables indicating whether or not the hemp flower product chosen deviated from air-drying by being infrared radiated (IR) or freeze-dried (FD) and whether it contained less (500 MG) or more (2,500 MG) than the baseline 1,000 mg CBD per 1-oz. (30 mL) bottle. The price variable $Price_{ijk}$ varied as indicated in Table 1. Finally, ε_{ijk} is the extreme value error term that is independently and identically distributed.

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

The WTP for CBD oil using IR (Equation (4)) and FR (Equation (5)) dried hemp flowers and CBD oils with 500 mg (Equation (6)) or 2,500 mg (Equation (7)) of CBD, relative to the 1,000 mg CBD per 1-oz. (30 mL) bottle using hemp flower that was air-dried, all other attributes remaining the same, was estimated as follows and resulted in binary attribute estimates:

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

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

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

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

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

Due to non-linearity in Equations (4)–(7), the Monte-Carlo simulation assessed whether simulated WTP estimates differed from the baseline WTP estimates using a two-tailed t-test at P = 0.1, 0.05, and 0.01. This involved the creation of ten thousand simulated coefficients derived from the estimated means and standard deviations of each coefficient, which are now considered to follow a normal distribution asymptotically [20–22].

Adding more than the three main study factors (drying method, CBD content and price) allowed assessment of consumers' WTP with and without the aforementioned drying information treatment (T) shown in section 3.3, for example,

$$U_{ijk} = \beta_1 IR_{ijk} + \beta_2 FD_{ijk} + \beta_3 500MG_{ijk} + \beta_4 2500MG_{ijk} + \beta_5 Price_{ijk} + \beta_6 T \cdot IR_{ijk} + \beta_7 T \cdot FD_{ijk} + \beta_8 T \cdot 500MG_{ijk} + \beta_9 T \cdot 2500MG_{ijk} + \beta_{10} T \cdot Price_{ijk} + \mu_{ijk} \tag{8}$$

by adding T interactions to the initial treatment factors. As such, WTP estimates for IR without (Equation (9)) and with the information treatment (Equation (10)), for example, are calculated as follows:

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

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

WTP estimates for the three main effects could thus be differentiated by information treatment by constructing alternative specifications of Equations (9) and (10). Using Monte Carlo simulation, we can again test for statistically significant differences between attributes by consumer segment (i.e., $WTP_{IR} - WTP_{TIR} \neq$

0). Finally, testing for information treatment (T) effects could also be performed using other binary consumer segment characteristics such as age, gender, income, and education as well as other consumer characteristics about concern over CBD oil quality and periodic CBD oil expenditures, for example (see Table A2 for a list of consumer characteristics tested).

4. Results

The results of the online study of retail prices for CBD oil are described first. Choice experiment results follow as are respondent demographics of CBD oil users.

4.1 Online Study

Summary statistics and variable definitions of the CBD oil product information collected are shown in Table A1. As shown in Table 2, results indicated that CBD content does play an important role as a price determinant and diminishingly so (although not statistically significantly so). Among ailments to be treated, the results indicated pain treatment to be the most important price determinant. Finally, customer ratings had a small price effect, given a small standard deviation in satisfaction ratings (Table A1). As such, signs and size of coefficients were deemed appropriate, as was the explanatory power of the model using this cross-section of price data. The impact of CBD content on price over the range of CBD content observed in the data (Figure 2), illustrates the potential to charge higher prices with greater CBD content. Higher CBD content per bottle also leads to packaging and shipping cost efficiencies and hence price increases diminish at higher CBD content. Further, consumers using CBD oil cannot reduce droplet size beyond a certain point, and oil quality deteriorates with successive openings of the storage container. Said quality deterioration thus limits the extent to which CBD content could be feasibly raised.

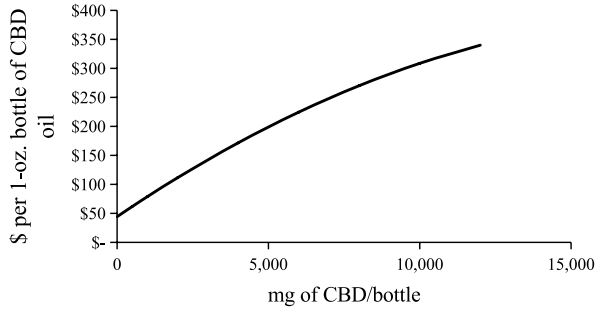

Figure 2. Estimated price per 1-oz. (30 mL) bottle of CBD oil with varying CBD content holding all other variables constant, 2021 U.S. online prices.

Note: See right most column of Table 2 for model specification.

Table 2. Price determinants of 1-oz. (30 mL) CBD oil using U.S. online retail offerings using all vs. a subset of explanatory variables, 2021.

Description[a]	Coefficient estimates (Std. Err.)	
	Full specification	Modified specification
Constant	–165 (79)^{**,b}	–189 (67)***
CONT	4×10^{-2} (6×10^{-3})***	4×10^{-2} (6×10^{-3})***
$CONT^2$	-9×10^{-7} (6×10^{-7})	-9×10^{-7} (6×10^{-7})
US	–10 (15)	
NATURAL	2 (9)	
ORGANIC	–10 (8)	
CO_2	14 (9)	8 (8)
PAIN	12 (10)	17 (8)**
ANXIETY	2 (10)	
SLEEP	12 (8)	14 (9)
AIR	61 (32)*	54 (30)*
HEAT	13 (13)	
RATE	43 (16)***	45 (14)***
NRATE	-1×10^{-3} (5×10^{-3})	
R^2	66.5%	65.5%
Adj. R^2	62.5%	63.5%
AIC[c]	10.3	10.2

Note:

[a] Please see Table A1 for variable descriptions. Results of model specifications using logistic and square root functional forms of *CONT* available upon request. Both specifications use 124 observations.

[b] The statistical significance of the coefficient estimates.

[c] Akaike Information Criterion with smaller values indicating lesser misspecification error.

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

Since the data collection method for this market assessment did not allow for the collection of explanatory variables that may vary by the individual consuming the product, the following choice experiment results are expected to add further insight.

4.2 Consumer Choice Experiment

The online consumer survey, including the CE component, took an average of 20 minutes (with a median of 14.4 minutes). Participants below the age of eighteen were not allowed to take the survey. Approximately 1,004 eligible respondents participated and completed the survey. Of the total sample, 549 were excluded from the final analysis as they had never tried CBD products. Of the remaining 455 respondents, 40% (184 respondents) had tried or regularly consumed CBD in the form of oil, 30% were between 18 and 25 years old, 52%

were 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.

A few more men answered the survey (54% of the total respondents) 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 and the no mold guarantee could not be discussed 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 was in line with the initial study goals. About seventy percent of the respondents said they spend up to $100 monthly on CBD products; others said they would spend more. Finally, of the 455 respondents with CBD experience, 49% received the drying method information treatment (section 3.3) before the CE, and hence, the randomization of the information treatment performed as expected.

Sample selection bias may exist because of the selection of CBD consumers only. Nonetheless, compared to census data in the U.S. regarding gender, age, and household income, the surveyed sample appears to be representative of the U.S. population (Table 4).

Table 3. Descriptive statistics of U.S. survey respondents that had used CBD, 2022.

Variable	Definition	Mean (Std.) Dev.
GENDER[a]	1 = male; 0 = female & other	0.55 (0.50)[b,c]
AGE	Respondent age in years	38.5 (15.7)[c]
CHILD	Children per household	1.00 (1.12)[c]
COLLEGE	1 = college and higher; 0 = high-school and below	0.77 (0.42)[c]
INCOME	Annual household income in thousands of USD	87.1(56.0)
T	1 = received information treatment (section 3.3); 0 = otherwise	0.49 (0.50)
KNOWHOW	Respondent self-assessment of fraction of U.S. people their age that know more than themselves about CBD products	0.64 (0.27)
QUALITY	Respondent concern about CBD quality (0 = no concern; 1 = very concerned)	0.56 (0.33)
CONTAMINANT	Respondent concern about CBD contaminants (0 = no concern; 1 = very concerned)	0.48 (0.34)
CONT	Usual purchase quantity of mg of CBD per 1-oz. (30 mL) bottle	1,657 (765)
MEDICAL	1 = CBD use for medical condition; 0 = otherwise	0.47 (0.50)
PAIN	1 = CBD use for pain relief; 0 = otherwise	0.56 (0.50)
BOUGHT	1 = purchased CBD within last year; 0 = otherwise	0.82 (0.39)
AMOUNT[d]	Amount of CBD (1 = among top three; 0 = otherwise)	0.31 (0.46)
LOCAL[d]	Local product (1 = among top three; 0 = otherwise)	0.15 (0.36)
LAB[d]	Lab results labeled (1 = among top three; 0 = otherwise)	0.23 (0.42)
ORGANIC[d]	Organic product (1 = among top three; 0 = otherwise)	0.21 (0.41)
DRY[d]	Drying method (1 = among top three; 0 = otherwise)	0.13 (0.34)
MOLD[d]	No mold guarantee (1 = among top three; 0 = otherwise)	0.13 (0.34)
LOWEXP	< $100/month on CBD (1 = yes; 0 = otherwise)	0.70 (0.46)
HIEXP	> $100/month on CBD (1 = yes; 0 = otherwise)	0.18 (0.39)
NONE	Answered "None" to all bids (1 = yes; 0 = no)	0.11 (0.31)
Number of observations		455

Note:

[a] Five respondents answered "Other Gender".

[b] Numbers in parentheses are standard deviations.

[c] U.S. Census and Statista report i) 49.0% males in 2021(> 18 years old) [23]; ii) median age in 2021 was 38.8 years old [23]; iii) 1.94 children per household < 18 years old in 2021[24]; and iv) people that had graduated from college, or another higher education was 37.9 percent [25].

[d] Respondents were asked to select the top three most important factors when purchasing CBD. Factors included mix of cannabinoids, design of label, price per unit of ingredient, price per bottle, local origin, brand, total amount of CBD, presence of THC, no mold guarantee, hemp drying method, reviews from other purchasers, lab testing results, amount of CBD per serving and organic production method.

Table 4. Gender, age, household size, education and income differences between CBD users and non-users, 2022.

Variables	Definition	CBD users	Non-users	All	U.S.[a]
GENDER[b]	1 = male; 0 = female & other	0.547[c] (0.498)[d]	0.406[c] (0.492)	0.470 (0.500)	0.490
AGE	Age in years	37.5[c] (15.7)	48.5[c] (20.6)	43.5 (19.3)	38.8
CHILD	Children per household	1.00[c] (1.12)	0.54[c] (1.02)	0.75 (1.09)	1.93
EDUCATION	1 = College and higher; 0 otherwise	0.77[c] (0.42)	0.71[c] (0.46)	0.74 (0.44)	0.38
INCOME	Annual household income in USD	87,099[c] (55,965)	68,434[c] (52,293)	76,892 (73,892)	70,784
Number of observations		455[e]	549	1,004	

Note:

[a] U.S. Census Bureau data for 2021 [23,25,26]. Age and income are medians. The number of children under age 18 was sourced from Statista [24].

[b] Five respondents answered "Other Gender".

[c] 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.

[d] Numbers in parentheses are standard deviations.

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

On average CBD product users or consumers, compared to non-users, are statistically significantly more likely to be male, younger, have a larger household, and are slightly more educated and affluent.

While 11% of respondents repeatedly chose not to purchase CBD oil, respondents chose more or less equally among the remaining drying methods—freeze dried (32%), air dried (31%), and infrared radiated (27%) suggesting relatively small disdain toward infrared radiation. Given this approximately even distribution of respondent choices concerning drying method, the utility model (Equation 3) measuring the effects of drying method, CBD content, and price, relative to a baseline of air-dried, 1000 mg CBD per 1-oz. (30 mL) bottle, without interaction effects showed statistically significant CBD content and pricing effects (Table 5).

The price coefficient being positive is problematic. Respondents, on average, appear to purchase more as the price rises. Perhaps greater affluence among CBD users, compared to non-users lessens price sensitivity or quality/safety is associated with price given the recent availability of these products with relatively little product information and/or uncertainty about how it would perform. Statistical significance is also observed in the coefficients on the CBD concentration, both positive, which means that 500 and 2,500 mg CBD oil increases a consumer's utility relative to the 1,000 mg CBD oil bottle. The positive utility effect is larger for the 2,500 mg CBD oil.

Table 5. Conditional logit model results detailing the impact on consumer utility as a function of CBD content, drying method, and price relative to CBD oil derived from air-dried hemp flower with 1,000 mg of CBD per 1-oz. (30 mL) bottle, US, 2022.

CBD attribute	Coefficient estimate (Std. Error)	Log likelihood	Schwarz criterion	McFadden's LRI
IR	–0.0315 (0.0427)			
FD	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)***			
P	0.0008 (0.0003)***			

Note: *** indicate significance at the 99% levels using 455 observations. IR = infrared radiated, FD = freeze-dried, P = price per 1-oz. (30 mL) bottle of CBD oil.

Using these coefficient estimates, WTP estimates follow in Table 6. The WTP results for the baseline model show that, compared to an air-dried hemp flower derived CBD oil bottle with 1,000 mg CBD content, 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 results indicate that hemp growers targeting CBD oil attributes may well adhere to current practice—selling at an average of 1,490 mg CBD per 1-oz. (30 mL) bottle (Table A1) and choosing a drying method that best suits them.

Adding interaction effects, using Equation (8), for a host of binary effects summarized in Table A2, four effects with statistically significant differences in their WTP were found and are summarized in Table 7. All other effects were insignificant including the information treatment effect (section 3.3).

Table 6. Willingness to pay estimates for product CBD oil attributes without interaction effects relative to CBD oil derived from air-dried hemp flower with 1,000 mg of CBD per 1-oz. (30 mL) bottle, US, 2022.

Attribute	Estimated WTP (simulated)
IR	$37.21
FD	–$85.30
500 mg CBD	–$329.18
2,500 mg CBD	–$719.18

Note: IR = infrared radiated, FD = freeze-dried, P = price per 1-oz. (30 mL) bottle of CBD oil.

Again, in comparison to air-dried 1,000 mg CBD oil: i) consumers younger than 55 years old are willing to pay significantly less for 500 mg (–$137) and 2,500 mg (–$234) CBD oil, whereas consumers 55 years of age or older tend to be willing to pay significantly more for freeze dried ($37) as well as 2,500 mg ($99) CBD oils;

Table 7. Statistically significant WTP differences by consumer demographic and monthly CBD expenditure relative to air-dried CBD oil containing 1,000 mg of CBD, 2021.

Factor	Attribute	Estimated WTP	Estimated WTP
		Below 54 years old	Over 54 years old
	IR	$2.95 (22.78)	–$15.80 (19.51)
Age	FD	–$22.49 (23.82)	$36.66** (16.71)
	500 mg	–$137.05*** (37.12)	–$24.72 (20.83)
	2,500 mg	–$234.06*** (48.09)	$98.59*** (16.38)
		Female	Male
	IR	n.a.	–$57.65 (49.20)
Gender	FD	n.a.	–$60.02 (49.53)
	500 mg	n.a.	–$167.04** (79.88)
	2,500 mg	n.a.	–$285.55*** (110.45)
		Expense > $49/month	Expense < $49/month
	IR	–$20.85 (25.30)	n.a.
CBD Expenditure	FD	–$45.35* (26.76)	n.a.
	500 mg	–$121.01*** (36.34)	n.a.
	2,500 mg	–$190.62*** (43.58)	n.a.
		Inc.[3] > $30k	Inc. < $30k
	IR	–$4.75 (40.18)	n.a.
Household Income	FD	–$72.78 (54.85)	n.a.
	500 mg	–$163.91*** (81.16)	n.a.
	2,500 mg	–$367.79*** (140.23)	n.a.

Note: *, **, *** indicate significance at the 90%, 95%, and 99% level, respectively. IR = infrared radiated, FD = freeze-dried. Standard errors are reported in parentheses. Statistically insignificant results p > 0.99 are marked as n.a. Positive statistically significant findings are highlighted in bold.

ii) male consumers are willing to pay significantly less for 500 mg (–$167) and 2,500 mg (–$286) CBD oil; iii) 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 iv) 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. These results are somewhat at odds with the utility results presented in Table 6 where greater utility was reported for higher CBD content. Thus, although consumers derive increasing utility with higher CBD concentration, only older consumers (≥ 55 years of age) are willing to pay for greater CBD content.

5. Conclusions

The objectives of this study were to present information about CBD oil pricing concerning CBD oil content and consumer preferences toward drying methods using online sales data from the fall of 2021 and an online choice experiment conducted in 2022. Tested also was whether information about drying methods would impact WTP for CBD oil attributes and whether or not some of those WTP differences would vary by targeting consumer segments. The online market analysis showed that CBD oil prices are mainly driven by their CBD concentration and customer ratings when it comes to selling prices set by CBD oil retailers in the U.S. The analysis of WTP of surveyed U.S. consumers, however, did not entirely support the retailers' approach. The survey results suggest that attempting to market CBD oil products to consumer segments that would be willing to pay more for CBD content or drying method resulted in very few statistically significant differences. Much of that finding was a result of reporting a statistically significant positive coefficient estimate on price in the utility function. This suggests that significant uncertainty exists about CBD oil given its recent market reintroduction. Also, consumers may interpret higher prices to reflect higher quality/product safety, thereby offering perceived quality assurance. The results further suggested that the drying method used on hemp flowers for CBD oil production combined with CBD content did not significantly matter to CBD consumers, except for consumers 55 years of age or older who are willing to pay more the higher the CBD content using freeze-dried flowers. 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 and adhere to the status quo. It is expected that other factors may need to be accounted for when setting the selling price of CBD products, which suggests that further research is needed. With an immature market, as the one for CBD oil, more consumer information (not on drying method) about the potential benefits of CBD oil consumption and daily intake rate suggestions as well as further consumer ratings of CBD oil products are likely needed before processors can make more informed market segmentation choices. Despite being largely insignificant, the findings reported within this study are expected to guide further research that may well need to be performed using a non-hypothetical choice experiment to avoid shortcomings of online choice experiments albeit at greater cost.

Author Contributions

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Data Availability

Data is available from the authors upon request.

Conflict of Interest

There is no conflict of interest.

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Appendix

Table A1. Summary statistics of online consumer choices for CBD oil, U.S., Fall 2021.

Variable	Definition	Mean (Std. Dev.)
P	USD per 1-oz. (30 ml) CBD bottle	$92.29 (64.78)
CONT	mg of CBD per 1-oz. (30 ml) CBD bottle	1,490 (1,764)
US	1 = domestic origin; 0 = foreign	0.91 (0.29)
NATURAL	1= natural; 0 = otherwise	0.27 (0.45)
ORGANIC	1 = organic (certified or stated); 0 = otherwise	0.60 (0.49)
CO_2	1 = CO_2 extracted oil; 0 = otherwise	0.47 (0.50)
PAIN	1 = targeting pain; 0 = otherwise	0.47 (0.50)
ANXIETY	1 = targeting anxiety, 0 = otherwise	0.52 (0.50)
SLEEP	1 = targeting insomnia; 0 = otherwise	0.48 (0.50)
AIR	1 = Air-dried hemp; 0 = otherwise	0.04 (0.20)
HEAT	1 = Heat-dried hemp; 0 = otherwise	0.02 (0.15)
RATE	customer star rating (out of 5)	4.73 (0.28)
NRATE	number of customer ratings	391 (655)
Number of observations (with customer ratings and P > $0.016/mg)		124

Table A2. Binary effects tested for assessment of WTP differences from air-dried, 1,000 mg CBD content 1-oz. (30 mL) with no statistically significant effects on WTP.

Variable	Definition	Mean (Std. Dev.)
T	1 = received information about drying methods; 0 = otherwise	0.490 (0.500)
YOUNG	1 = 18 to 24 years old; 0 = otherwise	0.303 (0.460)[a]
MIDDLE-AGED	1 = 25 to 54 years old; 0 = otherwise	0.516 (0.500)
OLDER	1 = over 54 years old; 0 = otherwise	0.180 (0.385)
GENDER	1 = male; 0 = female & other	0.547 (0.498)[a]
EDUCATION	1 = College and higher; 0 = high-school and below	0.771 (0.420)[a]
QUALITY	1= CBD quality concern over 49[b]; 0 = otherwise	0.473 (0.500)
CONTAMINANT	1= CBD contaminant concern over 49[b]; 0 = otherwise	0.536 (0.499)
DAILY	1 = daily use of CBD; 0 = otherwise	0.240 (0.427)
MONTHLY	1 = weekly or monthly use of CBD; 0 = otherwise	0.576 (0.495)
CBD < 10	1 = typical daily CBD dose in mg; 0 = otherwise	0.215 (0.412)
10 ≤ CBD ≤ 30	1 = typical daily CBD dose; 0 = otherwise	0.248 (0.433)
30 < CBD < 50	1 = typical daily CBD dose; 0 = otherwise	0.220 (0.415)
LOCALc	Local product (1 = among top three[c]; 0 = otherwise)	0.15 (0.36)
LAB	Lab results labeled (1 = among top three; 0 = otherwise)	0.23 (0.42)
MOLD	No mold guarantee (1 = among top three; 0 = otherwise)	0.13 (0.34)
CBD < $49	1 = monthly spending on CBD below $49; 0 = otherwise	0.534 (0.499)
$50 < CBD <$100	1 = month. spending on CBD $50 to $100; 0 = otherwise	0.284 (0.451)
CBD > $100	1 = month. spending on CBD above $100; 0 = otherwise	0.182 (0.387)
RURAL	1 = rural respondent; 0 = otherwise	0.160 (0.367)
MEDICAL	1 = CBD use for medicine or pain; 0 = otherwise	0.754 (0.431)
LOW INCOME	1 = household income below $30k; 0 = otherwise	0.209 (0.407)[a]
MID INCOME	1 = Inc. above $30k and below $80k; 0 = otherwise	0.360 (0.481)[a]
UPPER INCOME	1 = Inc. above $80k and below $190k; 0 = otherwise	0.382 (0.487)[a]
HIGH INCOME	1 = Inc. above $190k; 0 = otherwise	0.048 (0.215)[a]
RECREATIONAL THC	1 = THC legal in respondent state for recreational use; 0 = otherwise	0.479 (0.500)
MEDICAL THC	1 = THC legal in respondent state for medical use; 0 = otherwise	0.741 (0.439)
THC LEGAL	1 = THC legal in state for recreational and medical use; 0 = otherwise	0.741 (0.439)
CBD LEGAL	1 = THC illegal in state (CBD legal); 0 = otherwise	0.259 (0.439)
FAST	1 = respondent response time below 776 seconds (mode) ; 0 = otherwise	0.422 (0.494)
MEDIUM	1 = duration between 1 and 2 times the mode (776 s); 0 = otherwise	0.448 (0.498)
SLOW	1 = duration above twice the mode (> 1,552 sec.); 0 = otherwise	0.130 (0.336)
Number of observations		455

Note:

[a] 77.9% of the U.S. population was 18 years of age or older in 2021 [23]. Of that cohort, 11.5% were between 18 and 24 years old, 50.2% were between 25 and 54 years of age, and 38.3% were older. Males and people that had graduated from college, or another higher education level are reported in Table 5. The 2021 breakdown of low, middle, upper, and high-income tiers (as defined above) was 21.3, 33.4, 32.1, and 13.3 percent, respectively [24].

[b] Respondents could register no-concern = 0 to 100 = very concerned using a sliding scale on CBD quality and concern over contaminants.

[c] Respondents were asked to select the top three most important factors when purchasing CBD. Factors included mix of cannabinoids, design of label, price per unit of ingredient, price per bottle, local origin, brand, total amount of CBD, presence of THC, no mold guarantee, hemp drying method, reviews from other purchasers, lab testing results, amount of CBD per serving and organic production method.