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Review article

Antioxidant activities of kombucha tea: a systematic review and meta-analysis of *in vitro* studies

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Abstract

Objective: Human body is always exposed to oxidants which could be suppressed with antioxidant supplementation. Kombucha is a fermented tea beverage that has been shown to have antioxidant properties. The current systematic review and meta-analysis aimed to evaluate the antioxidant potential of kombucha tea based on the existing literature.

Materials and methods: A systematic literature search following the PRISMA 2020 guidelines was conducted to include eligible studies (original research in English language on the antioxidant activity of kombucha tea, with available full text). Data extraction was performed independently by three reviewers. Overall, the study process was undertaken from September 2024 to May 2025; final search conducted on September 112024. Random-effects meta-analysis was selected to summarize the statistical information of the antioxidative-related parameters.

Results: Fourteen studies were included in this systematic review and meta-analysis. Our results showed that kombucha had a significant effect against unfermented tea control in 2,2-diphenyl-1-picrylhydrazyl/DPPH assays (% radical scavenging ability = 9.84% (95% CI = 4.63 to 15.05%, $p = 0.0002$)) and half-maximal inhibitory concentration (IC_{50}) = -64.54 mg/L (95% CI = -99.06 to -30.03 mg/L, $p = 0.0002$). However, other parameters such as 2,2'-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid)/ABTS assays, ferric reducing antioxidant power, intracellular reactive oxygen species (ROS), total phenolic compounds, and total flavonoid contents did not differ significantly between kombucha and control groups.

Conclusion: The current systematic review and meta-analysis presented a significant difference of antioxidant capacity (DPPH) of kombucha tea compared to control (unfermented tea). Nevertheless, due to high heterogeneity in the included studies, more studies should be conducted to validate kombucha tea antioxidant activity.

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Introduction

Antioxidants are defined as any substance with the ability to neutralize reactive oxygen species (ROS) and their derivatives, such as reactive nitrogen species (RNS) or reactive sulphur species (RSS) (Martemucci et al. 2022; Baruah et al. 2025). ROS are the by-products of cellular metabolism formed following mitochondrial oxidases and other cellular compartments activity (Gulcin 2025). Meanwhile, RNS and RSS are formed through ROS reaction with nitric oxide and thiol, respectively (Salehi et al. 2018; Mandal et al. 2022).

Although ROS are naturally produced in our bodies, their overproduction may occur in some situations such as aging, psychological stress, infection, inflammation, cancer, and excessive exercise (Pizzino et al. 2017; Jena et al. 2023). ROS elevation could induce cellular damage via senescence induction and increased production of inflammatory cytokines. Antioxidants are vital to prevent the ROS-associated cellular damage (Salehi et al. 2018; Kozlov et al. 2024). Furthermore, antioxidants are also beneficial to prevent the development of various chronic diseases including cancer, cardiovascular disease, and inflammatory or autoimmune disease (Zehiroglu and Ozturk Sarikaya 2019; Ayoka et al. 2022; Blagov et al. 2024). Herbal substances may be beneficial to help in improving antioxidative activities and preserve human health (Parham et al. 2020; Stevanny et al. 2020; Sukweenadhi et al. 2020).

Kombucha is a traditional beverage that originated from Manchuria, China and traditionally produced through the fermentation of tea leaves (*Camellia sinensis*) (Barros et al. 2024; Falasifah et al. 2025). It involved a symbiotic culture of bacteria and yeast (SCOBY) consisting of acetic acid bacteria (*Komagataeibacter*, *Gluconobacter*, and *Acetobacter*), lactic acid bacteria (*Lactobacillus* and *Lactococcus*), and osmophilic yeast (*Schizosaccharomyces pombe*, *Saccharomycodes ludwigii*, *Kloeckera apiculata*, *Saccharomyces cerevisiae, Zygosaccharomyces bailii*, *Torulaspora delbrueckii*, and *Brettanomyces bruxellensis*). This fermentation process occurs in an aerobic and high in sucrose (5–8% sugar) medium for several days (Villarreal-Soto et al. 2018; de Miranda et al. 2022; Anantachoke et al. 2023; Sarshar et al. 2025). Although several studies have reported the antioxidant properties of kombucha and its potential health benefits (Hananta et al. 2025), the results have been controversial. Jakubczyk et al (2020) have reported best antioxidant properties of green tea kombucha compared with black, white, and red tea. Meanwhile, Cardoso et al (2020) reported a higher antioxidant capacity in black tea kombucha than green tea kombucha, although green tea types exhibited higher antibacterial and antiproliferative activities. On the other hand, a study reported that green tea exhibited greater antioxidant potential than kombucha with no difference in the concentration of total phenolic compounds (TPCs) (Teixeira Oliveira et al. 2023). Consequently, there is no definitive agreement regarding the antioxidant impact of kombucha in comparison to its unfermented substrate. To our knowledge, no systematic review has yet offered a quantitative synthesis (meta-analysis) of these data. This gap in the literature makes it challenging to determine whether the fermentation process increases the antioxidant potential *in vitro*. Therefore, we conducted a systematic review and meta-analysis aimed to summarize the findings of previous studies regarding antioxidant activity of kombucha tea.

Materials and Methods

This review followed the Preferred Reporting Items guidelines for Systematic Reviews and also Meta-analysis (PRISMA) 2020 (Page et al. 2021). Since the current systematic review included *in vitro* studies, the protocol could not be published in the international prospective register of systematic reviews (PROSPERO). Supplementary Table 1 shows the PRISMA 2020 checklist filled following the completion of this manuscript writing.

Literature search

A comprehensive literature search was conducted to assess the antioxidant activity of kombucha tea from seven databases: PubMed, ProQuest, Taylor and Francis, SAGE, JSTOR, Wiley, and Emerald. The review was conducted between September 2024 and May 2025. The articles were retrieved with no publication date and geographical restriction. The search terms applied in the current systematic review are listed in Table 1. Literature search was limited to those published in English language and with available full-text. In addition, we manually searched additional possible studies from the references of the included studies.

Table 1. Search terms

Databases	Search terms
PubMed	(((“reactive Oxygen Species”) OR (“ROS”)) AND (“antioxidant”)) AND (“kombucha”)
ProQuest	(“reactive oxygen species”) AND (“antioxidant”) AND (“kombucha”)
Taylor and Francis	(((“reactive oxygen species”) OR (“ROS”)) AND (“antioxidant”)) AND (“kombucha”)
Sage	(((“reactive oxygen species”) OR (“ROS”)) AND (“antioxidant”)) AND (“kombucha”)
JSTOR	(((“reactive oxygen species”) OR (“ROS”)) AND (“antioxidant”)) AND (“kombucha”)
Wiley	(((“reactive oxygen species”) OR (“ROS”)) AND (“antioxidant”)) AND (“kombucha”)
Emerald	(((“reactive oxygen species”) OR (“ROS”)) AND (“antioxidant”)) AND (“kombucha”)

Study selection

The inclusion criteria are: (1) original article, (2) written in English, (3) accessible full-text, and (4) investigated the antioxidant activity of kombucha tea. Meanwhile, the exclusion criteria are: (1) secondary article sources including review, editorial, correspondence, letter, or commentary, (2) no appropriate control (unfermented tea), or (3) no antioxidant markers detection. The current review primarily included studies which reported *in vitro* antioxidant assays using chemical-based test. However, to expand the number of included studies, research done using cell-based *in vitro* assay was also included.

Data extraction

Three authors (KT, AMS, and LH) extracted further information independently about the research that has been included, using Rayyan QCRI, a semi-automatic screening tool for systematic review (Ouzzani et al. 2016; Umar et al. 2022, 2023). Inter-rater discrepancies were addressed through meticulous re-evaluation and conversation of the article among evaluators until an accordance was reached, subsequently verified by a senior author (TPU). The extracted data were as follows: (1) First author and publication year; (2) study design; (3) country of study origin; (4) method; (5) antioxidant activity, including 2,2-diphenyl-1-picrylhydrazyl/DPPH assay, 2,2'-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid)/ABTS assay, ferric ion reducing antioxidant power (FRAP), intracellular ROS generation, TPCs, and total flavonoid contents (TFCs). Missing or incomplete data were estimated from research graphs or diagrams. However, if this was impossible, the studies were excluded.

Quality assessment

The risk of bias analysis was conducted using a tool developed by Silva et al (2020) as an assessment tool for *in vitro* laboratory-based systematic review. The following parameters were considered during the critical appraisal: (i) sample size calculation, (ii) samples with similar dimensions, (iii) control group, (iv) standardization of procedures, (v) statistical analysis, and (vi) other risk of bias. Other risk of bias may include: selective reporting bias and blinding. Each parameter was determined as “low,” “high,” or “unclear” risk of bias. Three independent reviewers (MMS, SVK, and LL) conducted the assessment, and any discrepancies were resolved through discussion with a senior author (ZA).

Types of outcome measures

The outcome measures assessed in this systematic review included free radical scavenging activity (DPPH-% and half-maximal inhibitory concentration (IC_{50}); ABTS-% and IC_{50}; and FRAP), antioxidative compounds level (TPCs and TFCs), and oxidative stress marker levels (intracellular ROS). All these parameters provided a comprehensive list of different aspects of antioxidant activities.

Statistical analysis

Statistical analyses (meta-analyses) were conducted using RevMan 5.4 (Cochrane Collaboration). The analyzed parameters were numerical variables; thus, it was followed by comparing the previously determined measures the kombucha (green tea leaves are the primary kombucha types tested due to the highest antioxidative capacities (Jakubczyk et al. 2020) and control groups (unfermented tea) to obtain the Standardized Mean Difference (SMD) or Mean Differences (MD) value and 95% Confidence Interval (95% CI). For data presented as a diagram or a graph, the numerical values were extracted using the WebPlotDigitizer version 5.0 (https://automeris.io/WebPlotDigitizer; Pacifica, California, USA). The conclusion was declared statistically significant if the overall outcome SMD or MD did not intersect the line 0 with p value < 0.05. Then, heterogeneity analysis was carried out by I^2 value determination. If the I^2 value is >50% then, there is significant heterogeneity between studies and random-effect model (REM) will be used. Otherwise, fixed-effect model (FEM) was used. For variables with significant heterogeneity, sensitivity analyses were undertaken to determine the stability of the results through the leave-one-out meta-analysis

Results

Literature retrieval

Following literature search, 481 articles were retrieved during the preliminary process. After deduplication, 42 duplicate records were removed, leaving 439 articles which undergone abstracts, titles, and keywords screening. The process resulted in 42 relevant papers which were allocated for full-text screening. After full-text screening, 14 studies were included for review and eleven studies were statistically analysed. Figure 1 illustrates the literature retrieval process.

Study characteristics

The characteristics of the included studies are shown in Table 2. All studies (Kaewkod et al. 2019; Fibrianto et al. 2020; Jakubczyk et al. 2020, 2024; Khaleil 2020; Ziemlewska et al. 2021, 2023, 2024; Li et al. 2022; Xu et al. 2022; Zhang et al. 2023; Sales et al. 2023; Xiong et al. 2023; Dechakhamphu et al. 2023) were published between 2019 and 2024. All studies were done as *in vitro* studies (n=14). The studies were conducted in various countries: Poland (n=5), China (n=3), Thailand (n=2), Brazil (n=1), Indonesia (n=1), Saudi Arabia (n=1), and South Korea (n=1). All investigations used tea-based kombucha derived from various types of tea sources. The fermentation period of kombucha ranged from 7 to 30 days. The included studies assessed different antioxidant activity (using ABTS, DPPH, FRAP, TFC, TPC, and intracellular ROS assays).

Table 2. Characteristics of the included studies

Author (Year)	Country	Methods			Kombucha Antioxidant Activities							
		Tea-Based (exp)	Fermentation duration	Cell objects	DPPH (%)	DPPH (IC_{50}, mg/L)	ABTS (%)	ABTS (IC_{50}, mg/L)	FRAP (µM Fe(II)/L)	TPC (mg/L)	TFC (mg/L)	Intracellular ROS (%)
Dechakhamphu et al. (2023)	Thailand	*Cyperus rotundus* rhizomes and tubers	10 days	N/A	-	76.7 ± 9.6	-	314.2 ± 16.9	-	-	-	-
Fibrianto et al. (2020)	Indonesia	*Camellia sinesis* leaves	3 days	N/A	-	23.4 ± 1.73	-	-	-	269 ± 0.71	-	-
Jakubczyk et al. (2020)	Poland	Green Tea (*Camellia sinesis*) leaves	1, 7, and 14 days	N/A	91.4 ± 0.57[a]	-	-	-	4801.1 ± 69.2[a]	239.1 ±4.67[a]	146.8 ± 3.4[a]	-
Jakubczyk et al. (2024)	Poland	Green Tea (*Camellia sinesis*) leaves	7-14 days	N/A	91.26 ± 1.74[a]	-	96.48 ± 4.94	-	4341.6 ± 82.63[a]	299.6 ± 3.1[a]	946.74 ± 222.62[a]	-
Kaewkod et al. (2019)	Thailand	Green Tea (*Camellia sinesis*) leaves	3, 6, 9, 12, and 15 days	Caco-2 cells	-	-	-	-	-	1087.49 ± 23.12[a]	-	-
Khaleil et al. (2020)	Saudi Arabia	Black and green tea	7 days	N/A	155	-	-	-	-	180	18	-
Li et al. (2022)	China	Green Tea (*Camellia sinesis*) leaves	7 days	N/A	-	-	37.77 ± 0.62	-	4749.39 ± 131.42	317.54 ± 5.93	104.27 ± 2.67	-
Sales et al. (2023)	Brazil	Black tea leaves	9 days	HK-2 cells	-	-	-	-	-	214 ± 2.98	-	77.03 ± 3.35
Xiong et al. (2023)	China	Bamboo leaves	14 days	N/A	-	-	-	-	1850.83 ± 138.12	303.64 ± 9.11	-	-
Xu et al. (2022)	South Korea	Green tea	6 days	N/A	95.99 ± 3.11	-	-	-	-	1360.71 ± 28.96	-	-
Zhang et al. (2023)	China	De'ang sour tea	30, 60, 90, 120 days	N/A	25.01 ± 4.8[b]	-	-	-	-	-	-	-
Ziemlewska et al. (2021)	Poland	Yerba mate tea (*Ilex paraguariensis*) leaves	14 days	N/A	-	219.04 ± 0.11	-	174.02 ± 0.14	-	-	-	-
Ziemlewska et al. (2023)	Poland	*Aronia melanocarpa* leaves	20 days	Human fibroblasts	-	791 ± 7.4	-	128 ± 2.67	-	-	-	-
Ziemlewska et al. (2024)	Poland	Radish (*Raphanus sativus*) leaf	7, 14, and 21 days	Human fibroblasts	43.23 ± 0.12[a]	-	96.8 ± 0.5	-	-	-	-	84.53 ± 1.16

Numerical data are presented as mean ± standard deviation. [a]Data was acquired from fermentation day 6 to 9 (mostly day 7 due to the highest antioxidant power reported in previous studies), [b]Data was acquired from fermentation day 30). ABTS = 2,2'-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid), DPPH = 2,2-diphenyl-1-picrylhydrazyl, FRAP = ferric ion reducing antioxidant power, N/A = not available ROS = reactive oxygen species, TPCs = total phenolic compounds, TFCs = total flavonoid contents.

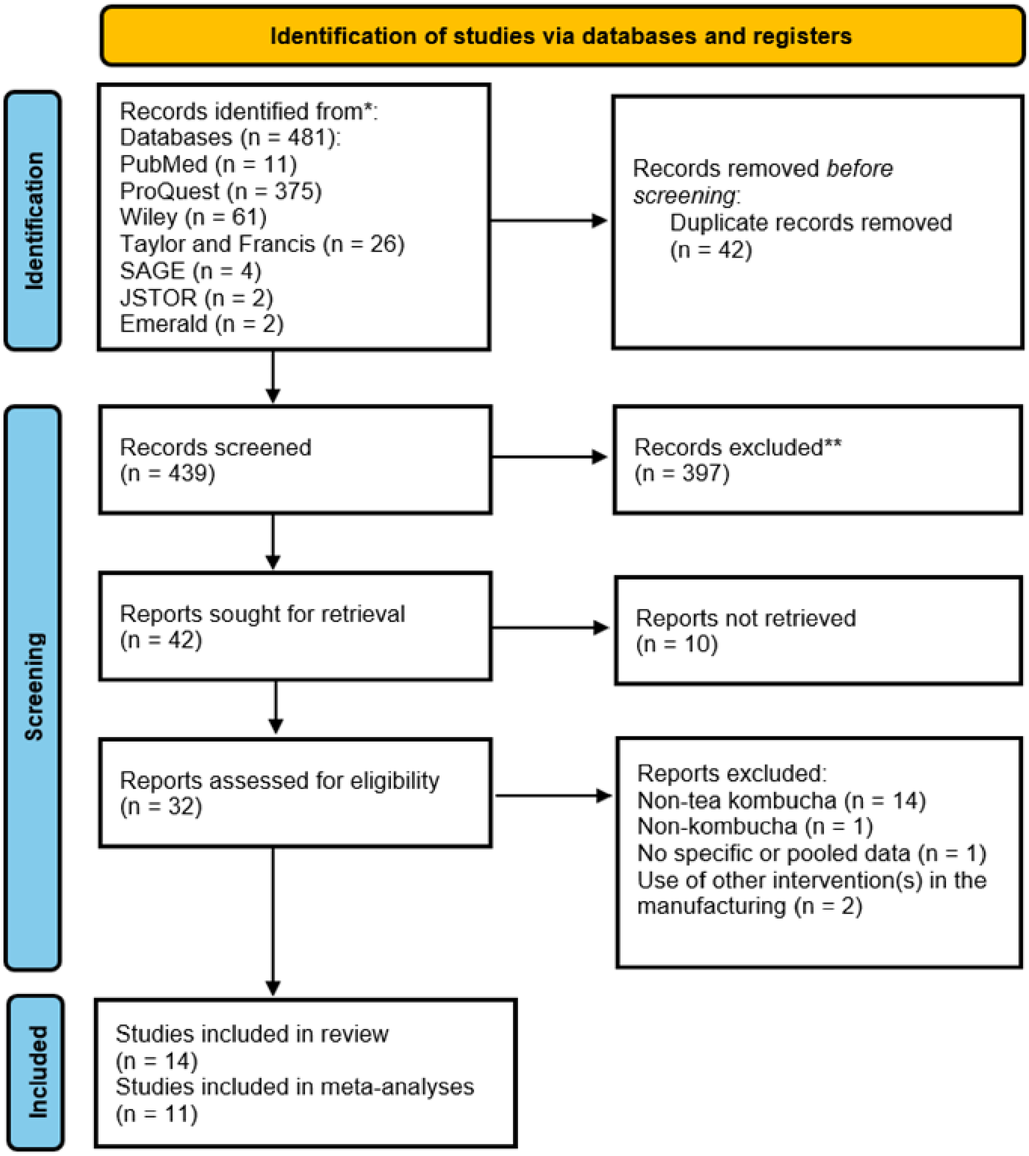

Figure 1. PRISMA flowchart

Meta-analysis

Eleven studies were included for meta-analysis, which was used to determine antioxidant capacity (radical scavenging ability), antioxidant reducing capability, oxidative stress marker, and total amount of antioxidant compounds. Regarding free radical scavenging capacity, DPPH assay showed significant difference between kombucha tea and unfermented tea, for both parameters (radical scavenging ability % and IC_{50}), as determined from three studies data. The overall mean difference of scavenging percentage was 9.84% (95% CI = 4.63 to 15.05%, p = 0.0002). Meanwhile, kombucha overall IC_{50} was lower than the required concentration for unfermented tea, with overall effect of -64.54 mg/L (95% CI = -99.06 to -30.03 mg/L, p = 0.0002). Meanwhile, ABTS assays did not show a significant difference between tested groups, although having a similar tendency as DPPH measurements. The ABTS scavenging percentage difference was at 28.89% (95% CI = -4.58 to 62.37%, p = 0.09) and IC_{50} difference was at -4.82 mg/L (95% CI = -40.27 to 30.62 mg/L, p = 0.79). Meta-analysis data is available in Figure 2.

The current meta-analysis was expanded to determine reducing capacity and oxidative stress level (Figure 3), along with antioxidant compound amount (Figure 4). All analysis reflected insignificant result, with the MD or SMD as follows: FRAP (SMD = 1.38, 95% CI = -6.34 to 9.10, p = 0.73), intracellular ROS (MD = 7.71%, 95% CI = -1.86 to 17.29%, p = 0.11), TPCs (MD = -21.20 mg GAE/L, 95% CI = -116.97 to 74.58 mg GAE/L, p = 0.66), and TFCs (MD = -53.54 mg GAE/L, 95% CI = -158.69 to 51.61 mg GAE/L, p = 0.32). Similar to radical scavenging ability assays, all measurements were having considerable heterogeneity, with I^2 values ranging from 78% to 100%.

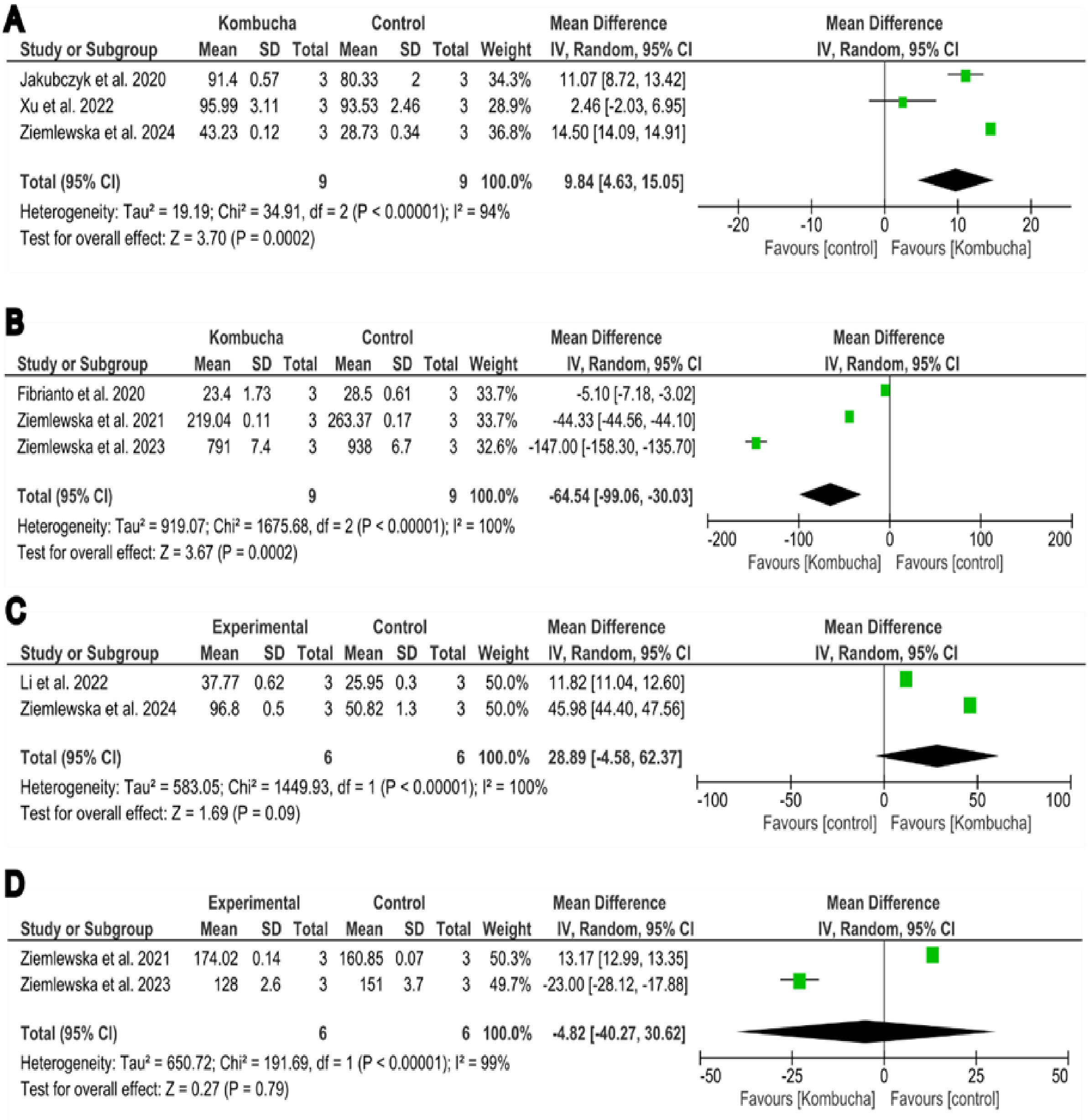

Figure 2. Statistical analysis of free radical scavenging ability. (A) DPPH scavenging percentage, (B) DPPH IC_{50}, (C) ABTS scavenging percentage, (D) ABTS IC_{50}.

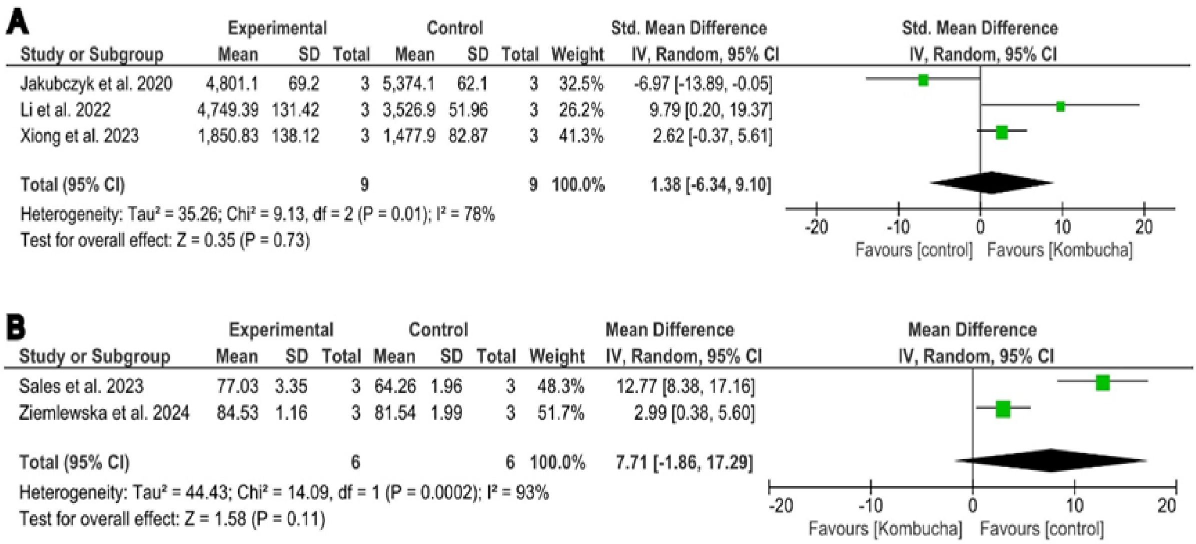

Figure 3. Antioxidant and oxidative stress parameters. (A) FRAP, (B) Intracellular ROS.

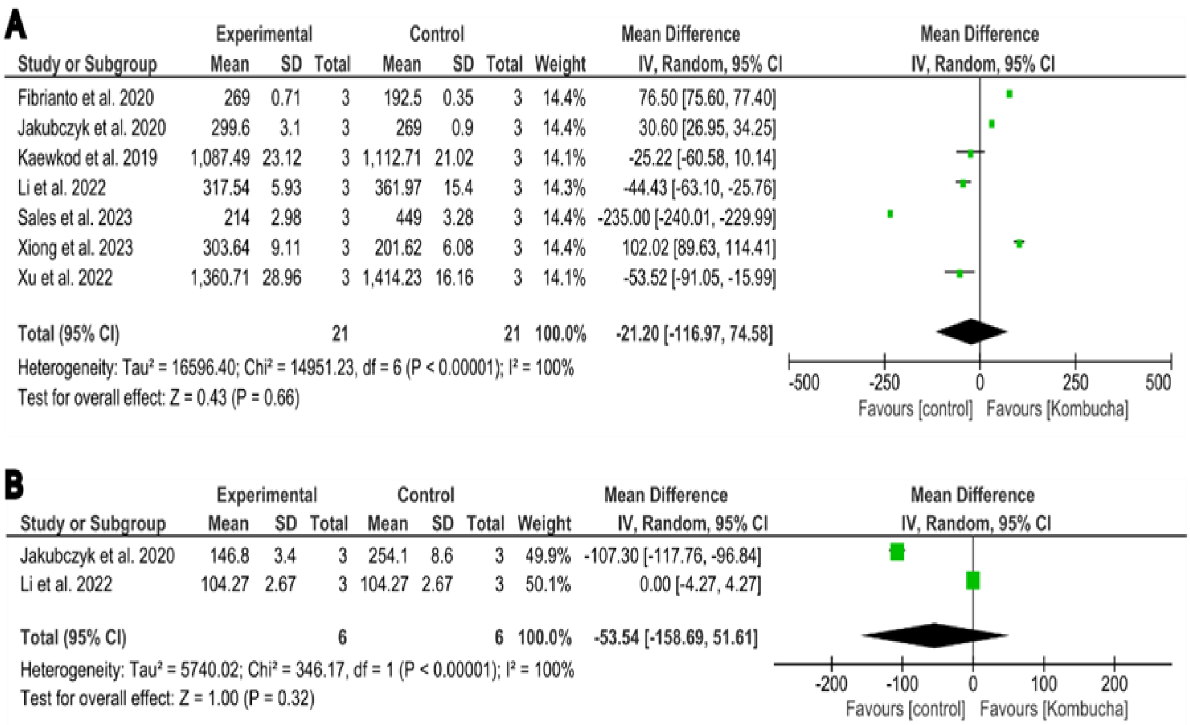

Figure 4. Total antioxidant compounds. (A) TPCs, (B) TFCs).

Risk of bias

Following quality assessment with risk of bias analysis, all studies did not report any sample size calculation (D1). However, it should be noted that all studies were conducted as triplicate, which is a very common measure in *in vitro* studies. Meanwhile, for the domains sample with similar dimensions (D2) and standardization of procedures (D4), all studies showed a low risk of bias. In control group (D3) assessment, three studies did not use any control, and only one study did not report a clear statistical analysis (D5). The majority of the studies showed a low risk of bias in other risk (D6) (9/14; 64.29%) (Figure 5 and Figure 6).

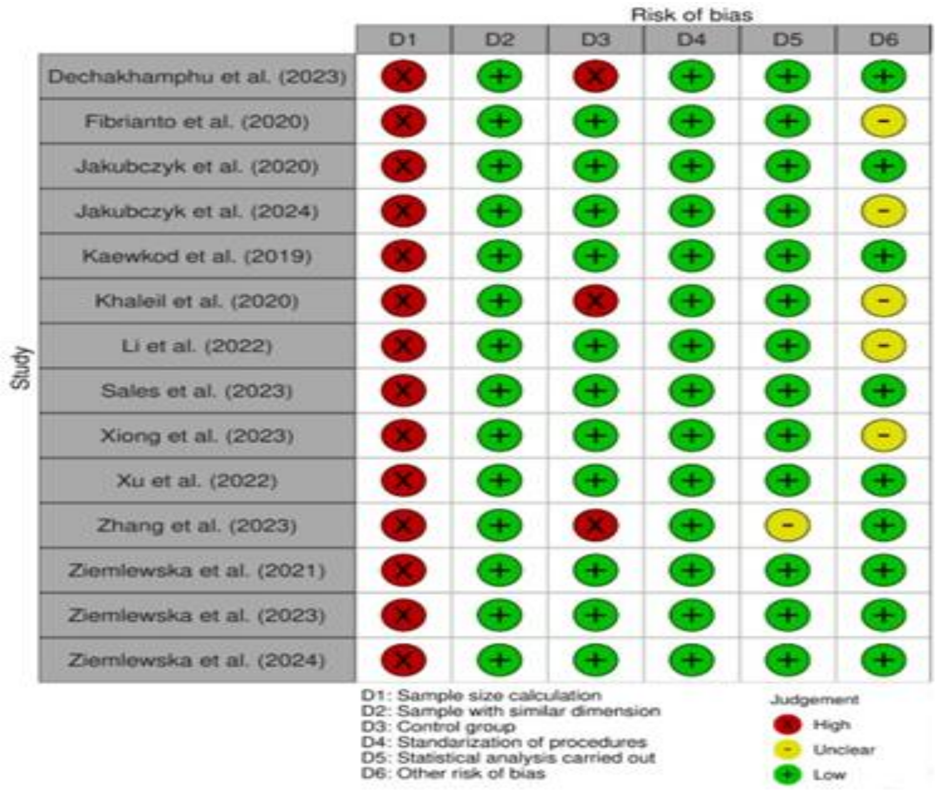

Figure 5. Traffic plot of risk of bias

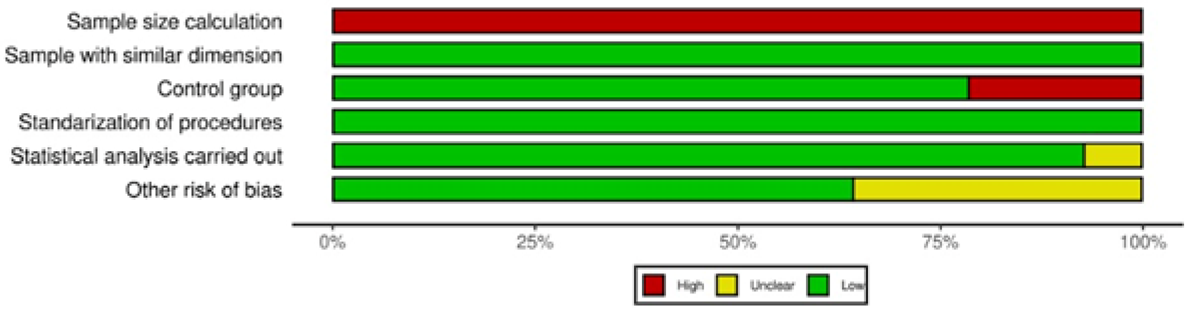

Figure 6. Summary plot of risk of bias

Discussion

Nowadays, numerous customers perceive fermentation as an organic approach to food preservation that may augment the health benefits of products, such as by improving essential amino acids, proteins, vitamins, and different metabolites (Sharma et al. 2020; García-Barón et al. 2025). From an antioxidant perspective, fermentation increases the levels of various enzymes that facilitate the production, release, and generation of bioactive chemicals from the substrate (Abbaspour 2024; Sarıtaş et al. 2024). Various factors contribute to this process including elevated phytochemicals (e.g. polyphenols and flavonoids), antioxidant peptides, and antioxidant polysaccharides generated through microbial hydrolysis or biotransformation (Zhou et al. 2020; Zhao et al. 2021; Luo et al. 2024; Fitsum et al. 2025). Furthermore, fermentation can facilitate the degradation of plant cell walls, thereby aiding in the release or generation of diverse antioxidant molecules (Zhao et al. 2021, 2024).

Kombucha is an example of fermented beverages which showed growing popularity. Despite coming from Asia, kombucha popularity is spreading to Europe and other parts of the world (Bishop et al. 2022; Andrade et al. 2025). Research on the various base types of teas, their composition, and their health-promoting qualities is limited, despite the fact that kombucha antioxidant qualities have been thoroughly examined (Gaggìa et al. 2018; Jakubczyk et al. 2020; Xiong et al. 2023).

Among the bioactive compounds present in kombucha yeasts, organic acids, catechins, and polyphenols are the primary chemicals that possess antioxidant functions (Alaei et al. 2020; Abaci et al. 2022; Bortolomedi et al. 2022; das Chagas et al. 2024; Martihandini and Rochimat 2024) Although tea leaves already exhibit antioxidant properties, fermentation of tea leaves with SCOBY could further enhance the antioxidant properties via increased production of gallic acid and glucuronic acid (Rahmani et al. 2019; Chou et al. 2024). Thus, kombucha may exhibit superior antioxidant properties compared to tea (Sun et al. 2015; Jakubczyk et al. 2020). Because of resonance stabilization, phenolic compounds are able to donate hydroxyl hydrogen with ease, and this hydrogen supply gives them a great ability to scavenge DPPH (Wang et al. 2018; Muliasari et al. 2023). The other most widely used techniques are ABTS-based antioxidant capacity assays. The interaction between an antioxidant and the pre-generated ABTS•+ radical cation forms the basis of the ABTS/PP test (Ilyasov et al. 2018). The fading of absorption spectra characteristic peaks at 414, 417, 645, 734, and 815 nm makes it simple to quantitatively detect ABTS scavenging (Ilyasov et al. 2020).

Our review showed a trend of increment of the DPPH assay antioxidant activity, but not in ABTS assay. This may be explained by the different mechanisms involved. DPPH responds to hydrogen-donating phenolics, such as catechol and gallic acid (Brighente et al. 2007; Akar et al. 2017). Meanwhile, ABTS respond to a broader range of antioxidants and are not limited to hydrogen-donating phenolics (Christodoulou et al. 2022). Regarding tea types, this study utilized the data from green tea when possible, since it is considered to have the highest DPPH scavenging ability (88%) compared to black tea and tea waste material following fermentation process (Jayabalan et al. 2008; Cheepchirasuk et al. 2025), along with highest overall antioxidant activities than black and red tea (Jakubczyk et al. 2020). However, this difference on antioxidant assays activity on kombucha needs further evaluation.

Our study showed a few limitations, especially in the level of certainty of evidence. The results from all of the studies were pre-preliminary (*in vitro* experiments), which showed low certainty of evidence compared to clinical trials. Despite these limitations, our study was the first to provide valuable sources of evidence about how tea-based kombucha shows potential as an antioxidant agent. Furthermore, all included studies showed significant heterogeneity in the result, which may impact study generalizability and interpretation since the included studies varied significantly in methodologies, tea types, fermentation durations, geographical variations, and analytical conditions. This significant variation presumably arises from numerous critical variables. The fermentation duration in the included research varied significantly from three to thirty days, which substantially affects the ultimate content of organic acids and phenolic compounds (Jayabalan et al. 2007). Moreover, the tea substrate is a significant variable, whether comparing teas of the same species (*Camellia sinensis*, green and black tea) (Jakubczyk et al. 2020) or distinct species (such as bamboo leaf, *Ilex paraguariensis,* and *Cyperus rotundus*) (Ziemlewska et al. 2021; Xiong et al. 2023; Dechakhamphu et al. 2023). This study also included a relatively small amount of research papers, particularly of DPPH, which may also reduce the statistical power and robustness of the conclusions.

In conclusion, the current systematic review and meta-analysis presented a significant difference of antioxidant capacity of kombucha tea compared to control (unfermented tea) as measured by DPPH assays. However, this significance is not applicable for ABTS assays and FRAP. In addition, oxidative stress level and antioxidant compound amount also do not differ significantly. Nevertheless, due to high heterogeneity in the included studies, more studies should be conducted in more detail to determine the antioxidant activity of kombucha tea. Future research should include standardizing the reporting process, such as a full description of the SCOBY composition, the exact substrate used, and all the fermentation parameters (e.g. time, temperature, and sugar concentration). Additionally, a positive control (such as Trolox, gallic acid, and ascorbic acid) alongside the unfermented tea (negative) control should be employed to confirm assay performance. *In vivo* studies may also be conducted to ascertain the physiological significance and bioavailability of the antioxidant compounds present in kombucha.

Conflicts of interest

The authors declare no conflict of interest.

Availability of data and materials

This published article contains all of the generated or analysed data obtained during this investigation.

Authors' Contributions

Conceptualization, Z.A.; Methodology, Z.A., M.M.S., K.T., L.H., J.S., and T.P.U.; Formal analysis and results interpretation, Y.T.N.S., A.M.S., and T.P.U., validation, Z.A., M.M.S., S.V.K., L.L., E.S., and T.P.U.; writing-original draft preparation, K.T., A.M.S., and C.T.; Writing-review and editing, M.M.S. and T.P.U.; Supervision, Z.A., L.L., L.H., J.S., and E.S. All authors reviewed the results and approved the final version of the manuscript. All authors were involved in the revision of the draft manuscript and have agreed to the final content.

References

Abaci N, Senol Deniz FS, Orhan IE (2022) Kombucha – An ancient fermented beverage with desired bioactivities: A narrowed review. Food Chem X 14:100302. https://doi.org/10.1016/j.fochx.2022.100302

Abbaspour N (2024) Fermentation's pivotal role in shaping the future of plant-based foods: An integrative review of fermentation processes and their impact on sensory and health benefits. Appl Food Res 4:100468. https://doi.org/10.1016/j.afres.2024.100468

Akar Z, Küçük M, Doğan H (2017) A new colorimetric DPPH(•) scavenging activity method with no need for a spectrophotometer applied on synthetic and natural antioxidants and medicinal herbs. J Enzyme Inhib Med Chem 32:640–647. https://doi.org/10.1080/14756366.2017.1284068

Alaei Z, Doudi M, Setorki M (2020) The protective role of Kombucha extract on the normal intestinal microflora, high-cholesterol diet caused hypercholesterolemia, and histological structures changes in New Zealand white rabbits. Avicenna J phytomedicine 10:604–614

Anantachoke N, Duangrat R, Sutthiphatkul T, et al (2023) Kombucha Beverages Produced from Fruits, Vegetables, and Plants: A Review on Their Pharmacological Activities and Health Benefits. Foods 12:1818. https://doi.org/10.3390/foods12091818

Andrade DK, Wang B, Lima EM, et al (2025) Kombucha: An Old Tradition into a New Concept of a Beneficial, Health-Promoting Beverage. Foods 14:1547. https://doi.org/10.3390/foods14091547

Ayoka TO, Ezema BO, Eze CN, Nnadi CO (2022) Antioxidants for the Prevention and Treatment of Non-communicable Diseases. J Explor Res Pharmacol 7:179–189. https://doi.org/10.14218/JERP.2022.00028

Barros VC, Botelho VA, Chisté RC (2024) Alternative Substrates for the Development of Fermented Beverages Analogous to Kombucha: An Integrative Review. Foods 13:1768. https://doi.org/10.3390/foods13111768

Baruah P, Padhi D, Moorthy H, et al (2025) Navigating the dichotomy of reactive oxygen, nitrogen, and sulfur species: detection strategies and therapeutic interventions. RSC Chem Biol 6:338–357. https://doi.org/10.1039/d5cb00006h

Bishop P, Pitts ER, Budner D, Thompson-Witrick KA (2022) Kombucha: Biochemical and microbiological impacts on the chemical and flavor profile. Food Chem Adv 1:100025. https://doi.org/10.1016/j.focha.2022.100025

Blagov A V, Summerhill VI, Sukhorukov VN, et al (2024) Potential use of antioxidants for the treatment of chronic inflammatory diseases. Front Pharmacol 15:1378335. https://doi.org/10.3389/fphar.2024.1378335

Bortolomedi BM, Paglarini CS, Brod FCA (2022) Bioactive compounds in kombucha: A review of substrate effect and fermentation conditions. Food Chem 385:132719. https://doi.org/10.1016/j.foodchem.2022.132719

Brighente IMC, Dias M, Verdi LG, Pizzolatti MG (2007) Antioxidant Activity and Total Phenolic Content of Some Brazilian Species. Pharm Biol 45:156–161. https://doi.org/10.1080/13880200601113131

Cardoso RR, Neto RO, dos Santos D'Almeida CT, et al (2020) Kombuchas from green and black teas have different phenolic profile, which impacts their antioxidant capacities, antibacterial and antiproliferative activities. Food Res Int 128:108782. https://doi.org/10.1016/j.foodres.2019.108782

Cheepchirasuk N, Kaewkod T, Suriyaprom S, et al (2025) Functional metabolites and inhibitory efficacy of kombucha beverage on pathogenic bacteria, free radicals and inflammation. Sci Rep 15:19187. https://doi.org/10.1038/s41598-025-03545-z

Chou Y-C, Lin H-W, Wang C-Y, et al (2024) Enhancing Antioxidant Benefits of Kombucha Through Optimized Glucuronic Acid by Selected Symbiotic Fermentation Culture. Antioxidants 13:1323. https://doi.org/10.3390/antiox13111323

Christodoulou MC, Orellana Palacios JC, Hesami G, et al (2022) Spectrophotometric Methods for Measurement of Antioxidant Activity in Food and Pharmaceuticals. Antioxidants 11:2213. https://doi.org/10.3390/antiox11112213

das Chagas EGL, Zamarian FC, de Souza HF, et al (2024) Extraction of polyphenols and antioxidant compounds from SCOBY, as a by-product of Kombucha, using different types of extraction. Discov Food 4:54. https://doi.org/10.1007/s44187-024-00106-7

de Miranda JF, Ruiz LF, Silva CB, et al (2022) Kombucha: A review of substrates, regulations, composition, and biological properties. J Food Sci 87:503–527. https://doi.org/10.1111/1750-3841.16029

Dechakhamphu A, Wongchum N, Chumroenphat T, et al (2023) In Vitro and In Vivo Evaluation for Antioxidant and Anti-Diabetic Properties of Cyperus rotundus L. Kombucha. Foods 12:4059. https://doi.org/10.3390/foods12224059

Falasifah R, Dewanti BSD, Zubaidah E, Sucipto S (2025) The influence of sugar concentration and fermentation time of green tea kombucha (Camellia sinensis) on its halal and safety aspects. Adv Food Sci Sustain Agric Agroindustrial Eng 8:423–432

Fibrianto K, Zubaidah E, Muliandari NA, et al (2020) Antioxidant activity optimisation of young Robusta coffee leaf kombucha by modifying fermentation time and withering pre-treatment. IOP Conf Ser Earth Environ Sci 475:12029. https://doi.org/10.1088/1755-1315/475/1/012029

Fitsum S, Gebreyohannes G, Sbhatu DB (2025) Bioactive compounds in fermented foods: Health benefits, safety, and future perspectives. Appl Food Res 5:101097.

https://doi.org/10.1016/j.afres.2025.101097
Gaggìa F, Baffoni L, Galiano M, et al (2018) Kombucha Beverage from Green, Black and Rooibos Teas: A Comparative Study Looking at Microbiology, Chemistry and Antioxidant Activity. Nutrients 11:1. https://doi.org/10.3390/nu11010001
García-Barón SE, Carmona-Escutia RP, Herrera-López EJ, et al (2025) Consumers' Drivers of Perception and Preference of Fermented Food Products and Beverages: A Systematic Review. Foods 14:713. https://doi.org/10.3390/foods14050713
Gulcin İ (2025) Antioxidants: a comprehensive review. Arch Toxicol 99:1893–1997. https://doi.org/10.1007/s00204-025-03997-2
Hananta L, Kurniawan SV, Arieselia Z, et al (2025) Antioxidant, Antimicrobial, Anti-Inflammatory, and Gut Microbiota Modulation Effects of Kombucha: a Literature Review. J Urban Heal Res 3:1–9
Ilyasov IR, Beloborodov VL, Selivanova IA (2018) Three ABTS•+ radical cation-based approaches for the evaluation of antioxidant activity: fast- and slow-reacting antioxidant behavior. Chem Pap 72:1917–1925. https://doi.org/10.1007/s11696-018-0415-9
Ilyasov IR, Beloborodov VL, Selivanova IA, Terekhov RP (2020) ABTS/PP Decolorization Assay of Antioxidant Capacity Reaction Pathways. Int J Mol Sci 21:1131. https://doi.org/10.3390/ijms21031131
Jakubczyk K, Kałduńska J, Kochman J, Janda K (2020) Chemical Profile and Antioxidant Activity of the Kombucha Beverage Derived from White, Green, Black and Red Tea. Antioxidants 9:447. https://doi.org/10.3390/antiox9050447
Jakubczyk K, Łopusiewicz Ł, Kika J, et al (2024) Fermented Tea as a Food with Functional Value-Its Microbiological Profile, Antioxidant Potential and Phytochemical Composition. Foods 13:50. https://doi.org/10.3390/foods13010050
Jayabalan R, Marimuthu S, Swaminathan K (2007) Changes in content of organic acids and tea polyphenols during kombucha tea fermentation. Food Chem 102:392–398. https://doi.org/10.1016/j.foodchem.2006.05.032
Jayabalan R, Subathradevi P, Marimuthu S, et al (2008) Changes in free-radical scavenging ability of kombucha tea during fermentation. Food Chem 109:227–234. https://doi.org/10.1016/j.foodchem.2007.12.037
Jena AB, Samal RR, Bhol NK, Duttaroy AK (2023) Cellular Red-Ox system in health and disease: The latest update. Biomed Pharmacother 162:114606. https://doi.org/10.1016/j.biopha.2023.114606
Kaewkod T, Bovonsombut S, Tragoolpua Y (2019) Efficacy of Kombucha Obtained from Green, Oolong, and Black Teas on Inhibition of Pathogenic Bacteria, Antioxidation, and Toxicity on Colorectal Cancer Cell Line. Microorganisms 7:700. https://doi.org/10.3390/microorganisms7120700
Khaleil M (2020) A Bioprocess Development Study of Polyphenol Profile, Antioxidant and Antimicrobial Activities of Kombucha Enriched with Psidium Guajava L. J Microbiol Biotechnol Food Sci 9:1204–1210. https://doi.org/10.15414/jmbfs.2020.9.6.1204-1210
Kozlov A V, Javadov S, Sommer N (2024) Cellular ROS and Antioxidants: Physiological and Pathological Role. Antioxidants 13:602. https://doi.org/10.3390/antiox13050602
Li S, Zhang Y, Gao J, et al (2022) Effect of Fermentation Time on Physiochemical Properties of Kombucha Produced from Different Teas and Fruits: Comparative Study. J Food Qual 2022:2342954. https://doi.org/10.1155/2022/2342954
Luo X, Dong M, Liu J, et al (2024) Fermentation: improvement of pharmacological effects and applications of botanical drugs. Front Pharmacol 15:1430238. https://doi.org/10.3389/fphar.2024.1430238
Mandal M, Sarkar M, Khan A, et al (2022) Reactive Oxygen Species (ROS) and Reactive Nitrogen Species (RNS) in plants– maintenance of structural

individuality and functional blend. Adv Redox Res 5:100039. https://doi.org/10.1016/j.arres.2022.100039

Martemucci G, Costagliola C, Mariano M, et al (2022) Free Radical Properties, Source and Targets, Antioxidant Consumption and Health. Oxygen 2:48–78. https://doi.org/10.3390/oxygen2020006

Martihandini N, Rochimat I (2024) Characteristics of four variants of kombucha tea as candidate of functional health drink. J Mandala Pharmacon Indones 10:227–237

Muliasari H, Sopiah B, Yuanita E, Ningsih BNS (2023) Free-radical scavenging activity and total phenolic compounds of red and green Poinsettia leaves (Euphorbia pulcherrima Willd.) from Lombok Island. Makara J Sci 27:3

Ouzzani M, Hammady H, Fedorowicz Z, Elmagarmid A (2016) Rayyan—a web and mobile app for systematic reviews. Syst Rev 5:210. https://doi.org/10.1186/s13643-016-0384-4

Page MJ, McKenzie JE, Bossuyt PM, et al (2021) The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ 372:n71. https://doi.org/10.1136/bmj.n71

Parham S, Kharazi AZ, Bakhsheshi-Rad HR, et al (2020) Antioxidant, Antimicrobial and Antiviral Properties of Herbal Materials. Antioxidants 9:1309. https://doi.org/10.3390/antiox9121309

Pizzino G, Irrera N, Cucinotta M, et al (2017) Oxidative Stress: Harms and Benefits for Human Health. Oxid Med Cell Longev 2017:8416763. https://doi.org/10.1155/2017/8416763

Rahmani R, Beaufort S, Villarreal-Soto SA, et al (2019) Kombucha fermentation of African mustard (Brassica tournefortii) leaves: Chemical composition and bioactivity. Food Biosci 30:100414

Salehi B, Martorell M, Arbiser JL, et al (2018) Antioxidants: Positive or Negative Actors? Biomolecules 8:124. https://doi.org/10.3390/biom8040124

Sales AL, Iriondo-DeHond A, DePaula J, et al (2023) Intracellular Antioxidant and Anti-Inflammatory Effects and Bioactive Profiles of Coffee Cascara and Black Tea Kombucha Beverages. Foods 12:1905. https://doi.org/10.3390/foods12091905

Sarıtaş S, Portocarrero ACM, Miranda López JM, et al (2024) The Impact of Fermentation on the Antioxidant Activity of Food Products. Molecules 29:3941. https://doi.org/10.3390/molecules29163941

Sarshar M, Azmayesh L, Khoshhal F, et al (2025) Kombucha tea in cancer care: A review of its anti-cancer potential and role in integrative oncology. Avicenna J Phytomedicine Epub ahead: https://doi.org/10.22038/ajp.2025.26369

Sharma R, Garg P, Kumar P, et al (2020) Microbial Fermentation and Its Role in Quality Improvement of Fermented Foods. Fermentation 6:106. https://doi.org/10.3390/fermentation6040106

Silva EJNL, Prado MC, Soares DN, et al (2020) The effect of ozone therapy in root canal disinfection: a systematic review. Int Endod J 53:317–332. https://doi.org/10.1111/iej.13229

Stevanny B, Umar TP, Ernanto JH, Hidayat R (2020) Peanut (Arachis hypogaea) Shells Extract and Apis dorsata Honey Reduce Matrix Metalloproteinase-3 in Monosodium Iodoacetate-Induced Osteoarthritic Rats. J Biomed Transl Res 6:74–78

Sukweenadhi J, Setiawan F, Yunita O, et al (2020) Antioxidant activity screening of seven Indonesian herbal extract. Biodiversitas 21:2062–2067

Sun T-Y, Li J-S, Chen C (2015) Effects of blending wheatgrass juice on enhancing phenolic compounds and antioxidant activities of traditional kombucha beverage. J food drug Anal 23:709–718. https://doi.org/10.1016/j.jfda.2015.01.009

Teixeira Oliveira J, Machado da Costa F, Gonçalvez da Silva T, et al (2023) Green tea and kombucha characterization: Phenolic composition, antioxidant capacity and enzymatic inhibition potential. Food Chem 408:135206. https://doi.org/10.1016/j.foodchem.2022.135206

Umar TP, Samudra MG, Nashor KMN, et al (2022) Health professional student's volunteering activities during the COVID-19 pandemic: A systematic literature review. Front Med 9:797153.

https://doi.org/10.3389/fmed.2022.797153

Umar TP, Sayad R, Mokresh ME, et al (2023) Health-related quality of life among adult patients with Ehlers-Danlos Syndrome: a systematic review and meta-analysis. Mediterr J Clin Psychol 11:1–30

Villarreal-Soto SA, Beaufort S, Bouajila J, et al (2018) Understanding Kombucha Tea Fermentation: A Review. J Food Sci 83:580–588. https://doi.org/10.1111/1750-3841.14068

Wang Y, Wei X, Wang F, et al (2018) Structural characterization and antioxidant activity of polysaccharide from ginger. Int J Biol Macromol 111:862–869. https://doi.org/10.1016/j.ijbiomac.2018.01.087

Xiong R-G, Wu S-X, Cheng J, et al (2023) Antioxidant Activities, Phenolic Compounds, and Sensory Acceptability of Kombucha-Fermented Beverages from Bamboo Leaf and Mulberry Leaf. Antioxidants 12:1573. https://doi.org/10.3390/antiox12081573

Xu H, Hong JH, Kim D, et al (2022) Evaluation of Bioactive Compounds and Antioxidative Activity of Fermented Green Tea Produced via One- and Two-Step Fermentation. Antioxidants 11:1425. https://doi.org/10.3390/antiox11081425

Zehiroglu C, Ozturk Sarikaya SB (2019) The importance of antioxidants and place in today’s scientific and technological studies. J Food Sci Technol 56:4757–4774. https://doi.org/10.1007/s13197-019-03952-x

Zhang S, Shi C, Liu C, et al (2023) Dynamic Analysis of the Bacterial Community and Determination of Antioxidant Capacity during the Fermentation of Sour Tea. Fermentation 9:161. https://doi.org/10.3390/fermentation9020161

Zhao L, Liu X, Wang S, et al (2024) Research progress on fermentation-produced plant-derived bioactive peptides. Front Pharmacol 15:1438947. https://doi.org/10.3389/fphar.2024.1438947

Zhao Y-S, Eweys AS, Zhang J-Y, et al (2021) Fermentation Affects the Antioxidant Activity of Plant-Based Food Material through the Release and Production of Bioactive Components. Antioxidants 10:2004. https://doi.org/10.3390/antiox10122004

Zhou Y, Wang R, Zhang Y, et al (2020) Biotransformation of phenolics and metabolites and the change in antioxidant activity in kiwifruit induced by Lactobacillus plantarum fermentation. J Sci Food Agric 100:3283–3290. https://doi.org/10.1002/jsfa.10272

Ziemlewska A, Nizioł-Łukaszewska Z, Bujak T, et al (2021) Effect of fermentation time on the content of bioactive compounds with cosmetic and dermatological properties in Kombucha Yerba Mate extracts. Sci Rep 11:18792. https://doi.org/10.1038/s41598-021-98191-6

Ziemlewska A, Zagórska-Dziok M, Mokrzyńska A, et al (2024) Comparison of Anti-Inflammatory and Antibacterial Properties of Raphanus sativus L. Leaf and Root Kombucha-Fermented Extracts. Int J Mol Sci 25:5622. https://doi.org/10.3390/ijms25115622

Ziemlewska A, Zagórska-Dziok M, Nizioł-Łukaszewska Z, et al (2023) In Vitro Evaluation of Antioxidant and Protective Potential of Kombucha-Fermented Black Berry Extracts against H(2)O(2)-Induced Oxidative Stress in Human Skin Cells and Yeast Model. Int J Mol Sci 24:4388. https://doi.org/10.3390/ijms24054388

Supplementary

Supplementary Table 1. PRISMA 2020 Checklist

TITLE			
Title	1	Identify the report as a systematic review.	Page 1
ABSTRACT			
Abstract	2	See the PRISMA 2020 for Abstracts checklist.	Page 1
INTRODUCTION			
Rationale	3	Describe the rationale for the review in the context of existing knowledge.	Page 3-4
Objectives	4	Provide an explicit statement of the objective(s) or question(s) the review addresses.	Page 4
METHODS			
Eligibility criteria	5	Specify the inclusion and exclusion criteria for the review and how studies were grouped for the syntheses.	Page 5
Information sources	6	Specify all databases, registers, websites, organisations, reference lists and other sources searched or consulted to identify studies. Specify the date when each source was last searched or consulted.	Page 5
Search strategy	7	Present the full search strategies for all databases, registers and websites, including any filters and limits used.	Page 5
Selection process	8	Specify the methods used to decide whether a study met the inclusion criteria of the review, including how many reviewers screened each record and each report retrieved, whether they worked independently, and if applicable, details of automation tools used in the process.	Page 5
Data collection process	9	Specify the methods used to collect data from reports, including how many reviewers collected data from each report, whether they worked independently, any processes for obtaining or confirming data from study investigators, and if applicable, details of automation tools used in the process.	Page 5
Data items	10a	List and define all outcomes for which data were sought. Specify whether all results that were compatible with each outcome domain in each study were sought (e.g. for all measures, time points, analyses), and if not, the methods used to decide which results to collect.	Page 6
	10b	List and define all other variables for which data were sought (e.g. participant and intervention characteristics, funding sources). Describe any assumptions made about any missing or unclear information.	Page 6
Study risk of bias assessment	11	Specify the methods used to assess risk of bias in the included studies, including details of the tool(s) used, how many reviewers assessed each study and whether they worked independently, and if applicable, details of automation tools used in the process.	Page 6
Effect measures	12	Specify for each outcome the effect measure(s) (e.g. risk ratio, mean difference) used in the synthesis or presentation of results.	Page 7
Synthesis methods	13a	Describe the processes used to decide which studies were eligible for each synthesis (e.g. tabulating the study intervention characteristics and comparing against the planned groups for each synthesis (item #5)).	Page 7
	13b	Describe any methods required to prepare the data for presentation or synthesis, such as handling of missing summary statistics, or data conversions.	Page 7
	13c	Describe any methods used to tabulate or visually display results of individual studies and syntheses.	Page 7
	13d	Describe any methods used to synthesize results and provide a rationale for the choice(s). If meta-analysis was performed, describe the model(s), method(s) to identify the presence and extent of statistical heterogeneity, and software package(s) used.	Page 6-7
	13e	Describe any methods used to explore possible causes of heterogeneity among study results (e.g. subgroup analysis, meta-regression).	N/A
	13f	Describe any sensitivity analyses conducted to assess robustness of the synthesized results.	N/A

Reporting bias assessment	14	Describe any methods used to assess risk of bias due to missing results in a synthesis (arising from reporting biases).	N/A
Certainty assessment	15	Describe any methods used to assess certainty (or confidence) in the body of evidence for an outcome.	N/A
RESULTS			
Study selection	16a	Describe the results of the search and selection process, from the number of records identified in the search to the number of studies included in the review, ideally using a flow diagram.	Page 8
	16b	Cite studies that might appear to meet the inclusion criteria, but which were excluded, and explain why they were excluded.	Figure 1
Study characteristics	17	Cite each included study and present its characteristics.	Page 8
Risk of bias in studies	18	Present assessments of risk of bias for each included study.	Page 9-10, Figure 5
Results of individual studies	19	For all outcomes, present, for each study: (a) summary statistics for each group (where appropriate) and (b) an effect estimate and its precision (e.g. confidence/credible interval), ideally using structured tables or plots.	Page 8, Table 1
Results of syntheses	20a	For each synthesis, briefly summarise the characteristics and risk of bias among contributing studies.	Page 9-10
	20b	Present results of all statistical syntheses conducted. If meta-analysis was done, present for each the summary estimate and its precision (e.g. confidence/credible interval) and measures of statistical heterogeneity. If comparing groups, describe the direction of the effect.	Page 8
	20c	Present results of all investigations of possible causes of heterogeneity among study results.	N/A
	20d	Present results of all sensitivity analyses conducted to assess the robustness of the synthesized results.	N/A
Reporting biases	21	Present assessments of risk of bias due to missing results (arising from reporting biases) for each synthesis assessed.	N/A
Certainty of evidence	22	Present assessments of certainty (or confidence) in the body of evidence for each outcome assessed.	N/A
DISCUSSION			
Discussion	23a	Provide a general interpretation of the results in the context of other evidence.	Page 11-12
	23b	Discuss any limitations of the evidence included in the review.	Page 12-13
	23c	Discuss any limitations of the review processes used.	Page 12-13
	23d	Discuss implications of the results for practice, policy, and future research.	Page 13
OTHER INFORMATION			
Registration and protocol	24a	Provide registration information for the review, including register name and registration number, or state that the review was not registered.	Page 5
	24b	Indicate where the review protocol can be accessed, or state that a protocol was not prepared.	N/A
	24c	Describe and explain any amendments to information provided at registration or in the protocol.	N/A
Support	25	Describe sources of financial or non-financial support for the review, and the role of the funders or sponsors in the review.	Page 13
Competing interests	26	Declare any competing interests of review authors.	Page 13
Availability of data, code and other materials	27	Report which of the following are publicly available and where they can be found: template data collection forms; data extracted from included studies; data used for all analyses; analytic code; any other materials used in the review.	Page 14