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Health Benefits and Adverse Effects of Kratom: A Social Media Text-Mining Approach

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Health Benefits and Adverse Effects of Kratom: A Social Media Text-Mining Approach

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Abstract: Background: Kratom is a substance that alters one's mental state and is used for pain relief, mood enhancement, and opioid withdrawal, despite potential health risks. In this study, we aim to analyze the social media discourse about kratom to provide more insights about kratom's benefits and adverse effects. Also, we aim to demonstrate how algorithmic machine learning approaches, qualitative methods, and data visualization techniques can complement each other to discern diverse reactions to kratom's effects, thereby complementing traditional quantitative and qualitative methods. Methods: Social media data were analyzed using the latent Dirichlet allocation (LDA) algorithm, PyLDAVis, and t-distributed stochastic neighbor embedding (t-SNE) technique to identify kratom's benefits and adverse effects. Results: The analysis showed that kratom aids in addiction recovery and managing opiate withdrawal, alleviates anxiety, depression, and chronic pain, enhances mood, energy, and overall mental well-being, and improves quality of life. Conversely, it may induce nausea, upset stomach, and constipation, elevate heart risks, affect respiratory function, and threaten liver health. Additional reported side effects include brain damage, weight loss, seizures, dry mouth, itchiness, and impacts on sexual function. Conclusion: This combined approach underscores its effectiveness in providing a comprehensive understanding of diverse reactions to kratom, complementing traditional research methodologies used to study kratom.

Keywords: kratom; social media analysis; topic mining; LDA; health benefits; adverse effects

1. Introduction

Kratom is a tree with leaves that contain substances that affect a person's mental state [1]. Kratom leaves are smoked, chewed, or brewed and ingested as a herbal solution [2]. Kratom is currently used worldwide for a variety of health-related reasons [3]. It is widely promoted on the Internet and sold as a product for pain relief and mood enhancement [4], with limited standards for safety. According to the literature, kratom has been used to alleviate pain, decrease fatigue, and elevate mood [2,3]. Furthermore, it has been recently used to help alleviate the unpleasant experience associated with opioid withdrawal [4,5]. However, kratom could have many potential health consequences [3], including fatal incidents and potential toxicity [6].

Several studies have examined the benefits and adverse effects associated with kratom use. Grundmann [5] stated that kratom is mainly used for acute or chronic pain, and helping with emotional or mental conditions such as anxiety, depression, or PTSD. Boyer

et al. [7] showed that Kratom could help relieve opioid withdrawal symptoms. Hassan et al. [8] reported that kratom users use it to work harder, be more active, increase sexual desire, and increase appetite. The majority of kratom users use it to enhance physical energy, improve their mood, and overcome fatigue [9]. According to Veltri and Grundmann [10], kratom is used to relieve acute or chronic pain and results in increased energy and focus, lessened depressed mood, lower levels of anxiety, and elevated mood. Furthermore, kratom users reported that they used it as a substitute to avoid other substances that could cause addiction or harm, such as opiates, to enhance social life and elevate their mood [11]. According to a systematic review by Swogger and Walsh [12], kratom is used to relieve negative moods or mental states, have an energizing effect, improving mood, fighting fatigue, and easing boredom. Anand and Hosanagar [13] stated that kratom helps to treat pain, opioid withdrawals, diarrhea, fever, malaria, and diabetes. Another study by Vicknasingam et al. [6] stated that kratom helps with increasing pain tolerance significantly and that kratom has pain-relieving properties based on self-reports collected in observational studies. According to the pharmaceutical assessment of kratom by White [14], kratom can help with withdrawal from substances that require professional help. In addition, Chancellor et al. [15] stated that kratom has been used for pain relief and mood enhancement supplements and alleviates unpleasant experiences associated with opiate withdrawal.

Swogger et al. [11] have qualitatively analyzed kratom information posted on psychoactive substance information websites. The authors found that kratom's adverse effects are related to nausea and stomachache, sweating, dizziness, vomiting, and itching. Other experiences are related to mouth numbness, visual alterations, and sedation. Grundmann [5] has studied kratom's side effects following an anonymous cross-sectional online survey of 8049 respondents. The results showed that kratom could cause nausea, constipation, dizziness/drowsiness, diarrhea, vomiting, heart palpitations, shortness of breath, stomach upset, fainting, irritability or agitation, and high blood pressure. Henningfield, Fant, and Wang [16] have studied the potential abuse of kratom according to the eight factors of the Controlled Substances Act (CSA). The results showed that kratom is associated with different negative side effects, including nausea, stomachache, cramping, alternating chills and sweats, dizziness and unsteadiness, and vomiting. Singh, Narayanan, and Vicknasingam [2] have analyzed the literature to understand the reported side effects associated with kratom use. The results showed that kratom could lead to loss of weight, dehydration, constipation, fatigue, shaking of hands, headaches, tiredness, loss of appetite, stomachaches, alternating between chills and sweats, dizziness, itching, numbness in the mouth and throat, sedation, visual alterations, and unsteadiness. White [14] reviewed the adverse effects associated with kratom use and found that kratom's side effects include tachycardia, hypertension, agitation or irritability, drowsiness, nausea, confusion, tremors, diaphoresis, hypothyroidism, and intrahepatic cholestasis. Finally, Eggleston et al. [17] conducted a retrospective review of kratom exposure and found that kratom use could cause agitation, tachycardia, drowsiness, vomiting, confusion, serious effects of seizure, withdrawal, hallucinations, respiratory depression, coma, and cardiac or respiratory arrest.

Different methodologies have been used to study kratom, including online surveys [5,16], systematic literature reviews [2,10,12,13,18], cross-sectional surveys, cross-sectional studies [19], randomized, placebo-controlled, double-blind studies [6], qualitative methods [11,20], and field face-to-face surveys [21,22]. A few studies used social media data to better understand the public perception of kratom use. Despite these studies, the status of kratom as a dietary supplement remains vague [10], and kratom's adverse effects and potential benefits are poorly documented [4,23]. Most of the reported reasons for using kratom, whether for pain relief or as a substitution for opioids, are only supported by limited basic and preclinical research [3,21,23]. Further, a very limited number of studies have addressed public perception and opinion about kratom using social media data. These studies have either reported sentiments about kratom [21], the adverse effects associated with kratom use [24], or kratom's benefits [23,24].

Given the limited studies on kratom use, this study aims to utilize social media data to understand the benefits and adverse effects of kratom as reported by potential users. A secondary aim is to demonstrate how algorithmic machine learning approaches can be combined with visualization and qualitative methods to discern diverse user reactions to drug effects. Traditional approaches used different quantitative and qualitative methodologies, such as online surveys, cross-sectional surveys, cross-sectional studies, randomized, placebo-controlled, double-blind studies, and field face-to-face surveys. These studies are limited in sample size and can be plagued with inaccurate responses [4,11,18,25,26]. Mining social media can complement these traditional approaches by providing a much larger exposure to the discourse about kratom's benefits and adverse effects. Social media also provides a less-structured medium for potential users to share their experiences. The benefits of leveraging social media for exploring various phenomena have also been affirmed elsewhere. The proposed approach provides a systematic method for mining such content in the context of kratom that can also be applied to other contexts, thereby complementing traditional quantitative and qualitative methods.

This research informs the existing literature about kratom's benefits and adverse effects. Methodologically, it extends prior research [22] by leveraging data analytics to analyze large scale social media data. Practically, it highlights critical information related to kratom's benefits and adverse effects from the public perspective, which can inform regulations, research, interventions, and awareness efforts aimed at mitigating adverse effects.

2. Materials and Methods

Figure 1 shows the methodology followed to identify the benefits and adverse effects of kratom according to the perception of social media users.
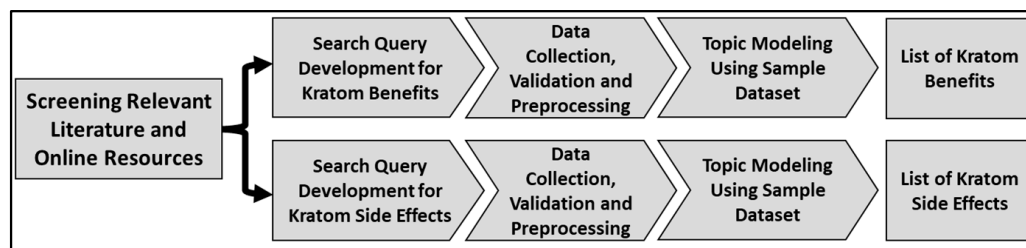

Figure 1. Research methodology.

2.1. Screening Relevant Literature

To identify relevant posts about kratom while minimizing noise commonly found in social media data, the researchers analyzed online resources including Mayo Clinic [27], Medical News Today [28], WebMD, as well as relevant articles [13,26,27,29,30] about kratom use. Based on the researchers' knowledge about kratom, a comprehensive list of relevant keywords that reflect the benefits and adverse effects of kratom were identified.

2.2. Search Query Development

Using the identified list of keywords about the benefits and adverse effects of kratom, two separate queries were developed to identify relevant social media posts about kratom's benefits and adverse effects. Tables 1 and 2 show the queries used to identify posts about kratom's benefits and posts about kratom's adverse effects. The search queries are structured to minimize the potential for cross-contamination. The adverse effects query (Table 2) specifically excludes posts with keywords associated with benefits.

Table 1. Search query for kratom benefits.

(kratom OR Kakuam OR Ketum OR Krathom OR kratom*)
AND (relief* OR alleviat* OR reduc* OR lessen* OR ease OR improv* OR prevent* OR avoid* OR cure* OR withdrawal OR enhance* OR treat* OR help* OR boost*)
AND (fatigue OR pain OR diarrhea OR cramps OR muscle OR libido OR mood OR depress* OR anti* OR suppress* OR addict* OR appetite OR hunger)
AND–(http OR https OR RT)

Table 2. Search query for kratom adverse effects.

(kratom OR Kakuam OR Ketum OR Krathom OR #kratom*)
AND (nausea OR itch* OR sweating OR (dry AND mouth) OR constipation OR (increas* AND urin*) OR appetite OR seizure OR hallucinations OR (muscle AND aches) OR insomnia OR (irritability OR irritable) OR hostility OR aggression OR (emotional AND changes) OR (runny AND nose) OR jerky OR "weight" OR appetite OR chill* OR vomit* OR liver OR "muscle pain" OR dizziness OR dizzy OR drowsiness OR elusion OR depress* OR breath* OR bronchitis OR coma OR death OR rash* OR dermatitis OR diarrhea OR headache OR suicide OR suicidal OR heart OR bleed* OR cancer OR memory, OR addict*, OR Hostil* OR Aggress* OR inability)
AND–(http OR https OR RT)
AND–(relief* OR alleviat* OR reduc* OR lessen* OR ease OR improv* OR prevent* OR avoid* OR cure* OR withdrawal OR enhance* OR treat* OR help* OR boost*)

2.3. Data Collection and Preprocessing

Using the developed search queries, data about kratom's benefits and adverse effects were collected from the Reddit and Twitter social media platforms using BrandWatch. We collected all posts from 1 January 2017 to 31 March 2022.

The collected posts were validated for relevance. A random sample of 100 posts about kratom's benefits and side effects was manually inspected to determine whether these posts discussed kratom's benefits and side effects. Two independent researchers completed the manual validation process to achieve reliability in the labeling process, and the inter-rater reliability (kappa statistic) [31] was calculated to ensure that different researchers would eventually obtain similar results.

To prepare the posts for topic modeling, we have converted all posts to lowercase, removed stop words, removed hashtags and mentions, removed punctuation marks and special characters, removed numbers and words with numbers, removed words that consist of less than three characters, lemmatized each post, and represented each post using bi-grams [32]. Such preprocessing techniques ensure that the input data are cleaned, normalized, and structured in a way that allows topic modeling algorithms to focus on meaningful patterns and relationships within the text [33–35].

2.4. Topic Identification and Validation

Text-mining is an artificial intelligence (AI) technology based on natural language processing (NLP) that is applied to unstructured data and text to extract meaningful and non-trivial patterns or knowledge from the data [36–38]. Topic modeling is a text-mining technique used to identify patterns and knowledge and has demonstrated potential in the health informatics field [34,39–41].

We identified relevant topics about kratom's benefits and adverse effects using the collected data by performing topic modeling using the latent Dirichlet allocation (LDA) algorithm [35,41,42], visualizing and labeling the topics from LDA using PyLDAVis [43] and the t-distributed stochastic neighbor embedding (t-SNE) technique [44], and finally, identifying a list of benefits and adverse effects of kratom use.

Topic models using LDA are considered statistical-based models that help identify themes from unstructured data [40,45]. Such models can help summarize unstructured data, such as text, in an automated fashion and help simplify the process of manual content analysis. In this work, topic models using LDA were optimized using the coherence score

measure [41]. The coherence score was selected to optimize topic models because it is considered to be the best measure for LDA applications that require end-user interaction with the generated topics [40]. It helps provide a better human interpretability of the topics generated [46] compared to other unstable measures like perplexity [45]. While the coherence score appears to increase with the increase in the number of topics, such an increase diminishes as the number of topics increases. Therefore, the optimal number of topics was estimated using an elbow method [41,47].

To label the topics for kratom's benefits and adverse effects, we visualized LDA results using PyLDAVis and t-SNE, and then we labeled each topic using the top thirty relevant keywords within each topic. t-SNE is optimized by simply replacing the default multidimensional scaling (MDS) method with t-SNE for dimensionality reduction in the pyLDAvis visualization. This choice leverages t-SNE's ability to maintain a local structure and create more intuitive visual clusters of topics, leading to a potentially more informative and insightful topic model visualization.

In order to achieve reliability in the labeling process, two independent researchers completed the labeling of topics, and the inter-rater reliability (kappa statistic) [31] was calculated to make sure that different researchers would eventually obtain similar results.

The final list of kratom's benefits and the list of kratom's adverse effects were generated by merging related topics of the LDA topic model. The merging process was performed by comparing the listed topics and their meanings and synthesizing the topics into a final list of high-level topics. This process was conducted by one researcher and validated by another.

3. Results

As shown in Table 1, the collected posts for benefits were selected based on the criteria of having at least one kratom-related keyword, one kratom benefit-related keyword, and one side effect-related keyword. The size of the data collected about kratom's benefits was 57,683 posts, with 50,331 (87.3%) posts collected from Reddit and 7352 (12.7%) posts collected from Twitter. The posts were collected from a total of 22,940 social media users.

As shown in Table 2, the collected posts for adverse effects were selected based on the criteria of having at least one kratom-related keyword and one related side effect and excluding kratom benefit-related keywords. The size of the data collected about kratom's adverse effects was 32,266 posts, with 28,337 (87.8%) posts collected from Reddit and 3929 (12.2%) posts collected from Twitter. The posts were collected from a total of 14,135 social media users. Table 3 summarizes data about the collected posts.

Table 3. Summary statistics about posts collected.

	Benefits		Adverse Effects	
Reddit	50,331	87.3%	28,337	87.8%
Twitter	7352	12.7%	3929	12.2%
#of Social Media Users	22,940		14,135	

The validation process of whether posts discuss kratom's benefits and side effects showed that the majority of the posts were relevant, with a kappa statistic of 0.99, indicating an almost perfect agreement between the two raters about posts being relevant.

3.1. Topic Identification and Validation—Kratom Benefits

Based on the coherence score and the elbow method, LDA optimization yielded an estimated parameter value of 52 topics, as shown in Figure 2.
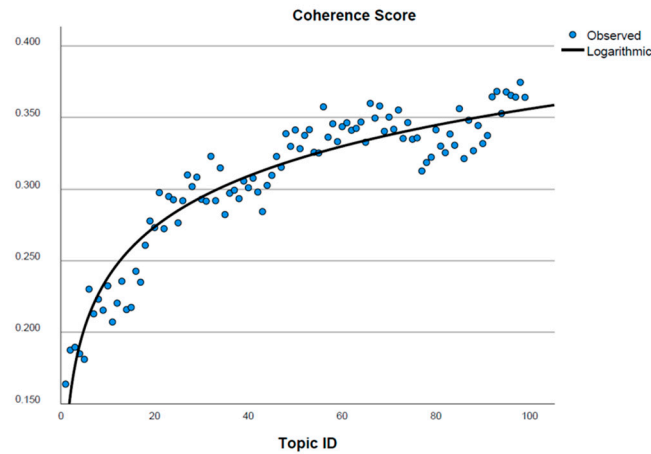
Figure 2. Optimal number of kratom benefit topics based on coherence score.

The LDA model results were visualized using PyLDAVis and t-SNE (Figure 3) and analyzed by two independent researchers.

Figure 3. Kratom benefit topic visualization and analysis through PyLDAVis using t-SNE.

The analysis and labeling process returned eight topics regarding kratom's benefits, as shown in Table 4 (see Appendix A for example posts). We achieved a kappa statistic of 0.86, indicating almost perfect agreement between the two raters [31].

Table 4. Kratom benefits identified through topic-mining.

Kratom Benefits	Percentage
Help with Addiction and Opiate Withdrawal	32.49%
Relief Anxiety and Depression	26.08%
Chronic Pain Relief and Pain Management	22.49%
Mood and Energy Improvement	7.23%
Improve Mental Health and Improve Life	5.46%
Help with Blood Pressure	2.79%
Improve Sex Drive	1.88%
Help Fall Asleep	1.57%

3.2. Topic Identification and Validation—Kratom Adverse Effects

Based on the coherence score and elbow method, LDA optimization yielded an estimated parameter value of 54 topics, as shown in Figure 4.
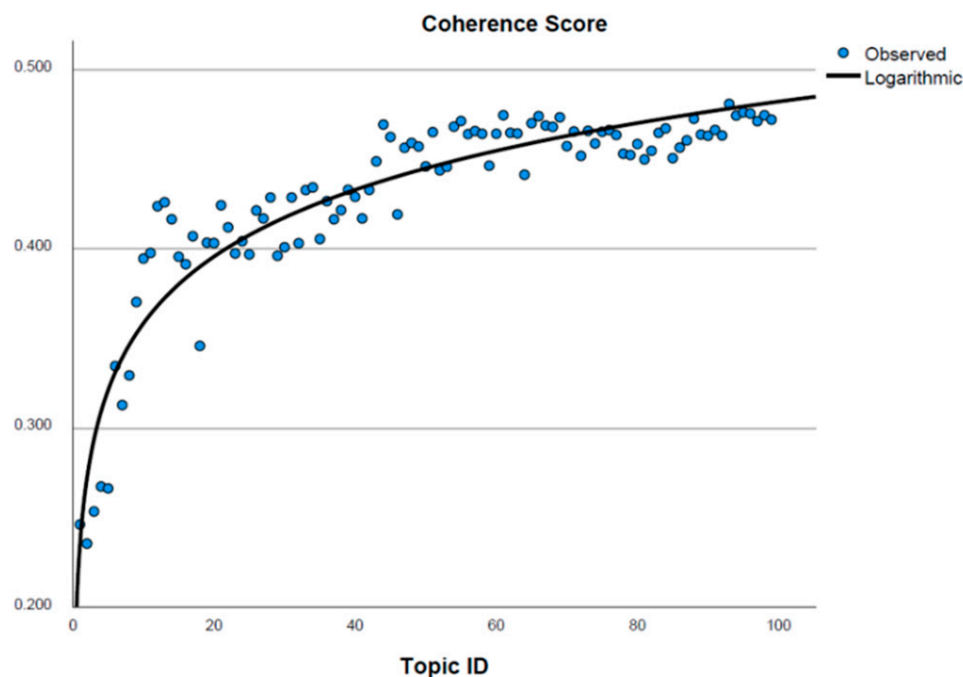
Figure 4. Optimal number of kratom adverse effects topics based on coherence score.

The LDA model results were visualized using PyLDAVis and t-SNE (Figure 5) and analyzed by two independent researchers.
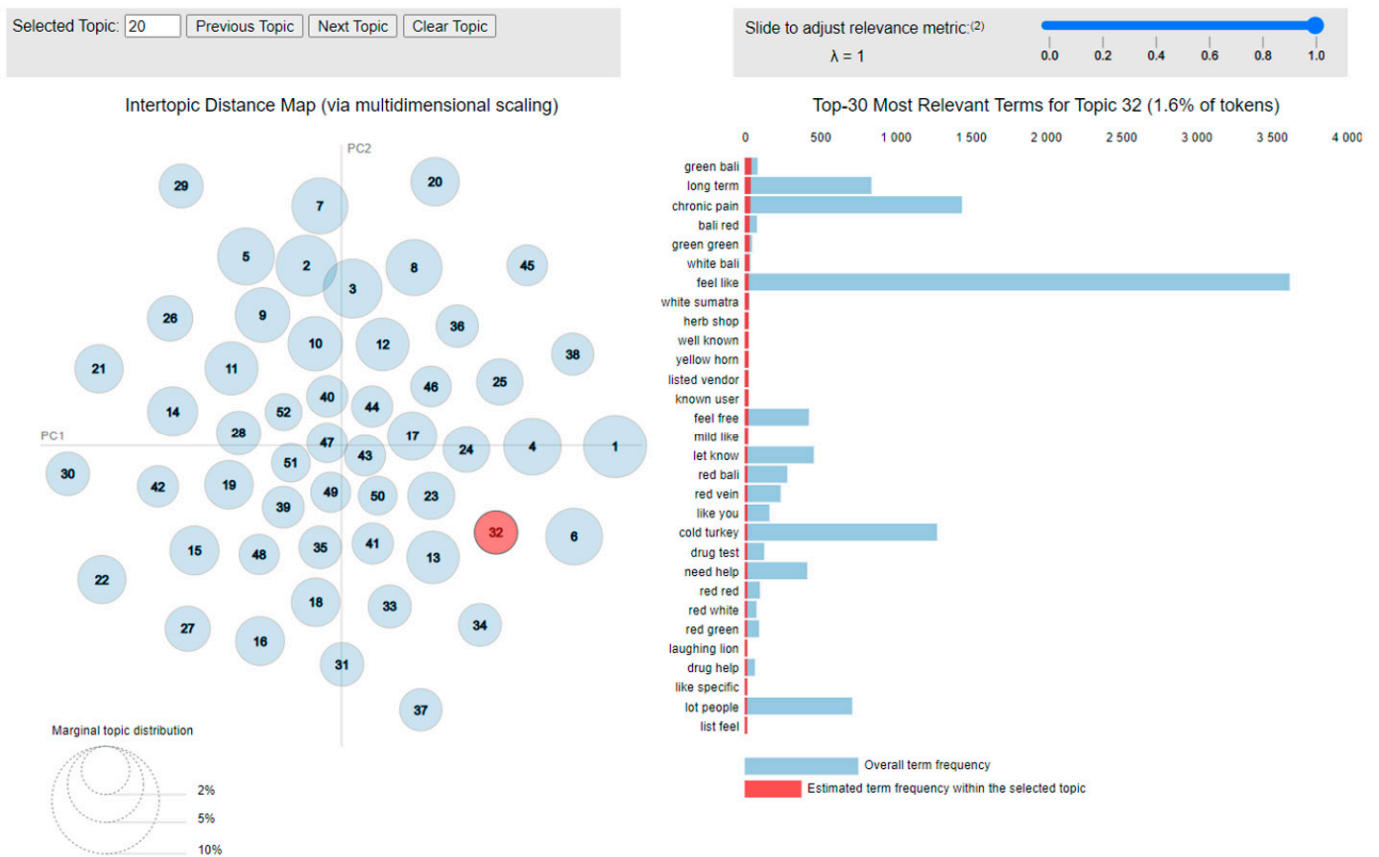
The analysis and labeling process returned 14 topics regarding kratom's adverse effects, as shown in Table 5 (see Appendix B for example posts). We achieved a kappa statistic of 0.91, indicating an almost perfect agreement between the two raters [31].

Table 5. Kratom adverse effects identified through topic-mining.

Kratom Adverse Effects	Percentage
Cause Nausea	46.80%
Upset Stomach and Constipation	12.60%
Heart Related Issues (Heart Attack, Cardiac Arrest, Heart Racing)	9.00%

Table 5. *Cont.*

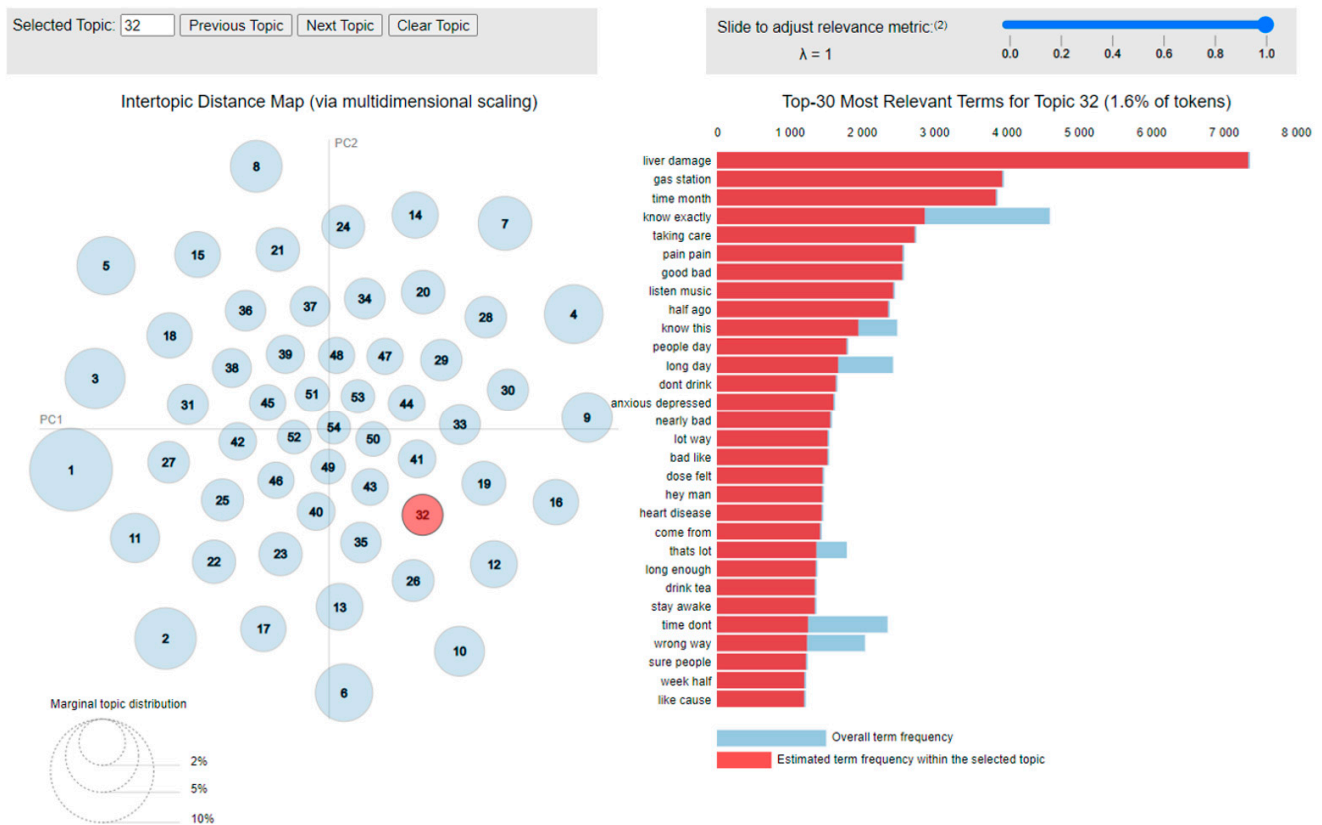| Kratom Adverse Effects	Percentage
Respiratory System Issues (Shortness of Breath, Respiratory Depression, Stop Breathing)	8.00%
Liver related issues (Liver Damage, Liver Pain, Liver Failure)	6.80%
Brain Damage and Cause Death	4.70%
Weight Loss	3.40%
Seizure	3.20%
Stay Hydrated—Dry Mouth	2.20%
Hair Loss	1.00%
Elevated Temperature	0.80%
Scratch Itch	0.80%
Runny Nose	0.50%
Kill Sex Life and Suppress Sex Drive	0.30%

Figure 5. Kratom adverse effects topic visualization and analysis through PyLDAVis using t-SNE.

4. Discussion

In this study, we have demonstrated the potential for applying text-mining and visualization techniques to analyze social media data concerning the benefits and adverse effects of kratom. The methodology involved extensive preprocessing, including text normalization, stop word removal, and lemmatization, to prepare the posts for subsequent analysis followed by topic modeling using the latent Dirichlet allocation (LDA) algorithm to identify meaningful patterns and topics within the collected data. To facilitate the labeling of topics obtained from LDA, the methodology leveraged advanced visualization techniques such as PyLDAVis and t-distributed stochastic neighbor embedding (t-SNE) to visualize the

LDA model results. Overall, this research provides a robust foundation for understanding kratom's effects, and its findings have several implications for both the academic field and practical applications. In essence, the methodology allowed us to analyze and label the topics more effectively by providing a clear and intuitive representation of the data and ultimately to extract valuable insights into kratom's benefits and adverse effects, providing a robust foundation for our research findings. In addition, the findings of this study can help increase public awareness about the benefits and adverse effects of kratom, as well as inform and enhance decision-making and safety regarding kratom use and legalization.

4.1. Kratom Benefits

This research expanded the existing literature on the use of social media data to address the benefits and health impacts of kratom. In terms of benefits, the findings inform the existing literature that reported health benefits of kratom use like chronic pain relief and pain management [5,6,10,22,48,49], addiction and opiate withdrawal [5,13–15,22,48], anxiety and depression relief [5,10], help falling asleep [50], improving sex drive [22,49,51,52], improving mental health and quality of life [11,12,52], and improving mood and energy [12,13,15,52]. Overall, the results revealed that kratom helps with easing aches, relieving and reducing pain, managing pain, overcoming and easing unpleasant adverse effects of opioid addiction and withdrawal, self-treating symptoms of depression and anxiety, inducing sleep and treating sleep disorders like insomnia, enhancing sexual performance, increasing sex drive and desire, boosting libido, helping with mental health woes, helping with emotional or mental conditions, helping to cope with stressful life events, and boosting mood and increases in body energy. In addition, the results indicate that kratom helps lower blood pressure, which has not been reported in clinical trials and would warrant future clinical research.

The practical applications of these findings are significant. For instance, individuals suffering from chronic pain or those seeking to overcome opioid addiction might consider kratom as part of their treatment regimen. Additionally, healthcare providers could explore kratom's potential as an alternative therapy, potentially reducing reliance on traditional painkillers and supporting mental health improvements. However, it is essential for users and healthcare providers to be aware of the correct dosages and monitor for any adverse effects.

4.2. Kratom Adverse Effects

Our research also delves into the adverse effects of kratom, supporting the existing literature that reported adverse effects like brain damage and death [7,13,14,53–55], nausea [5,10,11,13,14,53,54], hair loss [3,13,49,54], heart-related issues [13,52,56,57], elevated temperature/hot flashes [9,57], decreased sex drive [58–60], liver-related issues [11,53], runny nose [2,20,61], itching [11,13,14,54,60], seizure [13,14,53,54], respiratory system issues [3,7,13,54], dry mouth [13,53,54], upset stomach and constipation [5,11,13,53,54,58,60], and weight loss [3,8]. In essence, kratom could cause nausea, brain damage, and lead to death; additionally, it may result in hair loss, lead to heart-related issues including heart palpitations, cardiac arrest, heart attacks, and heart racing. Further, it may lead to increased body temperature, suppressing sex drive and causing low libido, liver-related issues including liver pain and failure, runny nose, itching and scratches. Kratom use could also cause seizure, shortness of breath, respiratory depression, dehydration and dry mouth, upset stomach, abdominal pain, constipation, and weight loss. Consistent with [60], our study revealed that the effect of kratom on the 'sex drive' was controversially perceived. Many social media users reported that kratom improved their sexual drive, while some experienced negative effects. Such findings warrant further investigation using in-depth laboratory studies. This duality in user experiences suggests that kratom's effects can vary significantly among individuals, possibly due to differences in dosage, individual physiology, or the concurrent use of other substances.

The implications of these findings are critical for public health and safety. While kratom may offer several benefits, the potential for severe adverse effects necessitates

caution. Regulatory bodies and healthcare professionals should consider these risks when advising on or regulating kratom use. Additionally, our findings highlight the need for further research to understand the dose-dependent nature of kratom's effects, which could inform safer usage guidelines and reduce the likelihood of adverse outcomes.

4.3. Linking Findings to Research Questions and Hypotheses

This study aimed to explore both the benefits and adverse effects of kratom as perceived by social media users. Our findings align well with the research questions, providing comprehensive insights into the dual nature of kratom's effects. The hypotheses that kratom offers significant benefits in pain relief, addiction treatment, and mental health improvement are supported by our results. Similarly, the hypotheses regarding the potential for adverse effects are corroborated by the reported negative outcomes.

4.4. Implications for the Field and Practical Applications

The implications of this study are multifaceted. For the field of health informatics and public health, our research highlights the utility of social media data as a rich source of real-world evidence. The methodology demonstrated here can be applied to other substances or health topics to gauge public perception and experiences comprehensively.

Practically, the findings underscore the importance of balanced and informed decision-making regarding kratom use. While it offers promising benefits, the associated risks cannot be overlooked. Public health campaigns should aim to educate users about both the potential advantages and dangers of kratom, promoting informed and safe use. Healthcare providers should remain vigilant and consider individual patient contexts when discussing or recommending kratom as a therapeutic option.

4.5. Limitations and Future Research

This research is not without limitations. First, the analysis process of the results from topic modeling was very challenging given the mixed nature of the text analyzed, where part of the text was short and focused—posts from Twitter, while the other part was lengthy and detailed—posts from Reddit. Second, the queries were not able to completely filter irrelevant posts as the search queries were mainly developed to identify any post with kratom-related keywords as well as other relevant keywords. Third, the adverse effects and benefits of kratom could be dose-dependent. Fourth, the percentage reported is based on the fact that a post belongs to a specific topic. However, the LDA topic modeling algorithm provides a probability distribution for each post over all topics. Accordingly, a post can belong to more than one topic. The strength of membership is captured by the respective probability that a given post belongs to a specific topic. Finally, while we utilized social media data to gain insights into reported experiences, it is crucial to acknowledge that the content retrieved may not exclusively represent testimonials from kratom users. The inherent nature of online platforms introduces the potential for the inclusion of propaganda and disinformation.

Future research may focus on heavy kratom users to explore their experiences comparatively. Furthermore, there is a need to address the issue of fake news and misinformation on social media to have a more reliable dataset for analysis. Future studies may also need to focus on the challenges associated with analyzing text of variable lengths and its implications on the results obtained from social media analytics. Finally, advanced artificial intelligence techniques could help better understand social media content and reveal more useful information about kratom's benefits and adverse effects.

5. Conclusions

In this study, we have examined the benefits and adverse effects of kratom by analyzing social media data collected from Reddit and Twitter using custom queries based on the existing literature. Data about benefits and adverse effects were analyzed separately using topic modeling. Results showed that kratom is associated with several benefits

including chronic pain relief and pain management, helping with addiction and opiate withdrawal, providing relief for anxiety and depression, aiding in falling asleep, improving sex drive, helping with blood pressure, improving mental health, and improving life, mood, and energy. On the other hand, kratom has significant adverse effects. These adverse effects include brain damage and death, nausea, hair loss, heart-related issues, elevated temperature and hot flashes, killing and suppressing sex drive, liver-related issues, runny nose, itching, seizure, respiratory system issues, dry mouth, upset stomach, constipation, and weight loss.

This study addresses a critical gap in the literature by using a machine learning-based approach to explore the health benefits and adverse effects of kratom from user-generated social media content, which provides real-time and large-scale data. Traditional studies often rely on controlled clinical settings or self-reported surveys, which may not capture the full spectrum of user experiences. The proposed approach uses the state of art topic mining, specifically the latent Dirichlet allocation (LDA) algorithm [50,51], to automatically extract themes from data.

The LDA model results were visualized using the PyLDAVis method [43], a web-based interactive visualization method for visualizing and interpreting topics. In this method, we used the t-distributed stochastic neighbor embedding (t-SNE) technique, which visualizes high-dimensional data by giving each data point a location in a two or three-dimensional map [44]. This interactive visualization method shows the most useful terms for interpreting a given topic and allows researchers to interactively adjust this determination. Researchers can select a topic on the left of the visualization to unveil the most useful words on the right for easily interpreting the chosen topic. Therefore, it enables researchers to explore many topic–word relationships in a compact manner.

Our methodology is different in that it integrates advanced visualization techniques with machine learning, providing a novel way to analyze and interpret large volumes of social media data. Before applying the methodology, we ensured that key assumptions for topic modeling and data preprocessing were satisfied, such as the independence of topics and the normalization of text data. This rigorous approach ensures the validity and reliability of our findings. The proposed approach could complement traditional quantitative and qualitative methods to discover health benefits and adverse reactions to drugs from large scale data collected from social media.

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Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Data were collected from Reddit and Twitter social media platforms using BrandWatch. The data could be obtained by running the queries in Brandwatch.

Appendix A. Example Posts for Kratom Benefits Identified through Topic-Mining

Kratom Benefits	Example Posts
Chronic Pain Relief and Pain Management	*"I take #kratom for chronic pain", "I'll have chronic pain the rest of my life, kratom lets me manage it without the brain fog or side effects of meds, now they're trying to ban it", "kratom has helped me with pain management", "taking kratom which helps my daily chronic pain. I took an extra dose to help with the pain. It seems to have calmed down a little unless I move the wrong way", "taking kratom which helps my daily chronic pain. I took an extra dose to help with the pain. It seems to have calmed down a little unless I move the wrong way", and "I live with chronic pain but it's very manageable while taking kratom. I don't take narcotics anymore because of the help I receive from Kratom"*
Help with Addiction & Opiate Withdrawal	*"kratom has helped give me 440 days of freedom from a decade long pill addiction", "kratom helped me get away from the chains of addiction", "I got off of hydrocodone because I got so addicted to them. It's poison! Kratom helps all my symptoms without addiction", "I take this every day. It helped me get over an addiction to opiates. I'm so thankful for Kratom!", "with the help of #kratom I am able to go to work today and provide for myself. Something I couldn't do while I was deep in my addiction", and "Kratom kills withdrawal symptoms from pain meds as well as head drugs. Use it as a tool to help you! I can show you how"*
Relief Anxiety and Depression	*"Kratom and Kava are two of my favorites for anxiety, depression, and pain relief. I've used them for a decade", "You should try some kratom. Helping my depression and anxiety. Really really helping my depression", "I use Kratom for pain & anxiety", "It also helps my anxiety and severe stomach issues", "It helps me with no side effectsadverse for Bipolar 1, PTSD, Anxiety, ADD and Chronic Fatigue", and "I'm a big hype man for kratom as a herbal anxiety medication. I used to take all kinds of medications for it that inevitably made my depression worse and started using kratom powder to get myself off benzos. It has massively helped both my anxiety and depression"*
Help Fall Asleep	*"Ever since my friend told me about kratom a few years ago, it has turned my life around so much!!!!! My anxiety is a lot better now, (I'm still a generally quiet person though) I sleep much better at night without laying in my bed for multiple hours at a time looking at the ceiling, waiting to fall asleep", "Couldn't agree more, interesting how something that helps me to stay energized and motivated to be productive during the day also helps me to fall asleep"*
Improve Sex Drive	*"Not obsessively thinking about Kratom all the time. Sex drive returning and appetite improving. Feelings of nausea diminishing. Good stuff", "So far, I'm finding a lot of motivation in my renewed sex drive and appreciation for music", "Within 15 min the effects of this powder were in full force. it was as if I had taken some type of sexual enhance", "I jumped off Kratom taking 20 g/day for 6 months and felt nothing. Just started taking it again strictly for the health benefits. My blood pressure and sex drive were amazing when I was taking it"*
Help with Blood Pressure	*"Kratom is very effective at treating pain, depression, very safe and fights high blood pressure", "Helps with anxiety, blood pressure", "Kratom was doing fine ability to lower blood pressure", "Kratom takes away pain (lowers blood pressure)"*
Improve Mental Health and Improve Life	*"I mostly use it for mental health but have also managed pain with it", "it helps me with pain energy and mental health, and it detoxes you", "Have you tried #kratom ? It's done wonders for my mental health", "I'm having a hard time stopping using kratom. It has actually improved my life so far", and "I took Kratom for ptsd and anxiety and depression. Worked wonders on all three and improved my life drastically"*
Mood and Energy Improvement	*"Kratom has helped me tremendously with energy and mood", "I have more energy and a better mood", "Now I enjoy kratom for hunger suppression and mood enhancement, and there are a few carbs along for the ride", "More energy and mood lift for sure. I'm the same way. I like kratom for mood lift, energy but also for the pain relief", and "I take it in the mornings for anxiety and the mood lift"*

Appendix B. Example Posts for Kratom Adverse Identified through Topic-Mining

Kratom Adverse	Example Posts
Brain Damage and Cause Death	*"Tradition of non-science explains how kratom gets labeled cause of death by "coroners"", "kratom as an anticancer agent. It has #psychoactive potential, but could it also cause frontal lobe brain damage", "New Information on the Death of ***** by Kratom overdose claim", "kratom led to seizures and significant brain damage", and "I can hardly remember words for the life of me. I have an extensive vocabulary oh, but I'm not sure whether to blame it on brain damage or using too much kratom"*
Cause Nausea	*"I have had intense nausea every time I've used Kratom", "No. But I've experienced nausea on large doses of Kratom", "Kratom nausea isn't the same deal. Careful friend", "Yea, nausea is a very common side effect of Kratom use", and "Kratom and beer sounds vomit inducing. Nausea city"*
Hair Loss	*"Daily use of very high doses like 15-50g can cause rapid hair loss and a lil liver damage but yea kratom usually pretty safe", "True but Kratom can become a pretty nasty habit in itself. Personally, hair loss, weight loss, depression after long term use", "I lost weight and muscle mass and hair loss constipation, looked like a cancer patient. And I couldn't stop taking kratom", "I'd say the hair loss thing should be a warning on all packages of kratom if it remains legal", and "Eating Kratom a lot leads to constipation, eating unknown traces of heavy metals, constipation, hair loss, and many other things"*
Heart Related Issues (Heart Attack, Cardiac Arrest, Heart Racing)	*"Yeah, Kratom makes my heart race really bad. Ended up in the ER once", "Kratom slows your heart, anesthesia slows it a shit load more. Stop taking it now", "Kratom can mess with the heart rate so I really wouldn't recommend mixing it with speed", "Kratom has some calcium channel blocking compounds so be careful with that and your heart", and "coworker of mine started doing kratom. Had an enormous heart attack three weeks later"*
Elevated Temperature	*"My body temperature does get crazy sometimes from kratom, only specific batches", "I also switch strains and vendors too that I used to keep a steady rotation on my body would have chills then go onto sweats the fluctuating body temperature is horrible", "It's great for pain and mood but can make hot flashes/sweating worse", and "I find that kratom itself can give me hot flashes though and I'll start sweating profusely at times"*
Kill Sex Life and Suppress Sex Drive	*"Kratom took away my sexual desire and drive", "Both kratom and Lexapro will suppress sex drive and functioning", "Side note, I am sexually useless on days I use kratom", and "Nobody really knows what the actual side effects are from kratom, especially with disorders like depression, but there is definitely a hormonal side effect based off a lot of anecdotal evidence of lowered sex drive"*
Liver related issues (Liver Damage, Liver Pain, Liver Failure)	*"Just to let ya'll know, it's not all propaganda that Kratom is dangerous. I suffered liver damage from a small amount of Kratom", "I also had liver problems after Kratom. Just weed for me now", "Mixing booze with kratom is actually quite nice, but surely hard on the liver", "kratom appears to be cardio and liver toxic actually", and "Looks like my liver and long term Kratom use don't like each other"*
Runny Nose	*"Having my own surgery tomorrow after a week break from Kratom. Main issue for me has been runny nose", "I quit kratom CT taking roughly 3g a day and only got a stomachache, runny nose, and a bit moody for like 2-3 days", "5 years of kratom here, I've been on the same dosage since I started and only get a runny nose, and some lethargy", "I get a runny nose from kratom too, I have no solutions other than take less", and "I have not had that experience, at most it lasts 2 days with runny nose and maybe some trouble sleeping for a night"*
Scratch Itch	*"Long term kratom user from multiple sources and vendors, itching is very common", "It didn't happen at first, she loved kratom...but in a few days, she started itching, then hived out bad", "I get itching from kratom and pretty much any other opioid or opiate", "Itching is DEFINITELY a side effect of kratom, just as it is with other classic opioids", and "if I take kratom every day, I get rashes within a week"*
Seizure	*"I had a seizure last time I took Kratom", "Had a seizure a couple months ago. Only thing I had was Kratom", "The first time I took phenibut, kratom and adderall I had a seizure", "yeah I know it sounds stupid but when I had the seizure I was just on kratom", and "my cousin had a seizure from drinking too much kratom"*
Respiratory System Issues (Shortness of Breath, Respiratory Depression, Stop Breathing)	*"Kratom does cause respiratory depression, at least a little bit", "Benzos plus kratom can lead to respiratory depression. Be safe", "Yea do not ever mix an opiate and kratom, that will give anyone respiratory depression", "It does not cause respiratory depression. And you're fine, not a single person has died from kratom alone", and "kratom does cause respiratory depression, for me. It's identical to opiates. Again, this is just my experience"*
Stay Hydrated–Dry Mouth	*"Kratom made me feel emotionless, dizzy, and gave me a dry mouth", "Been trying different strains and have dry mouth", "Hmm, Kratom doesn't cause me dry eyes but a dry mouth is another story", "I do know Kratom makes me very thirsty and dries out my mouth", and "Although Kratom is a very safe herb taking too much for your metabolism can lead to nausea/vomiting, loss of libido, dry mouth, constipation"*
Upset Stomach and Constipation	*"I like Kratom but I do not like the constipation it causes", "Although Kratom is a very safe herb taking too much for your metabolism can lead to nausea/vomiting, loss of libido, dry mouth, constipation", "I quit kratom CT taking roughly 3g a day and only got a stomach ache, runny nose, and a bit moody for like 2-3 days", "Don't mix immodium and kratom. Kratom causes constipation", and "Kratom. Wasn't really worth it for the nausea and constipation"*
Weight Loss	*"True but Kratom can become a pretty nasty habit in itself. Personally, hair loss, weight loss, depression after long term use", "Yes and the weight loss is why I'm stopping kratom", "Thanks for the suggestion but I think that kratom is behind this, possibly indirectly from causing weight loss", "I am dealing with excessive weight loss right now and suspect kratom has something to do with it", and "Kratom usually takes my appetite so that causes weight loss"*

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