CORRELATION BETWEEN ANTIOXIDANT ACTIVITY AND SENSORY ACCEPTANCE IN HERBAL TEA BLENDS

Hubungan antara Aktivitas Antioksidan dan Penerimaan Sensoris pada Campuran Teh Herbal

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ABSTRACT

The development of herbal tea as a functional beverage requires balancing antioxidant activity and sensory acceptance, as increasing phenolic compounds may reduce palatability. This study aimed to investigate the relationship between antioxidant properties and sensory acceptance in herbal tea blends formulated from *Clitoria ternatea*, *Lavandula angustifolia*, *Cymbopogon nardus*, and lemon peel. Five formulations were analyzed for total phenolic content (TPC) using the Folin–Ciocalteu method and antioxidant activity using the DPPH assay (IC_{50}). Sensory evaluation was conducted using a 7-point hedonic scale. Data were analyzed using ANOVA, Pearson correlation, and multivariate approaches, including Principal Component Analysis (PCA) and Hierarchical Cluster Analysis (HCA). Results showed that higher TPC was associated with stronger antioxidant activity, indicated by lower IC_{50} values. The formulation with a higher proportion of *Clitoria ternatea* exhibited the highest TPC (5.41 mg GAE/mL) and strongest antioxidant activity (IC_{50} 33.21 ppm), but showed lower sensory acceptance, particularly in taste and overall liking. TPC was positively correlated with antioxidant activity and color intensity, but negatively correlated with aroma, taste, and overall liking. In contrast, taste showed a very strong positive correlation with overall liking, identifying it as the primary determinant of consumer preference. Multivariate analysis revealed a clear separation between antioxidant-related variables and sensory attributes, indicating an inverse relationship between functional properties and consumer acceptance. These findings highlight the need to optimize formulations to achieve a balance between functional efficacy and sensory quality.

Keyword: herbal tea, phenolic compounds, antioxidant activity, sensory evaluation, multivariate analysis

ABSTRAK

Pengembangan teh herbal sebagai minuman fungsional memerlukan keseimbangan antara aktivitas antioksidan dan penerimaan sensoris, karena peningkatan senyawa fenolik berpotensi menurunkan palatabilitas. Penelitian ini bertujuan mengkaji hubungan antara aktivitas antioksidan dan penerimaan sensoris pada campuran teh herbal berbasis bunga telang, bunga lavender, sereh wangi, dan kulit lemon. Lima formulasi dianalisis kandungan fenolik total (TPC) menggunakan metode Folin–Ciocalteu serta aktivitas antioksidan menggunakan metode DPPH (IC_{50}). Uji sensoris dilakukan dengan skala hedonik 7 poin, dan data dianalisis menggunakan ANOVA, korelasi Pearson, serta analisis multivariat (PCA dan HCA). Hasil menunjukkan bahwa peningkatan TPC diikuti oleh peningkatan aktivitas antioksidan yang ditandai dengan penurunan nilai IC_{50}. Formulasi dengan proporsi Clitoria ternatea lebih tinggi menghasilkan TPC tertinggi (5,41 mg GAE/mL) dan aktivitas antioksidan terkuat (IC_{50} 33,21 ppm), namun memiliki penerimaan sensoris lebih rendah. TPC *berkorelasi positif dengan aktivitas antioksidan dan intensitas warna, tetapi berkorelasi negatif dengan atribut sensoris. Sebaliknya, rasa berkorelasi sangat kuat dengan penerimaan keseluruhan. Analisis multivariat menegaskan adanya hubungan berlawanan antara karakteristik antioksidan dan preferensi konsumen, sehingga diperlukan optimasi formulasi untuk mencapai keseimbangan keduanya, yaitu teh herbal dengan aktivitas antioksidan tinggi tanpa menurunkan penerimaan konsumen.*

***Kata kunci**: teh herbal, senyawa fenolik, antioksidan, penerimaan sensoris, PCA*

INTRODUCTION

Herbal tea has emerged as a prominent category of functional beverages, driven by increasing consumer demand for natural products with health-promoting properties. Plant-derived ingredients such as *Clitoria ternatea*, *Lavandula angustifolia*, *Cymbopogon nardus*, and citrus peel are rich in phenolic compounds, including flavonoids, anthocyanins, and phenolic acids, which are widely recognized for their antioxidant capacity (Kruk et al., 2022; Smeding et al., 2023). These compounds exert their activity primarily through hydrogen atom transfer and electron donation mechanisms, enabling the neutralization of reactive oxygen species and contributing to the prevention of oxidative stress-related disorders (Zahra et al., 2024). Among these, *Clitoria ternatea* has attracted considerable attention due to its high anthocyanin content (ternatins), which not only provides strong radical scavenging activity but also imparts an intense blue coloration, making it attractive for functional beverage development (Khoo et al., 2017; Negi, 2025).

Despite the recognized functional potential of phenolic-rich plant materials, the development of herbal tea formulations presents a critical challenge in balancing bioactivity and sensory quality. Phenolic compounds are frequently associated with bitterness, astringency, and undesirable aftertaste, which can negatively impact consumer acceptance (Lesschaeve & Noble, 2005). At the same time, aromatic components from herbs such as *Lavandula angustifolia* and citrus-derived volatiles may enhance sensory appeal but do not necessarily contribute proportionally to antioxidant capacity (Göksu Sürücü et al., 2024; Zhang et al., 2024). These contrasting effects highlight a fundamental trade-off between functional properties and palatability, particularly in multi-component systems where ingredient interactions can significantly influence both phytochemical composition and sensory perception.

To date, most studies have primarily focused on single-ingredient extracts or have evaluated antioxidant activity independently from sensory characteristics (Ma et al., 2019;Peng et al., 2019). Research addressing multi-component herbal tea formulations remains limited, particularly in terms of systematically linking antioxidant-related parameters with sensory acceptance. Furthermore, the application of integrated statistical approaches to unravel complex relationships among these variables is still underexplored. Multivariate techniques such as Principal Component Analysis (PCA) and Hierarchical Cluster Analysis (HCA) have demonstrated strong potential in food science for revealing underlying patterns and sample differentiation; however, their use in evaluating the trade-off between antioxidant properties and consumer preference in herbal tea systems is not yet well established. Therefore, this study introduces a novel integrative framework combining antioxidant profiling, sensory evaluation, and multivariate statistical analysis to elucidate the relationship and inherent trade-off between functional properties and consumer acceptance in complex herbal tea formulations.

Accordingly, this study aimed to evaluate the effects of different herbal tea formulations on total phenolic content (TPC), antioxidant activity, and sensory acceptance. In addition, Pearson correlation analysis, PCA, and HCA were employed to investigate the relationships among antioxidant-related variables and sensory attributes, as well as to identify formulations that achieve an optimal balance between functional efficacy and consumer preference.

METHODS

Materials and Chemicals

The flower of Lavandula angustifolia and leaves of Cymbopogon nardus were collected in Rumah Atsiri Indonesia (Karanganyar, Indonesia) (7°39'16.8"S 111°06'08.1"E) at 10.00 A.M., on sunny, non-rainy days, in September 2020. The flower of Clitoria ternatea was obtained from agrotourism village in Dukuh (Kopeng, Indonesia) (7°24'02.7"S 110°25'13.4"E) at 08.00 A.M., on sunny, non-rainy days, in September 2020, and lemons were bought in the local market of Semarang, Indonesia. Plants were dried using the gravimetric oven method according to AOAC (2005) with slight modification thereupon moisture content showed <8% (dry-basis).

Chemicals such as DPPH (2,2-diphenyl-2-picrylhydrazyl), methanol, ethanol, gallic acid, sodium carbonate, nitric acid, magnesium, ammonia, Mayer, Wagner, and Dragendorff reagent were purchased from Sigma Aldrich (Germany). Iron (III) chloride, hydrochloric acid, sulfuric acid, chloroform, and folin-ciocalteu reagent were supplied from Merck (Germany).

Sample Preparation

Dried plant materials were prepared in 5 formulations of herbal tea:

F1 = 25% Lavandula angustifolia: 25% Clitoria ternatea: 25% Lemon Peel: 25% Cymbopogon nardus

F2 = 40% Lavandula angustifolia: 20% Clitoria ternatea: 20% Lemon Peel: 20% Cymbopogon nardus

F3 = 20% Lavandula angustifolia: 40% Clitoria ternatea: 20% Lemon Peel: 40% Cymbopogon nardus

F4 = 20% Lavandula angustifolia: 20% Clitoria ternatea: 40% Lemon Peel: 20% Cymbopogon nardus

F5 = 20% Lavandula angustifolia: 20% Clitoria ternatea: 20% Lemon Peel: 40% Cymbopogon nardus

In order to extract the herbal tea, each formulation was infused using tea bag and dipped in 100 ml of 70^0C water for 5 minutes (Hajiaghaalipour et al., 2016).

Determination of Total Phenolic Content and Antioxidant Assay

Total phenolic content (TPC) was determined using the Folin–Ciocalteu colorimetric method following the previous antioxidant research article published by Ma et al. (2019). with slight modifications. Gallic acid (10–50 ppm) was used to construct the standard calibration curve. Briefly, 300 µL of each herbal tea formulation was mixed with 1.5 mL of diluted Folin–Ciocalteu reagent (1:10, v/v). After 3 min, 1.2 mL of 7% Na_2CO_3 solution was added, and the mixture was incubated for 20 min at room temperature. Absorbance was measured at 760 nm using a UV–Vis spectrophotometer. The results were expressed as mg gallic acid equivalents per mL sample (mg GAE/mL).

The antioxidant activity of the herbal tea formulations was evaluated using the DPPH radical scavenging assay following the method reported by (Peng et al., 2019) with some modification. Each formulation was diluted in methanol to obtain different concentrations ranging from 0.25 to 1.00 ppm. One milliliter of sample solution was mixed with 2 mL of DPPH solution (100 ppm in methanol), vortexed, and incubated in the dark at 37°C for 30 min. The absorbance was subsequently measured at 516 nm using a UV–Vis spectrophotometer. Antioxidant activity was expressed as IC_{50} values, representing the concentration required to inhibit 50% of DPPH radicals, where lower IC_{50} values indicate stronger radical scavenging activity.

Sensory Acceptance Test

Hedonic test was used to determine the consumer's preference of 5 herbal tea formulations (Stone et al., 2021). The formulations are placed in order, served at room temperature in a sealed bottle to volunteer participants. The hedonic scale was used to vary between 1 and 7 (7 is like very much, 6 is like moderately, 5 is like slightly, 4 is neither like nor dislike, 3 is dislike slightly, 2 is dislike moderately, and 1 is dislike very much). The samples were evaluated in terms of color, smell, taste, and overall acceptability.

Statistical Analysis

The experiments were conducted using a completely randomized design

(CRD). Total phenolic content (TPC), antioxidant activity (IC_{50}), and sensory evaluation data were analyzed using SPSS software (IBM SPSS Statistics, version 30.0.0). All measurements were performed in triplicate and expressed as mean ± standard deviation. Prior to analysis, data normality and homogeneity of variance were assessed. For normally distributed data, differences among the five formulations were evaluated using one-way analysis of variance (ANOVA), followed by Duncan's multiple range test to determine significant differences at $\alpha = 0.05$. For data that did not meet the assumptions of normality, non-parametric analysis was performed using the Kruskal–Wallis test at a 95% confidence level. When significant differences were observed, pairwise comparisons were further conducted using the Mann–Whitney test.

To examine the relationships among antioxidant-related parameters (TPC and IC_{50}) and sensory attributes (taste, aroma, color, and overall acceptability), Pearson's correlation analysis was performed using R software (R Foundation for Statistical Computing, Vienna, Austria). Furthermore, multivariate analysis was carried out using Principal Component Analysis (PCA) in R to explore the overall relationship patterns among variables and to visualize sample distribution. The PCA results were interpreted based on score plots, loading plots, contribution values, and $\cos^2$ values. Hierarchical Cluster Analysis (HCA) was also performed in R to classify samples according to their similarity in antioxidant and sensory characteristics, and the results were presented in the form of a dendrogram.

RESULT AND DISCUSSION

Total Phenolic Content, Antioixdant Activity, and Sensory Acceptance

In this study, total phenolic content (TPC) was determined using a linear regression equation based on gallic acid standard and expressed as gallic acid equivalents (GAE) of the extract ($y = 0.0082x + 0.082$; $R^2 = 0.9996$). The TPC values differed significantly among the formulations (Table 1). The lowest phenolic content was observed in F4 (2.64 mg GAE/mL), while the highest was recorded in F3 (5.41 mg GAE/mL). Antioxidant activity of the herbal tea blend formulations was evaluated using the DPPH radical scavenging assay and expressed as IC_{50} values (Table 1). All methanolic extracts exhibited varying antioxidant capacities. The lowest IC_{50} value was observed in sample 3 (33.21 ppm), indicating very strong antioxidant activity, whereas the highest IC_{50} was recorded in sample 4 (148.63 ppm), corresponding to moderate antioxidant activity.

The higher total phenolic content (TPC) observed in sample 3 can be attributed to the greater proportion of *Clitoria ternatea*, which is well known to be rich in phenolic compounds, particularly anthocyanins (e.g., ternatins) and flavonoids (Sitompul & Martati, 2025). These compounds possess multiple hydroxyl groups attached to aromatic rings, which are highly effective in donating hydrogen atoms or electrons to neutralize free radicals (Sanli et al., 2025). As a result, formulations with higher Clitoria ternatea content exhibited increased phenolic concentration and consequently stronger antioxidant activity, as reflected by the lower IC_{50} value. In contrast, sample 4, which contained a higher proportion of lemon peel, showed lower TPC and weaker antioxidant activity. Although lemon peel contains phenolic compounds such as flavanones (e.g., hesperidin and naringin), their extractability and antioxidant effectiveness in methanolic extracts may be lower compared to the anthocyanin-rich compounds in *Clitoria ternatea* (Sanli et al., 2025). Additionally, some phenolic compounds in citrus peel are often bound to cell wall components or present in glycosylated forms, which can reduce their availability and reactivity in radical scavenging assays such as DPPH (Munir et al., 2024).

Furthermore, the structural characteristics of phenolic compounds play a crucial role in antioxidant capacity. Anthocyanins have conjugated double-bond systems and multiple hydroxyl substitutions, which enhance electron delocalization and stabilize radical intermediates more effectively than many citrus-derived phenolics (Ikhsan et al., 2026). This structural advantage contributes to their higher radical scavenging efficiency, explaining the significantly lower IC_{50} observed in sample 3 compared to sample 4.

Table 1. TPC and antioixdant activity of herbal tea blends

Sample	TPC (mg GAE/ml)	IC_{50} (ppm)	Antioxidant Activity*
1	$3{,}68 \pm 0{,}04^{a}$	$85{,}16 \pm 3{,}47^{a}$	Strong
2	$4{,}28 \pm 0{,}04^{b}$	$65{,}09 \pm 1{,}85^{b}$	Strong
3	$5{,}41 \pm 0{,}19^{c}$	$33{,}21 \pm 2{,}94^{c}$	Very strong
4	$2{,}64 \pm 0{,}19^{d}$	$148{,}63 \pm 16{,}35^{d}$	Moderate
5	$3{,}06 \pm 0{,}31^{e}$	$92{,}68 \pm 0{,}97^{a}$	Strong
Sig.	< 0,001	< 0,001	

the experiment was done by triplicate for each formula,different notation shows a significant difference (α = 0,05)

*very strong antioxidant activity = IC_{50} <50 ppm; strong = IC_{50} 50-100 ppm; moderate = IC_{50} 101-150 ppm; weak = IC_{50} >150 ppm.

In the sensory evaluation of the herbal tea blend formulations, four attributes (taste, aroma, color, and overall acceptability) were assessed, and the results are presented in Table 2. Overall, the formulation significantly influenced the level of consumer acceptance. Increasing the proportion of *Clitoria ternatea* resulted in higher consumer preference for color; however, it was associated with lower preference scores for aroma, taste, and overall acceptability. In contrast, sample 2, which was dominated by *Lavandula angustifolia*, was the most preferred in terms of aroma. Based on taste and overall acceptability, sample 1 was identified as the most preferred formulation by consumers.

Table 2. Sensory acceptance of herbal tea blends

Sample	Color	Smell	Taste	Overall Acceptance
1	4.29 ± 1,64	5,56 ± 1,002	6,19 ± 1,64	5,71 ± 0,66
2	2.81 ± 1,53	6,27 ± 1,39	3,94 ± 1,49	4,35 ± 1,09
3	5.97 ± 1,17	3,39 ± 1,31	3,02 ± 1,17	3,68 ± 0,94
4	3.16 ± 1,61	5,97 ± 0,75	3,13 ± 1,66	3,90 ± 1,07
5	2.63 ± 1,36	4,77 ± 1,73	4,32 ± 1,36	4,40 ± 1,32
Sig.	< 0,001	< 0,001	< 0,001	< 0,001

Correlation and multivariate analysis of antioxidant-related and sensory properties

Pearson correlation analysis and multivariate statistical approaches were employed to further investigate the relationships among antioxidant-related parameters and sensory attributes of the herbal tea blends (Table 3; Figures 1–2). A strong positive correlation was observed between TPC and antioxidant activity (IC_{50}) ($r = 0.937$, $p \leq 0.05$), indicating that phenolic compounds substantially contributed to the radical scavenging capacity of the formulations. Phenolic compounds are well known for their ability to donate hydrogen atoms or electrons to neutralize free radicals due to the presence of hydroxyl groups attached to aromatic rings (Kruk et al., 2022). Consequently, formulations with higher phenolic concentrations generally exhibited stronger antioxidant capacity.

TPC also showed a moderate positive correlation with color intensity ($r = 0.757$). This relationship is likely associated with anthocyanins and flavonoid-derived pigments naturally present in *Clitoria ternatea*, which possess conjugated double-bond systems capable of absorbing visible light and producing intense blue-purple coloration (Negi, 2025). In addition, phenolic oxidation reactions may generate quinones and polymerized compounds that further intensify color formation during processing or extraction (Zhou et al., 2021). However, the correlation was not statistically significant ($p > 0.05$), indicating that color development was not exclusively governed by phenolic content and may also be influenced by pigment stability, pH conditions, extraction efficiency, and interactions among formulation ingredients (Khoo et al., 2017).

In contrast, sensory attributes exhibited a different relationship pattern. Taste showed an extremely strong positive correlation with overall acceptance (r = 0.993, p ≤ 0.05), confirming that taste was the primary determinant of consumer preference. This finding is consistent with sensory perception principles, where taste directly determines palatability and strongly influences hedonic acceptance (Smeding et al., 2023). In herbal beverages, bitterness, astringency, and aftertaste associated with phenolic compounds may reduce consumer preference when present at excessive levels (Lesschaeve & Noble, 2005).

Aroma also exhibited a positive correlation with overall acceptance (r = 0.367), although the relationship was comparatively weaker and statistically insignificant. This suggests that aroma contributed to the sensory experience but was not the dominant factor influencing liking. Unlike taste, which is perceived immediately during consumption, aroma perception in herbal tea products may vary depending on volatile compound release, brewing method (Göksu Sürücü et al., 2024), infusion temperature (Zhang et al., 2024), and individual familiarity with herbal notes such as lavender. As a result, aroma enhanced product character but did not independently determine consumer acceptance.

Table 3. Pearson's correlation coefficients (r) of phenolic content, antioxidant activity, and sensory acceptance of herbal tea blends

Variable	TPC	IC_{50}	Color	Aroma	Taste	Overall Liking
TPC	1.000	0.937*	0.757	–0.601	–0.199	–0.222
IC50	0.937*	1.000	0.610	–0.609	–0.002	–0.055
Color	0.757	0.610	1.000	–0.749	–0.112	–0.126
Aroma	–0.601	–0.609	–0.749	1.000	0.287	0.367
Taste	–0.199	–0.002	–0.112	0.287	1.000	0.993**
Overall liking	–0.222	–0.055	–0.126	0.367	0.993**	1.000

*TPC, total phenolic contents; IC_{50}, half maximal inhibitory concentration
*Significant correlation with P ≤ 0.05; **Significant correlation with P ≤ 0.01.

These relationship patterns were further clarified through Principal Component Analysis (PCA), in which the first two principal components explained 86.58% of the total variance, accounting for 55.25% and 31.33%, respectively (Figure 1).

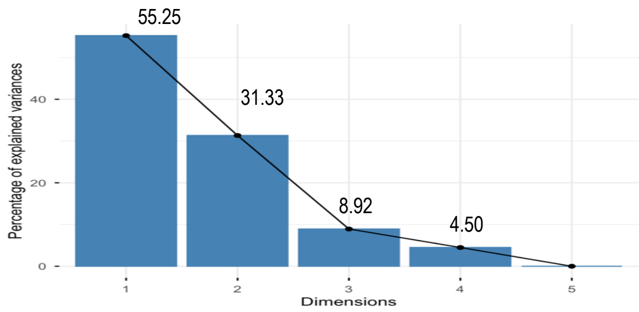

Figure 1. Scree plot of principal components showing percentage of explained variance

The PCA biplot (Figure 2) revealed a clear separation between antioxidant-related variables and sensory acceptance attributes. TPC and IC_{50} were closely grouped and oriented opposite to taste and overall acceptance, indicating an inverse relationship between antioxidant-related characteristics and sensory preference. This suggests that formulations with higher phenolic-associated antioxidant activity tended to exhibit lower consumer acceptability. Interestingly, color was positioned together with TPC and IC_{50} rather than with sensory attributes, suggesting that color variation was more strongly influenced by phytochemical composition than by sensory perception alone. This observation was consistent with the Pearson correlation analysis, which demonstrated a moderate association between TPC and color intensity.

The PCA loading and contribution analyses further supported these findings (Table 4). TPC (24.83%), aroma (21.73%), color (20.98%), and IC_{50} (20.37%) were identified as the primary contributors to PC1, indicating that these variables largely governed sample discrimination along this axis. Meanwhile, taste (42.91%) and overall acceptance (41.29%) contributed predominantly to PC2, confirming that this component mainly represented palatability and consumer preference. The $\cos^2$ values also demonstrated good representation of antioxidant-related variables on PC1 and sensory variables on PC2, supporting the reliability of the PCA model.

Sample distribution in the PCA score plot (Figure 2) highlighted the distinct characteristics of each formulation. Sample 3 was clearly associated with TPC, IC_{50}, and color, indicating stronger antioxidant-related properties likely resulting from a higher proportion of phenolic-rich ingredients. In contrast, Sample 1 was positioned closer to taste and overall acceptance, reflecting superior sensory preference and suggesting a more balanced flavor profile. Sample 4 showed a stronger association with aroma, which may be attributed to the higher contribution of aromatic volatile compounds from Lavandula angustifolia. Meanwhile, Samples 2 and 5 occupied intermediate positions, suggesting more balanced characteristics without strong dominance of either antioxidant-related or sensory attributes.

Table 4. PCA loading, contribution (%), and cos² values of variables

Variable	PC1	PC2	PC3	PC4	Contribution to PC1 (%)	Contribution to PC2 (%)	cos² PC3	cos² PC4
TPC	−0.498	−0.181	−0.430	0.245	24.83	3.27	0.823	0.062
IC50	−0.451	−0.295	−0.494	−0.337	20.37	8.69	0.675	0.163
Color	−0.458	−0.196	0.473	0.648	20.98	3.82	0.695	0.072
Aroma	0,466	0.012	−0.574	0.618	21.73	0.02	0.720	0.000
Taste	0.234	−0.655	0.111	−0.149	5.46	42.91	0.181	0.806
Overall liking	0.258	−0.643	0.080	0.052	6.63	41.29	0.220	0.776

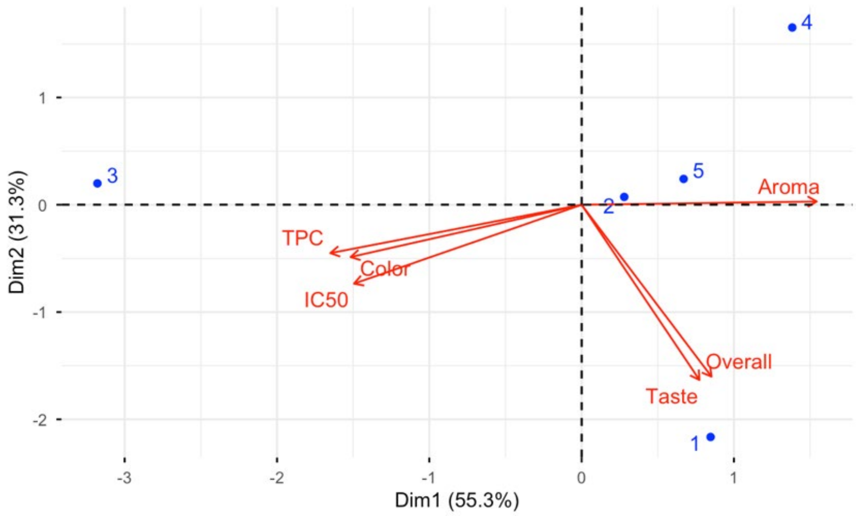

Figure 2. PCA biplot and score plot of TPC, IC50 value, and sensory acceptance

The Hierarchical Cluster Analysis (HCA) confirmed the grouping pattern observed in the PCA biplot (Figure 3). Samples 2 and 5 formed the closest cluster at the lowest linkage distance, indicating high similarity in their antioxidant-related and sensory profiles. Sample 4 clustered with samples 2 and 5 at a moderate distance, suggesting partial similarity, particularly in sensory characteristics. Sample 1 formed a separate branch before joining the main cluster, reflecting its distinct association with taste and overall acceptance. Meanwhile, sample 3 showed the greatest dissimilarity and was separated at the highest linkage distance, supporting the PCA result that associated this sample with stronger antioxidant-related properties.

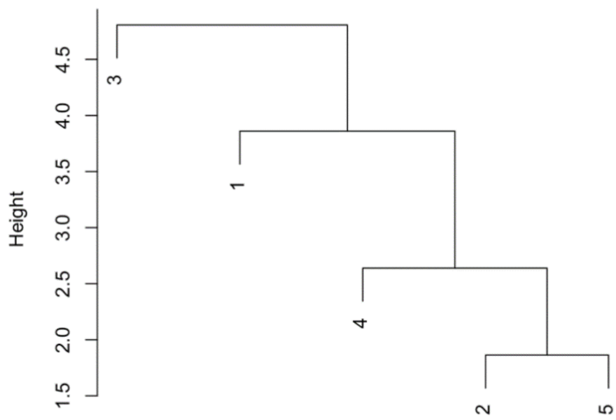

Figure 3. Hierarchical clustering dendrogram of herbal tea blend formulations

CONCLUSION

This study demonstrated that formulation differences significantly influenced both antioxidant-related properties and sensory acceptance of herbal tea blends. Sample 3, characterized by the highest proportion of Clitoria ternatea, exhibited the highest total phenolic content and strongest antioxidant activity, confirming the major contribution of anthocyanin-rich phenolics to radical scavenging capacity. In contrast, Sample 1 showed the highest scores for taste and overall acceptance, indicating that sensory preference was not directly aligned with antioxidant potency.

Correlation and multivariate analyses consistently revealed a clear separation between antioxidant-related variables (TPC and IC_{50}) and sensory acceptance attributes. PCA and HCA further confirmed that formulations with stronger phenolic-associated antioxidant properties tended to cluster separately from formulations with higher consumer preference. Importantly, color was grouped together with TPC and IC_{50} rather than with sensory liking variables, suggesting that color intensity in herbal tea blends is more strongly governed by phytochemical composition than by hedonic perception.

These findings propose a novel conceptual framework in herbal tea formulation, namely the “phytochemical–palatability trade-off”, in which increasing phenolic-driven antioxidant functionality enhances visual and bioactive characteristics but simultaneously reduces sensory acceptance, particularly taste and overall liking. This study therefore highlights that optimization of herbal tea products should not solely target maximal antioxidant capacity, but rather achieve a balance between functional bioactivity and consumer palatability. The integration of correlation analysis, PCA, and HCA provides a comprehensive multivariate approach for identifying optimal formulations with balanced functional and sensory qualities, offering a valuable strategy for the development of consumer-oriented functional beverages.

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