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Grading and Characterization of Hemp Biomass

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ABSTRACT

There are validated methods of sampling biomass, however a method for characterizing and grading the plant biomass is then required but not currently available. The purpose of this study is to characterize and quantify the plant's main structures in a typical harvest that will be packaged or bagged for receipt by an end-user processor. The hypothesis for this experiment is that a large variation of material will be recognized based on the state it was harvested from. The methods and equipment that were used for CBD potency and moisture percentage were the Shimadzu LC-2030C HPLC System and Shimadzu MOC63U Unibloc Moisture Analyzer respectively. For separating the biomass samples, the methods and equipment used were a Gilson Universal Sample Splitter and a 12 Inch Gilson Tapping Shaker Sieve. The results from the experiment displayed that the Alabama-grown hemp biomass samples were slightly above average in CBD potency and moisture. The Colorado-grown hemp biomass sample was lower in CBD Potency and significantly lower in moisture. The Kentucky-grown hemp biomass sample was the highest of the state-based CBD potencies. The Oregon-grown hemp was 55.6% lower in CBD potency than the average sample population and moisture was far below the sample population average. The Tennessee-grown hemp was slightly higher in CBD potency and moisture with our sample population. Additionally, we identified unique correlations involving regional differences and environmental factors. In conclusion, there are large amounts of variability in hemp processing and hemp material from its harvested material makeup. By creating a classification and grading template based on these insights, processors and farmers can optimize harvest methods, pricing models, and biomass selection, increasing the control of market predictability and quality control across the industry.

INTRODUCTION

The hemp industry has increased substantially in recent years, factors which have been responsible for overall growth have been the hemp's unique presence in pharmaceuticals, textiles, bioplastics, and wellness products. The global industrial hemp market was valued at $5 billion in 2023 and is projected to reach around $16 billion by 2030, which makes the compound annual growth rate (CAGR) over 16%. A major impact for Hemp's growth in the United States was the ratification of the 2018 Farm Bill which federally legalized hemp cultivation, removing it from the Controlled Substances Act. Now the U.S is upon the top three hemp-producing countries globally. CBD is the primary cannabinoid that is extracted from buds, stems, seeds, and leaves. CBD has a multitude of applications; it can be used for its material properties in developing hemp derived plastics and physical products; it can also be used for its medicinal properties and derived from its cannabinoids. The pharmaceutical industry currently has CBD derived Patents for medicinal uses. Cannabinoids also provide benefits for inflammation and neurological disorders. Upstream from this there are requirements for extraction and purification of CBD, starting with plant biomass. There are validated methods of sampling the biomass, however a method for characterizing and grading the plant biomass is then required but not currently available.

Due to the growth of the hemp industry and processors beginning to grow to large scaling operations, biomass procurement has become more complex when identifying and selecting hemp biomass to process within a company's operational infrastructure. With this growing importance, there still lacks an industry standard for grading and valuing hemp as a profitable input for hemp processors. In the current state of the industry, the potency of CBD is the primary and main pricing element, in most cases overlooking the biological makeup of the hemp biomass that a hemp processor is receiving. Stems, leaves, and seeds are biological materials that can impact equipment performance, extract purity, and increase need for further downstream process refinement that can increase costs, labor, and inconsistency of end-product.

Even without an industry standard for grading hemp biomass, there are many challenges that present themselves with the agricultural processing standards between farms throughout the country. These challenges are inconsistent with harvest methodologies based on farmer experience and infrastructure, no industry standard for drying methodologies, and no industry standard for processing hemp biomass post-drying for bagging and packaging. These issues can create uncertainty in what product a hemp processor may receive to their facility, which may create challenges if systems are set up to process certain styles or makeup of hemp biomass. By implementing standards at the grading level, farmers can be consulted to present best practices of desirability, quality control, and CBD capture, while also understanding how certain processes can create further profitability in an agricultural operation.

The purpose of this study is to characterize and quantify the plant's main structures in a typical harvest that will be packaged or bagged for receipt by an end-user processor. This will provide the agricultural industry with a standard to potentially adopt, and establish proper efficiency, transparency, buyer confidence, and accurate pricing, benefiting the industry as a whole and helping sustain the projected growth. Additionally, this standard could be used as a tool to educate and enable farmers to understand the value of the crop that the processor values for their use.

Cannabidiol Percentage or "CBD %" is the most desirable aspect of the hemp processor targeting CBD. The percentage is a makeup of the weighted proportionality of the plant biomass being tested. Higher CBD potencies are more desirable by processors as this would yield higher amounts of CBD extracts. 8% CBD or higher is typically seen as high CBD, offering better opportunities for yield capture. Below 8% CBD is typically considered lower and is less desirable due to lesser yields. High scale processors will often extract biomass as low as 3%, due to the amount of hemp biomass that they are able to process while still observing profitability.

Moisture Percentage is the weighted proportionality of moisture that exists within the plant biomass being tested. Moisture % targets of 15% Moisture or less are seen as desirable. Moisture that exceeds these levels can create challenges due to potential for product rotting when bagged, it can dilute total CBD %

downward due to moisture capturing proportional weight within a CBD % test, and it can create excess water within a hemp processor's solvent that can dilute solvency capability for product extraction.

Buds are the flowering material of the plant that contains much of the CBD from the hemp plant. Buds are seen as very desirable as they display a healthy grown hemp biomass crop and displays that hemp biomass was not over processed during the post-drying process.

Stems are the non-flowering material that supports the plant structure during the growing cycle and are not desirable for many reasons. Stems do not produce CBD, most equipment that hemp processors implement are not efficient at handling excessively stemmy material, and stem weight within biomass must still be processed with solvents and equipment that could be processing higher quality inputs.

Typically, seeds are the first input into growing a successful hemp crop as a farmer, however, they can be produced by the flowering buds during the growing process. If female hemp plants encounter male plant pollen from the intended acreage or hemp acreage up to 15 miles away, this pollen can create a hermaphroditic transformation ceasing CBD growth and cross gendering the plant species. This will cause a plant to begin to create seeds within the plant structure. Erratic, unplanned, or interrupted light outside of a day's normal sunlight patterns can also create this hermaphroditic transformation. Seeds contain miniscule levels of CBD, however, contain protein that can harm purity targets within product extraction.

Leaves are plant material that is non-budded, but act as a critical agent for plant growth during the growth cycle. Leaves contain little CBD in comparison to buds. If hang-drying or field-drying many of these leaves will fall off the plant creating little issues downstream. Leaves are typically a larger challenge for farmers combining hemp biomass and mechanically drying. Leaves add little to no value for a hemp processor.

Fine biomass is the smallest size material of hemp material makeup. Fine biomass is desirable as CBD particulate begins to remove itself from the bud material, it will collect in a powder-styled substance with other aspects of biomass material. It can typically be rich in CBD, if there were material amounts of CBD grown with the plant. Challenges can be interfaced with fine biomass as it can create issues with process filtration for removal during extraction, can create risks with dust in processing facilities, and can be prone to caking in process systems. Additionally, fine biomass can be a challenge during farmer processing where they mill the material to fine levels for efficiency in bagging, and milling all aspects of the plant into this makeup, versus only the CBD rich elements.

LITERATURE REVIEW

The overall increase in hemp production has initiated comprehensive research into characterizations, processing, and quality assessment of hemp biomass. With cannabidiol (CBD) becoming a leading therapeutic and industrial substance, it is crucial to understand the diversity of biomass quality and composition (Lazarjani et al., 2021a; Singh et al., 2023). CBD extraction yield and quality of the final product depend significantly on the biological makeup of the biomass, i.e., the relative percentage of buds, leaves, stems, and seeds (Brighenti et al., 2024).

There are existing standardized sampling protocols for related species such as (Hop Growers of America, n.d.), but an available standardized grading system for identifying structural and chemical variability is lacking. Research draws attention to the critical role of biomass moisture content influencing not only product stability but also efficiency of extraction, where more than 15% moisture is susceptible to microbial spoilage as well as dilution through extraction with a solvent (UGA Cooperative Extension, n.d.; Fućak et al., 2023). Stems and seeds, with low CBD content and the potential to cause damage to processing equipment and extraction purity, also need precise separation and quantification methods (Analakkattillam et al., 2022).

Local cultivation habits and climate conditions significantly contribute to biomass fluctuations. As an illustration, the history of farming in Kentucky, that is, tobacco plant cultivation experience, is linked with increased CBD concentration and improved proportionally structured biomass, underlining the impact of geographic and genetic factors (Lewey, 2025). Genetic factors and pollination behavior on seed development and cannabinoid composition have been addressed, highlighting crop uniformity issues (Nagarkatti et al., 2009).

Advancements in analytical equipment, such as high-performance liquid chromatography (HPLC), offer precise determination of cannabinoid contents, still enhancing quality control and regulatory compliance (Brighenti et al., 2024; Analakkattillam et al., 2022). Diversity in harvesting, drying, and post-harvest treatment is a source of variation that complicates biomass valuation as well as process optimization (Lazarjani et al., 2021b).

This literature collectively highlights the need for an overall classification and grading system that integrates chemical potency, structural content, and moisture factors. Such a system would give greater transparency across the supply chain, enable more efficient pricing models, and enable growers and processors to synchronize cultivation and processing operations with market demands

MATERIALS AND METHODS

The first part of the sequence was selecting biomass that fulfilled the established criteria. The first factor was diversity. Diversity is relevant because of genetic variation, chemical profiles, and environmental influences. Selecting biomass from diverse locations ensures a broader range of growing conditions, climates, harvesting methodologies, and soil compositions, and reduces the risk of bias from a single region's crop. The U.S. states selected for diversity were Oregon (n = 5), Alabama (n = 7), Kentucky (n = 16), Colorado (n = 1), and Tennessee (n = 1). The second factor applied was the timeframe, set between 2022 and 2024. This period was chosen to ensure relevance to current hemp quality and industry standards. Additionally, in 2021–2022 the USDA finalized regulations on hemp testing, disposal, and compliance, implementing stricter quality control measures that made biomass from this timeframe more reliable and legally compliant. The harvest years represented in this study included 2022 ($n = 11$), 2023 ($n = 5$), and 2024 ($n = 14$).

After selecting biomass that met the established criteria, each sample was put through a Gilson Universal Sample Splitter to ensure unbiased and uniform distribution for further analysis. A 100-gram sample was then measured using a standard scientific scale. The sample was then passed through a 12-inch Gilson Tapping Shaker Sieve to further separate the biomass into its components: buds, leaves, stems, and fine biomass. Each component was then individually weighed and documented.

Following sieving, each component was manually examined and classified according to physical characteristics. Buds were identified as solid, intact flowering structures; stems as woody structural material; leaves as non-flowering leaf tissue; seeds as hemp seeds; and fine biomass as a dust-like material that passed through the smallest sieve and could not be reliably placed into other categories. Classification was manually performed by visual inspection prior to weighing each component.

The shaker sieve contained sieves of various sizes: 2 inches, 1 inch, ¾ inch, ½ inch, ¼ inch, and 0.0555 inch.

The hemp biomass CBD potency was measured with a Shimadzu LC-2030C HPLC System, which utilizes liquid chromatography to determine cannabinoid levels within hemp samples. The CBD potency was reported as a percentage of total biomass weight.

The hemp biomass moisture percentage was measured with a Shimadzu MOC63U Unibloc Moisture Analyzer, which provides loss-on-drying (LOD) measurements for moisture within hemp biomass. Moisture content was reported as a percentage of the total biomass weight.

Statistical analyses were performed using Google Sheets. Pearson correlation coefficients (r) and corresponding p-values were calculated using all 30 hemp biomass samples to evaluate relationships between CBD potency and selected biomass characteristics. Statistical significance was defined as $p < 0.05$. Scatterplots were visually inspected to assess approximate linearity and identify potential influential outliers before Pearson correlation analyses were performed. Because this study was exploratory and evaluated a limited number of predefined correlations, no correction for multiple comparisons was applied; therefore, the reported p-values should be interpreted accordingly. Shapiro-Wilk tests indicated that bud mass deviated significantly from normality ($W = 0.86$, $p < 0.001$), while CBD potency ($W = 0.93$, $p = 0.053$) and moisture ($W = 0.97$, $p = 0.44$) did not significantly deviate from normality. Because Pearson correlation assumes approximate normality, we additionally computed Spearman's rank correlation for the bud mass relationship as a robustness check; the result was consistent with the Pearson estimate ($\rho = 0.81$, $p < 0.000001$ vs. $r = 0.80$, $p < 0.000001$), supporting the reported association.

RESULTS

The sample population was not evenly distributed across states: Kentucky (n = 16), Alabama (n = 7), Oregon (n = 5), Colorado (n = 1), and Tennessee (n = 1). Therefore, the interpretation of each result should be based on the volume of the sample population rather than generalizable regional trends, especially for states like Colorado and Tennessee. Making accurate conclusions regarding the comparison of datasets should only be done when each sample is proportionally quantifiable. Therefore, the observations presented below should be interpreted as descriptive rather than representative of statewide or regional trends. Large variability was realized from our experiment from sample to sample and additionally from state to state, with each state showing unique characteristics. The Alabama-grown hemp biomass samples were slightly above average in CBD potency and moisture. The biomass was below average in total weights for buds, stems, seeds, and fine biomass. It exceeded the average in leaves. The single Colorado-grown hemp biomass sample was lower in CBD potency and significantly lower in moisture. The sample exceeded in buds, stems, and leaves. It was absent of seeds and was far below the sample population average in fine biomass weight. Because Colorado was represented by only one sample, this observation is descriptive and should not be interpreted as representative of all Colorado-grown hemp. Among the sampled states, Kentucky exhibited the highest average CBD potency and had above-average moisture content. Buds and seeds were above average. Stems were in line with the sample average. Leaves and fine biomass were below the average across our sample population.

The Oregon-grown hemp biomass was 55.6% lower in CBD potency than the average sample population and moisture was far below the sample population average. The fine biomass was substantially heavier than the sample population average and stems were higher than the population average. The seeds and leaves content were below average for our sample population. The single Tennessee-grown hemp biomass was slightly higher in CBD potency and moisture than our sample population average. The sample was absent of buds and leaves, as well as having very little stems and seeds. The fine biomass made up nearly 98.95% of the entire weight of the sample and far exceeded the average from the overall sample population. Because Tennessee was represented by only one sample, this observation should be interpreted as descriptive rather than representative of Tennessee-grown hemp.

The harvest year for the Hemp biomass samples that were grown in 2024 (latest year) had a higher CBD potency compared to older, previous years. Samples harvested in 2024 exhibited higher average CBD potency than samples harvested in 2022 and 2023. This observation should be interpreted descriptively and does not establish the cause of this difference.

Kentucky (KY) samples had more of a balanced biomass distribution, with a moderate fine biomass percentage (30.85%) and a lower stem content (40.88%). Alabama (AL) samples a higher fine biomass percentage (45.27%).

The Pearson's correlation coefficient formula plays an important role in CBD analysis by helping researchers develop data derived expectations. These expectations allow for market efficiency, transparency, and improved decision making in product formulation, cultivation, and market dynamics. Using Pearson's Correlation Coefficient Formula to measure and calculate the strength of a linear correlation between two variables ranging from -1 to 1, highlighted other aspects of variability that were recognized in our dataset. Higher moisture levels typically had higher CBD potency, but the correlation was not strong, meaning other variables (e.g., genetics, growing conditions) also play a role in CBD potency with correlation results of (r=0.58, Moderate Positive Correlation, 95% CI = 0.27 to 0.78) and (p=0.00084, Statistically Significant). Higher buds' mass correlated with higher CBD potency, since CBD is concentrated in buds; with results- r=0.80 (Strong Positive Correlation, 95% CI = 0.61 to 0.90), $p < 0.000001$ (Statistically Significant). Another trend uncovered is the negative correlation between distance to Kentucky and CBD potency, Correlation Results - r=-0.49 (Moderate Negative Correlation, 95% CI = -0.72 to -0.16), p=0.006 (Statistically Significant). The farther the distance from Kentucky the more the average CBD potency decreased. This association may reflect differences in geography, cultivation practices, genetics, environmental conditions, or other unmeasured factors; however, these variables were not directly evaluated in this study, and therefore no causal relationship can be inferred.

Non-statistically significant correlations were recognized individually with stem mass, seed mass, fine biomass mass, and CBD potency.

Table 1 – Sample breakdown of the state harvested, the harvest year, initial mass of the gathered sample, the CBD Potency Percentage, the Moisture Percentage, the Buds mass in grams, the Stems mass in grams, the Seeds mass in grams, the Leaves mass in grams, and the Fine Biomass in grams.

Identifying Information			Overall Measurements			Buds	Stems	Seeds	Leaves	Fine Biomass
Sample	States	Grow year	Mass (g)	CBD Potency	Moisture	Mass (g)	Mass (g)	Mass (g)	Mass (g)	Mass (g)
Sample #1	AL	2024	100	9.11	16.04	16.02	0.53	0.00	53.42	29.48
Sample #2	TN	2022	100	8.18	11.76	0.00	0.47	0.26	0.00	98.95
Sample #3	OR	2022	100	3.35	10.85	0.53	2.22	0.00	24.56	69.50
Sample #4	AL	2023	100	6.81	12.22	3.93	0.00	0.00	47.86	47.85
Sample #5	OR	2022	100	3.11	10.47	0.39	1.10	0.00	30.31	68.74
Sample #6	AL	2023	100	6.94	9.97	12.33	0.00	0.00	50.31	33.93
Sample #7	KY	2024	100	12.55	13.51	26.90	0.52	2.68	49.18	20.41
Sample #8	OR	2023	100	8.82	7.24	13.57	0.30	0.82	40.16	42.33
Sample #9	KY	2022	100	6.02	10.24	1.43	0.00	0.10	43.65	51.81
Sample #10	AL	2022	100	10.86	10.45	23.14	0.51	0.13	31.33	44.55
Sample #11	KY	2024	100	6.37	9.89	7.99	0.54	10.18	48.40	31.30
Sample #12	KY	2024	100	9.98	12.41	26.56	2.08	0.00	41.96	27.22
Sample #13	KY	2024	100	12.72	12.14	31.47	0.31	0.01	42.61	23.97
Sample #14	AL	2024	100	9.11	16.04	9.72	0.52	0.00	52.43	34.34
Sample #15	CO	2022	100	6.23	7.03	32.40	8.20	0.00	39.73	18.31
Sample #16	KY	2024	100	13.98	15.51	45.29	0.96	0.00	37.41	13.44
Sample #17	KY	2024	100	9.54	11.22	22.18	0.44	0.00	38.21	35.97
Sample #18	AL	2023	100	3.82	6.36	1.85	0.45	0.00	26.72	70.24
Sample #19	KY	2023	100	14.49	13.80	39.60	0.52	1.40	38.98	21.13
Sample #20	KY	2022	100	7.73	9.45	1.36	0.00	0.00	0.00	98.43
Sample #21	AL	2024	100	10.27	13.63	14.29	0.00	0.00	54.82	30.76
Sample #22	KY	2024	100	12.75	13.43	51.22	0.00	0.00	33.44	15.06
Sample #23	KY	2024	100	3.41	9.14	0.00	0.00	0.00	9.87	88.81
Sample #24	OR	2022	100	3.47	10.83	0.00	0.00	0.00	17.75	84.01
Sample #25	OR	2022	100	3.78	10.47	0.00	2.72	0.00	31.86	65.06
Sample #26	KY	2024	100	4.54	7.78	0.00	0.00	3.01	10.45	84.47
Sample #27	KY	2022	100	4.75	10.22	0.00	11.40	0.00	0.00	87.89
Sample #28	KY	2024	100	12.82	16.99	52.82	1.27	0.00	33.17	10.77
Sample #29	KY	2022	100	4.78	16.06	34.15	1.34	0.00	35.83	27.81
Sample #30	KY	2024	100	12.58	13.83	53.11	0.35	0.00	30.36	15.52

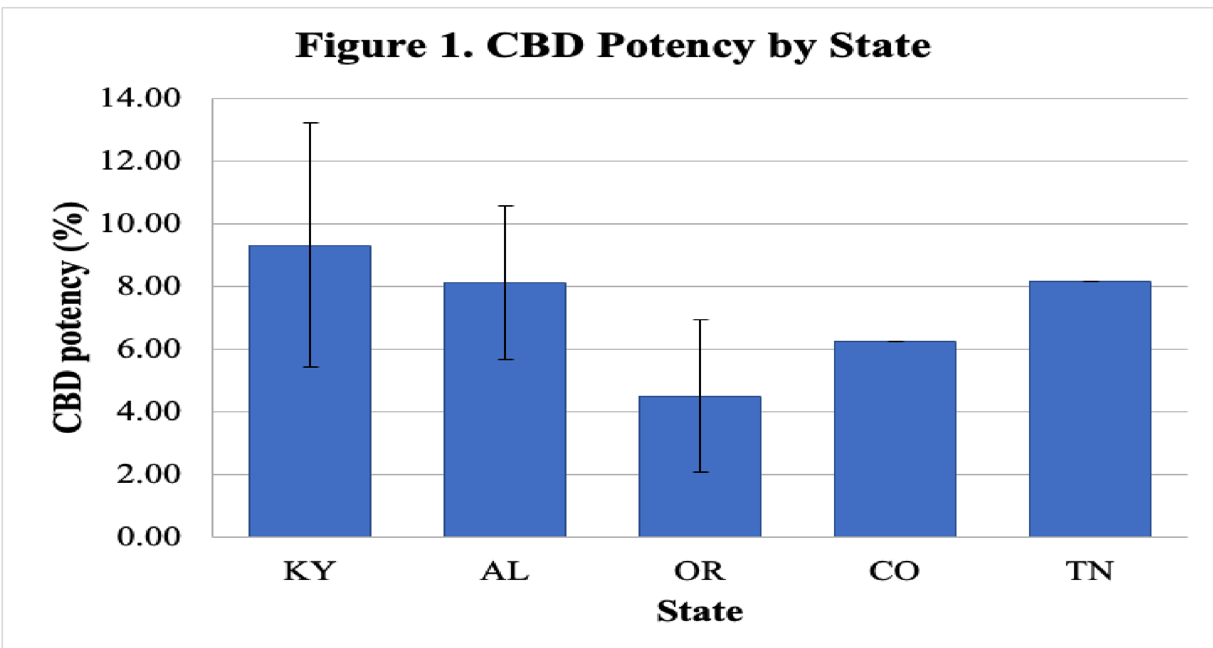
Source: Original data collected and analyzed by the author.

Table 2 – Aggregate of samples by state displaying the number of samples, the CBD Potency Percentage, the Moisture Percentage, the Buds mass in grams, the Stems mass in grams, the Seeds mass in grams, the Leaves mass in grams, and the Fine Biomass in grams.

	Total Samples	Potency (%)	Moisture (%)	Buds (g)	Stems (g)	Seeds (g)	Leaves (g)	Fine Biomass (g)
All Samples	30	8.10	11.63	17.41	1.23	0.62	33.16	46.40
AL	7	8.13	12.10	11.61	0.29	0.02	45.27	41.59
CO	1	6.23	7.03	32.40	8.20	0.00	39.73	18.31
KY	16	9.31	12.23	24.63	1.23	1.09	30.85	40.88
OR	5	4.51	9.97	2.90	1.27	0.16	28.93	65.93
TN	1	8.18	11.76	0.00	0.47	0.26	0.00	98.95

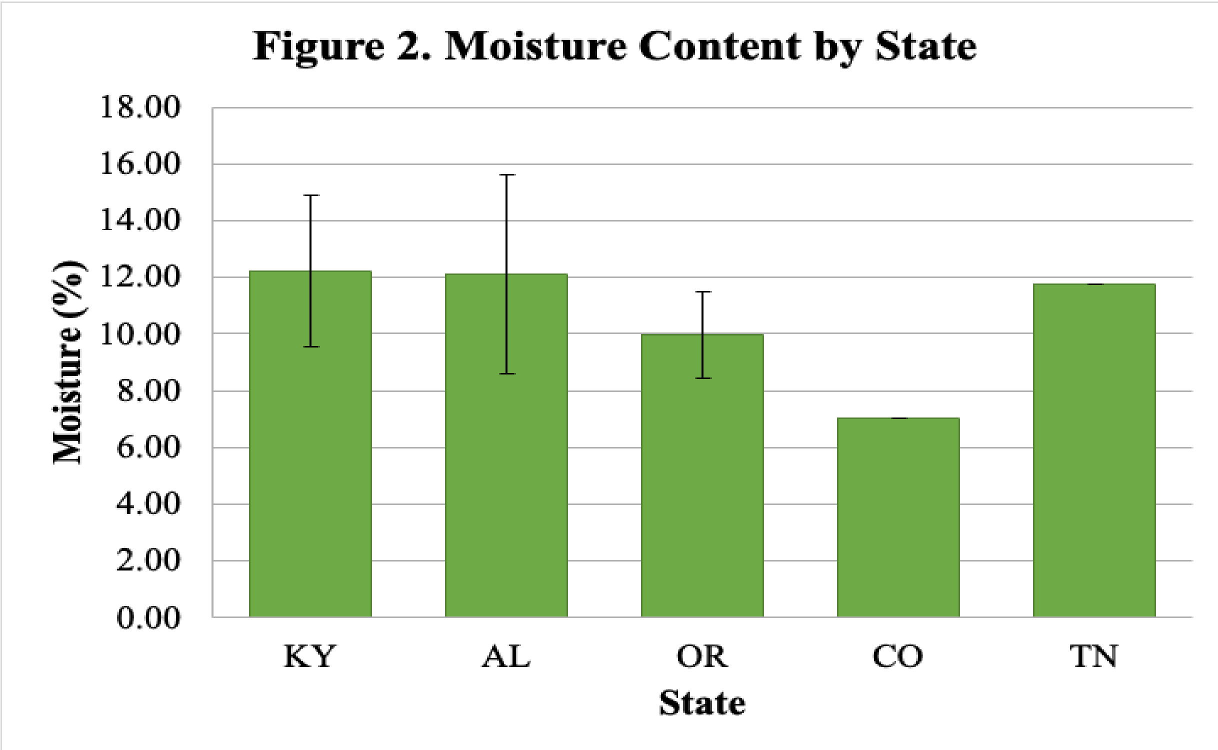
Source: Original data collected and analyzed by the author.

Figure 1 – Mean CBD potency (%) of hemp biomass samples by state. Error bars represent ±1 standard deviation. Colorado and Tennessee each consisted of a single sample; therefore, no standard deviation is shown.



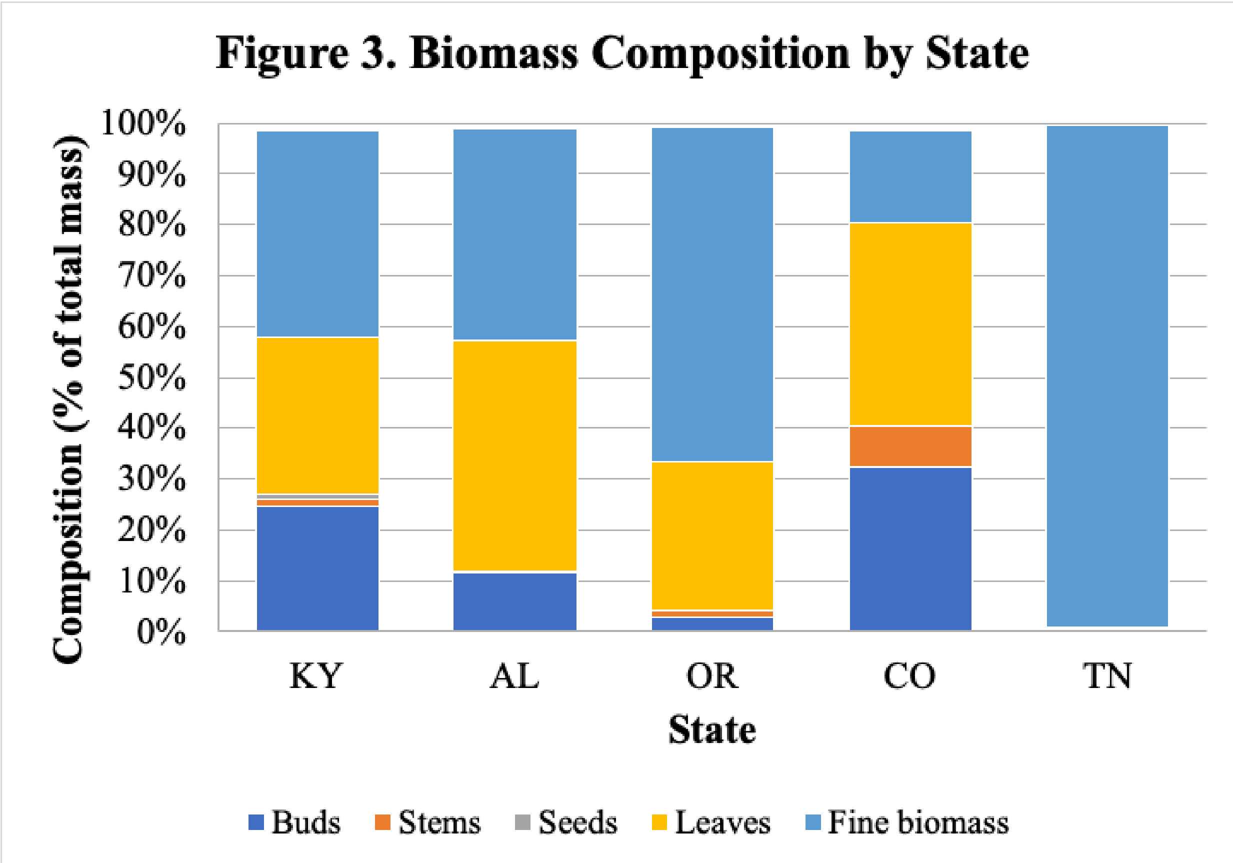
Source: Original data collected and analyzed by the author.

Figure 2 – Mean moisture content (%) of hemp biomass samples by state. Error bars represent ±1 standard deviation. Colorado and Tennessee each consisted of a single sample.



Source: Original data collected and analyzed by the author.

Figure 3 – Average biomass composition by state expressed as the percentage of total biomass weight. Bars represent the mean proportion of buds, stems, seeds, leaves, and fine biomass for each state.



Source: Original data collected and analyzed by the author.

DISCUSSION AND CONCLUSION

The goal of this study was to create a standardized framework for grading and characterizing hemp biomass. By analyzing key biomass components such as CBD potency, moisture content, and biomass composition, we identified several statistically significant relationships and differences among the sampled hemp populations.

The results indicate that CBD potency is correlated with moisture content ($r=0.58$, $p = 0.00084$) and bud mass ($r=0.80$, $p < 0.000001$), supporting the importance of bud-rich biomass for high-yield CBD extraction. A moderate negative correlation was also observed between distance to Kentucky and CBD potency ($r = -0.49$, $p = 0.006$). Within this dataset, samples collected farther from Kentucky generally exhibited lower average CBD potency. However, the factors responsible for this relationship were not directly measured and should therefore be interpreted as possible explanations rather than causal conclusions.

Additionally, seeds and stems demonstrated a weak correlation, with CBD potency, suggesting minimal value in extraction. Within the sampled population, Alabama exhibited the greatest volatility in CBD potency (SD = 3.50). This variability may reflect differences in cultivation practices, environmental conditions, genetics, or post-harvest processing; however, these factors were not directly evaluated in this study.

Furthermore, our data suggest that sample size does not directly impact potency volatility ($r = 0.26$, $p > 0.05$).

As demonstrated by this study, there is considerable variability in hemp processing and hemp biomass composition. The findings demonstrate substantial variability in hemp biomass composition and CBD potency across the sampled population. A standardized grading framework based on these characteristics could address this variability and assist processors and growers in improving biomass evaluation, pricing consistency, harvest practices, and quality control throughout the hemp supply chain. Without such a framework, variability in hemp biomass quality and composition is not consistently characterized or communicated across the industry.

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