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ORIGINAL

Bioactive Compound Composition in Tea Varieties and Gambir for Biomedical Potential

Composición de Compuestos Bioactivos en Variedades de té y Gambir para su Potencial Biomédico

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ABSTRACT

A comparative study of Tea Varieties (Green Tea, black tea) and Gambir sourced from Indonesia is crucial for understanding their potential as natural therapeutic agents. This research aimed to analyze and compare the moisture, ash, catechin, and tannin content of these three plant-based products. The study employed a quantitative descriptive method, with data analysis conducted using the One-Way Analysis of Variance (ANOVA) to assess significant differences between the samples. The primary sources of information were laboratory measurements. The results show significant variations in all tested parameters. Gambir had the highest catechin and tannin content, at 11,51 mg/g and 6,50 mg/g, respectively, surpassing both green tea and black tea. Green tea exhibited the highest moisture and ash content, while gambir had the lowest. The findings highlight the unique chemical profile of each plant, with gambir's high catechin concentration making it a valuable, yet underutilized, source for therapeutic applications. The distinct chemical and physical profiles of these plants underscore the importance of standardized quality control measures to ensure their consistency and efficacy. This research provides a crucial foundation for the development of standardized herbal products and supports future investigation into the biomedical potential of these indigenous Indonesian resources. This study, through a comprehensive comparative analysis of green tea, black tea, and gambir, confirms their distinct chemical compositions. These findings serve as a valuable resource for future research aimed at isolating specific Bioactive Compounds and exploring their mechanisms of action in various disease models.

Keywords: Bioactive Compounds; Catechins; Gambir; Tea Varieties; Tannins.

RESUMEN

Un estudio comparativo de las variedades de té (té verde, té negro) y gambir procedentes de Indonesia es fundamental para comprender su potencial como agentes terapéuticos naturales. El objetivo de esta investigación era analizar y comparar el contenido de humedad, cenizas, catequinas y taninos de estos tres productos de origen vegetal. El estudio empleó un método descriptivo cuantitativo, y el análisis de los datos se realizó mediante el análisis de varianza unidireccional (ANOVA) para evaluar las diferencias significativas entre las muestras. Las principales fuentes de información fueron las mediciones de laboratorio.

Los resultados muestran variaciones significativas en todos los parámetros analizados. El gambir tenía el mayor contenido de catequina y tanino, con 11,51 mg/g y 6,50 mg/g, respectivamente, superando tanto al té verde como al té negro. El té verde presentaba el mayor contenido de humedad y cenizas, mientras que el gambir tenía el más bajo. Los resultados ponen de relieve el perfil químico único de cada planta, ya que la alta concentración de catequina del gambir lo convierte en una fuente valiosa, aunque infrautilizada, para aplicaciones terapéuticas. Los distintos perfiles químicos y físicos de estas plantas subrayan la importancia de las medidas de control de calidad estandarizadas para garantizar su consistencia y eficacia. Esta investigación proporciona una base crucial para el desarrollo de productos herbales estandarizados y respalda futuras investigaciones sobre el potencial biomédico de estos recursos autóctonos de Indonesia. Este estudio, a través de un análisis comparativo exhaustivo del té verde, el té negro y el gambir, confirma sus distintas composiciones químicas. Estos hallazgos constituyen un recurso valioso para futuras investigaciones destinadas a aislar compuestos bioactivos específicos y explorar sus mecanismos de acción en diversos modelos de enfermedades.

Palabras Clave: Compuestos Bioactivos; Catequinas; Gambir; Variedades de Té; Taninos.

INTRODUCTION

Tea, derived from the leaves of *Camellia sinensis*, ranks among the most consumed beverages in the world. The popularity of tea results from its various types, which depend on processing methods. The two main varieties, green tea and black tea, differ in their bioactive compounds due to different oxidation processes. Green tea undergoes minimal oxidation, which preserves high catechin levels, including epigallocatechin gallate (EGCG). These catechins have well-documented antioxidant, anti-inflammatory, and neuroprotective effects.[1,2] In contrast, black tea undergoes full oxidation, resulting in the conversion of catechins to theaflavins and thearubigins, compounds that not only alter the flavor profile but also contribute to potential health benefits, including improved cardiovascular health and metabolic regulation.[3,4]

Gambir (*Uncaria gambir Roxb.*), a medicinal plant native to Indonesia, is primarily composed of catechins and tannins. These compounds share similar health-promoting properties with tea, exhibiting strong antioxidant, anti-inflammatory, and antimicrobial activities.[1,5] Research highlights their relevance in wound healing and digestive health, paralleling the benefits associated with the consumption of tea.[1,5] The presence of these bioactive constituents connects gambir and tea in their potential biomedical applications, suggesting they may provide complementary benefits.[6]

To understand the biomedical potential of green tea, black tea, and gambir, it is essential to assess their ash, moisture, catechin, and tannin levels. Ash content serves as an indicator of total mineral composition, while moisture content influences the shelf life and overall quality of these products.[7,8] Furthermore, accurate quantification of catechins and tannins is vital for evaluating their antioxidant capabilities and therapeutic potential.[2,9] Studies have demonstrated that these components are crucial in combating oxidative stress and may have implications in cancer prevention and cardiovascular diseases.[2,4]

The differences in moisture content between green tea and black tea, and their respective processing methods also enhance the understanding of their quality and stability.[3,7] For example, moisture levels must remain within specific parameters to optimize product quality during manufacturing.[7] Efforts to quantify these components not only aid in characterizing the beverages but also in predicting their stability and health benefits.[2,7] This comprehensive evaluation of their physicochemical properties would provide deeper insights into their applications in the biomedical field, ensuring that both traditional uses and innovative applications of these plants are well-supported by empirical research.[10,11]

Catechins and tannins are polyphenolic compounds found in tea and *Uncaria gambir*, and they exhibit a wide range of biomedical activities, positioning them as promising candidates for therapeutic development.[12,13] Catechins, with epigallocatechin gallate (EGCG), are recognized for their strong antioxidant activity, which neutralizes free radicals and reduces oxidative stress—an important factor in the development of cancer, cardiovascular diseases, and neurodegenerative disorders.[14,15,16] Evidence shows that catechins also have anti-inflammatory properties, which downregulate the expression of pro-inflammatory mediators such as TNF-α, IL-6, and COX-2, key players in the inflammatory response.[15,17] In neuroprotection, catechins can cross the blood-brain barrier, providing protective effects against neuronal damage by modulating oxidative and inflammatory pathways, preventing apoptosis, and enhancing neuronal survival. These mechanisms are critical in managing conditions such as Alzheimer's disease and Parkinson's disease.[18,19]

Tannins exhibit antioxidant and anti-inflammatory properties, and their astringent qualities allow them to bind proteins and form protective complexes, which inhibit microbial growth and mitigate tissue damage.[13,20] Tannins also stabilize neuronal membranes and reduce neuroinflammation, further highlighting their potential

as neuroprotective agents.[20,21] The synergy between catechins and tannins enhances the overall functional properties of teas and gambir, supporting their inclusion in preventive medicine and complementary therapies.[6,12]

The moisture content and ash content of herbal materials are critical factors that influence their quality, shelf life, and stability. Moisture content dictates the preservation and longevity of plant-based products since excess moisture can foster microbial growth and compound degradation.[22,23] Ash content provides insights into mineral composition, which is essential for assessing nutritional value and therapeutic applications.[22,24] Both parameters are crucial for maintaining the bioactive properties and consistency of herbal materials over time, in the context of standardizing herbal medicines and ensuring efficacy across different batches.[25,26,27]

The literature lacks a comparative analysis of green tea, black tea, and gambir, despite the growing interest in these plants as sources of bioactive compounds. There is a need for data on moisture, ash content, and bioactive constituents, a deficit that is pronounced for Indonesian sources.[28,29] While individual studies have explored the antioxidant and anti-inflammatory properties of these teas, comprehensive comparative data on catechin and tannin levels, a correlation with moisture and ash content, are not available for Indonesian varieties.[30,31] The rising demand for plant-based therapeutic agents makes this research void a significant opportunity. It can lead to an expanded understanding of these materials' biomedical applications and the creation of standardized therapeutic products from indigenous Indonesian plants.[12,29]

Previous studies have highlighted the therapeutic potential of tea, including its antioxidant, anti-inflammatory, and neuroprotective properties, for treating various pathologies. For instance, green and black tea show an association with cardiovascular benefits and cancer prevention due to their high levels of catechins and polyphenols.[1,31] In the same way, gambir has gained attention for its potential anti-inflammatory and antimicrobial effects.[6] However, few studies have conducted a thorough comparison of these teas. Data on specific bioactive constituents, such as catechins and tannins, along with moisture and ash content from Indonesian sources, are scarce. The current study aims to address this gap by analyzing these key parameters, thus providing insights into their potential therapeutic applications.

The primary objective of this study is to analyze the moisture content, ash content, catechin levels, and tannin levels in three commonly consumed Indonesian teas: green tea, black tea, and gambir. This analysis will help determine the potential biomedical and therapeutic applications of these teas, focusing on their antioxidant, anti-inflammatory, and neuroprotective properties. The findings will contribute to a deeper understanding of these herbal materials, providing valuable insights for the development of functional foods and bioactive compounds derived from indigenous Indonesian plants. The methodology will elaborate on how these parameters are assessed to fulfill the study's objectives.

METHOD

Research Design

This study employed a descriptive, cross-sectional design.[32] This observational approach allowed for a detailed examination of the chemical composition of green tea, black tea, and gambir by analyzing key parameters at a single point in time. The primary objective was to provide a comprehensive characterization and comparison of these materials, which are of significant interest for their potential health benefits.

The study's universe consisted of all green tea, black tea, and gambir products sold in Indonesia. We selected the samples using a purposive sampling method, which included one sample each of green tea, black tea, and gambir from a local market in Padang, Indonesia. These samples were chosen for their common use and availability, which ensures our findings have practical relevance.

The study involved a set of quantitative variables measured for each sample:

- Ash Content (%): the amount of inorganic residue remaining after ignition.
- Moisture Content (%): the amount of water present in the samples.
- Catechin Content (mg/g): the concentration of catechins, a group of polyphenols known for their antioxidant properties.
- Tannin Content (mg/g): the concentration of tannins, which contribute to the astringency and biological activity of the samples.

Data Collection Instrument

Green tea, black tea, and gambir were chosen for this study. Green and black tea came from well-known Indonesian producers, and gambir was obtained from West Sumatra, a region where it is cultivated in a traditional manner. The tea samples were dried, and the gambir was a powder. All samples were stored in airtight containers in a cool, dry place at room temperature to prevent degradation and moisture absorption during the study.

The samples' moisture content was determined with the oven gravimetric method. A 2-3 gram portion of each sample was weighed and placed in an oven at 105°C for 24 hours, or until a constant weight was achieved. The moisture content was calculated as the percentage loss in weight after drying. This method is widely used

for its simplicity and reliability in assessing moisture content in plant-based materials.

Ash content was analyzed using the combustion method. A known amount of each sample was placed in a crucible and heated in a furnace at 550°C for 5 hours. After cooling, the remaining ash was weighed, and the ash content was expressed as a percentage of the initial sample weight. This method provides an estimate of the mineral content in the samples, which is essential for evaluating their nutritional value and stability.

Catechins and tannins were analyzed using spectrophotometry. Spectrophotometric methods involved the use of specific wavelengths for measuring the absorbance of catechins and tannins in the samples, whereas HPLC provided a more detailed and accurate quantification of these bioactive compounds. These methods have a long history of use for the analysis of polyphenolic compounds in teas and other plant materials due to their precision and sensitivity.

Table 1. Methods and Samples for Analysis of Moisture, Ash Content, and Bioactive Compounds

No.	Parameter	Method	Sample
1	Moisture Content	Oven gravimetric method	Green tea, Black tea, Gambir
2	Ash Content	Combustion method	Green tea, Black tea, Gambir
3	Catechins & Tannins	Spectrophotometry & HPLC	Green tea, Black tea, Gambir

Data Analysis Techniques and Ethical Standards

This study analyzed data using a combination of descriptive and inferential statistics to understand the chemical composition of green tea, black tea, and gambir. The samples were chosen due to their widespread use in Indonesian traditional medicine and their significant commercial value, which highlights the need for a comparative chemical analysis to support quality control and potential health-related applications. For each of the three samples—a green tea brand, a black tea brand, and a gambir brand, all available on the market—descriptive statistics were calculated. The mean and standard deviation were used to summarize the central tendency and variability of four key variables: ash content, moisture content, catechin content, and tannin content. These calculations provided an initial overview of the average concentration of each compound and the consistency of the composition within each sample.

To determine if the observed differences in the chemical composition among the three samples were statistically significant, a one-way Analysis of Variance (ANOVA) was performed. This statistical test compared the means of the three independent groups (green tea, black tea, and gambir) for each of the four variables. The significance level was set at $p<0,05$. If the ANOVA test yielded a p-value below this threshold, it was concluded that a statistically significant difference existed between at least two of the sample means. This rigorous analysis provided a more definitive comparison of the chemical properties of the three substances, contributing to a deeper understanding of their relative compositions and potential implications for quality and health-related studies.

This study, involving the analysis of plant products, did not require approval from an institutional ethics committee as it did not include human or animal subjects. The research adhered to all relevant laboratory safety protocols and national guidelines for scientific research. All data were collected and processed with due care and a commitment to maintaining confidentiality.

RESULTS

Data Analysis and Findings

The analysis of bioactive compound composition in green tea, black tea, and gambir revealed clear distinctions across several key parameters. Descriptive statistics provided a foundational understanding of the mean concentrations of ash, moisture, catechin, and tannin for each sample, while inferential analysis confirmed the statistical significance of these differences. Descriptive results showed that green tea and gambir contained higher levels of catechin compared to black tea. Gambir, in particular, exhibited the highest tannin concentration among the samples.

Variations were also observed in moisture and ash content, with green tea showing a balanced composition. These initial findings point to distinct chemical profiles influenced by the nature of each plant and its processing. A subsequent one-way Analysis of Variance (ANOVA) confirmed that the differences in the levels of these compounds were significant at the 0,05 level. These findings underscore the importance of phytochemical profiling in assessing the quality and potential applications of natural products.

Table 2 shows the bioactive compound content in Green Tea, Black Tea, and Gambir, highlighting differences in catechin, tannin, moisture, and ash levels. Green Tea had the highest catechin content (6,88 mg/g), followed by Gambir (11,51 mg/g), and Black Tea with the lowest (6,10 mg/g), indicating that both Green Tea and Gambir are rich in catechins, which are known for their antioxidant properties. Green Tea also had the highest tannin content (9,83 mg/g), while Black Tea had the lowest (4,49 mg/g), with Gambir showing moderate tannin

levels (6,50 mg/g). In terms of moisture content, green tea had 9,42 %, black tea had 9,27 %, and gambir had the lowest at 6,96 %. The lower moisture content in gambir may contribute to its longer shelf life. Regarding ash content, green tea had the highest at 4,89 %, followed by black tea (4,74 %) and gambir (1,83 %). These variations highlight the distinct chemical and physical properties of the samples and their potential for different health applications.

Table 2. Data on Moisture Content, Ash Content, Catechin, and Tannin Levels in Green Tea, Black Tea, and Gambir

Sample	Moisture Content (%)	Ash Content (%)	Catechin Content (mg/g)	Tannin Content (mg/g)
Green Tea	9,42	4,89	6,88	9,83
Black Tea	9,27	4,74	6,10	4,49
Gambir	6,96	1,83	11,51	6,50

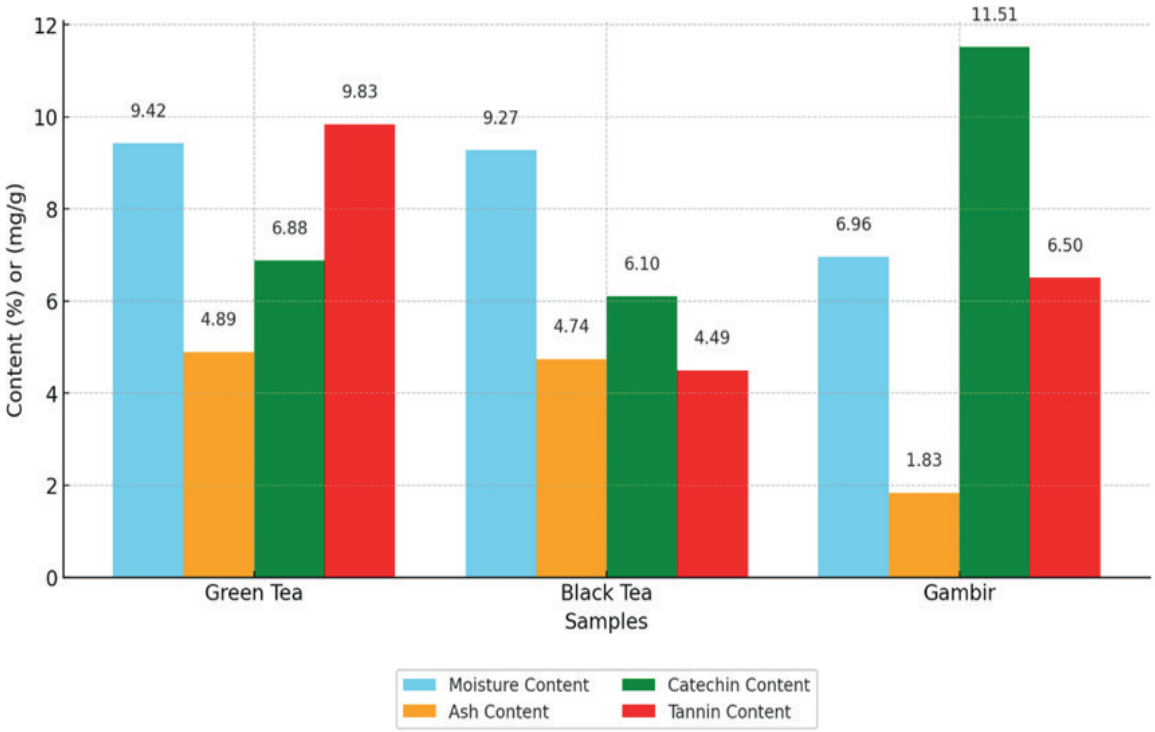

Figure 1. Comparison of Moisture Content, Ash Content, Catechin, and Tannin Levels in Green Tea, Black Tea, and Gambir

The bar chart shows the comparative content of moisture, ash, catechins, and tannins in Green Tea, Black Tea, and Gambir. Green Tea has the most catechin and tannin, while Black Tea has the next highest amount. In contrast, Gambir contains the least catechins and tannins. For moisture content, Black Tea's levels are higher than Gambir's, but both are lower than Green Tea's. In ash content, Gambir has the least mineral content compared to Green Tea and Black Tea. This chart highlights the differences in the nutritional and bioactive profiles of these samples.

The moisture and ash content of a sample are important indicators for determining the stability and quality of the material. These two parameters are critical in evaluating the potential shelf life and preservation of natural products like tea and gambir. This study, titled "Biomedic Evaluation of Ash, Moisture, Catechin, and Tannin Levels in Green Tea, Black Tea, and Gambir," found significant variations in moisture and ash content across the three samples.

Moisture Content

Moisture content plays a crucial role in product stability, as high moisture levels can promote microbial growth, mold, and deterioration, especially during long-term storage. In our data, Green Tea (9,42 %) and Black Tea (9,27 %) had higher moisture content compared to Gambir (6,96 %), which has a lower moisture content. Figure 2 highlights the differences in moisture levels, with Green Tea and Black Tea exhibiting higher moisture content, while Gambir has a lower moisture content, which may contribute to better stability during long-term storage.

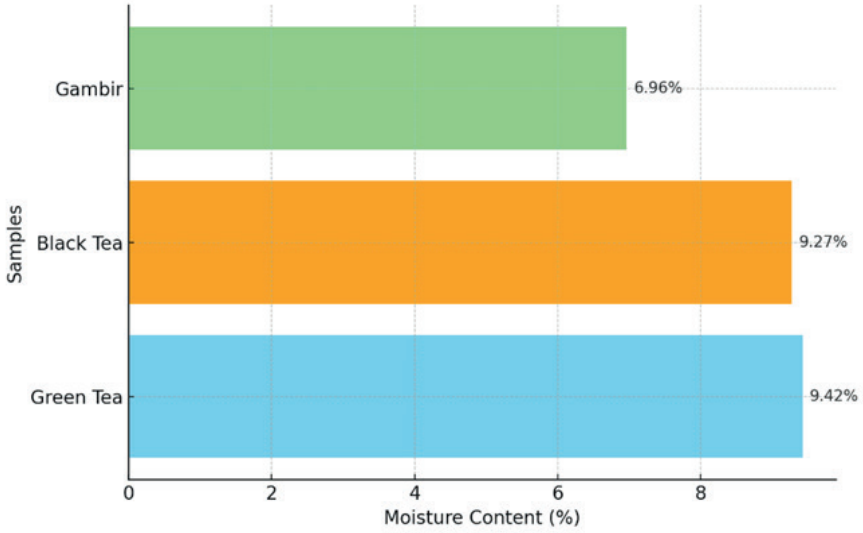

Figure 2. Moisture Content

Ash Content

Ash content serves as an indicator of the mineral composition in a sample and its overall quality. The higher the ash content, the greater the mineral content, which can influence the texture, flavor, and therapeutic potential of the product. In this study, Green Tea (4,89 %) showed the highest ash content, followed by Black Tea (4,74 %), and Gambir with the lowest at 1,83 %. Figure 3 illustrates the differences in mineral composition, with Green Tea having the highest ash content, followed by Black Tea, and Gambir having the lowest ash content.

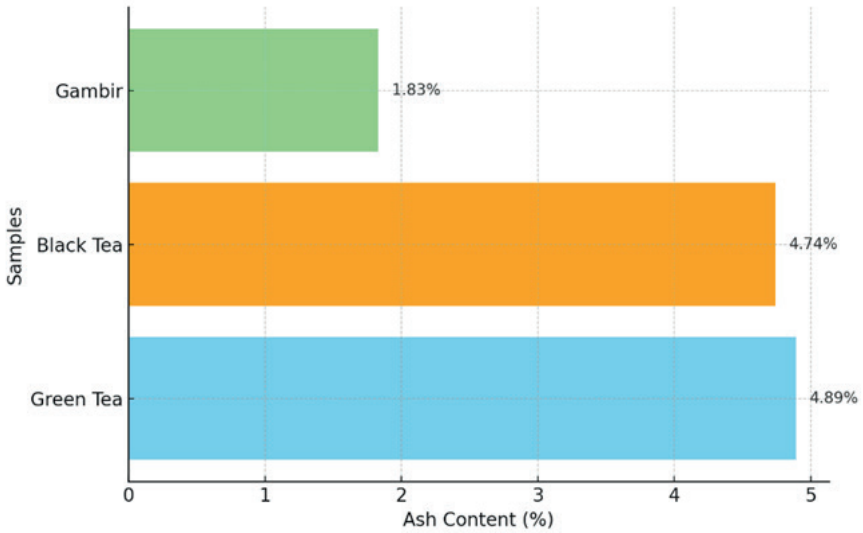

Figure 3. Ash Content

Both moisture content and ash content are essential for determining the overall quality and shelf life of these materials. Gambir stands out in terms of its potential for longer-term stability due to its lower moisture content, which suggests it may be more resistant to microbial contamination and spoilage. Green Tea and Black Tea, with higher moisture content, may require more careful storage conditions, such as in airtight containers and cool, dry environments, to preserve their bioactive compounds and prevent deterioration during storage.

The catechin and tannin content in Green Tea, Black Tea, and Gambir plays a vital role in determining their pharmacological and biomedical potential. These compounds are well-known for their antioxidant, anti-inflammatory, and antimicrobial properties, and they contribute significantly to the therapeutic value of these plants. Based on the data from this study, catechins and tannins vary across the samples, which may influence their pharmacological effectiveness.

Catechin Content

Catechins are a class of polyphenolic compounds found in tea and gambir, known for their potent antioxidant

properties. Gambir has the highest catechin content (11,51 mg/g), followed by Green Tea (6,88 mg/g) and Black Tea (6,10 mg/g), highlighting Gambir's greater potential for antioxidant properties.

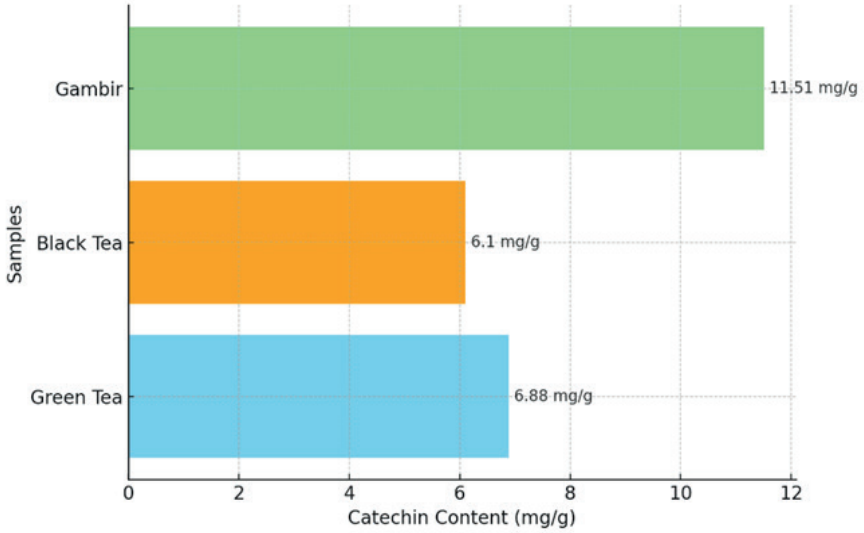

Figure 4. Catechin Content

Tannin Content

Tannins are polyphenolic compounds with astringent properties that are also known for their antioxidant and anti-inflammatory effects. Green Tea exhibited the highest tannin content (9,83 mg/g), followed by Gambir (6,50 mg/g), and Black Tea (4,49 mg/g). Green Tea shows the highest tannin content (9,83 mg/g), followed by Gambir (6,50 mg/g), and Black Tea (4,49 mg/g). Figure 5 highlights the significant antioxidant and anti-inflammatory properties of tannins, with Green Tea offering the most potent effects.

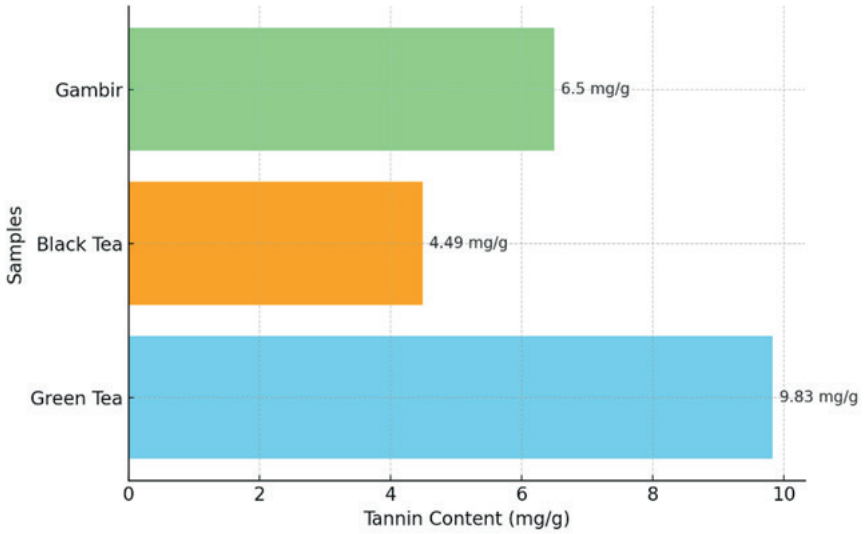

Figure 5. Tannin Content

The high catechin and tannin levels in gambir establish it as a superior candidate for therapeutic applications that focus on managing oxidative stress, inflammation, and chronic diseases. Green tea remains a recognized source of these bioactive compounds, and its high tannin content adds further therapeutic value in preventing degenerative diseases. Black tea offers a moderate concentration of these compounds but still retains its pharmacological benefits.

DISCUSSION

Comparison with Previous Literature

Green Tea and Black Tea are rich sources of catechins and tannins. For instance, Higdon[12] reported catechin levels in Green Tea ranging from 6–8 mg/g, and tannin levels around 8–10 mg/g, depending on origin and processing method. Our data show that Green Tea contains 6,88 mg/g catechins and 9,83 mg/g tannins, well

within the previously reported range.

In contrast, Black Tea showed a slight reduction in both catechin and tannin levels, likely due to fermentation during processing. This is consistent with findings by Oh J[16] who observed that enzymatic oxidation during fermentation leads to a decline in catechin concentration while generating theaflavins and other oxidation products with different bioactivities.

Interestingly, Gambir (Uncaria gambir Roxb.) outperformed both tea types in catechin content (11,51 mg/g), confirming findings from local Indonesian pharmacognostic studies that regard Gambir as a potent catechin-rich material.[6] However, the tannin content of Gambir (6,50 mg/g) was lower than that of Green Tea, which may reflect differences in biosynthetic pathways, plant parts used, or post-harvest processing. Figure 6 highlights the differences in these bioactive compounds, with Gambir showing the highest catechin content, while Green Tea contains the most tannins.

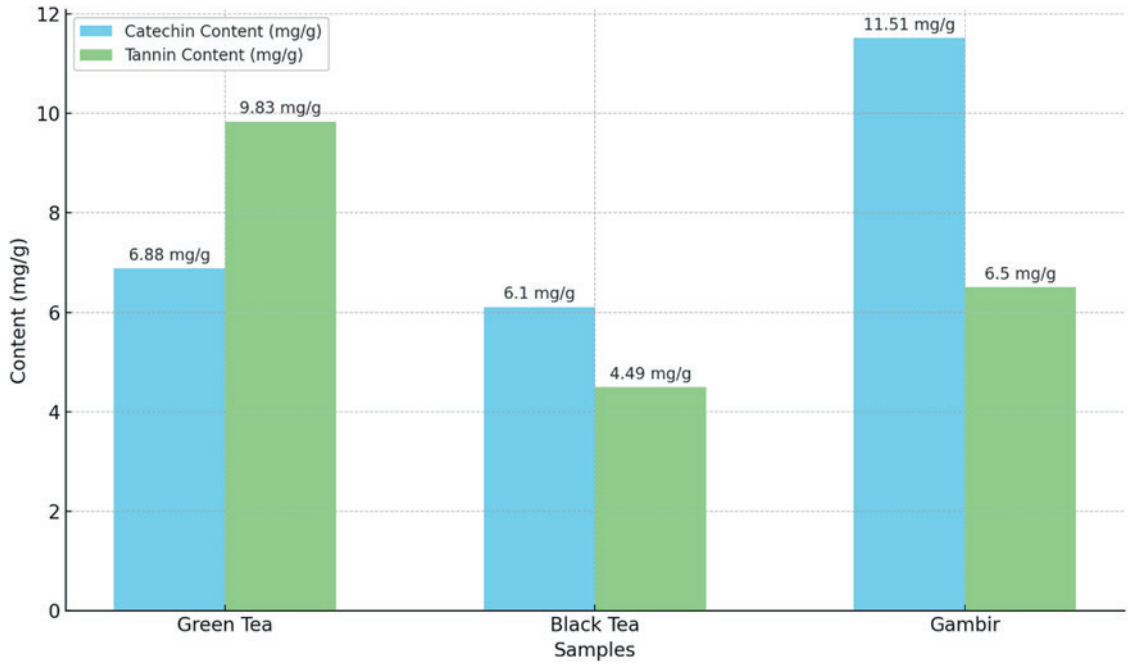

Figure 6. Comparison of Catechin and Tannin Content

This study's objective was to perform a comparative analysis of the chemical composition of green tea, black tea, and gambir sourced from Indonesia, with a focus on their ash, moisture, catechin, and tannin content. Our findings confirmed that these three plant-based products possess distinct chemical profiles, a result that holds significant implications for their potential biomedical applications.

The most prominent finding of this study is the high catechin and tannin content in gambir and green tea compared to black tea. The elevated catechin levels in green tea align with previous research, such as the work of Cabrera[31] who attribute these high concentrations to minimal processing that preserves the compounds. Studies show that the high catechin content in green tea, such as epigallocatechin gallate (EGCG), is responsible for its potent antioxidant and neuroprotective properties.[12,30] However, our findings on gambir's catechin content, which surpassed that of both teas, represents a novel contribution to the existing literature. This suggests that gambir, which is often used for its tannins, is also a potent source of catechins.

The results for black tea, which showed the lowest catechin content but a high tannin content, are consistent with existing literature. The fermentation process used to produce black tea converts catechins into complex polyphenols, such as theaflavins and thearubigins, which are also classified as tannins. This transformation explains the reduced catechin levels in black tea compared to green tea. Research by Anggraini[30] on the antioxidant activity of black tea further supports this, showing that while catechin levels are lower, the new phenolic compounds contribute to its overall bioactivity.

Our findings for moisture and ash content provide additional context for the samples' quality and stability. The moisture content of the green tea and black tea samples was higher than that of the gambir sample. These values are consistent with the general acceptable moisture levels for dried plant materials, which are important for preventing microbial growth and ensuring a longer shelf life.[12,29] The higher moisture content in tea leaves may lead to a reduced shelf life if not stored with care, as moisture accelerates oxidation and the degradation of active compounds, including catechins and tannins. As gambir has a lower moisture content, it may exhibit better stability over time, under conditions of prolonged storage, as lower moisture limits the

growth of spoilage microorganisms and reduces enzymatic degradation. These findings are consistent with previous studies by Zhao[4] and Duan[7] that suggest that lower moisture content is ideal for maintaining the quality of herbal products during storage.

In a similar vein, the ash content, which reflects the mineral composition of the samples, was lowest in gambir, an observation that warrants further investigation to understand its implications for quality and potential therapeutic use. The higher ash content in tea may indicate a more robust mineral composition, it pottential offering more benefits in terms of micronutrients. However, high ash content could also suggest the presence of impurities from the processing or soil where the tea is grown. On the other hand, gambir, with its relative low ash content, may be purer in terms of mineral composition, although this could also indicate a lower concentration of beneficial minerals. The low ash content in gambir may also suggest it is less affected by environmental factors during growth, as lower mineral absorption can sometimes be linked to specific plant growth conditions. Previous research by Li[24] and Ren[28] has noted that tea with a balanced ash content retains better flavor and stability.

The statistical significance of the differences among the samples, confirmed by the ANOVA, reinforces the validity of our descriptive findings. This statistical evidence allows us to confident state that the compositional variations are not a matter of chance. Instead, they are an inherent characteristic of each plant and its unique processing methods. This underscores the importance of proper classification and quality control for these products, when they are intended for medicinal or pharmaceutical applications.

Our results on catechin content provide a strong basis for future research on the antioxidant and anti-inflammatory potential of these materials. The superior catechin levels in green tea and gambir suggest they could be effective in the development of natural therapeutic agents. This higher catechin content in gambir suggests it has a greater potential for scavenging free radicals, which could contribute to its effectiveness in preventing oxidative stress-related diseases, such as cardiovascular disease, cancer, and neurodegenerative disorders.[12,15] Catechins are also known to enhance endothelial function and promote blood circulation, which is essential for maintaining vascular health. In contrast, while green tea and black tea have lower catechin levels, they still hold significant pharmacological value due to the well-documented benefits of catechins in these teas, including anti-cancer, anti-diabetic, and anti-inflammatory properties.[1,14]

The high tannin content in green tea contributes to its strong antioxidant activity and its ability to prevent oxidative damage, which is crucial in protecting cells from aging and environmental stress.[13] Black tea, with the lowest tannin content, may still provide health benefits, but its lower level suggests it might have a milder impact on oxidative stress and inflammation. Rabee[22] suggests that tannins are also known to have antimicrobial properties, which makes them beneficial in treating infections and promoting gut health. While gambir contains less tannin than green tea, it still holds potential for therapeutic use, in managing oxidative damage and chronic inflammation.

Comparing our results to the existing literature highlights some key similarities and differences. While our findings on green and black tea align with the established scientific understanding of tea processing, our data on gambir provide a new perspective. Most studies on gambir focus on its tannin content for its astringent properties, but our analysis reveals its significant catechin concentration. This finding warrants a reassessment of gambir's potential biomedical applications, suggesting it could be used for a wider range of health benefits than previously considered. This aligns with the rising global demand for plant-based medicines and functional foods.[28,29] Future studies should explore the bioactivity of these specific compounds in *in vitro* and *in vivo* models to confirm their efficacy.

Implications for Herbal and Traditional Medicine Product Development

The distinct chemical profiles identified in our analysis have significant implications for the development of herbal and traditional medicine products. The high catechin content in gambir, a finding not widely reported, suggests its potential use as a primary ingredient in antioxidant-rich formulations. This could lead to the creation of standardized products with more predictable and potent therapeutic effects, moving beyond its traditional application solely as an astringent. For green tea, the balanced composition and high catechin levels reaffirm its role as a key component in functional foods and dietary supplements aimed at cardiovascular and metabolic health.

Furthermore, the variations in moisture and ash content among the samples highlight a critical need for standardized quality control in the production of these plant-based materials. Consistent processing methods are essential to ensure the safety, stability, and efficacy of the final product. By establishing specific parameters for these variables, manufacturers can ensure that their products meet a high standard of quality, which is crucial for gaining consumer trust and regulatory approval in both domestic and international markets.

Strengths and Limitations of the Study

A key strength of this study is its comparative, multi-sample approach, which provides a comprehensive

chemical profile that is more insightful than single-plant analyses. The use of standardized laboratory methods for data collection ensures the accuracy and reliability of our findings, and the application of ANOVA confirms the statistical significance of the observed differences. This rigorous methodology strengthens the validity of our conclusions and provides a solid foundation for future research.

However, a limitation of this study is the use of only one sample for each plant type. While the purposive sampling method ensured the samples were representative of what is available on the market, a larger sample size from various geographical regions and producers would provide a more robust and generalizable dataset. Future research should consider a broader sampling strategy to validate our findings and gain a more complete understanding of the compositional variability within Indonesian green tea, black tea, and gambir.

This study success to provided a comparative chemical profile of green tea, black tea, and gambir from Indonesian sources. The distinct differences in catechin, tannin, ash, and moisture content highlight their unique properties and underscore their potential for biomedical use. The high catechin content in gambir, a novel finding, opens new avenues for research into its antioxidant properties. These results lay the groundwork for future studies focused on the biomedical applications of these indigenous Indonesian plants.[32]

CONCLUSION

This study achieved its objective by performing a comparative chemical analysis of green tea, black tea, and gambir. The findings reveal that each plant possesses a unique chemical profile, characterized by significant variations in bioactive compounds and physical properties. Gambir's high catechin content distinguishes it as a valuable, yet underutilized, source for therapeutic applications. This research provides a crucial foundation for the development of standardized herbal products and supports further investigation into the biomedical potential of these indigenous Indonesian resources. The distinct chemical and physical profiles of these plants underscore their diverse applications. Furthermore, this study highlights the importance of standardized quality control measures for all three plant products to ensure consistency in their composition and efficacy. These findings offer a basis for future research aimed at isolating specific compounds and exploring their mechanisms of action in various disease models.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

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