



The Effect of Withering Methods on Physicochemical and Sensory Properties of Liberica Coffee Leaf Tea (*Coffea liberica*)

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Abstract— This study aims to evaluate the effect of different withering methods on physicochemical and organoleptic properties of Liberica coffee leaf tea (*Coffea liberica*) and to identify the optimal treatment. The experiment was conducted using a Completely Randomized Design (CRD) with five withering treatments, including no withering, room temperature withering for 10 h, air withering for 10 h, oven withering at 60°C for 30 min, and steaming for 2 min, each with four replications. The observed parameters included powder moisture content, pH, color (L*, a*, b*), antioxidant activity, total phenols, total tannins, flavonoids, and sensory attributes, namely color, aroma, acidity, taste, aftertaste, and overall acceptance. The results showed that withering method significantly affected color, moisture content, antioxidant activity, total phenols, total tannins, flavonoids, and organoleptic attributes related to aftertaste and overall acceptance, while pH, aroma quality, acidity, and taste were not significantly affected. The non-withered sample demonstrated the highest antioxidant activity and total phenolic content. The room temperature withering for 10 h produced antioxidant activity (57.59%) that was not significantly different from the non-withered sample, but offered superior sensory performance. This treatment produced a dark orange (brownish) infusion with L* (45.75), a* (29.25), and b* (49.50), the highest overall hedonic acceptance (3.72), and the most preferred color (3.84). In conclusion, withering at room temperature for 10 h represents the optimal processing method for producing Liberica coffee leaf tea with a balanced combination of functional properties and consumer acceptability.

Keywords— Liberica coffee leaf tea; withering method; antioxidant activity; phenolic compounds; sensory evaluation

Manuscript received July 10, 2025; revised Dec 15, 2025; accepted Dec 20, 2025. Available online Dec 31, 2025
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I. INTRODUCTION

Tea is a product derived from processing tea plant (*Camellia sinensis*) using various methods. It is a beverage commonly consumed by the public, served both hot and cold. Using advanced technology, tea is not only produced from *Camellia sinensis* leaf but also leaf of other plants [1,2].

Coffee plant (*Coffea sp.*), belonging to *Rubiaceae* family, consists of several species. However, for commercial cultivation purposes, only three types are commonly known, namely *C. arabica*, *C. canephora* (Robusta), and *C. liberica* [3,4]. Coffee leaf is one part that has not been used as a food product. In general, Kahwa leaf beverage is a traditional Sumatran drink made from processed coffee leaf, resulting in a

product known as 'daun kahwa' [5]. Flavonoid content in tea is influenced by several factors, namely leaf age, tea picking method, tea variety, planting season, and processing procedures [6]. Recent studies have shown that coffee leaf tea contains significant levels of polyphenols, flavonoids, and antioxidant activity, comparable to or exceeding those of conventional teas, depending on processing conditions [7,8].

In tea production, each processing stage significantly affects quality. One crucial processing stage is withering, which is conducted as an initial step to reduce the moisture content in the leaf, enabling subsequent processes to proceed effectively. During withering process, compounds that contribute to flavour, color, and aroma are formed due to the oxidation of polyphenols [9,10]. The purpose of withering in green tea

processing is to deactivate polyphenol oxidase enzyme, thereby reducing the oxidation of antioxidant compounds [11]. During withering process, several chemical changes occur, including the inactivation of polyphenol oxidase enzymes, an increase in caffeine content, the conversion of chlorophyll and proteins into amino acids, and the oxidation of carotenoids, which can lead to the formation of volatile substances [12].

Based on the description above, this study aims to determine the influence withering method of Liberica coffee leaf on physicochemical and organoleptic properties of tea, and to identify the optimal treatment.

II. MATERIAL AND METHODS

A. Material

The main ingredients used in tea-making process were mature Liberica coffee leaf, obtained from Mekar Jaya Village, Betara District, Tanjung Jabung Barat Regency, Jambi Province (00 57' 46.980'' N 1030 22' 13.404'' E).

The materials used for testing parameters include 2,2-diphenyl-1-picrylhydrazyl (DPPH) (SIGMA Aldrich), ascorbic acid (Merck), and PA-grade methanol (Merck). Meanwhile, the equipment used includes a UV-Vis spectrophotometer, vortex mixer, and pH meter.

B. Methods

Study Design

This study used Completely Randomized Design (CRD), which comprised the factor of withering duration of Liberica coffee leaf tea. There were five treatment levels with four replications, resulting in a total of 20 experimental units. The treatments used were as follows, P0 = No withering, P1 = Withering at room temperature for 10 hours, P2 = Air withering (P2) under shaded, well-ventilated ambient conditions (27–32°C) for 10 h (08:00–18:00), with leaf spread in a single layer and turned periodically, P3 = Oven withering at T=60°C, t=30 minutes, and P4 = Steaming for t=2 minutes.

Material Preparation

Liberica coffee leaf used in this study was mature, specifically the fifth to eighth leaf from the shoot, with uniform size.

Production of Liberica Coffee Leaf Tea

Leaf were harvested, sorted based on size, leaf integrity, and defects, then weighed and washed with running water before being drained. Subsequently, withering was carried out according to the respective treatments, including no withering, withering at room temperature for 10 hours, air withering for 10 hours, oven withering at T=60°C, t=30 minutes, and steaming for t=2 minutes. The drying process was carried out using an oven at 60°C for 6 hours. Leaf were finely ground using a blender and sifted through a 20-mesh sieve [13].

Tea Brewing

About 2 grams of Liberica coffee leaf tea was brewed in 200 ml of water at 100°C, homogenized for 3 minutes. Tea was then strained, and the infusion was poured into a container [13].

Moisture Content

Moisture content was determined using the oven method [14].

Acidity Level (pH)

Acidity level was measured using a pH meter [14].

Antioxidant Activity

Antioxidant activity was assessed using DPPH method [15]. A 0.2 mL sample was pipetted into a screw cap tube, followed by the addition of 3.8 mL of DPPH solution. The dissolved sample was homogenized using a vortex mixer and kept in a dark place for 30 minutes. Subsequently, the sample was transferred to a cuvette, and the absorbance was measured using a spectrophotometer at a wavelength of 517 nm. The antioxidant activity of the sample was expressed as % inhibition and can be calculated using the following formula:

$$\% \text{ Inhibition} = \frac{\text{Blank absorbance} - \text{Sample absorbance}}{\text{Blank absorbance}} \times 100\% \quad \text{eq (1)}$$

Total Phenol Folin-Ciocalteu Method

A total of 0.2 mL sample and 1 mL of Folin-Ciocalteu reagent were mixed until homogeneous. Subsequently, 3 mL of 20% Na₂CO₃ solution was added, and the solution was vortexed until homogeneous. The solution was incubated in a dark room for 2 hours until a blue color formed, and the absorbance was measured with a spectrophotometer at a wavelength of 760 nm. Phenol content obtained was expressed as mg gallic acid equivalent/gram sample [16].

Total Tannin Folin-Ciocalteu Method

About 0.2 mL of the sample solution was mixed with 0.2 mL of Folin Ciocalteu reagent. Subsequently, 4 mL of 20% Na₂CO₃ was added, and the solution was vortexed. The solution was left in a dark room for 30 minutes, and the absorbance was measured with a spectrophotometer at a wavelength of 760 nm [17].

Flavonoid

Total flavonoid content was determined using the colorimetric method. A Liberica coffee infusion sample of 500 μL was pipetted into a screw cap tube, then 100 μL of 10% AlCl₃, 100 μL of 1M CH₃COOK, and 4.3 mL of distilled water were added. The sample was vortexed, incubated in a dark room for 30 minutes, and further transferred to a cuvette. The absorbance was measured with a UV-Vis spectrophotometer at a wavelength of 415 nm. Total flavonoid content was determined based on the quercetin standard curve and expressed in μg/mL units [18].

Color

Objective color analysis of Liberica coffee leaf tea was performed using a color box. The color box consisted of a square enclosure (50 × 50 × 50 cm) equipped with four 8-W neon lamps. Brewed samples were placed at the center of the box and photographed using a camera positioned approximately

40 cm from the sample. The captured images were processed using Adobe Photoshop to obtain L*, a*, and b* values, where L* represents lightness (0 = black, 100 = white), a* indicates the red–green axis, and b* represents the yellow–blue axis. The obtained values were further visualized using ColorHexa tool (www.colorhexa.com) [19].

Sensory Evaluation

Sensory evaluation was conducted to assess the acceptance of Liberica coffee leaf tea samples by panelists. The assessment was performed through two types of tests, namely hedonic and hedonic quality, with observed parameters including taste, color, aroma, and overall acceptance. The evaluation comprised a group of 25 semi-trained panelists [20].

Data Analysis

Data were analyzed using analysis of variance (ANOVA) at a 5% significance level. When a significant treatment effect was observed ($p < 0.05$), mean comparisons were performed using Duncan New Multiple Range Test (DNMRT). All statistical analyses were conducted using SPSS software (IBM SPSS Statistics, version 25).

III. RESULT AND DISCUSSION

Product Description

The untreated Liberica coffee leaf tea powder, at room temperature, with air-drying, and in an oven, showed an even brown color and a coarse texture. The steaming treatment produced an even green color of the powder. The infusion of untreated Liberica coffee leaf tea, with prolonged room temperature withering, air-withering, and oven-withering, yielded a brown hue, while the infusion from steaming treatment has a yellowish hue.

The appearance and description of Liberica coffee leaf tea powder and infusion, influenced by the duration of withering, are shown in **Figure 1**.

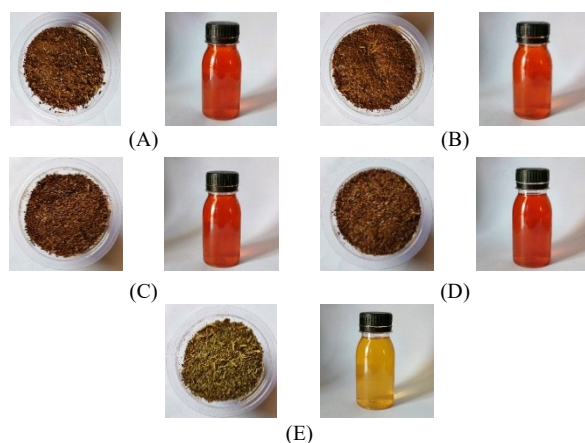


Fig 1. (A) Liberica coffee leaf tea powder and infusion without withering effect; (B) Liberica coffee leaf tea powder and infusion with room temperature withering effect; (C) Liberica coffee leaf tea powder and infusion with air withering effect; (D) Liberica coffee

leaf tea powder and infusion with oven withering effect; (E) Liberica coffee leaf tea powder and infusion with steaming withering effect.

Moisture Content

Moisture content is a crucial parameter in tea, as it can affect the shelf life. Tea with high moisture content tends to become damp and deteriorate quickly. Moreover, high moisture content facilitates the growth of microorganisms, leading to changes in the food product [21].

Table 1 shows that withering influenced the moisture content of the resulting Liberica coffee leaf tea. The average moisture content ranged from 3.34% to 4.41%, with the highest occurring in the treatment without withering.

TABLE 1
 AVERAGE VALUES OF MOISTURE CONTENT AND PH OF
 LIBERICA COFFEE LEAF TEA

Withering Method	Moisture Content (%)	Acidity Level (pH)
Without withering	4.41 ± 0.39 ^b	6.01 ± 0.21
Room temperature	3.68 ± 0.17 ^{ab}	6.24 ± 0.81
Air	3.53 ± 0.90 ^a	6.19 ± 0.03
Oven	3.34 ± 0.44 ^a	6.10 ± 0.05
Steaming	3.42 ± 0.46 ^a	6.11 ± 0.08

Note: Numbers followed by different lowercase letters in the same column indicate a significant difference at the 5% level according to DMRT.

Acidity Level (pH)

Table 1 shows that withering did not affect the pH of Liberica coffee leaf tea, with values ranging from 6.01 to 6.24. The highest value was observed in withering treatment at room temperature.

According to ANOVA results ($p > 0.05$), the treatment did not have a significant effect on the pH content of the resulting Liberica coffee leaf tea. Chemical changes occurred during withering process, including a reduction in solid content, a decrease in starch and gum content, a rise in sugar content, a reduction in protein content, an increase in amino acids, and the breakdown of proteins into amino acids [9], [12].

Antioxidant Activity

As shown in **Table 2**, withering significantly affected antioxidant activity. The highest antioxidant activity was observed in samples without withering, amounting to $62.31 \pm 0.75\%$ activity. Conversely, the steaming treatment yielded the lowest activity at $54.93 \pm 1.43\%$. Across all treatments, the average antioxidant activity varied between 54.93% and 62.31%, consistently showing a decrease in antioxidant potential when withering was applied compared to the unwithered control.

Temperature is a crucial factor that can affect antioxidant activity, as heating leads to an acceleration of initiation reactions and a decrease in antioxidant activity [22]. In this study, antioxidant activity of Liberica coffee leaf tea decreased when subjected to withering treatment. This is possibly due to

the loss of antioxidant compounds during withering process, as well as chemical changes that occur in the antioxidant source [9],[12]. Furthermore, withering can induce chemical alterations in phenolic and flavonoid compounds, which are primary contributors to antioxidant properties of Liberica coffee leaf.

TABLE 2
 AVERAGE VALUES OF ANTIOXIDANT ACTIVITY AND TOTAL PHENOLS OF LIBERICA COFFEE LEAF TEA INFUSION INFLUENCED BY WITHERING METHODS

Withering Method	Antioxidant Activity (%)	Total Phenols (mg GAE/L)
Without withering	62.31 ± 0.75 ^b	536.12 ± 18.71 ^c
Room temperature	57.59 ± 2.28 ^{ab}	452.64 ± 16.91 ^b
Air	55.35 ± 3.64 ^a	375.52 ± 7.78 ^a
Oven	58.81 ± 5.04 ^b	469.30 ± 6.66 ^b
Steaming	54.93 ± 1.43 ^a	358.39 ± 8.45 ^a

Note: Numbers followed by different lowercase letters in the same column indicate a significant difference at the 5% level according to DMRT.

Total Phenols

ANOVA results showed that withering treatment had a significant effect on the total phenolic content of Liberica coffee leaf tea. The sample without withering showed the highest antioxidant activity (62.31 ± 0.75%) and the highest total phenolic content (536.12 ± 18.71 mg GAE/L). This indicates that withering processes, particularly with heat and oxygen exposure, tend to reduce the levels of phenolic compounds, known for significant antioxidant properties. Phenols are the precursor compounds of phenolics found abundantly in plants. Meanwhile, phenolic compounds are the largest group that act as natural antioxidants in plants [23,24]. The presence of heat and oxygen contributes to the changes during withering process. Consequently, phenolic compounds oxidize due to the activity of polyphenol oxidase enzymes, forming reactive ortho semiquinone radicals that further react with amino compounds, imparting a brown color to Liberica coffee leaf tea [25].

Air and steaming withering methods produced the lowest total phenolic contents (375.52 ± 7.78 and 358.39 ± 8.45 mg GAE/L, respectively), supporting the hypothesis that the combination of heat and oxygen strongly contributed to phenolic degradation. Meanwhile, room temperature withering preserved higher phenolic content compared to oven and steaming methods, possibly due to reduced thermal degradation.

Total Tannins

The lowest tannin content was observed in the steaming treatment, possibly due to enhanced enzymatic oxidation during the steaming process (Table 3). Consequently, tannin levels in the non-withered tea remained high due to limited enzymatic oxidation. This is consistent with the viewpoint expressed by Chen Y, Zeng L, Liao Y, Li J, Zhou B, Yang Z, Tang J [26]; Anan Xu, Lin Chen, Yuxuan Shi, Huajie Wang, Qun Ye, Yuefei Wang, Zhonghua Liu, Ping Xu [27] that the tannin levels in

green tea (without enzymatic oxidation) are higher due to experiencing minimal enzymatic oxidation.

The highest tannin content was found in the unwithered sample (189.47 ± 4.38 mg TAE/L), while the lowest was in the steamed sample (84.62 ± 7.42 mg TAE/L). This significant decrease in tannin content under steaming may be attributed to enhanced enzymatic oxidation during the steaming process. Without withering, enzymatic activity remains minimal, preserving tannin levels. These results are consistent with the view expressed by Anan Xu, Lin Chen, Yuxuan Shi, Huajie Wang, Qun Ye, Yuefei Wang, Zhonghua Liu, Ping Xu [27], stating that tannin content in green tea remains high due to limited oxidation.

TABLE 3
 AVERAGE VALUES OF TOTAL TANNINS AND FLAVONOID OF LIBERICA COFFEE LEAF TEA INFUSION INFLUENCED BY WITHERING METHODS

Withering Method	Total Tannins (mg TAE/L)	Flavonoids (mg QE/L)
Without withering	189.47 ± 4.38 ^c	64.14 ± 9.18 ^b
Room temperature	121.53 ± 3.51 ^c	55.08 ± 6.09 ^{ab}
Air	99.03 ± 4.41 ^b	52.20 ± 4.18 ^a
Oven	139.47 ± 8.28 ^d	58.00 ± 6.94 ^{ab}
Steaming	84.62 ± 7.4 ^a	51.83 ± 3.40 ^a

Note: Numbers followed by different lowercase letters in the same column indicate a significant difference at the 5% level according to DMRT.

Flavonoids

ANOVA results in Table 3 show that withering treatment had a significant effect on the total flavonoid content (mg QE/L), with average values ranging from 64.14 to 51.83 mg QE/L. The non-withering method produced the highest total flavonoid content, which decreased when the sample was subjected to any withering treatments. According to N. Felicia, I. W. R. Widarta, and N. L. A. Yusarini [28] flavonoids degrade at temperatures of 100°C due to the sensitivity to heat, attributed to the presence of hydroxyl and ketone groups, as well as unsaturated double bonds.

Color of Liberica Coffee leaf tea

Color is an essential aspect of food or beverage products. In general, food products are expected to have good nutritional value and texture, as well as a pleasant taste and an appealing color to attract consumers [29-31].

Table 4 shows that withering method for Liberica coffee leaf tea affected the values of L*, a*, and b*. The brightness in tea is associated with the oxidation that occurs during withering process, leading to a transformation of tannin compounds into theaflavins and thearubigins [30].

Theaflavin and thearubigin content affects the evaluation of a* and b*, where theaflavin plays a role in determining the brightness of tea infusion (reddish yellow), while function in determining the stability of tea infusion color (dark reddish-brown) [32]. These two compounds are responsible for the formation of color in Liberica coffee leaf tea.

TABLE 4
 AVERAGE VALUES OF COLOR AND COLOR DESCRIPTION OF LIBERICA COFFEE LEAF TEA INFUSION INFLUENCED BY WITHERING METHODS

Withering Method	L*	a*	b*	Color	Description of Color
Without withering	44,25 ± 1,71 ^a	30,50 ± 1,73 ^b	42,25 ± 2,06 ^a		Dark orange (Brown tone)
Room temperature	45,75 ± 3,40 ^a	29,25 ± 2,06 ^b	49,50 ± 1,73 ^b		Dark orange (Brown tone)
Air	45,50 ± 1,29 ^a	29,00 ± 1,41 ^b	51,25 ± 2,50 ^b		Dark orange (Brown tone)
Oven	45,25 ± 0,96 ^a	30,25 ± 2,50 ^b	43,25 ± 2,50 ^a		Dark orange (Brown tone)
Steaming	56,50 ± 2,38 ^b	19,20 ± 51,71 ^a	54,25 ± 2,75 ^c		Strong orange

Note: Numbers followed by different lowercase letters in the same column indicate a significant difference at the 5% level according to DNMR.

Theaflavin and thearubigin content affects the evaluation of a* and b*, where theaflavin plays a role in determining the brightness of tea infusion (reddish yellow), while function in determining the stability of tea infusion color (dark reddish-brown) [32]. These two compounds are responsible for the formation of color in Liberica coffee leaf tea.

Organoleptic

Color is the first parameter perceived by consumers and consequently serves as an important indicator of product quality. As shown in **Table 5**, the room temperature withering treatment produced the most preferred color among consumers. This treatment resulted in a dark orange (brownish) brew color rated significantly higher by panelists (score 3.84) than the steaming treatment (2.64). Although the L*, a*, and b* values did not represent the highest or lowest values observed among all treatments, the combination of L* (45.75), a* (29.25), and b* (49.50) reflects a balanced interaction between lightness, redness, and yellowness, producing a visually appealing color to consumers. Similar results have been reported in studies on tea pigment formation, where intermediate oxidation during withering/processing stage led to optimal development of

theaflavins and thearubigins, key compounds that determine liquor color and are associated with higher sensory quality compared to extremes of oxidation [33].

Tannin oxidation into theaflavins (reddish-yellow color) and thearubigins (dark reddish-brown color) during withering process contributes to the formation of the desired color in tea [34]. Previous studies on different withering methods in black tea processing have also reported significant differences in polyphenol oxidation, theaflavin/thearubigin content, and sensory attributes among treatments [35].

Table 5 shows that withering treatment had no significant effect on aroma, acidity, and taste. This result is in line with studies where variations in withering time or type primarily affected color and nonvolatile components rather than basic taste attributes when sensory scores were compared among tea samples [36]. The evaluation of hedonic quality for the aftertaste of steeped Liberica coffee leaf tea indicates that withering method affects the aftertaste. Withering process in tea serves a similar purpose as fermentation, where it aims to reduce catechin content in tea.

TABLE 5
 AVERAGE VALUES OF ORGANOLEPTIC PROPERTIES OF LIBERICA COFFEE LEAF TEA INFUSION INFLUENCED BY WITHERING METHODS

Withering Methods	Hedonic Color	Hedonic Quality of Aroma	Hedonic Quality of Acidity	Hedonic Quality of Taste	Hedonic Quality of Aftertaste	Overall Hedonic Acceptance
Without withering	3.60 ± 0.58 ^b	3.04 ± 1.06	2.84 ± 0.99	3.08 ± 0.81	3.48 ± 0.82 ^b	3.28 ± 0.61 ^{ab}
Room temperature	3.84 ± 0.47 ^b	2.68 ± 0.69	2.64 ± 0.76	2.92 ± 0.76	2.96 ± 0.73 ^a	3.72 ± 0.54 ^c
Air	3.76 ± 0.52 ^b	2.96 ± 0.68	2.56 ± 0.71	2.64 ± 0.64	2.80 ± 0.76 ^a	3.64 ± 0.64 ^{bc}
Oven	3.60 ± 0.71 ^b	2.84 ± 0.80	2.72 ± 0.84	3.04 ± 1.06	3.04 ± 0.79 ^{ab}	3.28 ± 0.82 ^{ab}
Steaming	2.64 ± 0.81 ^a	2.52 ± 0.77	2.72 ± 0.74	3.08 ± 1.15	2.84 ± 0.99 ^a	3.04 ± 0.8 ^a

Note: Numbers followed by different lowercase letters in the same column indicate a significant difference at the 5% level according to DNMR.

*Hedonic Color Score: 1 (Very Dislike), 2 (Dislike), 3 (Somewhat Like), 4 (Like), 5 (Very Like)

*Hedonic Quality Aroma Score: 1 (Very atypical of coffee), 2 (Not typical of coffee), 3 (Somewhat typical of coffee), 4 (Typical of coffee), 5 (Very typical of coffee)

*Hedonic Quality Acidity Score: 1 (Very low acidity), 2 (Low acidity), 3 (Moderate acidity), 4 (High acidity), 5 (Very high acidity)

*Hedonic Quality Taste Score: 1 (Very non-bitter), 2 (Not bitter), 3 (Moderately bitter), 4 (Bitter), 5 (Very bitter)

*Hedonic Quality Aftertaste Score: 1 (Very non-astringent), 2 (Not astringent), 3 (Moderately astringent), 4 (Astringent), 5 (Very astringent)

*Hedonic Overall Acceptance Score: 1 (Very Dislike), 2 (Dislike), 3 (Somewhat Like), 4 (Like), 5 (Very Like)

Tea subjected to withering will have a lighter astringent taste compared to tea without the process. Studies on black tea have shown that as catechins decrease during processing, the formation of polymeric compounds such as theaflavins and thearubigins correlates with reduced astringency and improved sensory scores [36-38]. For example, black tea has a milder astringent taste compared to green tea.

IV. CONCLUSION

In conclusion, withering method significantly affected the color, moisture content, antioxidant activity, total phenols, total tannins, flavonoids, and sensory attributes related to aftertaste and overall hedonic acceptance of Liberica coffee leaf tea, while pH, aroma quality, acidity, and taste were not significantly affected. The non-withered sample retained the highest antioxidant activity and total phenolic content. However, the room temperature-withered sample (10 h) showed antioxidant activity that was not significantly different ($p > 0.05$) from the non-withered sample, despite having lower total phenols and tannins. This treatment achieved the highest overall hedonic acceptance and the most preferred color among panelists. Therefore, withering at room temperature for 10 h was identified as the optimal processing method, providing a balanced combination of functional properties and consumer acceptability. The treatment also demonstrates significant potential for the development of Liberica coffee leaf tea as a value-added functional beverage.

ACKNOWLEDGMENT

The authors gratefully acknowledge funding support from the Institute for Research and Community Service (LPPM), Universitas Jambi, through the Basic Research scheme (Contract No. 328/UN21.11/PT.01.05/SPK/2023)

CONFLICT OF INTEREST

The authors declare no conflict of interest.

During the preparation of this manuscript, generative AI tools (Grammarly, Quillbot, MS Office AI, and OpenAI) were used to improve the clarity, grammar, and overall readability of the text. The use of these tools was conducted under complete human oversight, and all intellectual and scientific content, data interpretation, and conclusions are entirely the responsibility of the authors. No generative AI tool was used to generate or analyze scientific data, and AI tools are not listed as authors or co-authors.

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