Research Article

การประเมินฤทธิ์ต้านอนุมูลอิสระ และปริมาณฟีนอลิกรวมเบื้องต้นของเครื่องดื่มชาพร้อมดื่มจากร้านสะดวกซื้อในประเทศไทย

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บทคัดย่อ

การประเมินฤทธิ์ต้านอนุมูลอิสระ และปริมาณฟีนอลิกรวมเบื้องต้นของเครื่องดื่มชาพร้อมดื่มจากร้านสะดวกซื้อในประเทศไทย

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เครื่องดื่มชาพร้อมดื่มเป็นที่นิยมและบริโภคในวงกว้างเนื่องจากความสะดวกในการบริโภคและการหาซื้อ ซึ่งการดื่มชามีประโยชน์ต่อสุขภาพหลายประการ แต่ข้อมูลเกี่ยวกับฤทธิ์ทางด้านชีวภาพ และประโยชน์ต่อสุขภาพของเครื่องดื่มชาพร้อมดื่มยังไม่เป็นที่ชัดเจน เนื่องจากสารสำคัญในชาอาจจะเสื่อมสลายไปได้ตามระยะเวลาในการเก็บรักษา **วัตถุประสงค์:** งานวิจัยนี้จึงมีจุดประสงค์เพื่อประเมินฤทธิ์ในการต้านอนุมูลอิสระและปริมาณฟีนอลิกรวมของเครื่องดื่มชาพร้อมดื่ม **วิธีการศึกษา:** คัดเลือกตัวอย่างเครื่องดื่มชา 12 ชนิด ทั้งชาเขียว ชาอู่หลง และชาดำ จากร้านสะดวกซื้อในจังหวัดพระนครศรีอยุธยา ระหว่างเดือนกรกฎาคม - ตุลาคม 2568 จากนั้นทำการบันทึกปริมาณคาเฟอีนที่กล่าวอ้างบนฉลากไว้ก่อนจะประเมินฤทธิ์ในการต้านอนุมูลอิสระด้วยวิธีการกำจัดไฮโดรเจนเปอร์ออกไซด์ และอนุมูลอิสระของดีพีพีเอช และปริมาณฟีนอลิกรวมในตัวอย่าง **ผลการศึกษา:** ในงานวิจัยนี้พบว่าความสามารถในการกำจัดไฮโดรเจนเปอร์ออกไซด์ของเครื่องดื่มชามีค่าอยู่ระหว่าง 0.45 ± 0.02 ถึง 1.56 ± 0.01 มิลลิกรัมวิตามินซีสมมูล ต่อเครื่องดื่ม 1 มิลลิลิตร และความสามารถในการกำจัดอนุมูลอิสระดีพีพีเอชมีค่าอยู่ระหว่าง 0.36 ± 0.02 ถึง 0.80 ± 0.02 มิลลิกรัมวิตามินซีสมมูล ต่อเครื่องดื่ม 1 มิลลิลิตร ปริมาณฟีนอลิกรวม 0.23 ± 0.01 ถึง 0.53 ± 0.01 มิลลิกรัมกรดแกลลิกสมมูลต่อ เครื่องดื่ม 1 มิลลิลิตร โดยพบว่าเครื่องดื่มชาดำ และชาอู่หลงมีฤทธิ์ในการกำจัดไฮโดรเจนเปอร์ออกไซด์สูงที่สุดในขณะที่เครื่องดื่มชาดำ และชาเขียวมีฤทธิ์ในการกำจัดอนุมูลอิสระดีพีพีเอชสูงที่สุด และพบว่าปริมาณฟีนอลิกรวมของเครื่องดื่มชาเขียว และชาอู่หลงสูงที่สุดอย่างมีนัยสำคัญทางสถิติ ($p < 0.05$) และพบมีความสัมพันธ์เชิงบวกในระดับปานกลางระหว่างปริมาณคาเฟอีน และปริมาณฟีนอลิกรวมกับฤทธิ์ในการกำจัดไฮโดรเจนเปอร์ออกไซด์ (ค่าสัมประสิทธิ์สหสัมพันธ์เพียร์สัน $r = 0.552$, $p < 0.001$ และ $r = 0.402$, $p < 0.05$ ตามลำดับ) **สรุปผลการศึกษา:** การบริโภคเครื่องดื่มชามีแนวโน้มที่จะให้ประโยชน์ต่อสุขภาพ โดยควรศึกษาฤทธิ์ต่อต้านออกซิเดชั่นด้วยวิธีอื่น และปริมาณพฤกษเคมีในเครื่องดื่มชาเพิ่มเติม

คำสำคัญ: ชา, เครื่องดื่มชาพร้อมดื่ม, เครื่องดื่ม, ฤทธิ์ต้านอนุมูลอิสระ, สารประกอบฟีนอลิก

Preliminary Evaluation of Antioxidant Activity and Total Phenolic Content of Ready-to-drink Tea Beverages from Convenient Stores in Thailand

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Abstract

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Ready-to-drink tea beverages are widely consumed in Thailand due to their convenience and accessibility. While tea is known to possess numerous health-promoting properties, the efficacy of these benefits in the ready-to-drink (RTD) formulation remains uncertain. This is primarily attributed to the potential instability and degradation of key phytochemicals in tea over time. **Objective:** This study aims to assess the antioxidant activity and total phenolic content of ready-to-drink (RTD) tea beverages. **Methods:** During July - October 2025, twelve commercially available tea beverages—purportedly derived from green, oolong, and black tea varieties—were purchased from convenience stores in Phra Nakhon Si Ayutthaya. The claimed caffeine content of each sample was documented. Subsequently, the antioxidant activity of the beverages was assessed using the hydrogen peroxide and 2,2-diphenyl-1-picrylhydrazyl (DPPH) free radical scavenging assays. Total phenolic content of these RTD tea beverages was also evaluated. **Results:** Hydrogen peroxide scavenging activity of tea beverages were in the range between 0.45 ± 0.02 to 1.56 ± 0.01 mg vitamin C equivalent (VCE)/ml RTD tea while DPPH radical scavenging activity were in the range between 0.36 ± 0.02 to 0.80 ± 0.02 mg VCE/ml RTD tea. Total phenolic content of tea beverages was in the range between 0.23 ± 0.01 to 0.53 ± 0.01 mg gallic acid equivalent/ml RTD tea. Among the tested samples, beverages prepared from black and oolong tea demonstrated the highest hydrogen peroxide scavenging activity, while black tea and green tea showed the highest DPPH radical scavenging activity ($p < 0.05$). Green tea and Oolong tea contained the highest phenolic content ($p < 0.05$). A moderate positive correlation between caffeine content, total phenolic content and hydrogen peroxide scavenging activity was observed (Pearson's correlation coefficient, r = 0.552, $p < 0.001$ and r = 0.402, $p < 0.05$, respectively). **Conclusion:** The results suggested that drinking tea beverages might have positive health benefits. Further investigations should assess antioxidant activity using alternative methods, as well as quantify phytochemical levels in tea beverages.

Keywords: Tea, Ready-to-drink tea, Beverage, Free radical scavenging activity, Phenolic content

Introduction

Tea (*Camellia sinensis var. sinensis*) has been extensively studied for its potential health-promoting properties, particularly its capacity to scavenge free radicals. Reactive oxygen species (ROS), a prominent class of free radicals, are recognized as key contributors to oxidative stress, which is implicated in the pathogenesis of numerous chronic diseases (Ng *et al.,* 2017; Rice-Evans *et al.,* 1997). In food industry, various processing techniques are employed to produce distinct types of tea, including black, oolong, and green tea. Typically, tea leaves are infused in hot water and consumed as a beverage (Yang and Liu, 2012). The health-promoting effects of tea consumption are predominantly attributed to its potent antioxidant activity, primarily derived from phenolic compounds such as catechins, tannins, and their derivatives (Pinto *et al.,* 2020). Moreover, tea contains caffeine, a purine alkaloid (1,3,7-trimethylxanthine), recognized for its diverse physiological benefits, including antioxidant properties. The antioxidant potential of tea is likely the result of synergistic interactions among phenolic compounds, caffeine, and other phytochemicals naturally present in tea leaves (Ösz *et al.,* 2022). Green tea is particularly rich in monomeric catechins, notably epigallocatechin-3-gallate (EGCG), which exhibit potent antioxidant effects (Bernatoniene and Kopustinskiene, 2018; Sheng *et al.,* 2023). Conversely, black tea undergoes extensive oxidative polymerization, resulting in the formation of theaflavins and thearubigins—compounds with distinct structural and chemical characteristics (Wiseman *et al.,* 1997). Oolong tea represents an intermediate oxidation state, containing both catechins and theaflavins, thereby offering a unique polyphenolic profile. Variations in oxidation levels and chemical composition among tea types account for their differential antioxidant capacities and associated health benefits.

The fast-paced nature of contemporary lifestyles has been identified as a significant contributor to adverse health outcomes, affecting both mental and physical well-being. Poor dietary habits and heightened psychological stress associated with such lifestyles are closely linked to increased oxidative stress. Tea consumption is traditionally believed to mitigate oxidative stress due to its rich antioxidant content. Additionally, the caffeine present in tea exerts psychostimulant effects, which may enhance cognitive function and work performance. However, time constraints inherent to modern routines often limit the feasibility of traditional tea preparation methods, such as hot water infusion. As a result, ready-to-drink (RTD) tea beverages have emerged as a convenient alternative, aligning with the demands of contemporary consumers. Despite their popularity, the extent to which RTD formulations retain the health-promoting properties of traditionally prepared tea remains uncertain, primarily due to the potential instability of bioactive phytochemicals during processing and storage.

Considering these considerations, the present study aims to conduct a preliminary evaluation of the antioxidant activity and total phenolic content of commercially available RTD tea beverages.

Materials and Methods

RTD tea samples and chemicals

Sample selection criteria in this study were (i) ready-to-drink tea beverage made with either tea leaves infusion or tea leaf extract (ii) available at local convenient store (iii) complete nutritional label provided on package. Based on these criteria, twelve RTD tea samples were purchased from the convenient stores in in Phra Nakhon Si Ayutthaya, Thailand during July – October 2025. Caffeine content was recorded from the claimed label before the study. Samples were kept in a refrigerator until further analysis. Deionized water was kindly provided by White House Cosme Co.,Ltd. (Chachoengsao, Thailand). 2,2-Diphenyl-1-picrylhydrazyl (DPPH), gallic acid, sodium carbonate and Folin-Ciocalteu reagent were purchased from Sisco Research Labatories Pvt. Ltd. (Mumbai, India).

95% Ethyl alcohol was purchased from Liquor Distillery Organization Excise Department (Chachoengsao, Thailand). Other chemicals were purchased from Tokyo Chemical Industry (Tokyo, Japan) in the highest quality grade.

Evaluation of Hydrogen Peroxide Scavenging Activity

Hydrogen peroxide scavenging activity was evaluated followed by the method describe by Kumar and Chaiyasut (2017). The reaction was initiated by mixing 1 ml of 0.15% w/v hydrogen peroxide solution and 1 ml of sample, at appropriate concentration. The mixture was then mixed thoroughly and measured for its UV absorbance at 230 nm using UV spectrophotometer (UV 900PV, Biometrics Technologies Inc., USA). Deionized water was used as a negative control. Ascorbic acid (vitamin C) was used as a standard. A 1 ml sample of the same concentration was mixed with 1 ml of deionized water, and the resulting solution was used as a blank to eliminate interference from potential contaminants during analysis. The hydrogen peroxide scavenging activity of the sample was calculated with the equation below.

$$H_2O_2\ Savenging\ Activity\ (\%) = \frac{Actrl - Asample}{Actrl} \times 100$$

When Actrl is absorbance of the mixture containing deionized water and Asample is absorbance of the mixture containing samples.

The results were expressed in the term of mg vitamin C equivalent (VCE)/ml of RTD tea.

DPPH radical scavenging activity

DPPH radical scavenging activity was determined followed by the method reported by Kumar and Chaiyasut (2017). One ml of RTD tea was mixed with 1 ml of 0.2 mM DPPH in 95% ethanol. The reactions were incubated in a dark chamber at room temperature for 30 min. The absorbance was measured at 517 nm. Ascorbic acid was used as a standard. DPPH radical scavenging activity of each RTD tea sample was expressed in a term of mg vitamin C equivalent (VCE)/ml of RTD tea.

Evaluation of total phenolic content

Total phenolic content (TPC) of RTD tea was determined with Folin-Ciocalteu assay, followed by a modified method reported by Olajuyigbe and Afolayan (2011). Diluted RTD tea at appropriate concentration (0.2 ml) was added to 1.0 ml of 0.2 N Folin-Ciocalteu phenol reagent in a test tube and kept for 5 min. Then sodium carbonate solution (7.5 % w/w, 0.3 ml) was added. After that, the reactions were kept in a dark place for 30 min, and then read for UV absorbance at 750 nm. Gallic acid was used as a standard. TPC of each sample was expressed as mg gallic acid equivalent (GAE)/ml of RTD tea.

Statistics

All samples were analyzed in triplicate. All values were expressed in terms of mean ± SD of triplicated experiment. To compare the antioxidant activity of RTD tea, analysis of variance was used. Significant differences between means were determined by Tukey's HSD (Honestly Significant Difference) test. Pearson's correlation coefficient was used to predict the relationship between total phenolic content, caffeine content and hydrogen peroxide scavenging activity, and between total phenolic content, caffeine content and DPPH scavenging activity. A probability value of $p < 0.05$ was adopted as the criteria for the significant differences. All statistic evaluations were made with Jamovi version 2.7 (The Jamovi Project).

Results and Discussion

The detail and caffeine content of twelve RTD teas used in this study were provided in **Table 1**. There were 8 RTD green tea samples, 1 green oolong RTD tea, 1 oolong RTD tea and 2 black RTD tea. The caffeine content of these RTD teas were in the range of 4.10 – 17.00 mg/100 ml. Average caffeine content from RTD tea in this study was 8.12 mg/100 ml. The result was lower than previous study of Nuengchamnong (2006) who collected 24 green tea beverages in Thailand and reported average caffeine content at 9.7 mg/100 ml. The highest caffeine content was

found in OT, which is claimed to be made from oolong tea, and the lowest caffeine content was found in GT1, which is claimed to be made from green tea. The finding in this study diverges from the previous report by Horzic et al. (2009) who indicated that the caffeine content was the lowest for oolong tea, followed by black tea and green tea. Another study by Chin et al. (2008), who analyzed the caffeine content of twenty commercially available tea products and observed the highest concentrations of caffeine in black and green tea samples. Given that the caffeine content was derived from the labeled claim, greater accuracy in the data and results could be achieved through direct quantification of caffeine in the tea samples.

Table 1 Detail of ready-to-drink tea used in this study.

Sample	Caffeine content claimed (mg/ 100ml)	Tea source claimed
GT1	4.10	Green tea
GT2	4.81	Green tea
GT3	7.64	Green tea
GT4	9.32	Green tea
GT5	9.69	Green tea
GT6	6.67	Green tea
GT7	7.46	Green tea
GT8	5.68	Green tea
GOT	8.00	Green oolong tea
OT	17.00	Oolong tea
BT1	12.00	Black tea
BT2	5.02	Black tea

Abbreviations: GT is green tea, GOT is green oolong tea, OT is oolong tea and BT is black tea.

Caffeine, a naturally occurring xanthine derivative, is widely present in various foods and beverages. According to the European Food Safety Authority (EFSA, n.d.), daily caffeine consumption ranges from 37 to 319 mg. In Ireland and the United Kingdom, tea is the predominant source of caffeine, contributing approximately 59% and 57% of total intake, respectively (EFSA, n.d.). Globally, however, coffee serves as the primary source, accounting for 40% to 94% of total caffeine consumption/day. Caffeine exhibits notable antioxidant properties, including the ability to scavenge reactive oxygen species and inhibit lipid peroxidation (Devasagayam, et al, 1996; Viera *et al.,* 2020). It also demonstrated efficacy in mitigating oxidative stress (Ösz *et al.,* 2022). The antioxidant properties of caffeine-containing beverages may result from synergistic interactions between caffeine and other phytochemicals. In caffeine-rich plants such as tea, xanthine alkaloids are typically complexed with compounds like tannins and catechins, both recognized for their potent antioxidant activity. During beverage preparation, these constituents are co-extracted, collectively enhancing the antioxidant potential of the final product (Ösz *et al.,* 2022). Furthermore, additives incorporated into ready-to-drink (RTD) formulations may modulate antioxidant activity, either augmenting or diminishing the overall efficacy depending on their compositions. For examples, sugar and milk added in black tea was reported with lowering total phenolic content and antioxidant activity as reported by Sharma, *et al*. (2008).

Reactive oxygen species (ROS) comprise a diverse group of molecules distinguished by their elevated reactivity relative to molecular oxygen. These species are naturally generated as byproducts of daily life aerobic metabolism (de Almeida *et al.,* 2022). ROS are broadly classified into radical species—such as superoxide anion and hydroxyl radical—and non-radical reactive species, including hydrogen peroxide (Sies, 2014). Hydrogen peroxide, often described as a double-edged sword, plays dual roles depending on its concentration. At low physiological levels, it functions as a signaling molecule that supports cell survival pathways, modulates immune cell activity, and regulates metabolic responses. However, under conditions of oxidative stress—where ROS production exceeds the body's antioxidant defenses—elevated hydrogen peroxide levels contribute to pathological processes such as inflammation, neurodegeneration, and cancer progression (Sies, 2014; de Almeida *et al.,* 2022). Furthermore, in the presence of transition metal ions, hydrogen peroxide can be converted into highly reactive species, thereby enhancing its cytotoxic potential (Halliwell *et al.,* 2000). A major practical limitation in antioxidant analysis lies in the inherent instability and rapid degradation of most primary radical species. For instance, the hydroxyl radical is highly reactive, engaging in immediate and non-specific reactions near its site of generation, which makes it difficult to evaluate *in vitro*. In contrast, hydrogen peroxide is more stable and offers greater analytical advantages (Shahidi and Samarasinghe, 2025). The *in vitro* assessment of hydrogen peroxide scavenging activity is both simple and rapid. However, a key challenge is that many phytochemicals and additives present in formulations also absorb light at 230 nm, potentially interfering with spectrophotometric measurements. To mitigate this effect, a separate blank sample was used for background subtraction at each concentration of the sample being tested (Al-Amiery *et al.,* 2015).

In this study, hydrogen peroxide scavenging activity of twelve RTD teas were shown in **Table 2**. From Table 2, the highest hydrogen peroxide scavenging activity was observed in black RTD tea sample (1.56 ± 0.01 mg VCE/ml RTD tea) and oolong RTD tea sample (1.55 ± 0.01 mg VCE/ ml RTD tea). The lowest hydrogen peroxide scavenging activity was observed in two green RTD tea samples (0.45 – 0.50 mg VCE/ml RTD tea).

Table 2 Hydrogen peroxide and DPPH radical scavenging activities, and total phenolic content of ready-to-drink tea used in this study.*

Sample	Hydrogen peroxide scavenging activity (mg VCE/ml RTD tea)	DPPH radical scavenging activity (mg VCE/ml RTD tea)	Total Phenolic content (mg GAE/ml RTD tea)
GT1	0.50 ± 0.08^{e}	0.78 ± 0.02^{a}	0.24 ± 0.00^{e}
GT2	0.45 ± 0.02^{e}	0.78 ± 0.03^{a}	0.25 ± 0.01^{e}
GT3	1.32 ± 0.00^{b}	0.67 ± 0.00^{b}	0.53 ± 0.01^{a}
GT4	1.31 ± 0.01^{b}	0.66 ± 0.03^{b}	0.47 ± 0.01^{b}
GT5	1.32 ± 0.02^{b}	0.58 ± 0.01^{c}	0.37 ± 0.02^{c}
GT6	1.07 ± 0.03^{c}	0.46 ± 0.03^{d}	0.30 ± 0.02^{de}
GT7	1.43 ± 0.02^{b}	0.41 ± 0.03^{d}	0.33 ± 0.02^{d}
GT8	1.27 ± 0.01^{b}	0.36 ± 0.02^{e}	0.27 ± 0.00^{e}

Table 2 Hydrogen peroxide and DPPH radical scavenging activities, and total phenolic content of ready-to-drink tea used in this study.* (*Continue*)

Sample	Hydrogen peroxide scavenging activity (mg VCE/ml RTD tea)	DPPH radical scavenging activity (mg VCE/ml RTD tea)	Total Phenolic content (mg GAE/ml RTD tea)
GOT	0.94 ± 0.00^{d}	0.42 ± 0.01^{d}	0.31 ± 0.01^{d}
OT	1.55 ± 0.01^{a}	0.58 ± 0.03^{c}	0.51 ± 0.02^{a}
BT1	1.38 ± 0.01^{b}	0.71 ± 0.01^{ab}	0.23 ± 0.01^{ef}
BT2	1.56 ± 0.01^{a}	0.80 ± 0.02^{a}	0.23 ± 0.01^{ef}

Abbreviations: GT is green tea, GOT is green oolong tea, OT is oolong tea, BT is black tea, VCE is vitamin C equivalent, GAE is gallic acid equivalent, RTD is ready-to-drink.

*Data are expressed as mean ± standard deviation of triplicated experiment. Data in column with different letters are significantly different ($p < 0.05$).

To validate the antioxidant activity of RTD tea, the DPPH radical scavenging assay was also employed. DPPH is a stable free radical characterized by its purple color. Upon interaction with antioxidants, which donate electrons, DPPH radical undergoes a color change from purple to yellow. This discoloration of DPPH radical can be measured at 517 nm, which serves as a visual and quantitative indicator of antioxidant capacity (Munteanu & Apetrei, 2021). Among the sample tested, black tea and two green tea samples showed the highest DPPH radical scavenging activity at level 0.78 – 0.80 mg VCE/ml RTD tea ($p < 0.05$) (Table 2). While another green tea RTD tea showed the lowest DPPH radical scavenging activity at 0.36 ± 0.02 mg VCE/ml RTD tea. Previous report by Satoh et al. (2005) indicated that reducing power and DPPH scavenging activity was the highest in green tea followed by oolong tea and black tea. Interestingly, black tea collected in this study showed both the highest reducing activity against hydrogen peroxide and DPPH scavenging activity. Oolong tea showed the highest reducing activity against hydrogen peroxide. There were few publications about evaluating antioxidant capacity of the RTD tea beverages, Nuengchamnong (2006) studied the DPPH radical scavenging activity of 24 green tea beverages in Thailand, by mixing the tea drink (0.1 ml) with 2.9 ml of 0.1mM DPPH solution, the results were reported in a term of % radical scavenging. Most of the green tea beverages in that study showed high DPPH scavenging activity (>80% inhibition), except one milk tea which had relatively low DPPH scavenging activity at 3.67 ± 0.35%. Most of the studies evaluates the antioxidant of tea beverages prepared from tea bags. When preparing tea beverage, water temperature and steeping time are the important parameters that affecting the antioxidant activity. As reported by Su *et al*. (2007), steeping tea in 100 °C water for 10 min led to loss of phenolic compound. The highest DPPH scavenging activity for oolong tea was reported to be strongest while using 5 g oolong tea steeping in 200 mL of 100 °C water for 3 min, with EC50 of 115.4 µL beverage.

The total phenolic content of the RTD tea samples was evaluated using the Folin–Ciocalteu assay. The Folin–Ciocalteu reagent, which is a complex of phosphomolybdic and phosphotungstic acids, is reduced by antioxidants, including phenolic compounds under alkaline conditions resulting in the formation of a blue chromophore (Munteanu & Apetrei, 2021). The highest

total phenolic content of RTD tea samples was achieved in oolong tea and one green tea samples (0.51 – 0.53 mg GE/ml RTD tea) while the lowest total phenolic content of RTD tea was found in two black tea samples (0.23 ± 0.01 mg GAE/ml RTD tea).

Our results were aligned with Zhao *et al*. (2019), who studied the antioxidant activities of 30 tea infusions, prepared by infusing 1 g of tea in 10 ml of boiling distilled water for 5 min. The results showed that total phenolic content of the tea varieties from Zhao's study was in the ranged between 24.77 ± 2.02 to 252.65 ± 4.74 mg gallic acid equivalent (GAE)/g dry weight of the tea leaves, which the green tea variety showed the highest TPC among the test samples, while black tea showed low to medium amount of TPC (37 – 101 mg GAE/dry weight). However, the previous study by Vinci *et al*. (2022) who studied the TPC and antioxidant activity of the tea infusion, prepared from 20 varieties of bagged tea, including green tea and black tea. The results from that study showed that green tea and black tea showed similarly TPC when steeping at 100°C for 10 min, in the range between 916.12 – 1126.62 mg GAE/g bagged tea. The stability of phenolic compounds in tea beverages is influenced by several factors, including exposure to light and heat, the pH of the formulation also impacts the stability of the phenolic compounds. To enhance stability, RTD formulations often incorporate synthetic antioxidants, which can help preserve phenolic integrity. Previous research has reported that tea polyphenols are pH-sensitive, exhibiting greater stability under acidic conditions. Additionally, the study by Zeng et al. (2016) indicated that storing tea beverages at low temperatures further improves the stability of tea polyphenols.

To evaluate the relationship between total phenolic content and caffeine content with the antioxidant activity of RTD tea beverages, Pearson's correlation coefficient was employed (Figure 1). The analysis revealed a moderate positive correlation between caffeine content and hydrogen peroxide scavenging activity ($r = 0.552$, $p < 0.001$), as well as between total phenolic content and hydrogen peroxide scavenging activity ($r = 0.402$, $p < 0.05$). No significant correlations were observed between caffeine content and DPPH scavenging activity, nor between total phenolic content and DPPH scavenging activity. This finding was unexpected, as numerous previous studies have demonstrated that phenolic compounds are the primary phytochemicals responsible for the antioxidant activity of tea, with most investigations conducted using freshly brewed tea leaves. For instance, Dobrinas *et al*. (2021) reported that total phenolic content was positively and significantly correlated with DPPH scavenging capacity across all infusion times. These contrasting results suggest that storage conditions and the presence of additives in ready-to-drink (RTD) formulations may play an important role in modulating antioxidant activity.

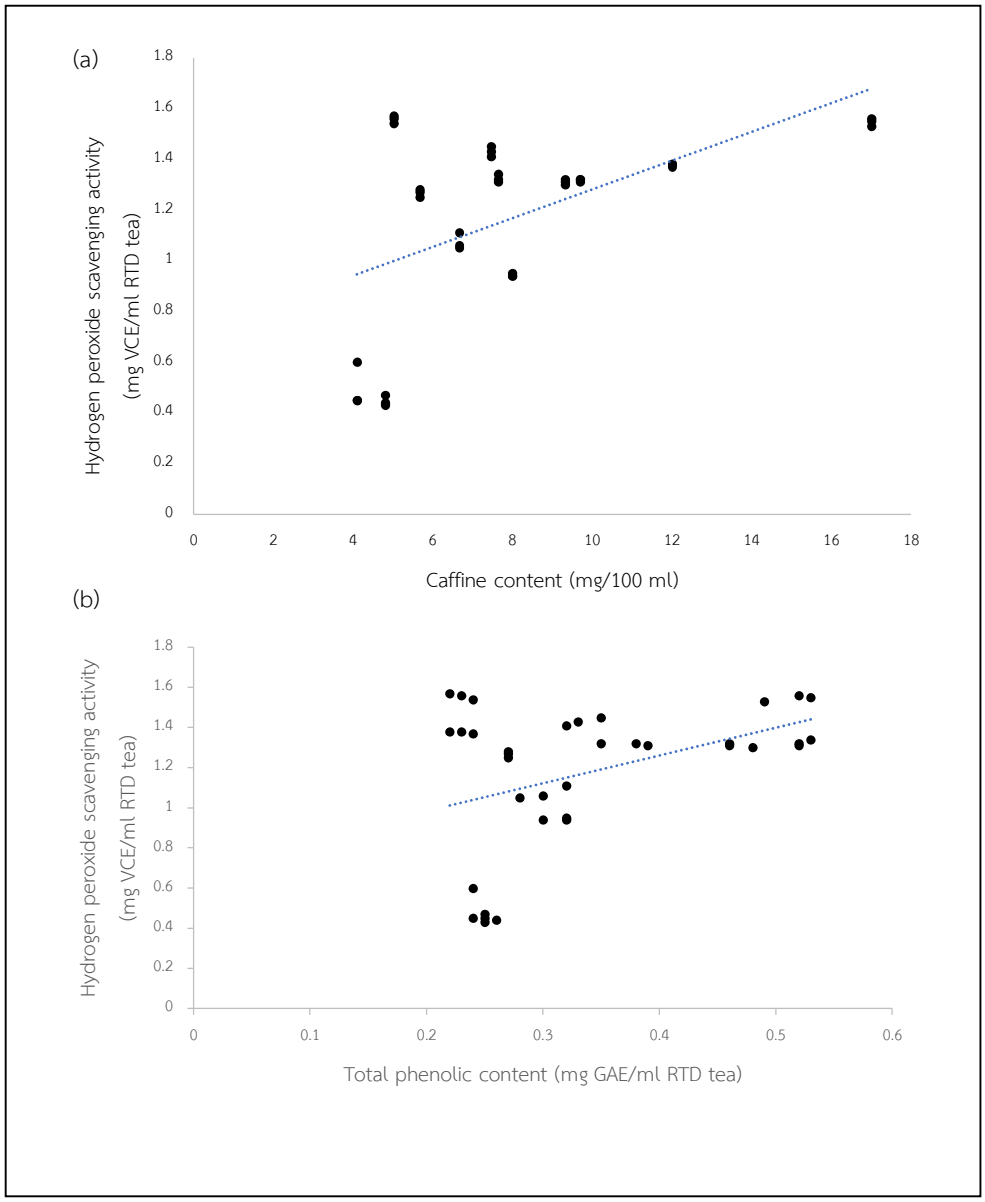

Figure 1 Correlogram indicating the relationship between caffeine content and hydrogen peroxide scavenging activity, Pearson's correlation coefficient r = 0.552, $p < 0.001$ (a) and total phenolic content and hydrogen peroxide scavenging activity, Pearson's correlation coefficient r = 0.402, $p < 0.05$) (b). Abbreviations: VCE is vitamin C equivalent, GAE is gallic acid equivalent, RTD is ready-to-drink.

Conclusions

In this study, twelve ready-to-drink (RTD) tea products, commercially available in convenience stores, were selected for preliminary evaluation of antioxidant activity using hydrogen peroxide and DPPH radical as the representative assay. Total phenolic content was also evaluated. The results demonstrated that all RTD tea samples exhibited measurable antioxidant activity. Among them, products derived from black tea and oolong tea showed the highest hydrogen peroxide scavenging capacity, while black tea and two green tea samples showed the highest DPPH radical scavenging activity. Oolong tea and one green tea samples showed the highest TPC, while both black tea samples had the lowest TPC. Moderate positive correlation between total phenolic content and caffeine content with the antioxidant activity of RTD tea beverages

were found. The findings from this study suggested that RTD beverages showed promising health-promoting properties. However, further investigation into their phytochemical composition, including measurement of exact caffeine content is warranted to elucidate the specific bioactive constituents responsible for the observed effects.

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