

The Effects of Brewing Condition on Tea's Caffeine Content and Sensory Quality

Pengaruh Kondisi Seduh terhadap Kandungan Kafein dan Kualitas Sensori Teh

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Abstract. Tea is a widely consumed beverage in Indonesia due to its distinctive flavor and bioactive compounds, including caffeine and antioxidants. This study aimed to evaluate the effects of brewing temperature and time on caffeine content and sensory acceptability, and to determine the optimal brewing conditions for green and black tea. Indonesian green tea and black tea were brewed at temperatures of 60, 70, 85, and 95 °C for 2, 5, 7, and 10 minutes using a tea-to-water ratio of 1.85 g per 250 mL of water. Caffeine content was determined using UV-Vis spectrophotometry, while sensory evaluation was conducted through a hedonic test to assess consumer preference. The results showed that higher brewing temperatures and longer steeping times increased the extraction of caffeine and antioxidants in both green and black tea. However, these conditions tended to reduce sensory acceptability. Therefore, the optimal brewing conditions were determined by balancing chemical extraction with sensory preference. For green tea, the optimal condition was identified as brewing at 85 °C for 7 minutes, producing a caffeine content of 312.51 ppm and an average hedonic score of 2.78 on a 5-point scale. For black tea, the optimal brewing condition was also 85 °C for 7 minutes, yielding a caffeine content of 283.86 ppm and a hedonic score of 3.93. These findings provide practical guidance for optimizing tea brewing conditions to achieve desirable sensory quality while maintaining beneficial bioactive compounds.

Keywords: black tea, caffeine, green tea, hedonic

Abstrak. Teh adalah minuman favorit di kalangan masyarakat Indonesia karena rasanya dan kandungan senyawa bermanfaat seperti kafein dan antioksidan. Penelitian ini bertujuan untuk menyelidiki pengaruh suhu dan waktu seduh terhadap kandungan kafein, dan aspek hedonik dan mengidentifikasi kondisi optimal dari suhu dan waktu seduh. Dua jenis teh, yaitu teh hijau dan teh hitam dari Indonesia, diseduh pada suhu 60, 70, 85, dan 95 °C, serta durasi 2, 5, 7, dan 10 menit. Rasio teh dengan air yang digunakan adalah 1,85 g per 250 mL air. Spektrofotometri UV-Vis digunakan untuk identifikasi kafein, dan survei sensori dilakukan untuk mengevaluasi kualitas hedonik teh. Suhu seduh yang lebih tinggi dan durasi yang lebih lama menghasilkan peningkatan kadar kafein dan antioksidan pada teh hijau dan teh hitam, meskipun berdampak negatif pada aspek sensori. Oleh karena itu, kondisi seduh optimal ditentukan dengan menyeimbangkan kandungan kafein dan antioksidan dengan rasa yang diinginkan. Untuk teh hijau, kondisi optimal diperoleh pada suhu 85 °C selama 7 menit, menghasilkan kandungan kafein sebesar 312,51 ppm dan rata-rata nilai hedonik sebesar 2,78. Untuk teh hitam, kondisi optimal diperoleh pada suhu 85 °C selama 7 menit, menghasilkan kandungan kafein sebesar 283,86 ppm dan rata-rata nilai hedonik sebesar 3,93.

Kata Kunci: hedonik, kafein, teh hijau, teh hitam

Practical Application: The results of this research are expected to provide valuable information for the beverage industry regarding optimal brewing conditions. Understanding the temperature and brewing time that yield high levels of caffeine while maintaining favorable sensory qualities can help achieve customer satisfaction. Additionally, knowing the optimal conditions can reduce excessive energy consumption and processing time in beverage production.

INTRODUCTION

Tea (*Camellia sinensis*) consumption has become increasingly popular in Indonesia, with green and black tea being the most commonly consumed varieties (Wibowo *et al.* 2022). Its unique aroma, color, and caffeine content have made it a favored alternative to coffee (Ulfa and Nofita 2018). The growing interest in

tea among Indonesians is influenced by several factors, including a long-standing tea-drinking culture, the wide availability of different tea types, and the perceived health benefits, such as reduced cardiovascular disease risk, enhanced cognitive function, and support for weight management.

Studies have highlighted the potential of both green and black tea to enhance antioxidant capacity,

particularly in individuals experiencing oxidative stress, while also positively influencing glucose, lipid, and uric acid metabolism (Peluso and Serafini 2017; Rob *et al.* 2020). Antioxidants play a crucial role in mitigating the harmful effects of reactive oxygen and nitrogen species (ROS/RNS) on physiological functions (Hasim *et al.* 2019; Wibowo *et al.* 2022). An imbalance between antioxidants and oxidants can increase oxidative stress, contributing to various diseases such as cardiovascular diseases, cancer, diabetes mellitus, and respiratory disorders (Phanindra *et al.* 2015; Theafelicia and Narsito 2023; Wibowo *et al.* 2022). Substituting tea for coffee has been associated with lower mortality rates from cancer and cardiovascular diseases (Van den Brandt 2018).

Green tea and black tea, both derived from the *Camellia sinensis* plant, are among the most widely consumed varieties worldwide. Indonesian tea is typically produced from *Camellia sinensis* var. *assamica*. Green tea is processed from young leaves that are plucked, wilted to reduce moisture content, cooled, gently rolled, and dried to remove residual moisture and stabilize the leaves. Unlike black tea, green tea undergoes non-enzymatic oxidation (non-fermentation), which preserves its catechin content, resulting in high levels of phenolic and flavonoid compounds (Nadiah dan Uthumporn 2015). The natural aroma of green tea is retained and is often enhanced with fragrances from other botanical sources, such as jasmine flowers.

In contrast, black tea is produced from older leaves that are torn, wilted, grinded, fermented, and dried (Rohmah *et al.* 2023). Black tea undergoes enzymatic oxidation, in which catechins are oxidized by polyphenol oxidase (PPO) to form theaflavins and thearubigins. These compounds impart a stronger taste, deeper color, and more pronounced aroma compared with green tea. Although structurally modified, these compounds retain antioxidant properties due to their similarity to catechins (Nadiah dan Uthumporn 2015).

Green tea is well known for its rich antioxidant content, primarily composed of polyphenols, particularly flavonoids. Among these, catechins are the most abundant group in tea, including epicatechin (EC), epicatechin gallate (ECG), epigallocatechin (EGC), and epigallocatechin-3-gallate (EGCG). EGCG in particular, is recognized for its potent antioxidant and anti-inflammatory properties (Nurtina *et al.* 2022). Overall, green tea contains higher levels of antioxidants and exhibits greater antioxidant activity compared to black tea (Anesini *et al.* 2008; Nadiah dan Uthumporn 2015; Leslie and Gunawan 2019).

Studies have shown that brewing conditions, such as temperature and time, significantly influence the caffeine content of tea (Labbé *et al.* 2006). Higher temperatures and longer brewing times generally lead to increased caffeine levels but can also affect the

sensory characteristics of the brewed tea (Lin *et al.* 2014; Muzolf-Panek *et al.* 2021; Sharif *et al.* 2014; Wardani *et al.* 2016; Yadav *et al.* 2018; Zou *et al.* 2018). The sensory profile is influenced by the polyphenol content in tea. Several studies have demonstrated that antioxidant levels in tea increased with higher brewing temperatures and longer brewing times (Muzolf-Panek *et al.* 2021; Chong dan Nyam, 2022). Additionally, excessive levels of antioxidants can contribute to a bitter taste in tea (Zou *et al.* 2018). However, research focused on optimizing these parameters to find the balance between caffeine content and desirable sensory qualities remains limited.

When determining optimal brewing conditions, it is essential to consider recommended caffeine intake levels for human consumption. A caffeine intake of up to 100 ppm is sufficient to delay sleep and improve alertness, while 200–250 ppm can enhance mood and alertness for about three hours in the morning. A dosage of 300–350 ppm is preferred for improving mood and alertness in the afternoon without affecting heart rate, making it a popular choice among consumers (Marriott 1994).

This study aims to examine the effects of the brewing process on caffeine content under different temperature and time conditions, while also considering consumer sensory preferences. The results are expected to identify the optimal brewing temperature and time conditions. Tea concentration and brewing parameters were adjusted based on previous research to optimize taste and bitterness levels, while exploring the combined effects of temperature and time on overall tea quality.

MATERIALS AND METHOD

Materials

The materials used in this study included commercial green tea (Pekoe, Sukabumi, West Java, Indonesia) and commercial black tea obtained from a farmer in Central Java, Indonesia. Green tea was produced from young leaves that were plucked, wilted to reduce moisture content, cooled, gently rolled, and subsequently dried. The dried leaves were then packaged into tea bags. While black tea was produced from older leaves that were torn, wilted, grinded, enzymatically oxidized (fermented), and dried to yield a fine, homogenized powder.

Tea samples and tea infusion preparation

Tea infusions were prepared by brewing 3.7 g of dried tea leaves (in a tea bag) with 500 mL of deionized water at four temperatures (60, 70, 85, and 95 °C) and four extraction times (2, 5, 7, and 10 minutes) using a gooseneck kettle with a built-in thermometer (Hario

Buono, Japan). Brewing time was measured from the moment the tea bag was immersed in hot water. At the end of extraction, the tea bag was removed, and the infusion was cooled to room temperature in a beaker prior to analysis.

Identification of caffeine content

The identification of caffeine content was performed using the method outlined by Vuletić *et al.* (2021), with some modifications. The modifications were made to the dilution ratio, where 1 mL of the extracted phase was diluted to a 10 mL solution, compared to a 0.1 mL solution diluted to 10 mL. Standard solutions of caffeine, ranging from 20 to 440 ppm, were prepared by dissolving caffeine in 100 mL of chloroform (Smartlab, Indonesia) and subsequently diluting it with chloroform at a 1:10 ratio. The absorbance of these standard solutions was measured at a wavelength of 277 nm using a UV-Vis Spectrophotometer (Hanon i3, China), with chloroform serving as the blank.

For the tea samples, the caffeine concentration was determined using the following procedure: 20 mL of each tea sample was mixed with 2 g of sodium carbonate (Na_2CO_3) (Pudak, Indonesia) to precipitate tannins. The mixture was then filtered using a vacuum pump (Rocker 300 oil-free, Taiwan) to recover the filtrate. The filtrate was evaporated using a heating mantle (B-ONE DHM-500s, Indonesia) until 5 mL of solution remained. Next, 5 mL of chloroform was added for extraction, and the mixture was shaken and allowed to separate. The chloroform layer was then isolated, and a 1 mL portion of this layer was diluted with fresh chloroform to a total volume of 10 mL. The absorbance of this solution was measured at 277 nm, and the absorbance values were used to determine the caffeine concentration in ppm.

Sensory test

The assessment was conducted in two stages. In the first stage, color, and caffeine content were used to select eight samples (four green teas and four black teas) from a total of 32 variants. In the second stage, these eight samples were evaluated by panelists for sensory attributes, including taste, aroma, and color. Sensory evaluation was performed using a 5-point hedonic scale, where 1 indicated “least preferred” and 5 indicated “most preferred.”

The panel consisted of 20 untrained participants from the Calvin Institute of Technology and served as a preliminary consumer preference test (Puspitasari *et al.* 2017; Lembono *et al.* 2025). Each sample was prepared using the tea infusion method, cooled to room temperature, and served in paper cups. Panelists evaluated each variant and were provided with water between samples to minimize carryover effects.

Statistical analysis

All caffeine measurements were performed in duplicate, and results are expressed as mean \pm standard deviation (SD). Statistical analyses were conducted using Microsoft Excel 2017. The interaction effects of brewing temperature and time were evaluated using two-way ANOVA, followed by Tukey’s test with the significance level set at $p \leq 0.05$. Comparisons between green and black tea were assessed using independent t-tests, with Levene’s test applied to evaluate the homogeneity of variances ($p \leq 0.05$). Sensory attributes (taste, color, and aroma) were analyzed using one-way ANOVA for each variant, with significance set at $p < 0.05$.

RESULTS AND DISCUSSION

The effect of temperature and brewing time on caffeine concentration in tea

Caffeine concentrations in green and black tea at different brewing times and temperatures are summarized in Table 1 and illustrated in Figure 1. Overall, caffeine levels increased with both temperature and extraction time, a trend consistent across all conditions. At higher temperatures, cell wall disruption enhances the release of soluble compounds, while increased solubility and diffusion coefficients further promote extraction (Muzolf-Panek *et al.* 2021; Saklar *et al.* 2015). A two-way ANOVA confirmed that the interaction between brewing temperature and time significantly affected caffeine content in both green and black tea ($p < 0.05$).

In green tea, the maximum caffeine concentration (437.57 ppm) occurred at 95 °C for 10 minutes (Figure 1A), consistent with reported values of 128.1–348.6 ppm under similar conditions (Labbé *et al.* 2006; Putri and Ulfin 2015). Considering the optimal caffeine dosage for alertness (300–350 ppm; Marriott 1994), this range was achieved at 85 °C for 7 minutes, whereas brewing at 95 °C produced excessively high levels. Thus, 85 °C for 7 minutes is recommended, particularly since this temperature is commonly supplied by water dispensers.

For black tea, the highest caffeine content (347.15 ppm) was also observed at 95 °C for 10 minutes (Figure 1B), aligning with previous reports of 189.52–378.67 ppm (Sharif *et al.* 2014; Wardani and Fernanda 2016; Yadav *et al.* 2018). However, to reach the optimal 300–350 ppm range, black tea required brewing at 85 °C for 10 minutes. While green tea exhibited higher caffeine concentrations and steeper extraction curves than black tea, this difference is attributable to processing: black tea undergoes full oxidation, and highly processed teas typically contain less caffeine. Nevertheless, Levene’s test and independent t-test showed no significant difference between the two tea types ($p > 0.05$), indicating comparable trends and variances across brewing conditions.

Table 1. Caffeine concentration (ppm) of green and black tea at various temperatures (°C) and brewing times (minute)

| Temperature (°C) | Brewing Time (minutes) | Caffeine Concentration (ppm) | |
|------------------|------------------------|------------------------------|--------------------------|
| | | Green Tea | Black Tea |
| 60 | 2 | 45.16±1.53 ^h | 125.00±9.04 ⁱ |
| | 5 | 169.19±8.08 ^g | 145.72±4.99 ^h |
| | 7 | 202.22±1.46 ^f | 194.96±0.83 ^g |
| | 10 | 255.63±5.24 ^d | 240.12±3.85 ^e |
| 70 | 2 | 59.71±0.07 ^g | 157.70±2.99 ⁱ |
| | 5 | 208.63±0.30 ^f | 193.96±3.48 ^g |
| | 7 | 266.10±11.61 ^e | 224.77±1.66 ^e |
| | 10 | 360.97±2.02 ^c | 291.14±5.06 ^c |
| 85 | 2 | 98.48±2.69 ^f | 204.58±0.81 ⁱ |
| | 5 | 209.21±1.73 ^d | 239.53±4.38 ^g |
| | 7 | 312.51±0.07 ^c | 283.86±1.92 ^d |
| | 10 | 359.43±0.45 ^a | 333.55±1.84 ^c |
| 95 | 2 | 163.98±3.04 ^e | 212.35±0.55 ^h |
| | 5 | 237.81±5.53 ^c | 277.85±2.29 ^f |
| | 7 | 376.84±0.51 ^b | 295.74±0.65 ^b |
| | 10 | 437.57±3.10 ^a | 347.15±1.56 ^a |

Note: Values represent the means of duplicate measurements for each type of tea. Different letters (a–p for green tea and a'–p' for black tea) indicate significant differences among concentration means across temperatures and brewing times, as determined by two-way ANOVA followed by Tukey's test at the 5% significance level ($p < 0.05$)

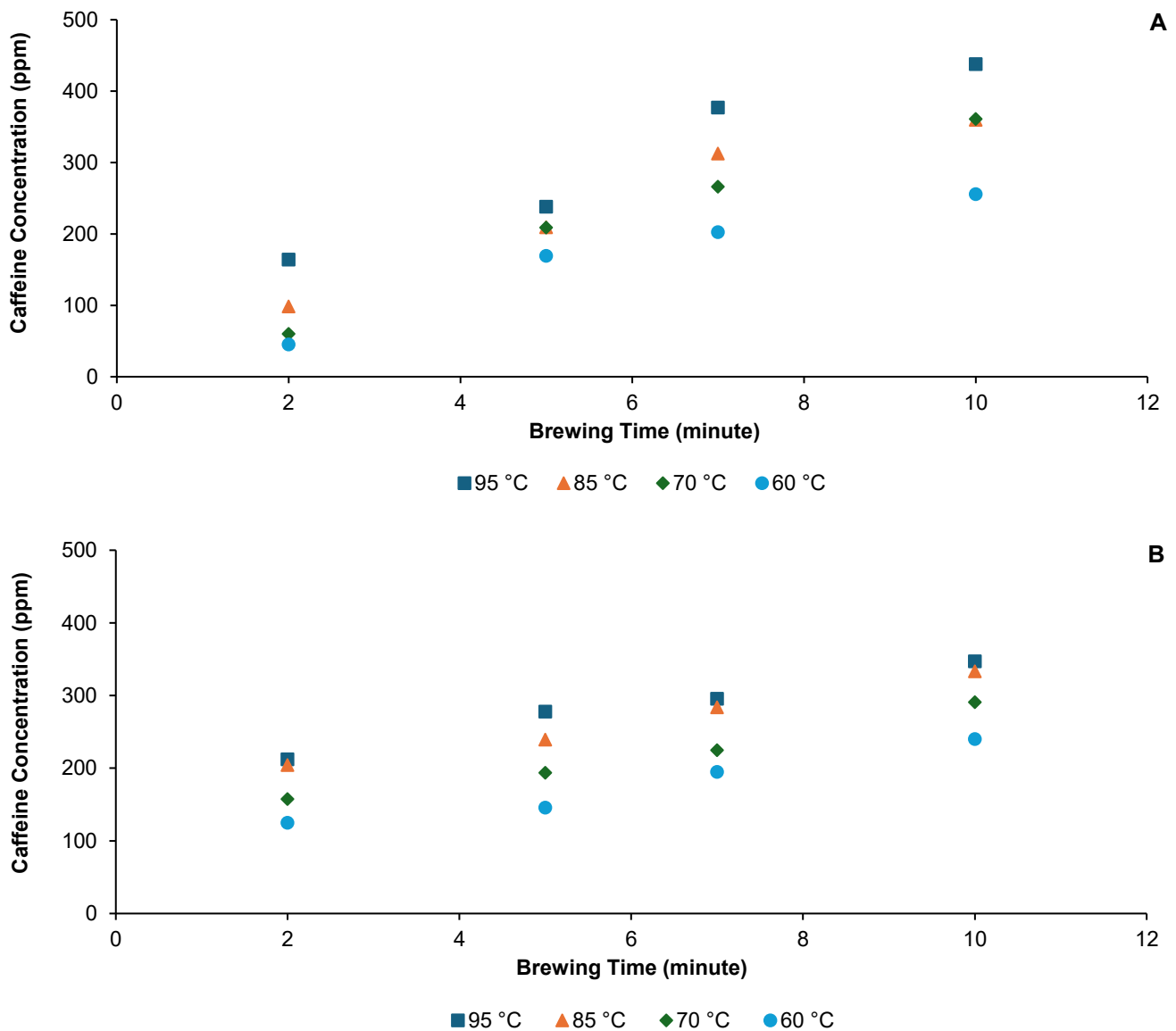


Figure 1. Caffeine concentration of green tea (A) and black tea (B) at temperatures ranging from 60 to 95 °C and brewing times of 2 to 10 minutes. Values represent the mean of duplicate measurements for each type of tea

The effect of temperature and brewing time on sensory quality in tea

The sensory assessment was conducted in two stages. First, 32 tea variants were prepared by combining four brewing temperatures (60, 70, 85, and 95 °C) with four extraction times (2, 5, 7, and 10 minutes) for both green and black tea. These were evaluated for caffeine content and color (Figures 2A and 2B). Based on this evaluation, eight samples were selected for sensory testing: those brewed at 70 °C and 85 °C for 5 and 7 minutes. Variants brewed at 95 °C were excluded due to their dark color, while those brewed at 60 °C or for 2 minutes contained very low caffeine levels (<200 ppm, Table 1). Samples brewed for 10 minutes were also excluded because of their dark color and excessive caffeine content, which would result in a bitter taste.

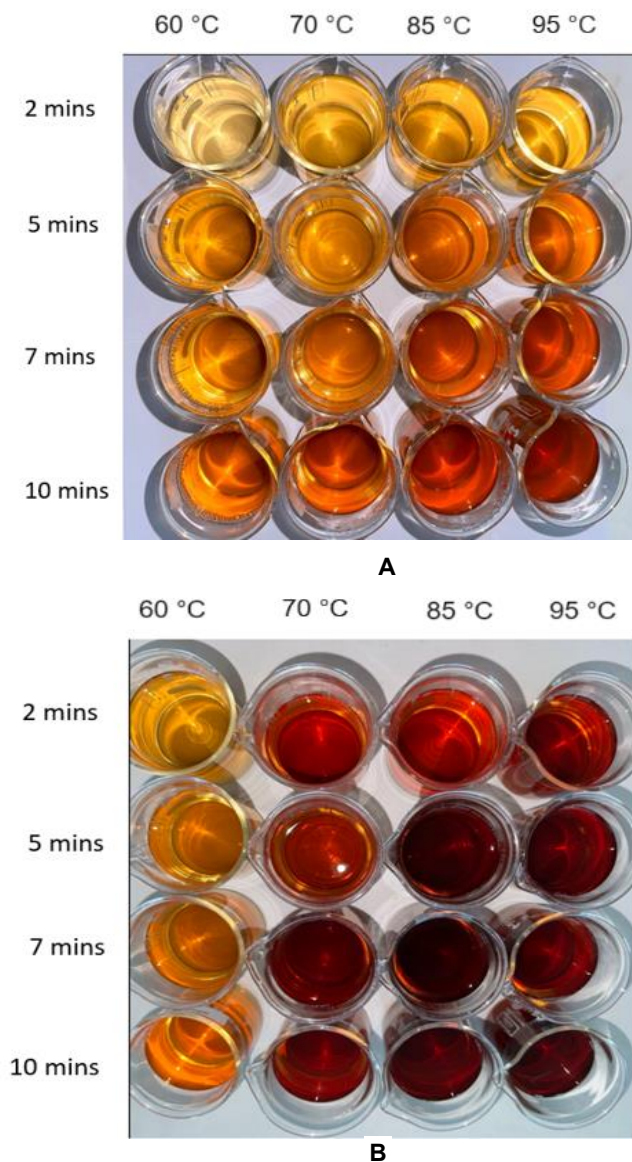


Figure 2. Color of green tea (A) and black tea (B) samples at various brewing temperatures and times

Thus, brewing at 70 °C and 85 °C for 5 or 7 minutes was identified as the most suitable condition for sensory testing. Although black tea contained slightly less caffeine than green tea, the levels remained sufficient to enhance alertness (Marriott 1994). The sensory outcomes are presented in Figures 3A and 3B, with summary scores in Tables 2 and 3.

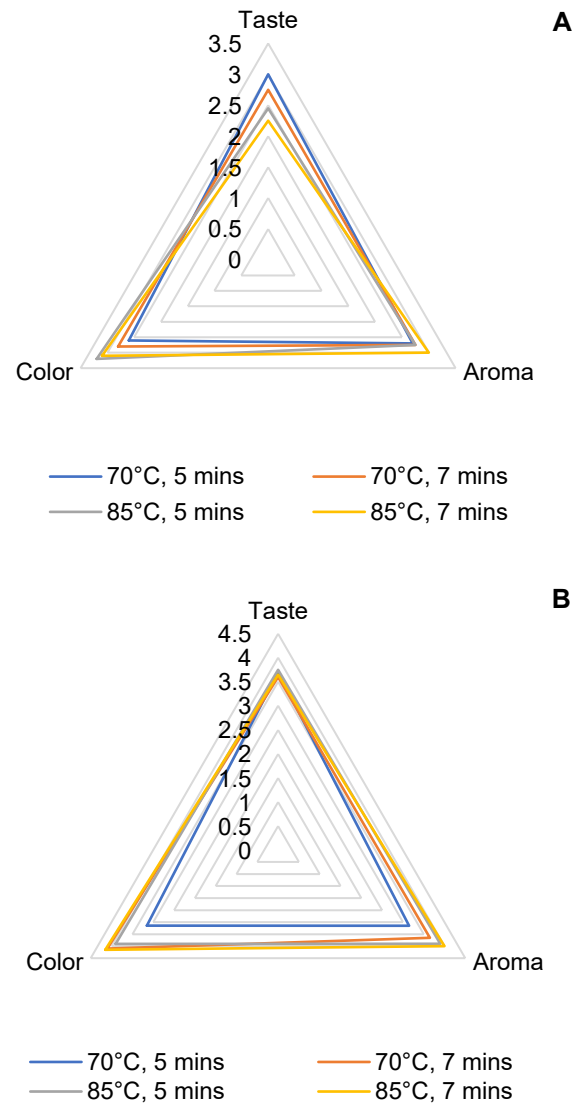


Figure 3. Sensory test results of green tea (A) and black tea (B)

Higher brewing temperatures and longer extraction times generally increased caffeine and antioxidant levels, with maximum concentrations observed at 95 °C for 10 minutes. However, these conditions negatively affected sensory quality. Bitterness and astringency are primarily attributed to caffeine and catechins, respectively, while amino acids contribute to umami taste (Zou *et al.* 2018; Parvez and Wani 2024). Excessive caffeine and catechin levels intensify bitterness and astringency, which are generally undesirable (Zou *et al.* 2018; Shannon *et al.* 2017).

Table 2. Sensory score of green tea

| Tea | Temperature (°C) | Time (min) | Final Score | | | Average Score |
|-----------|------------------|------------|-------------|-----------|-----------|------------------------------|
| | | | Taste | Aroma | Color | |
| Green tea | 70 | 5 | 3.00±0.92 | 2.70±0.80 | 2.60±0.99 | 2.77±0.91 ^a |
| Green tea | 70 | 7 | 2.75±0.97 | 2.75±0.79 | 2.80±1.06 | 2.77±0.93 ^a |
| Green tea | 85 | 5 | 2.45±1.15 | 2.75±1.12 | 3.20±0.95 | 2.80±0.91^a |
| Green tea | 85 | 7 | 2.25±1.16 | 3.00±1.12 | 3.10±1.07 | 2.78±1.17 ^a |

Note: Values are presented as mean ± standard deviation, with n= 20 samples. Different letter (a–d) indicate significant differences among sensory results at each temperature and brewing time, as determined by one-way ANOVA at a 5% significance level ($p<0.05$)

Table 3. Sensory score of black tea

| Tea | Temperature (°C) | Time (min) | Final Score | | | Average Score |
|-----------|------------------|------------|-------------|------------------------|-----------|------------------------------|
| | | | Taste | Aroma | Color | |
| Black tea | 70 | 5 | 3.70±1.08 | 3.15±0.75 ^a | 3.15±0.81 | 3.33±1.10 ^a |
| Black tea | 70 | 7 | 3.60±1.19 | 3.65±1.04 ^a | 4.10±1.25 | 3.78±1.17 ^a |
| Black tea | 85 | 5 | 3.75±1.07 | 3.90±0.97 ^a | 3.90±1.37 | 3.85±1.13 ^a |
| Black tea | 85 | 7 | 3.65±1.23 | 4.00±1.17 ^b | 4.15±1.39 | 3.93±1.26^a |

Note: Values are presented as mean ± standard deviation, with n= 20 samples. Different letter (a–d) indicate significant differences among sensory results at each temperature and brewing time, as determined by one-way ANOVA at a 5% significance level ($p<0.05$)

Previous studies reported similar trends: anti-oxidant content rises with temperature and time due to cell wall disruption, which promotes phenolic release (Muzolf-Panek *et al.* 2021), along with enhanced solubility and diffusion (Saklar *et al.* 2015). Saklar *et al.* (2015) found that polyphenol levels increased with brewing time at 75 °C but decreased with prolonged extraction at 95 °C, with a peak at 3 minutes when brewed at 85 °C. Excessive heating at 95 °C can degrade polyphenol (catechins) by converting epi-structured into non-epi-structured forms. Likewise, Bindes *et al.* (2019) reported optimal green tea polyphenol extraction around 80 °C, though both studies used higher tea concentrations than in the present work. Under the lower concentrations applied here, extending the brewing time up to 7 minutes was feasible to maximize polyphenol extraction.

The sensory evaluation indicated that the most preferred green tea was brewed at 85 °C for 5 minutes, achieving an overall score of 2.80, although the difference was not statistically significant (Table 2). This condition provided a high caffeine content while avoiding excessive bitterness. The sample brewed at 70 °C for 5 minutes received the highest taste score due to its milder flavor, whereas the 85 °C/7-minute sample was rated best for aroma. The most appealing color—a golden brown (hex code #AC4801)—was also obtained at 85 °C for 5 minutes (Figure 4, Colour of tea infusion).

For black tea, the most preferred variant was brewed at 85 °C for 7 minutes, producing a mild taste and a relaxing effect. Owing to fermentation, black tea contains lower antioxidant levels than green tea (Truong and Jeong 2021), which contributes to its less bitter flavor and higher taste score (Table 3). It also exhibited a pleasant aroma and a rich dark-brown color (hex code #280405).

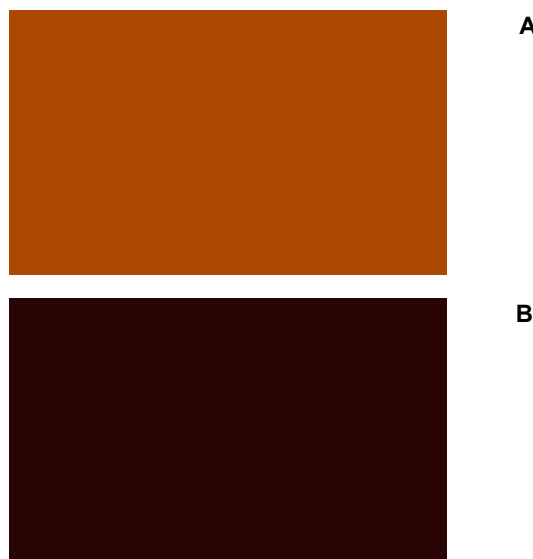


Figure 4. Color of favourite tea infusion: (A) green tea (golden brown), hex #AC4801; (B) black tea (dark brown), hex #280405

These findings align with previous research indicating that infusion quality—including color, taste, aroma, and overall acceptability—is highest when brewed for up to 5 minutes at 75–95 °C. In contrast, brewing at 85–95 °C for more than 20 minutes produced infusions that were excessively dark, bitter, and strongly aromatic, making them less desirable (Saklar *et al.* 2025).

Optimal brewing conditions for tea infusion

For green tea, the highest caffeine concentration was obtained at 95 °C for 10 minutes; however, this condition produced excessive bitterness and a dark color. The sensory test indicated that the sample brewed at 85 °C for 5 minutes had the most favorable taste, aroma, and color, despite its lower caffeine content. Consequently, 85 °C for 7 minutes was identified as the optimal brewing condition, yielding

caffeine levels within the recommended range for alertness (312.51 ppm) and a relatively high sensory score (2.78), comparable to the 85 °C/5-minute variant (2.80), although the difference was not statistically significant.

For black tea, the highest caffeine and antioxidant concentrations were also observed at 95 °C for 10 minutes, but this condition produce undesirable bitterness and color. Sensory evaluation showed that brewing at 85 °C for 7 minutes provided the best balance of taste, aroma, and color, producing 283.86 ppm of caffeine, slightly below the recommended range for alertness (300–350 ppm; Marriott 1994) but still sufficient to enhance alertness.

CONCLUSION

Brewing temperature and time significantly affected caffeine extraction, with higher values corresponding to increased caffeine content. A similar trend was observed in both green and black tea. Maximum concentrations were obtained at 95 °C for 10 minutes (437.57 ppm in green tea; 347.15 ppm in black tea); however, these conditions resulted in poor sensory quality due to excessive bitterness and dark color. The optimal brewing condition for both green and black tea was 85 °C for 7 minutes, which provided a favorable balance between caffeine concentration and sensory acceptability.

ACKNOWLEDGEMENT

The authors gratefully acknowledge the research funding provided by Calvin Institute of Technology. Additionally, the authors extend their appreciation to Gracia Amadea, Graduate student from Universitas Pelita Harapan, and Giovania Halim from Calvin Institute of Technology for their technical assistance.

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