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Evaluation of the Antioxidant Potential of Fermented Persimmon Leaf Tea

Akane Kasai, Hiroko Seki*

School of Bioscience and Biotechnology, Tokyo University of Technology, Japan

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Abstract Tea is consumed globally, and its production involves processes such as fermentation. In the production of Pu-erh tea, Pu-erh leaves are fermented with koji, which purportedly enhances the antioxidant activity of the tea by converting the gallate catechins contained in the leaves to hydrolyzed catechins. Notably, persimmon leaves contain substantial amounts of gallate catechins; consequently, the antioxidant effects of persimmon leaf tea could be enhanced by fermentation. Therefore, this study was undertaken to elucidate the changes in antioxidant activity during the fermentation of persimmon leaf tea and identify the components that contribute to the antioxidant effect. The levels of ascorbic acid, total polyphenols, and tannin in persimmon leaf tea were quantified, and their respective antioxidant effects were investigated. Additionally, changes in total polyphenol and tannin content during fermentation were assessed, and their correlation with antioxidant potency was explored. The findings revealed that tannin and gallic acid significantly contributed to the antioxidant effect of persimmon leaf tea. Furthermore, the total polyphenol content increased over time during fermentation; however, no consistent trend in antioxidant effect was observed. These results suggest that the polyphenols and tannin generated during the fermentation of persimmon leaf tea influence antioxidant activity. The study provides insights into how the fermentation process enhances the antioxidant properties of persimmon leaf tea, particularly through the generation of polyphenols and tannin. These findings suggest that optimizing fermentation conditions could maximize the health benefits of persimmon leaf tea. Additionally, understanding the role of these components could lead to the development of new fermentation techniques or products aimed at boosting antioxidant activity in various tea preparations. This research could serve as a foundation for further studies on the health-promoting effects of fermented teas and guide the tea industry in producing more beneficial beverages.

Keywords Persimmon Leaf Tea, Antioxidant Activity, Polyphenol

1. Introduction

Tea is one of the most consumed and highly popular luxury products worldwide, encompassing prominent types, such as green, black, and oolong teas, all of which are produced by fermentation of the same tea leaves [1]. The conventional fermentation process involves the polymerization of low-molecular-weight polyphenols in tea leaves. This process is catalyzed by oxidative enzymes in the leaves [2]. However, a notable subset of teas undergoes post-fermentation, where the fermentation of leaves is mediated by microbial action [3]. Chinese Pu-erh tea and Tokushima Prefecture's Awa Bancha serve as representatives of post-fermented varieties, both of which are prepared from tea plant leaves. However, Pu-erh tea is produced by fermentation with koji [4], whereas Awa Bancha fermentation is mediated by the action of lactic acid bacteria [5]. Notably, fermentation by lactobacilli imbues tea with a unique sour flavor [6]. Unlike the changes that occur in conventional tea fermentation processes, those mediated by lactobacilli result in a discernible reduction in the total catechin content [7]. Given that catechins exhibit high antioxidant activity [8], fermentation by lactic acid bacteria may reduce their antioxidant activity. Conversely, koji fermentation has been demonstrated to enhance the antioxidant activity of green tea, with reported increasing from 85.4% to 91.6% after an 8-day fermentation period [9]. Gallate catechins, such as epigallocatechin gallate, in green tea are decomposed into hydrolyzed catechins, including epigallocatechin and gallic acid, during koji fermentation. As fermentation progresses, these hydrolyzed catechins and gallic acid undergo further decomposition, following which the content of hydrolyzed catechins increases temporarily and then begins to decrease [10]. Total polyphenol content is highly correlated with 2,2-diphenyl-1-picrylhydrazyl (DPPH) radical scavenging activity [11], suggesting that the increase in antioxidant activity during fermentation can be attributed to the increase in the total polyphenol content. These observations suggest that fermentation should be stopped when water-disintegrating catechins and gallic acid reach their peak levels in the koji mold fermentation of green tea. Notably, the highest levels of these compounds are observed on days 3 and 5 of *Aspergillus oryzae* SR108 and *Aspergillus kawachii* HSW198 fermentation, respectively [12]. Moreover, the optimum fermentation time reportedly depends on the species and strain used [12].

Persimmon leaf tea stands out among teas owing to the high amounts of gallate catechins contained in persimmon leaves [13]. Persimmon leaf tea is a healthy tea prepared from dried persimmon leaves, where gallate catechin is decomposed to hydrolyzed catechins through koji fermentation [10], potentially improving the antioxidant effect of the tea. Furthermore, persimmon leaf tea contains a substantial amount of ascorbic acid, which exhibits antioxidant properties [14]; however, the amount of ascorbic acid may change during fermentation, thereby affecting the final antioxidant effect. Therefore, the aim of this study was to elucidate the changes in antioxidant activity during the fermentation of persimmon leaf tea and identify the components that contribute to the antioxidant effect.

2. Materials and Methods

2.1. Preparation of Fermented Persimmon Leaf Tea

Persimmon leaf tea (produced by Kotani Grain) was purchased from a retail store (Hachioji, Tokyo, Japan). Three types of koji were employed for fermentation: *Aspergillus oryzae* (koji mold: NBRC30113 [ATCC 22788, National Institute of Technology and Evaluation, Chiba] and NBRC100959 [RIB40, National Institute of Technology and Evaluation, Chiba]) and *Aspergillus awamori* (black koji mold: NBRL4388 [ATCC 14331, National Institute of Technology and Evaluation, Chiba]). To prepare fermented persimmon leaf tea, 2.4 g of potato dextrose broth (Difco, Becton, Dickinson and Company, NJ, USA) and 200 mL of pure water were mixed in a 300-mL triangular flask and autoclaved. After cooling, koji mold was introduced, and then 20g of dried whole persimmon leaf tea was added. The mixture was tightly sealed with plastic wrap and parafilm and subjected to fermentation in an incubator at 30 ℃ for 0–7 days. Subsequently, approximately 2 g of tea leaves were retrieved from the fermentation flask and introduced into a 50-mL beaker, autoclaved, and dried in a 50 ℃ incubator for 24 h to yield fermented persimmon leaf tea. This process was repeated daily from days 0 to 7. Similarly, a sample without the koji mold mixture was prepared as a blank. Tea leaves (2g) from fermented, blank, and unfermented persimmon leaf teas were weighed and subjected to extraction using 300 mL of boiling water for 5 min to obtain extracts of each sample.

2.2. Quantification of Ascorbic Acid, Total Polyphenol, and Tannin Content in Unfermented Persimmon Leaf Tea

To quantify ascorbic acid, the unfermented persimmon leaf tea (50 µL) was mixed with 35 µL of a chromogenic reagent (comprising a mixture of 4% ammonium molybdate (FUJIFILM Wako Pure Chemical Corporation, Osaka, Japan), 0.2% potassium phosphate (FUJIFILM Wako Pure Chemical Corporation), and 2.5 M sulfuric acid (FUJIFILM Wako Pure Chemical Corporation) at a ratio of 3:1:5) and allowed to react in a water bath at 40 ℃ for 20 min, after which, the absorbance was measured at 750 nm using a plate reader (Infinite F50Plus; Tecan Japan Co., Ltd., Kanagawa, Japan).

To quantify total polyphenol, unfermented persimmon leaf tea (0.125 mL) was mixed with 0.25 mL of Folin–Ciocalteu reagent (NACALAI TESQUE, INC., Kyoto, Japan) and allowed to stand for 3 min at 25℃. Subsequently, 0.325 mL of 1% sodium carbonate solution (FUJIFILM Wako Pure Chemical Corporation) was added. Absorbance was measured at 750 nm using a plate reader. The total polyphenol content in persimmon leaf tea was quantified relative to the equivalent concentration of gallic acid. In total polyphenol measurement, the value of ascorbic acid is subtracted because of the influence of ascorbic acid.

To measure tannin content, unfermented persimmon leaf tea (0.10 mL) was mixed with 0.30 mL of tartaric acid-iron reagent (0.1% iron sulfate: Kanto Chemical Co., Inc, Tokyo and 0.5% potassium sodium tartrate: FUJIFILM Wako Pure Chemical Corporation) and 0.6 mL of 0.1 M KH_2PO_4 buffer (pH 7.5/ NaOH: NACALAI TESQUE, INC.) Absorbance was measured at 540 nm using a plate reader. The tannin content in persimmon leaf tea was quantified relative to the equivalent concentration of tannin acid. As the quantity of tannin is almost unaffected by ascorbic acid [15], the measured values are used here.

2.3. DPPH Radical Scavenging Activity of Ascorbic Acid, Gallic Acid, Tannin, and Unfermented Persimmon Leaf Tea

To assess the DPPH radical scavenging activity of ascorbic acid, gallic acid, tannin acid, and unfermented persimmon leaf tea, 0.187 mg/100 g ascorbic acid, 12.0 mg/L gallic acid, and 57.8 mg/L tannin acid were prepared. Subsequently, ascorbic acid, gallic acid, tannin acid, and unfermented persimmon leaf tea (0.2 mL) were added into Eppendorf tubes (AS ONE CORPORATION, Osaka, Japan), mixed with 1.8 mL of 0.08 mg/mL DPPH solution (Tokyo Chemical Industry Co., Ltd., Tokyo, Japan), and allowed to react for 30 min at 25 ℃. Thereafter, absorbance (A) was measured at 540 nm using a plate reader. Similarly, absorbances (B) and (C) of samples where the 0.08 mg/mL DPPH solution was replaced with ethanol (FUJIFILM Wako Pure Chemical Corporation) to serve as a blank and where the sample was replaced with pure water to serve as a control, respectively, were measured. The DPPH radical scavenging activity was calculated using the following formula:

$$\text{DPPH radical scavenging activity (\%)} = (C - (A - B)) / C \times 100;$$

where, A: sample, B: blank, C: control

2.4. Changes in Total Polyphenol and Tannin Content over Time in Fermented Persimmon Leaf Tea

Total polyphenol content in fermented persimmon leaf tea and the blank was measured for 7 days. This measurement was conducted similar to that detailed in "**2.2 Quantification of Ascorbic Acid, Total Polyphenol, and Tannin Content in Unfermented Persimmon Leaf Tea.**"

2.5. Changes over Time in the Antioxidant Effect of Fermented Persimmon Leaf Tea

The antioxidant activities of fermented persimmon leaf tea and the blank were measured for 7 days. This measurement was conducted similar to that detailed in "**2.3 DPPH Radical Scavenging Activity of Ascorbic Acid, Gallic Acid, and Unfermented Persimmon Leaf Tea.**"

2.6. Statistical Analysis

Data were obtained in triplicate or through triplicate measurements with the same sample according to Fisher's three principles; *t*-tests were conducted to assess differences in means between groups; one-way analysis of variance was employed for comparisons involving three groups. All statistical analyses were performed at a 5% significance level using Microsoft Excel (Microsoft Corporation, Washington, USA).

3. Results

3.1. Quantification of Ascorbic Acid, Total Polyphenol, and Tannin Content in Unfermented Persimmon Leaf Tea

The concentration of ascorbic acid, total polyphenol, and tannin in unfermented persimmon leaf tea was 0.187 mg/100 g, 12.0 mg/L, and 57.8 mg/L, respectively (Table 1).

Table 1. Concentration of ascorbic acid, total polyphenol, and tannin in unfermented persimmon leaf tea

Ascorbic acid (mg/100 g)	0.187 ± 0.012
Total polyphenol (mg/L)	12.0 ± 2.7
Tannin (mg/L)	57.8 ± 1.8

Measurements were taken with n = 5.

Total polyphenol content was calculated as gallic acid equivalents.

Tannin content was calculated as tannic acid equivalents.

3.2. DPPH Radical Scavenging Activity of Ascorbic Acid, Gallic Acid, Tannin, and Unfermented Persimmon Leaf Tea

The DPPH radical scavenging activity of 0.187 mg/100 g ascorbic acid, 12.0 mg/L gallic acid, 57.8 mg/L tannin acid, and unfermented persimmon leaf tea was 4.5%, 36.4%, 68.5%, and 83.6%, respectively (Table 2).

Table 2. DPPH radical scavenging activity of 0.187 mg/100 g ascorbic acid, 12.0 mg/L of gallic acid, 57.8 mg/L of tannin acid, and unfermented persimmon leaf tea

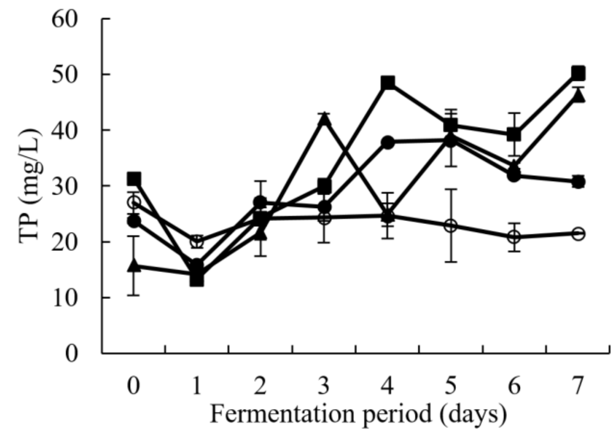
	DPPH radical scavenging activities (%)
0.187 mg/100 g ascorbic acid	4.56 ± 1.7
12.0 mg/L gallic acid	36.4 ± 1.0
57.8 mg/L tannin acid	68.5 ± 0.72
Unfermented persimmon leaf tea	83.6 ± 1.2

Measurements were taken with n = 5.

3.3. Changes in Total Polyphenol and Tannin Content over Time in Fermented Persimmon Leaf Tea

The changes in the total polyphenol content in fermented persimmon leaf tea over time are presented in Figure 1. Across the 7-day fermentation period, the blank sample exhibited variability in total polyphenol content, ranging between 20.0 and 27.0 mg/L, with no increasing or decreasing trend ($p > 0.05$). The NBRC30113 sample exhibited a decrease in total polyphenol content from 23.8 mg/L on day 0 to 15.9 mg/L on day 1 ($p < 0.05$), followed by a slight increase to 38.2 mg/L on day 5 ($p < 0.05$), and a subsequent decline to 30.8 mg/L on day 7 ($p > 0.05$). The RIB40 sample exhibited a decrease in the total polyphenol content from 31.4 mg/L on day 0 to 13.3 mg/L on day 1 (*p*

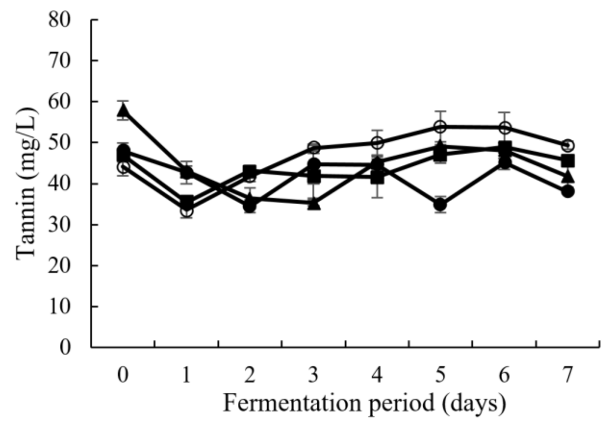
< 0.05), followed by an increase to 48.5 mg/L on day 4 ($p < 0.05$), a slight decrease to 39.2 mg/L on day 6 ($p < 0.05$), and an increase to 50.2 mg/L on day 7 ($p < 0.05$). The NBRL4388 sample exhibited a slight decrease in total polyphenol content from 15.7 mg/L on day 0 to 14.2 mg/L on day 1 ($p > 0.05$), followed by an increase to 42.0 mg/L by day 3 ($p < 0.05$), a decrease to 24.9 mg/L on day 4 ($p < 0.05$), an increase to 39.0 mg/L on day 5 ($p < 0.05$), a decrease to 33.6 mg/L on day 6 ($p < 0.05$), and an increase to 46.3 mg/L on day 7 ($p < 0.05$). Despite minor fluctuations overall, an increasing trend was observed across all experimental groups except the blank sample.



Measurements were taken with n = 5. Error bars indicate standard deviation.

Figure 1. Changes in the total polyphenol content over time in fermented persimmon leaf tea

The changes in tannin content in fermented persimmon leaf tea over time are presented in Figure 2. Across the 7-day fermentation period, the blank sample exhibited a decrease in tannin content from 44.1 mg/L on day 0 to 33.6 mg/L on day 1 ($p < 0.05$), followed by an increase to 53.9 mg/L on day 5 ($p < 0.05$), and a slight decrease to 49.4 mg/L on day 7 ($p > 0.05$). The NBRC30113 sample exhibited a decrease in tannin content from 48.0 mg/L on day 0 to 34.0 mg/L on day 2 ($p < 0.05$), followed by a slight increase to 44.8 mg/L on day 3 ($p > 0.05$). Thereafter, it decreased to 34.9 mg/L on day 5 ($p < 0.05$), followed by an increase to 45.2 mg/L on day 6 ($p < 0.05$) and a decrease to 38.0 mg/L on day 7 ($p < 0.05$). The RIB40 sample exhibited a decrease in tannin content from 46.9 mg/L on day 0 to 35.4 mg/L on day 1 ($p < 0.05$), followed by an increase to 43.1 mg/L on day 2 ($p < 0.05$), a slight decrease to 41.6 mg/L on day 4 ($p > 0.05$), and a slight increase to 48.9 mg/L on day 6 ($p < 0.05$). Thereafter, it decreased to 45.7 mg/L on day 7 ($p < 0.05$). The NBRL4388 sample exhibited a decrease in tannin content from 57.9 mg/L on day 0 to 35.3 mg/L on day 3 ($p < 0.05$), followed by an increase to 49.1 mg/L by day 5 ($p < 0.05$), a decrease to 41.8 mg/L on day 7 ($p < 0.05$). The tannin content varied between 34.4 and 57.9 mg/L in all test groups, with no increasing or decreasing trend.

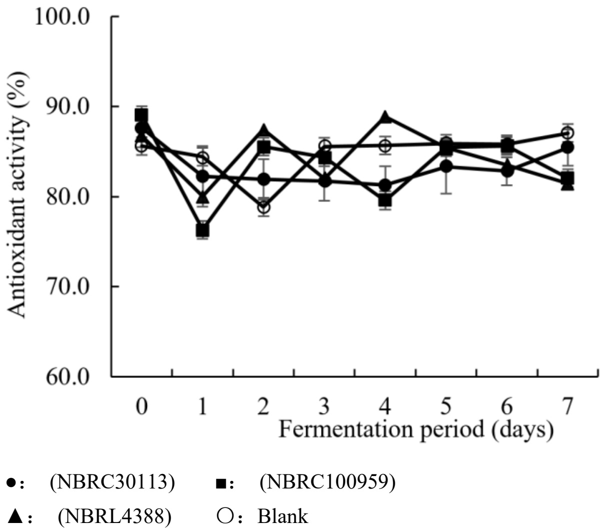


Measurements were taken with n = 5. Error bars indicate standard deviation.

Figure 2. Changes in the tannin content over time in fermented persimmon leaf tea

3.4. Changes in the Antioxidant Effect of Fermented Persimmon Leaf Tea over Time

Changes in the antioxidant activity of fermented persimmon leaf tea and the blank over time are depicted in Figure 3. The antioxidant activity of the blank sample varied between 78.9% and 87.1% over the 7-day fermentation period. However, the antioxidant activity ranged between 81.3% and 86.6% for NBRC30113, 76.3% and 89.1% for RIB40, and 81.4% and 88.9% for NBRL4388, with no increasing or decreasing trend observed in any of the groups ($p > 0.05$). In addition, a comparison of the antioxidant activity of unfermented persimmon leaf tea (Table 2) with that of each test group on each day revealed significantly higher values on only day 0 for RIB40 and day 4 for NBRL4388 ($p < 0.05$).



Measurements were taken with n = 5. Error bars indicate standard deviation.

Figure 3. Changes in the antioxidant activity of fermented persimmon leaf tea over time

4. Discussion

4.1. Quantification of Ascorbic Acid, Total Polyphenol, and Tannin Content in Unfermented Persimmon Leaf Tea

Murakawa et al. [16] reported that the ascorbic acid content in persimmon leaf tea immediately after processing from raw leaves to tea is 2–3 g/100 g, a value significantly different from our findings. Ascorbic acid content generally decreases in vegetables during storage [17], similar to that observed during green tea storage [18]. In this study, commercially available persimmon leaf tea was used; therefore, the low value obtained is likely attributable to the decrease in ascorbic acid content over time since the fresh leaves were collected.

Tsurunaga et al. [14] reported the total polyphenol content in powdered persimmon leaf tea to be 42 mg/g; however, the value in this study was lower than that because we used an extract. In addition, a comparison of the peaks of high-performance liquid chromatography (HPLC) of green tea and persimmon leaf tea revealed that the peak of green tea mainly corresponded to catechins, whereas that of persimmon leaf tea corresponded to gallic acid [19]. These results suggest that the DPPH radical scavenging activity of persimmon leaf tea is significantly influenced by polyphenols, including gallic acid.

Saeki et al. [20] reported that the tannin content in persimmon leaves is 0.51%, and about 70% of it can be extracted with 5-min hot water extraction. If extraction is conducted in the same manner as in this study, the tannin content would be approximately 34 mg/L, which is higher than that in the previous study [20]. On the contrary, a previous study measuring the total polyphenol content in persimmon leaf tea as catechin equivalents reported 247 mg/L [21]. A study measuring proanthocyanidins in persimmon leaves as tannin content reported that the tannin content varies by approximately 5-fold depending on the season [22], suggesting that the tannin content depends, to some extent, on the harvest time.

4.2. DPPH Radical Scavenging Activity of Ascorbic Acid, Gallic Acid, Tannin, and Unfermented Persimmon Leaf Tea

The DPPH radical scavenging activity of 0.187 mg/100 g ascorbic acid solution was measured at 4.56%, suggesting that ascorbic acid had a minimal effect on the radical scavenging activity of persimmon leaf tea. Notably, this activity is comparable to that reported for green tea and black tea, at 79.8% and 80.3%, respectively [23], highlighting their similar high antioxidant activity. The present study finding also aligns with that of previous research, where 1–10 mg/L ascorbic acid solution increased the DPPH radical scavenging activity in a concentration-dependent manner, with 0.187 mg/L ascorbic acid solution exhibiting an inhibition rate of 2.34% [24], similar to our results. Furthermore, the DPPH radical scavenging activity of 12.0 mg/L gallic acid solution was 36.4%. This increased activity, comparable to that of unfermented persimmon leaf tea, suggests that polyphenols are among the substances in persimmon leaves that exhibit antioxidant activities. This inference is supported by an HPLC analysis of polyphenols in persimmon leaf tea, which revealed a large peak of gallic acid [19]. These results suggest that among polyphenols, gallic acid exhibits a significant effect on the radical scavenging activity of persimmon leaf tea. The DPPH radical scavenging activity of 57.8 mg/L gallic acid solution was 68.5%.

Tannins are found in several plants, and a high correlation between tannin content and antioxidant activity has been reported in starfruit [25] and *Miang*, a traditional fermented tea of North Thailand [26]. In the present study, we also found a high correlation between total polyphenol content and antioxidant activity. The tannin content was high compared to the total polyphenol content, and the DPPH radical scavenging activity was also high. In persimmon leaf tea, tannin is one of the substances that greatly contribute to antioxidant activity.

4.3. Changes in the Polyphenol and Tannin Content over Time in Fermented Persimmon Leaf Tea

Previous studies have indicated the presence of epigallocatechin gallate in persimmon leaf tea [13], with further research demonstrating the decomposition of epigallocatechin gallate to epigallocatechin and gallic acid during fermentation in Bancha tea [27]. In this study, one molecule of epigallocatechin gallate in persimmon leaf tea produced one molecule each of epigallocatechin and gallic acid, resulting in a total of two molecules, thereby increasing the total polyphenol content. Various types of tannins have been identified in extracts of cocoa, pomegranates, cranberries, and grapes [28]. In addition, in the leaf of *Liquidambar formosana*, tannin types vary with season [29], and tannin levels are the highest in young leaves and lowest in mature leaves [30]. This finding suggests that many types of tannins are present in persimmon leaf tea and the amount and composition of tannins may vary depending on the time of harvest. It has been reported that ellagitannins, a type of tannin abundant in nuts, are degraded by *Aspergillus niger* and *Aspergillus oryzae* [31], and high concentrations of gallic acid inhibit enzyme activities [32]. It has also been reported that *A. niger* can grow on tannins and the amount of tannase produced by *A. niger* increased with increasing concentrations of tannic acid, one of the substrates [33], but the inhibitory concentration differed depending on the type of tannin. Contrarily, it has been reported that the inhibitory concentration differs depending on the type of tannin [34]. As shown in Figure 2, tannins that are easily degraded by koji were initially degraded, but the remaining tannins were not degraded as much because they were not easily degraded by koji.

4.4. Changes in the Antioxidant Effect of Fermented Persimmon Leaf Tea over Time

First, in both fermented and unfermented persimmon leaf teas, there was no significant increase or decrease trend in the antioxidant activity over 7 days. Antioxidant activity is considered to be greatly affected by polyphenols and tannins, and in the fermentation process of cacao beans, the total polyphenol content decreased from 7.2% to 5.6% and epicatechin content from 2.5% to 0.9% in 7 days, and antioxidant activity also decreased from 26.2% to 13.9% [35]. As shown in Figure 2, no significant change in antioxidant activity was observed because there was no increase or decrease in tannin content during the 7-day period. In tea, epigallocatechin gallate has been reported to break down into epigallocatechin and gallic acid [10]; epigallocatechin gallate present in persimmon leaf tea is also hypothesized to decompose into epigallocatechin and gallic acid during fermentation. A comparison of the antioxidant activity of 1 mM epigallocatechin gallate, epigallocatechin, and gallic acid revealed that epigallocatechin gallate exhibited the highest antioxidant activity at approximately 3800 molTE/mmol, followed by epigallocatechin at 1600 molTE/mmol and gallic acid at 1000 molTE/mmol [36]. The combined antioxidant activity of epigallocatechin and gallic acid was approximately 2600 mol TE/mmol, which was lower than that of epigallocatechin gallate. However, given that not all epigallocatechin gallate in persimmon leaves is degraded, the antioxidant activity may have remained unchanged owing to the remaining epigallocatechin gallate, although the content of epigallocatechin and gallic acid was increased by fermentation.

This study has some limitations. The quality of persimmon leaves is dependent on the growing environment, and the samples are not always identical. Hence, future studies on the effects of different environments and drying conditions of tea leaves on their quality, and studies using tea leaves produced under the same conditions, will provide more reliable results.

5. Conclusions

In this study, we investigated the components contributing to the antioxidant effect of persimmon leaf tea and assessed the influence of total polyphenol and tannin content on this effect. Our findings revealed that persimmon leaf tea contained more tannin and gallic acid than ascorbic acid. Tannin and gallic acid significantly contributed to the antioxidant effect of fermented persimmon leaf tea. Furthermore, the type of koji used for fermentation did not influence the antioxidant effect of fermented persimmon leaf tea. Notably, the total polyphenol content exhibited an increasing trend; however, no consistent trend in antioxidant activity was observed during the fermentation period. Consequently, it can be inferred that the antioxidant effect of polyphenols produced during decomposition differed from that of polyphenols present before decomposition; therefore, despite the increase in polyphenol content, the antioxidant effect remained unaffected. Additionally, it can be inferred that tannin contributed more to antioxidant activity than gallic acid, as the tannin content did not significantly change over time. Although numerous teas reportedly exhibit antioxidant properties, the action mechanism remains to be elucidated. Antioxidant activity is related to not only the presence of components that exhibit antioxidant properties but also their composition and the strength of their antioxidant effects. Our results provide partial insight into the underlying mechanism, and we intend to investigate the relationship between the analysis of polyphenol types and antioxidant effects in future research.

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