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EXPLORING THE IMPACT OF KOMBUCHA ON METABOLIC PARAMETERS: A SYSTEMATIC REVIEW AND METANALYSIS

ORIGINAL ARTICLE

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ABSTRACT

Background: Kombucha is the fastest growing product in the beverage market and one of the world's most popular low-alcohol fermented beverages, and can be characterized as a bittersweet probiotic drink, produced from the fermentation of black tea or sweetened green tea, with a symbiotic culture of acetic acid bacteria and yeast with bacteria. **Objective:** To verify the effects of Kombucha on blood glucose, dyslipidemia and body weight, through a Systematic Review (SR) and meta-analysis in rats with diabetes. Methods: The research question and developments were based on the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA). Two reviewers independently applied the eligibility criteria, according to the SYRCLE risk of bias tool and extracted data from the PubMed, SCOPUS, Web of Science, LILACS, Cochrane Central Register of Controlled Trials databases. A random effects model was used for the meta-analysis, to assess an effect size measure and heterogeneity, I2 and Cochran's Q test calculator. **Results:** A total of 2357 articles were found and, after evaluation, as a result of duplicate databases and exclusion criteria, 5 studies were included in the RS, and from these, 2 were included in the meta-analysis. These results of this SR referred to the reduction of blood glucose and lipid levels, such as LDL cholesterol, Col-T, TG, and the increase in HDL cholesterol levels, as well as the positive effect on body weight control. The results of the metanalysis showed that kombucha significantly increases HDL-c levels (Effect Size = 1.73; 95% CI 0.37; 3.08). Conclusion: Kombucha in diabetic rats leads to increased HDL-c levels. Further studies are recommended to investigate the use of it as an adjuvant treatment of DM.

Keywords: Kombucha, Systematic Review, Metanalysis, Diabetes, Functional foods.

1 INTRODUCTION

Kombucha is recognized as one of the fastest-growing fermented beverages worldwide, driven by increasing consumer interest in functional drinks that offer potential health benefits. This growth is supported by its association with improved gut health, immune system support, and energy-boosting properties. According to recent studies, the global kombucha market is expected to expand at a Compound Annual Growth Rate (CAGR) of 16-17% between 2023 and 2032. This surge in popularity is largely due to kombucha's appeal as a low-sugar, probiotic-rich alternative to traditional sugary beverages and recent research discusses the health benefits and composition of kombucha, highlighting its potential antioxidant, anti-inflammatory, and antimicrobial Properties (MDPI).

Kombucha is made by fermenting a sweetened infusion of either black or green tea, combined with sugar and a Symbiotic Colony of Bacteria and Yeast (SCOBY). The fermentation process typically lasts between seven to ten days, during which the yeast and bacteria convert the sugar into various compounds, including organic acids and vitamins (Martínez Leal *et al.,* 2018). A pilot study found that kombucha may lower blood sugar levels in people with type 2 diabetes. Participants who drank kombucha for four weeks showed a significant reduction in fasting blood glucose compared to a placebo group. While the results are promising, larger studies are needed to fully understand kombucha's potential as a treatment for diabetes (School of Health).

According to more recent studies, Diabetes Mellitus (DM) continues to be a major global health issue, affecting over 537 million adults worldwide, with projections reaching 783 million by 2045 (IDF Diabetes Atlas, 2022). In Brazil, around 16.8 million people live with diabetes, many of whom remain undiagnosed (IDF, 2022). Type 2 diabetes (DM2) remains the most prevalent form, responsible for approximately 90% of cases and contributing to millions of deaths annually due to direct complications of the disease (WHO, 2023).

Diabetes is a significant contributor to both morbidity and mortality worldwide. It remains one of the four main noncommunicable chronic diseases recognized by the World Health Organization (WHO) and is the third leading risk factor for premature mortality due to hyperglycemia (WHO, 2022; IDF, 2023). While kombucha has gained popularity for its potential health benefits, two systematic reviews have previously explored its effects. The most recent was conducted by Kapp and Sumner (2019), following Ernst's earlier review in 2003, highlighting the growing interest in kombucha's health implications.

Ernst (2003) and Kapp & Sumner (2019) investigated kombucha's health effects, analyzing both human and animal studies. Although some studies reported potential benefits, results were inconsistent, and many studies had design limitations, particularly due to the lack of comprehensive clinical trials on humans. Most research involved animal models, primarily rats, which limits the applicability of findings to human health. These reviews highlight the need for well-designed clinical studies to accurately assess kombucha's health effects and confirm its potential therapeutic benefits (MDPI) (SpringerLink).

This study is essential because most previous research on kombucha has relied heavily on animal models, particularly rats, leaving gaps in understanding its effects on humans. Despite some studies suggesting potential benefits for blood glucose, lipid profiles, and body weight, the findings have been inconsistent. By conducting a systematic review and meta-analysis of these animal studies, this research aims to provide clearer insights into the effects of kombucha on diabetes, offering a more solid foundation for future studies and potentially guiding future human trials.

2. OBJECTIVE

The aim of this study is to investigate the effects of kombucha on metabolic parameters such as glucose regulation, lipid metabolism, and body weight in diabetic rats. By analyzing these parameters, the study seeks to clarify existing discrepancies in the literature and provide a more comprehensive understanding of kombucha's potential therapeutic effects. This research intends to form a basis for future clinical

trials, contributing to the evaluation of kombucha as a possible intervention for diabetes and related metabolic disorders in humans.

3. METHODS

3.1 STUDY MODEL

Systematic review of studies of interventions - Cochrane Handbook for Systematic Reviews of Interventions version 5.1. The study was registered on the OpenScience Framework platform (https://osf.io/wn762) with the following registration number: DOI: 10.17605/OSF.IO/3U7GF.

3.2 PURPOSE OF THE STUDY

The initial search strategy included primary databases that concentrated on original scientific articles, theses, dissertations, abstracts, among other research activities, including five databases (PubMed, SCOPUS, Web of Science, LILACS, Cochrane Central Register of Controlled Trials) directly related to health, which led to a better control and reduced the risk of selection bias (Song *et al*., 2000).

3.3 DATABASES AND SEARCH STRATEGY

The MeSH descriptors were searched for "kombucha", "tea fungus", "kombucha tea", and the terms "kombucha tea" and "camelia sinensis" were found. In Medline, we found the terms: "tea fungus", "kombucha", "kampuchea tea", "fungus metabolites", "fermented tea" and "health benefits". The last term was removed from the strategy, since a small number of articles was found when this term was included. Therefore, the strategy used for this study was based on: "kombucha tea" OR ("camelia sinensis" AND "fermented tea") OR ("fungus metabolites" AND kombucha) OR (kombucha AND "tea fungus") OR "kampuchea tea" OR kombucha.

The systematic search was performed from May 11, 2017 to August 31, 2024 and followed the search strategy outlined above, together with the PubMed (Medline), Web of Science (Science and Social Science Citation Index) databases, the Latin American and Caribbean Center on Health Sciences Information (LILACS), Scopus and the

Cochrane Central Register of Controlled Trials (CENTRAL). In addition, the search for unpublished or unindexed studies in the literature, (the gray area of literature), was carried out with the aid of Google Scholar (http://scholar.google.com/), the Gray Literature Report from the New York Academy of Medicine (http://www.greylit.org/), and the World Health Organization - WHO (http://www.who.int/). In addition, checks were made in the clinical trial registry, including the Trials Central (http://www.trialscentral.org/) and ClinicalTrials.gov (https://clinicaltrials.gov/). A full search strategy is provided in Appendix 1.

Appendix 1: Search strategy according to the correspondent database

Database	Search Strategy
The Cochrane Central Register of Controlled Trials (CENTRAL)	#1: MeSH descriptor: [Kombucha] explode all trees. #2: MeSH descriptor: [tea fungus] explode all trees. #3: MeSH descriptor: [Kombucha tea] explode all trees. #4: #1 AND #2 AND #3
PubMed (Medline)	#1: "Kombucha tea" OR ("camelia sinensis" AND "fermented tea") OR ("fungus metabolites" AND Kombucha) OR (Kombucha AND "tea fungus") OR "kampuchea tea" OR Kombucha
EMBASE	#1: "Kombucha tea" OR ("camelia sinensis" AND "fermented tea") OR ("fungus metabolites" AND Kombucha) OR (Kombucha AND "tea fungus") OR "kampuchea tea" OR Kombucha
The Latin American and Caribbean Centre on Health Sciences Information	#1: "Kombucha tea" OR ("camelia sinensis" AND "fermented tea") OR ("fungus metabolites" AND Kombucha) OR (Kombucha AND "tea fungus") OR (kampuchea tea) OR (Kombucha) OR (Chá de Kombucha) OR (Té de Kombucha) OR (Thé kombucha)

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(LILACS/Bireme)	
SciElo e Scopus (Elsevier)	#1: "Kombucha tea" OR ("camelia sinensis" AND "fermented tea") OR ("fungus metabolites" AND Kombucha) OR (Kombucha AND "tea fungus") OR "kampuchea tea" OR Kombucha
Web of Science (Clarivate Analytics)	#1: "Kombucha tea" OR ("camelia sinensis" AND "fermented tea") OR ("fungus metabolites" AND Kombucha) OR (Kombucha AND "tea fungus") OR "kampuchea tea" OR Kombucha

Source: The author (2026).

In conducting the analysis of the articles that formed a part of this SR, we used the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) (Moher *et al*., 2009) while the research question that was defined followed the PICO (Participants, Intervention, Comparison, and Outcomes) strategy, systematizing the search for randomized controlled studies that used Kombucha in rats with diabetes, fed a standard diet and water, given the largest number of studies available to standardize the search methodology.

3.4 DATA SELECTION AND ANALYSIS

The titles and abstracts of all the articles identified by the search strategy were independently assessed by two researchers. All the abstracts that did not provide sufficient information on the inclusion and exclusion criteria, were selected for a full-text evaluation report.

In the second phase, the same reviewers independently assessed the full-texts of the articles and made the selection in accordance with the eligibility criteria. The stages of the search and selection of articles were as follows. The results of each search were recorded and documented to ensure their reproducibility. The following information was collected for each electronic search that was carried out: database identification, email server address, month and year of the search and the search strategy employed.

After the initial screening of the references found in the databases, the abstracts were read and analyzed for selection on the basis of the eligibility criteria. If the abstracts were unclear with regard to their content, we read the studies in full, while taking account of the need to observe the applied methods and understand the findings. For a more careful screening, we decided to select publications that were the most complete and the ones that best met the desired criteria for inclusion in case of duplicity or double standards, as well as those that had been subjected to repeated analysis and published in other formats with similar findings and were based on the same research.

3.5 ELIGIBILITY CRITERIA AND SELECTION OF ARTICLES

Therapeutic studies on kombucha in rats were included. However, the following were excluded: studies involving other animals such as pigs, birds and mice; studies linking kombucha with alternative treatments; observational studies; case studies; in vitro studies and clinical trials involving humans.

3.6 PROCESS OF EXTRACTING DATA FROM THE JOBS THAT WERE INCLUDED

Data were only extracted from sources which had methodological validation, that is, those conducted and analyzed by one evaluator and later by another. In addition to the findings, there was information about the features of the research and its methods; the population or study sample; the size of this sample; its composition; the frequency of use of kombucha; the therapeutic benefits of this drink; the period of use; the place of origin of the study (i.e., city, state, country); location where the research was conducted; name of the main author and date of publication.

3.7 A RISK ASSESSMENT OF BIAS

The risk of bias was assessed by the SYRCLE tool, created from the Cochrane Risk-of-Bias Tool (RoB), and adjusted to bias factors that play a key role in animal intervention studies. The items that make up the SYRCLE tool include the evaluation

of selection bias, performance bias, detection bias, friction bias, report bias and other biases (Hooijmans *et al.,* 2014).

3.8 STATISTICAL ANALYSIS

A random effects model was used for the meta-analysis, which can be regarded as the effect measure for the standardized mean difference. I^2 and Cochran's Q test were calculated to assess the degree of heterogeneity between the studies, with a significance of $P < 0.05$. The results were visualized by means of the forest plot graph for triglyceride and High-Density Lipoprotein (HDL) outcomes. The whole data analysis was performed using the statistical software - R Core Team (R Core Team 2018) (Vienna, Austria) with the aid of the metafor package (Viechtbauer 2010; Martínez Leal *et al.,* 2018).

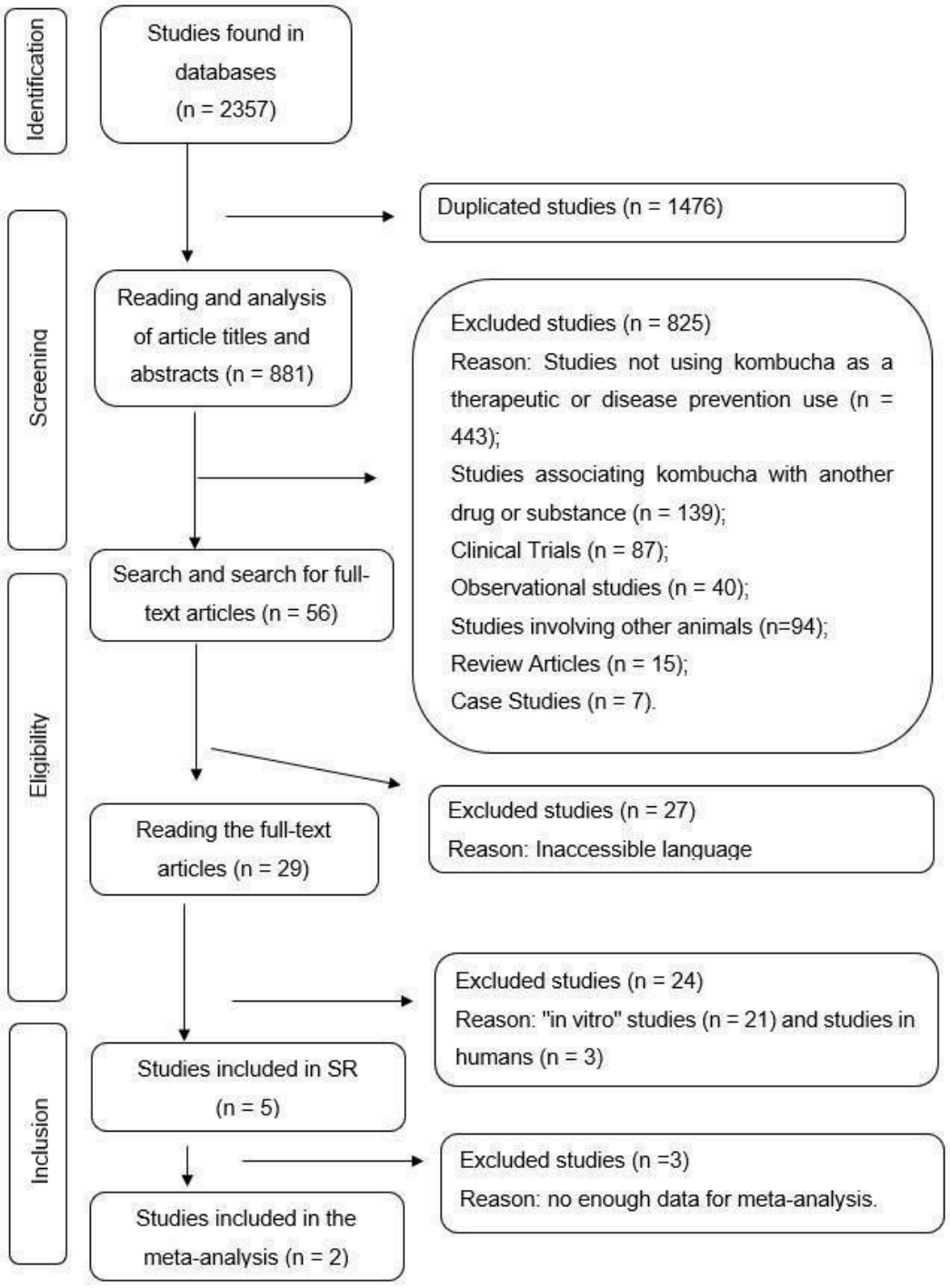
4. RESULTS

4.1 SELECTED STUDIES

In the course of search, a total of 2357 articles were found. Of these, 1476 were rejected because they had duplicate databases, leaving 881 for analysis. A further 852 articles were rejected after being subjected to exclusion criteria, which left 29 articles that were selected for full reading. A further 21 in vitro studies and 3 human studies were rejected, on the basis of the inclusion and exclusion criteria. As a result, this left five studies included for RS, and of these, two studies were included for meta-analysis.

(Figure 1).

Figure 1. Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) Flow Diagram of study selection



Source: The author (2026).

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There were five studies which stated that consumption of kombucha prepared with green tea significantly reduced blood glucose and lipid parameters, low-density lipoprotein cholesterol (LDL-c), total cholesterol and triglycerides, with increased highdensity lipoprotein cholesterol (HDL-c). In addition, some studies found signs of weight reduction in the green tea and kombucha group and a potential antihyperglycemic effect relative to the control group. The risk of bias assessment was carried out in accordance with the Cochrane Bias Risk Tool (RoB) (Sterne *et al*. 2019; Saklayen 2018) for the six animal studies described in SYRCLE (Table 1).

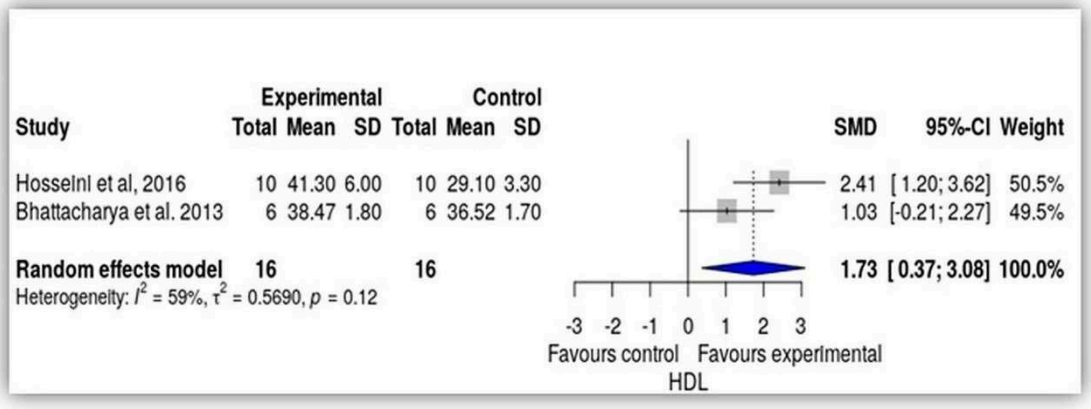
4.2 META-ANALYSIS

Studies by Hosseini *et al*. (2016) (American Diabetes Association 2014) and Bhattacharya *et al*.(2013) (Turner *et al*. 1996) that describe the effects of kombucha on HDL-c and blood glucose levels, were included in the metaanalysis. In their summary of the meta-analysis, they calculated a measure that significantly favors the increase of HDL-c.

With regard to the effect of kombucha on HDL-c, the forest plot graph (Figure 2) shows a greater increase in HDL-c levels compared with the control group (Effect Size = 1.73 (95% CI 0.37; In addition, the value of P = 0.12 showed that the studies are uniform. Forest Plot graph where inconsistency test (I^2): 62.32%, Q(degree of freedom= 1) = 4.7146, p-val = 0.1033. It should also be noted that the study by Hosseini *et al*. (2016) (American Diabetes Association 2014) makes the greatest contribution to the summary measure, as it has the largest sample size compared with the study by Bhattacharya *et al.* (2013) (Turner *et al*., 1996).

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Figure. 2. Heterogeneous measurements for a profile of high-density lipoprotein cholesterol (HDL-c)

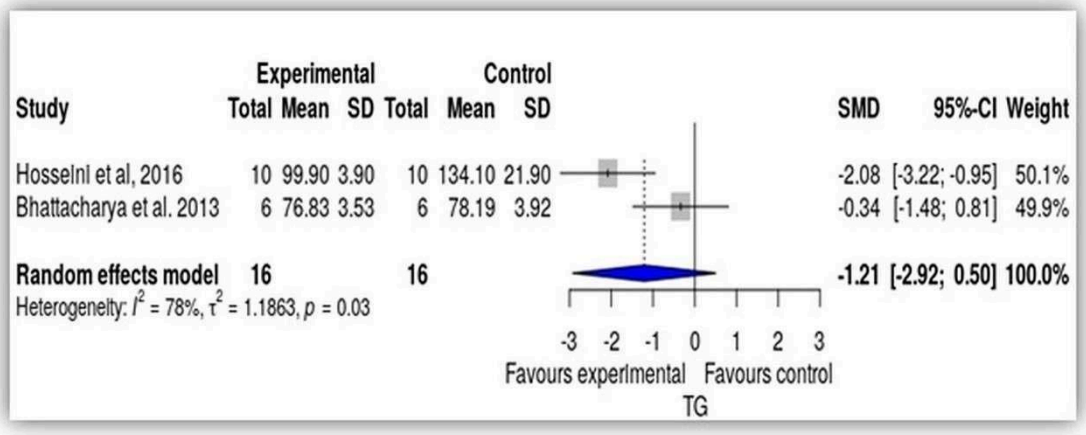


Source: The author (2026).

As for the effect of kombucha on Triglyceride (TG) levels, the forest plot graph (Figure 3) does not show any significant difference when compared with the control group, since the diamond shape crosses the vertical line (Effect Size = -1.21 ((95% CI 2.92; 0.50). including a Forest Plot graph where inconsistency test (I^2): 78.79%, Q(degree of freedom= 1) = 4.7146, p-val = 0.0299. However, the value of P = 0.03 demonstrates that the studies are heterogeneous. It is clear that, as in the previous graph, the study by Hosseini *et al*. (2016) makes a greater contribution to the summary measure.

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Figure. 3. Heterogeneous measurements for a profile of triglycerides



Source: The author (2026).

All studies are summarized in Table 2.

5. DISCUSSION

The findings from this systematic review and meta-analysis indicate that kombucha consumption increases HDL-c levels in diabetic rats. Five experimental studies (Bhattacharya *et al*., 2013; Dashti & Morshedi, 2000; Hosseini *et al*., 2015, 2016; Srihari *et al*., 2013) were analyzed, using the SYRCLE method to assess bias in animal research. Although most studies showed a high risk of bias, certain aspects, such as baseline group characteristics (e.g., gender, weight, and age), had a lower risk. Srihari *et al*., (2013) demonstrated low bias in group allocation and medication assignment.

In contrast, Bhattacharya *et al*., (2013) showed lower risk in group allocation, while Dashti & Morshedi (2000) reported similar consistency in outcomes across all measures, even when differences were not statistically significant. Variations in methodology were evident between studies, particularly in the type of kombucha used, with some studies employing green or black tea as the fermentation base. Additionally, diabetes in rats was induced using streptozotocin or alloxan, which act by destroying pancreatic β-cells through reactive oxygen species.

Hosseini *et al.* (2016) described the diabetogenic mechanism of alloxan, where the reduction product dialuric acid generates superoxide radicals, leading to β-cell destruction. Rats treated with kombucha after alloxan-induced diabetes exhibited significant reductions in blood glucose levels, consistent with the study's conclusions.There were also positive results in a hypoglycemic effect and evidence of how kombucha could control diabetes, as shown by Srihari *et al.,* (2013) in their evaluation of male streptozotocin-induced diabetic rats, with a reduction in glycosylated hemoglobin levels, increased plasma insulin, hemoglobin and glycogen, i.e., properties that are attributed to the flavonoids present in the drink. A similar effect was found by Dashti *et al*. (2000) when they followed up 15 diabetic rats induced by intraperitoneal injection of Streptozotocin and noted that kombucha may lower blood glucose levels (Alkhatib & Atcheson 2017).

The potential of kombucha as an antihyperglycemic agent, particularly in diabetes prevention and treatment, has been highlighted, notably by Srihari *et al*. (2013). While both black and green teas demonstrated benefits for glycemic control, the effects were amplified with kombucha due to its higher antioxidant content, attributed to fermentation (Bhattacharya *et al*. 2013). This effect is likely due to phenolic compounds such as caffeine derivatives, procyanidins, and chlorogenic acid, which enhance insulin sensitivity and anti-inflammatory responses (Alkhatib *et al.,* 2017). Polyphenols like catechin and Epigallocatechin Gallate (EGCG) also inhibit the enzyme 11β-HSD1, linked to metabolic disorders like type 2 diabetes (Alkhatib *et al.,* 2017).

The enzyme 11β-HSD1 plays a pivotal role in corticosteroid metabolism in peripheral tissues, and its overactivity is linked to conditions such as central obesity and metabolic syndrome. Inhibiting 11β-HSD1 has been shown to improve metabolic dysfunctions, supporting the hypothesis that selective inhibitors could treat metabolic syndrome and diabetes (Alkhatib *et al.,* 2017). Thus, kombucha's bioactive compounds present a promising therapeutic avenue for future research in treating diabetes and related disorders.

Certain bioactive compounds in kombucha, such as thiazolidinediones and fibrates, have been shown to inhibit 11β-HSD1, an enzyme linked to metabolic syndrome and

obesity (Alkhatib *et al.*, 2017). Preliminary studies suggest kombucha's positive effects on glucose and lipid metabolism, weight reduction, and adipokine levels. However, further research is needed to determine the appropriate therapeutic dose and maximum tolerated amount without disrupting cortisol's broader physiological effects. These findings should be validated through placebo-controlled trials to confirm kombucha's role in treating diabetes and related metabolic disorders (Anagnostis *et al*., 2013).

Insulin deficiency in diabetes can lead to significant weight loss due to muscle and fat degradation, resulting in cachexia and increased inflammation (Bhattacharya *et al*., 2013). Studies like Srihari *et al*. (2013) confirm that insulin is crucial for glucose transport into tissues, and its absence accelerates fat metabolism, leading to fatty acid release, which can cause severe hepatic fat accumulation, acidosis, and even death (Buczkowska & Jarosz-Chobot, 2001; Dimitriadis *et al*., 2011).

The study by Morshedi *et al.* (2006) indicated that kombucha could help prevent unwanted weight loss in diabetic rats. Similar findings were supported by Hosseini *et al*. (2015), who noted that kombucha, especially when made with green tea, provided greater protection against weight loss compared to controls, potentially due to the flavonoids in tea enhancing insulin sensitivity and glycemic control. Studies on human populations, such as by Tsang *et al*. (2012), showed kombucha's potential benefits in weight management, linking phenolic compounds to metabolic regulation of cortisol and improved insulin and lipid profiles. These polyphenols, particularly flavonoids, inhibit 11β-HSD1, a key enzyme involved in metabolic disorders like type 2 diabetes (Alkhatib *et al*., 2017). Furthermore, studies on broilers and diabetic rats found that kombucha can stabilize body weight by regulating fat metabolism (Afsharmanesh & Sadaghi 2014; Yang *et al*., 2011).

Hosseini *et al*. (2016) observed that kombucha, particularly with green tea, significantly reduced glycemic levels, LDL-c, cholesterol, and triglycerides, while increasing HDL-c. A meta-analysis of studies by Hosseini and Bhattacharya (2013) supported kombucha's beneficial effects on the lipid profile and triglycerides, pointing to the need for further human studies. However, the limited number of studies and high risk of bias were significant limitations in this review. Variations in brewing methods, fermentation times,

and temperature conditions influence kombucha's composition, as demonstrated by studies on glucuronic acid production under different storage conditions (Ansari *et al*., 2019; Amarasinghe *et al*., 2018).

6. CONCLUSION

The results of this systematic review and meta-analysis indicate that kombucha prepared with green tea significantly reduces blood glucose levels and improves lipid parameters, including lowering LDL-c, total cholesterol, and triglycerides, while increasing HDL-c. Further clinical research in humans is necessary to better understand the mechanisms of action of its metabolites and to establish its safety and efficacy as a functional beverage for human consumption, supported by concrete evidence of its effects.

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