Original Research

EFFECTS OF ROASTING AND BREWING CONDITIONS ON POLYPHENOLS, ANTHOCYANINS, AND SENSORY QUALITY OF BLACK RICE TEA

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ABSTRACT

Aims: To evaluate the variation in total polyphenol content (TPC), total anthocyanin content (TAC), and sensory quality of black rice tea under different roasting and brewing conditions, and to determine suitable processing parameters for production.

Methods: The study was conducted using a single-factor experimental design. The effects of roasting time (8-14 min at 200°C), brewing time (5–20 min), and water temperature (80–100°C) on TPC, TAC, and sensory characteristics were sequentially investigated. The brewing ratio was 5 g of raw material per 100 mL of water.

Results: Roasting for 12 min yielded the highest TPC and TAC values, reaching 32.55 mg GAE/100 mL and 2.49 mg/100 mL, respectively. During brewing, both parameters peaked at 15 min (31.12 mg GAE/100 mL and 3.62 mg/100 mL) and subsequently declined with prolonged extraction. A water temperature of 100°C provided optimal extraction efficiency. The combination of 12 min roasting and brewing at 100°C for 15 min resulted in the highest bioactive compound content and sensory quality.

Conclusion: Roasting and brewing parameters significantly influence the bioactive composition and sensory attributes of black rice tea. The optimal processing condition was identified as roasting for 12 min followed by brewing at 100°C for 15 min.

Keywords: *black rice tea, total polyphenols, total anthocyanins, roasting time, brewing conditions.*

I. INTRODUCTION

In recent years, consumer awareness of the role of nutrition in health has increased substantially, thereby driving a growing demand for plant-based food products. In Vietnam, studies on consumer behavior have shown that understanding of food safety and healthy dietary patterns significantly influences consumers'product selection decisions [1].

In addition, recent reviews have highlighted that herbal teas and cereal-based teas are increasingly favored due to their safety, ability to provide health-promoting bioactive compounds, and convenience of use [2]. The diversification of tea products derived from various raw materials such as ginger, chamomile, brown rice, Ganoderma lucidum, ginseng, and lotus further reflects the strong global growth trend of the herbal tea market in recent years [3].

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Black rice is a nutrient-rich food containing a wide range of antioxidant compounds, including polyphenols, flavonoids, anthocyanins, proanthocyanidins, tocols (vitamin E), γ-oryzanol, and phytic acid [4]. Among these, polyphenols represent the most prevalent group, predominantly distributed in the bran layer of brown rice, and play an important role in antioxidant activity, diabetes prevention, cholesterol reduction, and cardiovascular protection [5, 6]. Moreover, the bran layer of black rice is particularly rich in phenolics and flavonoids and contains high levels of anthocyanins, phenolic pigments responsible for the characteristic dark purple color and strong antioxidant activity, thereby contributing to the enhanced functional value and sensory quality of cereal-based tea products [7].

During the processing of black rice tea, especially during roasting and brewing, the content and characteristics of phenolic compounds can be significantly affected. In cereal-based tea products, roasting and brewing are two key processing steps that significantly influence the release, stability, and extraction efficiency of phenolic compounds and other bioactive substances. Polyphenols and anthocyanins are the major bioactive constituents of black rice; however, their stability varies under thermal processing conditions [7, 8]. Anthocyanins are generally more sensitive to heat than other phenolic compounds, and thermal treatments may lead to their partial degradation, thereby influencing both the nutritional value and sensory attributes of black rice tea [9]. These transformations not only influence nutritional value but also directly affect color, flavor, and overall sensory acceptability of black rice tea.

However, in practical tea processing, roasting, soaking, and brewing steps often occur sequentially and interact with one another, potentially leading to cumulative changes in polyphenol content and product quality. Although several recent studies have investigated polyphenol content and antioxidant activity of black rice following individual processing treatments [8-10], little research has systematically examined the combined effects of roasting and brewing conditions on both bioactive compounds and sensory quality of black rice tea. Appropriate roasting and brewing conditions may improve the extraction of phenolic compounds from black rice while maintaining desirable sensory quality of the tea infusion. Therefore, this study aims to evaluate the effects of roasting time, brewing time, and brewing temperature on total polyphenol content, total anthocyanins, and sensory quality of black rice tea. Based on these findings, suitable processing conditions are proposed to minimize the degradation of bioactive compounds, preserve nutritional value, and enhance sensory quality. The results of this study contribute to the optimization of black rice tea processing and address the growing consumer demand for tea products with high nutritional and functional value.

II. METHODS

2.1. Raw materials

Black rice cultivated in Điện Biên Province (Vietnam) was purchased from a local market in Gia Lâm District, Hanoi. The rice was milled (polished) before use.

The rice grains were selected to ensure uniform size, dark purple color, and the absence of broken grains, insects, or mold contamination. The rice had a moisture content of approximately 12-13%, typical for commercial black rice. After purchase, the rice was stored in airtight polyethylene bags at room temperature (25 ± 2ºC) in a dry environment until use. All experiments were carried out within two weeks after purchase to ensure sample stability.

2.2. Black rice tea processing procedure

The processing procedure for black rice tea in this study consisted of the following main steps: raw material selection → sorting and cleaning → washing → roasting → cooling → packaging → storage. The procedure was designed to ensure sensory quality while minimizing the degradation of total polyphenols and anthocyanins during processing.

2.3. Experimental design

After washing and draining, approximately 200 g of black rice was roasted at about 200ºC in a temperature-controlled electric oven for 8-14 min to evaluate the effect of roasting time on the contents of polyphenols, total anthocyanins, and selected quality attributes of black rice tea, based on previous studies [11-13]. After roasting, the rice was cooled, packaged at 5 g per sachet, and brewed in 100 mL of water at 100ºC for 10 min to obtain the tea infusion. The brewing temperature was controlled using a thermostatically heated water bath.

Based on the results obtained from the determination of the optimal roasting time, a subsequent experiment was conducted to evaluate the effect of brewing time on polyphenols, total anthocyanins, and sensory quality. Specifically, black rice tea prepared from rice roasted under the optimal condition was brewed in water at 100ºC for different infusion times ranging from 5 to 20 min, following previous studies on phenolic extraction in tea infusions [14, 15].

After identifying the optimal roasting time and brewing time, the effect of brewing water temperature in the range of 80-100ºC on the extraction of polyphenols, total anthocyanins, and sensory quality of black rice tea was further investigated, based on previous tea brewing studies [15, 16]. All experiments were performed in triplicate. The tea infusions were analyzed for total polyphenol content (TPC), total anthocyanin content (TAC) and sensory attributes to determine suitable roasting and brewing conditions for black rice tea.

2.4. Determination of total polyphenol content (TPC)

TPC of black rice tea extracts was determined using the Folin-Ciocalteu method, following the updated procedure described by Fonseca-Hernández et al. (2021) with minor modifications [17]. Briefly, 0.5 mL of the tea extract was mixed with 2.5 mL of 10% (v/v) Folin-Ciocalteu reagent (Sigma-Aldrich, USA) and 2.0 mL of 7.5% (w/v) sodium carbonate (Merck, Germany) solution. All solutions were prepared using distilled water. The mixture was incubated in the dark at room temperature for 30 min. Absorbance was then measured at 760 nm using a UV-Vis spectrophotometer (UV-1800, Shimadzu, Japan). A gallic acid standard curve was prepared in the range of 0–100 µg/mL, with the calibration equation y = 0.0089x - 0.0319 and a correlation coefficient (R^2) of 0.9937. TPC was calculated based on a gallic acid calibration curve (Sigma-Aldrich, USA) and expressed as mg GAE/100 mL of infusion. All measurements were performed in triplicate.

2.5. Determination of total anthocyanin content (TAC)

TAC was determined using the pH differential method with minor modifications [18, 19]. Potassium chloride and sodium acetate used for buffer preparation were analytical grade reagents purchased from Merck (Germany), and all solutions were prepared using distilled water. The sample was diluted separately in potassium chloride buffer (pH 1.0) and sodium acetate buffer (pH 4.5). After incubation in the dark for 15 min, absorbance was recorded at 510 and 700 nm using a UV-Vis spectrophotometer (UV-1800, Shimadzu, Japan). TAC was calculated from the absorbance difference between the two pH conditions and expressed as mg cyanidin-3-glucoside equivalents. The molar extinction coefficient (ε = 26,900 L/mol·cm), molecular weight (MW = 449.2 g/mol), path length (1 cm), and dilution factor were applied in the calculation. All measurements were performed in triplicate.

2.6. Sensory evaluation

The sensory quality of black rice tea was evaluated using the scoring method in accordance with Vietnamese Standard TCVN 3215-79, using a 0-5 point scale [20]. The weighting coefficients were 0.8 for appearance, 0.8 for color, 1.2 for aroma, and 1.2 for taste, and the final sensory score was calculated on a 20-point scale. Sensory criteria and scoring levels were established following TCVN 7975:2008 [21]. The evaluation was performed under standard laboratory conditions by a trained panel consisting of seven assessors.

2.7. Data analysis

All experiments were performed in triplicate and results were expressed as mean ± standard deviation. Data were processed using Microsoft Excel and Minitab 16.0 software (Minitab Inc., USA). Statistical significance was determined by one-way analysis of variance (ANOVA) at a significance level of $p < 0.05$.

III. RESULTS AND DISCUSSION

3.1. Effect of roasting time on total polyphenols, total anthocyanins, and sensory quality of black rice tea

Roasting time is an important factor in the processing of black rice tea, as it affects polyphenol content and overall sensory quality. The roasting process reduces moisture content, alters cellular structure, and promotes the formation of aroma-active compounds. However, prolonged roasting time or high temperatures may lead to polyphenol degradation and a reduction in nutritional value. Several studies have reported that roasting can increase phenolic content by releasing bound compounds and improving the sensory attributes of the product [22, 23].

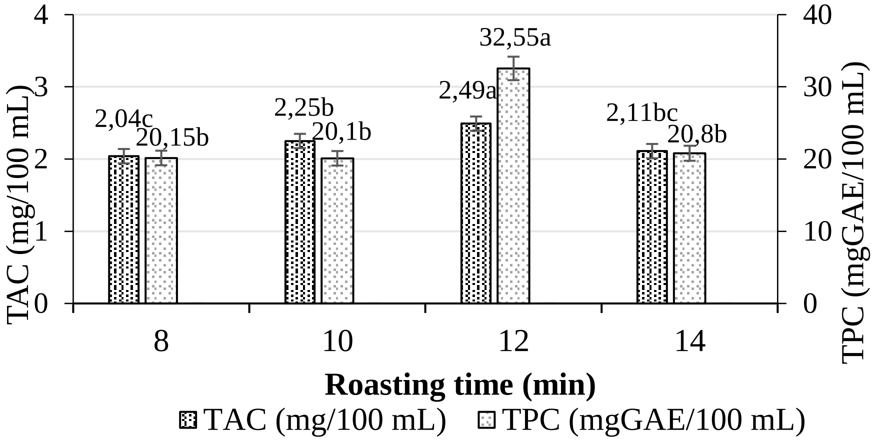

Figure 1. *Effect of roasting time on total polyphenols and total anthocyanins of black rice tea*

Values are means ± standard deviation. Within the same parameter (TPC or TAC), values marked by different letters indicate significant differences among roasting times ($p < 0.05$).

As shown in Figure 1, roasting time significantly affected both TPC and TAC of black rice tea. Specifically, the TPC increased as the roasting time was extended from 10 to 12 min, reaching a maximum value of 32.55 mg GAE/100 mL at 12 min, and then decreased significantly when the roasting time was further prolonged to 14 min. This suggests that a roasting time of 12 min promotes thermal disruption of the bran layer and cellular structure, thereby increasing the accessibility of polyphenolic compounds, which can be more effectively released and extracted during the subsequent brewing process. Moderate roasting may reduce the interactions between phenolic compounds and cell wall components, promoting the release of bound phenolics during roasting. However, longer roasting time may cause thermal degradation of heat-sensitive compounds and polymerization reactions, resulting in lower phenolic content [8, 22]. At shorter roasting times, the cellular structure is insufficiently disrupted, resulting in limited extraction efficiency; conversely, prolonged roasting may cause polyphenols to undergo thermal degradation or participate in heat-induced reactions, leading to reduced content and extractability. These findings are consistent with the study by He et al. (2024), which reported that phenolic compounds in rice increased to an optimal level and then declined with extended thermal treatment [13]. In addition, Jing et al. (2015) observed that high thermal intensity could induce structural alterations in heat-sensitive phenolic compounds [23].

A similar trend was observed for TAC. The TAC increased gradually as the roasting time was extended from 8 to 12 min, reaching the highest value at 12 min (2.49 mg/100 mL), and then decreased significantly to 2.11 mg/100 mL when the roasting time was prolonged to 14 min. This indicates that a roasting time of 12 min provides favorable conditions for cell structure disruption and the most efficient release of anthocyanins. However, because anthocyanins are thermolabile phenolic compounds, prolonged exposure to high temperatures results in their degradation and subsequent loss. This trend is in agreement with previous studies identifying anthocyanins as heat-sensitive compounds that readily degrade during extended thermal processing due to structural transformations and irreversible degradation pathways [22]. Similarly, a pronounced reduction in anthocyanin content with increasing heating intensity has been reported in sour cherry juice, where anthocyanin levels decreased significantly as both temperature and heating time increased [24].

Table 1. *Effect of roasting time on the sensory quality of black rice tea*

Roasting time (min)	Overall sensory quality score				Weighted sensory quality score	Classification
	Appearance	Color	Aroma	Taste		
8	3.91^{a}	4.00^{a}	3.25^{bc}	2.83^{a}	13.63	Fair
10	3.91^{a}	4.00^{a}	3.83^{ab}	3.58^{a}	15.23	Good
12	4.25^{a}	4.08^{a}	4.25^{a}	3.91^{a}	16.5	Good
14	3.66^{a}	3.25^{a}	2.66^{c}	3.16^{a}	12.53	Fair

Values are means ± standard deviation. Within the same column, values followed by different letters indicate significant differences ($p< 0.05$).

In terms of sensory attributes, black rice tea roasted for 12 min achieved a higher overall sensory score (16.5 points), with improved appearance, color, aroma, and taste. Insufficient roasting time led to incomplete thermal treatment of the rice grains, resulting in weak aroma and flavor, whereas prolonged roasting caused color darkening, loss of volatile aromatic compounds, and the development of burnt off-flavors due to overly intense thermal reactions. These findings are consistent with previous studies reporting that Maillard reactions and caramelization occur most effectively at an appropriate roasting time, thereby contributing to the formation of characteristic flavors in roasted products [13, 23].

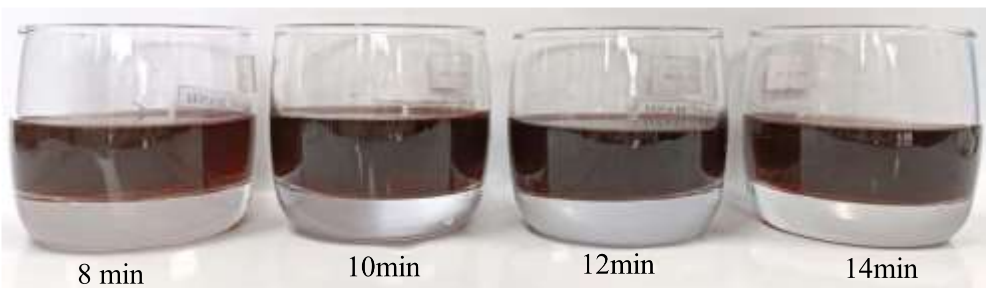

Figure 2. *Black rice tea infusions prepared from samples roasted at different roasting times*

Based on the obtained results, a roasting time of 12 min was determined to be suitable for producing black rice tea with relatively high TPC, TAC and favorable sensory attributes, therefore, this condition was selected for subsequent experiments.

3.2. Effect of brewing time on total polyphenol, total anthocyanin, and sensory quality of black rice tea

Brewing time is an important factor influencing the extraction of total polyphenols and total anthocyanins as well as the sensory quality of black rice tea. Changes in brewing duration may affect the release and stability of phenolic compounds in the infusion.

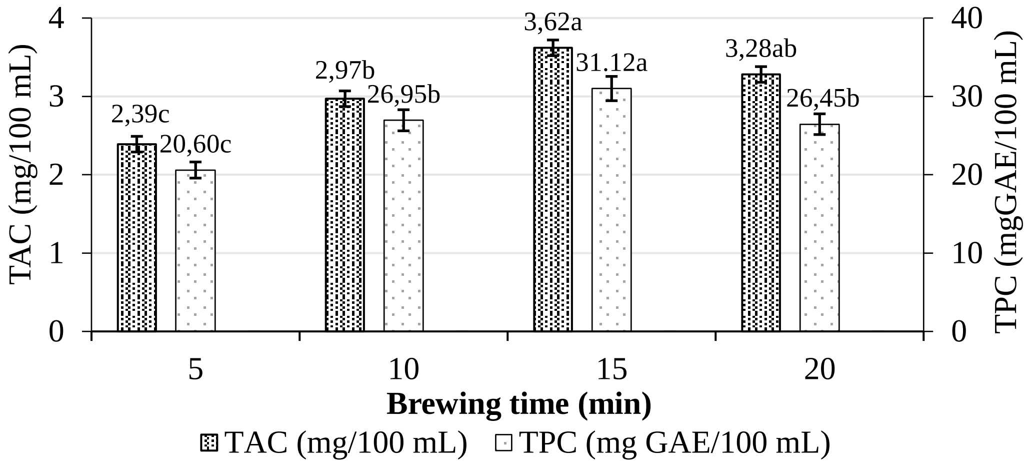

Figure 3. *Effect of brewing time on total polyphenol and total anthocyanin of black rice tea*

Values are means ± standard deviation. Within the same parameter (TPC or TAC), values marked by different letters indicate significant differences among roasting times ($p < 0.05$).

The results indicated that brewing time had a significant effect on both the TPC and TAC of black rice tea. Total polyphenols gradually increased as brewing time was extended from 5 to 15 min, reaching a maximum value of 31.12 mg GAE/100 mL at 15 min, and then decreased when the brewing time was prolonged to 20 min. This trend suggests that a brewing period of 5–15 min is favorable for the diffusion and dissolution of phenolic compounds into the infusion. This phenomenon can be attributed to the diffusion of soluble phenolic compounds from roasted rice particles into the aqueous phase during brewing. As extraction progresses, the concentration gradient between the solid particles and the solvent decreases, approaching equilibrium. Similar extraction processes have been reported in tea infusions, where phenolic release increases with brewing time until an optimal point is reached [25, 26]. During the initial stage, extending the brewing time promotes cell structure disruption and enhances mass transfer, thereby improving the extraction efficiency of polyphenols. However, when the brewing time exceeds the optimal level, the extraction process tends to reach diffusion equilibrium, while some heat-sensitive polyphenols may undergo oxidation or degradation, leading to a reduction in both content and biological activity. This observation is consistent with previous studies on the optimization of extraction time for bioactive compounds from plant materials [26-28], as well as the findings of Winiarska-Mieczan and Baranowska-Wójcik (2024), who identified 15 min as the optimal brewing time for various types of tea [15].

A similar trend was observed for TAC (Figure 3). The TAC increased from 2.39 mg/100 mL at 5 min to a maximum value of 3.62 mg/100 mL at 15 min, followed by a decrease to 3.28 mg/100 mL when the brewing time was prolonged to 20 min. This suggests that brewing up to 15 min may promote the release of anthocyanins into the infusion, possibly due to structural disruption of the rice grains during roasting.

However, because anthocyanins are heat-sensitive phenolic compounds, prolonged brewing at high temperatures may induce structural degradation, resulting in reduced anthocyanin content and biological activity. These findings are in agreement with previous studies reporting the thermal instability of anthocyanins during extended heat treatment [22].

Table 2. *Effect of brewing time on the sensory quality of black rice tea*

Brewing time (min)	Overall sensory quality score				Weighted sensory quality score	Classification
	Appearance	Color	Aroma	Taste		
5	3.41^{a}	3.25^{b}	2.50^{c}	2.58^{b}	11.43	Fair
10	3.58^{a}	3.50^{b}	3.08^{bc}	3.58^{a}	13.67	Fair
15	4.08^{a}	4.66^{a}	4.16^{a}	4.16^{a}	17.00	Good
20	3.33^{a}	3.33^{b}	3.41^{ab}	3.66^{a}	13.83	Fair

Values are means ± standard deviation. Within the same column, values followed by different letters indicate significant differences ($p < 0.05$).

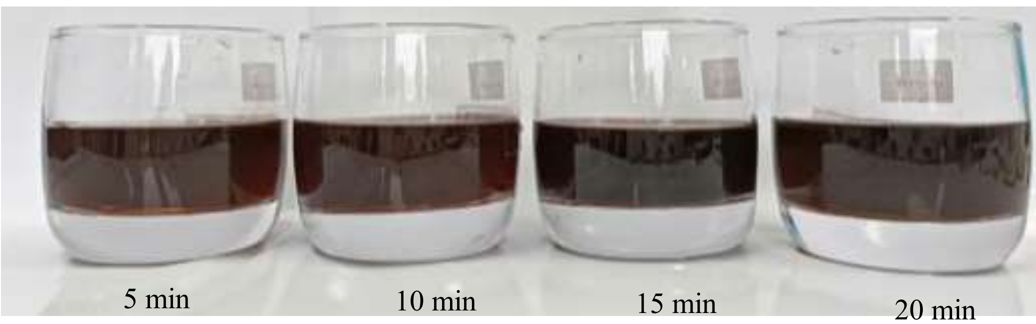

Figure 4. *Black rice tea infusions obtained at different brewing times*

In terms of sensory attributes, tea brewed for 15 min achieved the highest evaluation score (17.00 points), with an attractive color, pleasant aroma, and a balanced, smooth taste. At shorter brewing times, the tea tended to exhibit a weak flavor profile because aroma and taste contributing compounds were not sufficiently released. In contrast, excessively long brewing at high temperature may deteriorate sensory quality due to the loss of volatile compounds and the development of undesirable flavors, as reported in recent studies on the effects of brewing time on the sensory properties of tea [14, 15].

Overall, a brewing time of 15 min was identified as optimal for black rice tea, as it ensured high extraction efficiency of total polyphenols and total anthocyanins while maintaining desirable sensory quality.

3.3. Effect of brewing water temperature on total polyphenols, total anthocyanins and sensory quality of black rice tea

Brewing water temperature directly affects the extraction efficiency and quality of black rice tea. Higher temperatures promote cell structure disruption, enhancing the permeability and diffusion of polyphenols and anthocyanins, whereas excessively low temperatures limit the extraction process [14].

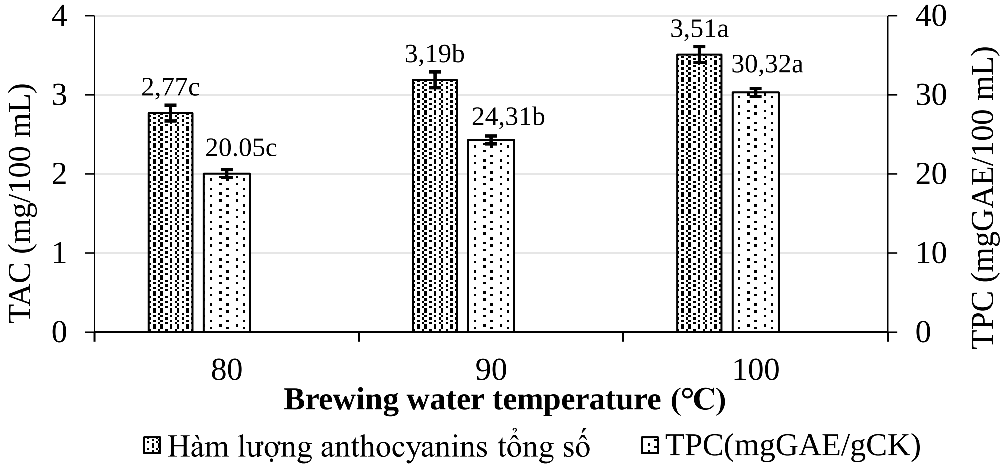

Figure 5. *Effect of brewing water temperature on total polyphenols and total anthocyanins of black rice tea*

Values are means ± standard deviation. Within the same parameter, values marked by different letters indicate significant differences ($p < 0.05$).

As shown in Figure 5, increasing the brewing water temperature from 80°C to 100°C resulted in a significant increase in polyphenol content in black rice tea, from 20.05 mg GAE/100 mL to 30.32 mg GAE/100 mL, indicating that brewing temperature significantly affects the extraction efficiency of phenolic compounds. At the lower temperature (80°C), plant cell structures are not completely disrupted, which limits the diffusion of polyphenols into the tea infusion. When the temperature is increased to 90-100°C, higher heat-induced energy promotes cell wall swelling and disruption, reduces solvent viscosity, and accelerates mass transfer, thereby enhancing polyphenol extraction efficiency. This observation is consistent with previous studies reporting the positive effect of elevated temperature on the release and diffusion of polyphenols during extraction [27, 28]. Similar trends have been observed in tea infusions and other cereal-based beverages, where higher brewing temperatures improve the extraction of phenolic compounds by enhancing solvent diffusivity and mass transfer efficiency [16, 26].

A comparable increase was observed in total anthocyanin content as the brewing water temperature rose from 80°C to 100°C, with values increasing from 2.77 mg/100 mL to 3.51 mg/100 mL (Figure 5). This enhancement can be attributed to the greater thermal energy at higher temperatures, which promotes plant tissue disruption and improves the solubility and mass transfer of anthocyanins into the tea infusion. Such behavior aligns with previous reports highlighting temperature as a critical factor in facilitating the extraction of anthocyanins and other phenolic compounds from plant materials [29, 30]. Anthocyanins are known to be thermally unstable, and high temperatures can promote their degradation via structural breakdown and chemical transformations [22]. This demonstrates the need to carefully control brewing conditions to avoid excessive loss of bioactivity.

Table 3. *Effect of brewing water temperature on the sensory quality of black rice tea*

Brewing water temperature (°C)	Overall sensory quality score				Weighted sensory quality score	Classification
	Appearance	Color	Aroma	Taste		
80	3.66[a]	3.58[a]	3.33[b]	3.16[a]	13.60	Fair
90	3.58[a]	3.41[a]	3.41[b]	3.16[a]	13.50	Fair
100	4.33[a]	4.08[a]	4.75[a]	3.91[a]	17.13	Good

Values are means ± standard deviation. Within the same column, values followed by different letters indicate significant differences (p< 0.05).

Figure 6. *Black rice tea infusions prepared at different brewing water temperatures*

Tea brewed at 100°C exhibited the highest sensory score (17.13), with enhanced color, aroma, and taste, while samples brewed at 80-90°C showed only moderate sensory quality. This finding agrees with previous studies reporting that higher brewing temperatures improve polyphenol extraction and sensory attributes of tea infusions [30, 31]. Accordingly, 100°C was identified as the optimal brewing temperature for black rice tea.

IV. CONCLUSIONS

The results showed that both roasting and brewing significantly affected polyphenols and anthocyanin contents, and sensory quality of black rice tea. The optimal conditions were roasting at 200°C for 12 min and brewing 5 g of tea with 100 mL of water at 100°C for 15 min. Under these conditions, high levels of polyphenols (30.32 mg GAE/100 mL) and anthocyanins (3.51 mg/100 mL) were obtained, and the tea exhibited favorable sensory attributes (17.13 points). These findings provide a scientific basis for optimizing black rice tea processing to enhance its bioactive compound content and overall product quality. However, this study was conducted under laboratory-scale conditions and focused mainly on selected bioactive compounds and sensory evaluation. Future studies may further examine the stability of bioactive compounds during storage, assess additional quality parameters, and evaluate the applicability of the optimized conditions in larger-scale production.

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