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REVIEW

Therapeutic benefits of white tea: A review of its multifaceted role in health management

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ABSTRACT

Introduction: White tea, derived from the *Camellia sinensis* plant, undergoes minimal fermentation, which helps preserve its antioxidant compounds and delicate flavour. This review aimed to comprehensively examine the therapeutic benefits of white tea by analysing its bioactive components, particularly catechins and flavonoids, and their roles in disease prevention and health promotion. **Methods**: The review followed the PRISMA framework. A comprehensive electronic search was performed across several databases, including PubMed, Science Direct, and Google Scholar, to identify articles published between the years 2000 and 2024. **Results:** A total of 1,008 article titles were initially identified; after applying the inclusion criteria, only 26 articles were selected for further analysis. Extensive research highlights the role of white tea in weight management, oxidative stress reduction, and its anti-ageing, anti-melanogenic, and anti-diabetic effects. Its bioactive components are linked to improved metabolic conditions and reduced risks of chronic diseases, including cancer and cardiovascular diseases. Additionally, white tea shows neuroprotective potential against Alzheimer's disease and offers hepatic protection. Optimal brewing methods enhance both its health benefits and flavour. **Conclusion**: White tea's rich bioactive profile and diverse health benefits position it as a valuable functional food with potential applications in disease prevention and health promotion. Understanding white tea's bioactive constituents and its role as a functional food provides valuable insight into its contribution to health and well-being.

Keywords: antioxidant properties; bioactive compounds; health benefits; therapeutic applications; white tea

INTRODUCTION

Tea is widely consumed worldwide (Hajiaghaalipour*et al.*, 2015; Samanta, 2022). The tea plant can thrive in regions with a warm climate, abundant rainfall, high humidity, and sufficiently diffused light. Under these conditions, tea plants have developed specific adaptations to warm, moist weather, diffused light, and acidic soils. Tea plants can grow optimally in regions with 18–23°C temperatures, annual precipitation of 1500–2000 mm, and a soil pH of 4.5–5.5 (Han *et al.*, 2018).

Tea is categorised based on the extent of fermentation, a process driven by the enzymatic oxidation of polyphenols facilitated by polyphenol

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oxidases and other oxidative enzymes (Kouhihabibidehkordi *et al.*, 2021). White tea is unfermented, preserving high catechin content and delicate flavour. Green tea is also unfermented, with oxidation halted by steaming or pan-frying, yielding a fresh taste (Hinojosa *et al.*, 2021). Oolong tea is semi-fermented (15–85%), combining the characteristics of green and black teas. Black tea undergoes complete fermentation, producing a robust flavour and dark colour (Ma *et al.*, 2022). Pu-erh tea is post-fermented through microbial ageing, enhancing its complexity over time. Therefore, fermentation levels and processing define each tea's unique bioactive profile and sensory properties (Wong, Sirisena & Ng, 2022) .

White tea is a rare variety sourced from the same *Camellia sinensis* plant as green, oolong, and black teas. The youngest leaves and buds, known as pekoe, produce high-quality white tea. It includes different grades, such as pekoe with one, two, or three young tea leaves rich in antioxidants. These young leaves used for white tea are typically small and not fully opened (Hadiansyah *et al.*, 2023). The buds used in white tea are silver or pale green with fine hairs, elongated and slender in shape, and have a soft texture. Minimal processing and low oxidation help retain many antioxidant compounds, providing a delicate flavour and aroma (Purwaningtyas & Shobib, 2022).

Numerous studies have investigated the biological effects of white tea, its active compounds, and their mechanisms of action (Dias *et al.*, 2013). Both *in vitro* and *in vivo* research demonstrate that white tea possesses significant biological activities, including anti-cancer, anti-microbial, skin-protective, and cardiovascular benefits (Tang *et al.*, 2019). White tea is particularly rich in bioactive compounds, such as catechins, flavonoids, and theaflavins, which are known to exert various biological effects (Cao *et al.*, 2019; Tang *et al.*, 2019). These bioactive compounds, particularly catechins and flavonoids in general, contribute to its ability to scavenge free radicals, inhibit lipid peroxidation, modulate inflammatory pathways, and improve vascular health (Luo *et al.*, 2023). Despite its rich composition of bioactive compounds and demonstrated biological activities, white tea remains under-represented in consumer markets. Moreover, while the general health benefits of tea have been widely reviewed, the specific mechanistic pathways underlying the therapeutic effects of white tea have not been sufficiently explored in the scientific literature. Based on this existing background, this review considered the potential therapeutic mechanism of white tea, mainly focusing on its high concentration of bioactive compounds like catechins and flavonoids, since it is a relevant but underexposed factor.

METHODOLOGY

This study followed the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) methodology. A systematic electronic search was performed across PubMed, ScienceDirect, and Google Scholar to identify relevant research articles published between the years 2000 and 2024. The search strategy employed a combination of Boolean operators to enhance search comprehensiveness. The keywords used included "white tea health benefits", "white tea bioactive compounds", "catechins in white tea", "flavonoids in white tea", "white tea brewing methods", and "white tea antioxidant properties". Examples of search strings applied were ("white tea" AND "health benefits") OR ("bioactive compounds" AND "white tea") and ("brewing methods" AND "antioxidant properties" AND "white tea"). In addition to database searches, manual screening was performed by reviewing the reference lists of relevant articles and previous literature reviews to identify additional eligible studies.

Articles were selected based on pre-determined inclusion and exclusion criteria. The inclusion criteria consisted of articles specifically focused on white tea, tea, its bioactive compounds, therapeutic benefits, or brewing methods; peer-reviewed studies published between the years 2000 and 2024; papers written in English; and articles with a clear and detailed methodology and relevant experimental or review data. Conversely, the exclusion criteria included studies that did not specifically analyse white tea (e.g., general tea studies without distinct white tea data) and articles with insufficient methodological rigour (i.e., non-peer-reviewed sources or commentary papers, studies with incomplete data or lacking relevance to the review objectives, and duplicate or redundant articles across databases). Data extraction was conducted systematically, recording key information such as author, year of publication, country, study design, sample size, intervention details, key findings, and outcomes. To ensure accuracy and eliminate redundant articles, the Rayyan reference manager was used to filter duplicate studies.

RESULTS

The PRISMA flowchart (Figure 1) illustrates the systematic selection process. During the identification stage, a total of 1,008 records were retrieved from the selected databases (PubMed: 731, Google Scholar: 104, ScienceDirect: 173). After removing 35 duplicate articles, 973 records remained. In the screening phase, 530 records were selected based on their relevance to the original research focus. Among these, 443 records were excluded after evaluating their titles, abstracts, and keywords. The eligibility assessment involved reviewing 64 full-text articles, of which 38 did not meet the inclusion criteria. Ultimately, 26 articles were selected for qualitative synthesis. These studies offered comprehensive insights into white tea's bioactive compounds, such as catechins and flavonoids, its antioxidant properties, and optimal brewing methods to maximise its health benefits. The selection process is detailed in Figure 1.

DISCUSSION

This review identified studies addressing the therapeutic benefits of white tea, its bioactive compounds, and optimal brewing methods. These studies highlighted the health-promoting properties of white tea, including its antioxidant, anti-inflammatory, and anti-cancer effects, attributed primarily to its catechins, flavonoids, and other bioactive components (Table 2). While significant evidence is available on the general health benefits of white tea, there remains limited research focused on its specific therapeutic applications across diverse populations (Table 3). This review underscores the need for further exploration on optimal brewing methods of white tea, bioavailability of its compounds and their potential health outcomes, particularly in clinical aspects.

Overview of white tea

History of white tea

The origins of white tea can be traced back to China around 600 A.D., remaining a closely guarded secret for centuries. Modern white tea, as recognised today, was developed during the Qing Dynasty and produced and distributed on a large scale (Figure 2a). After 1885, specific

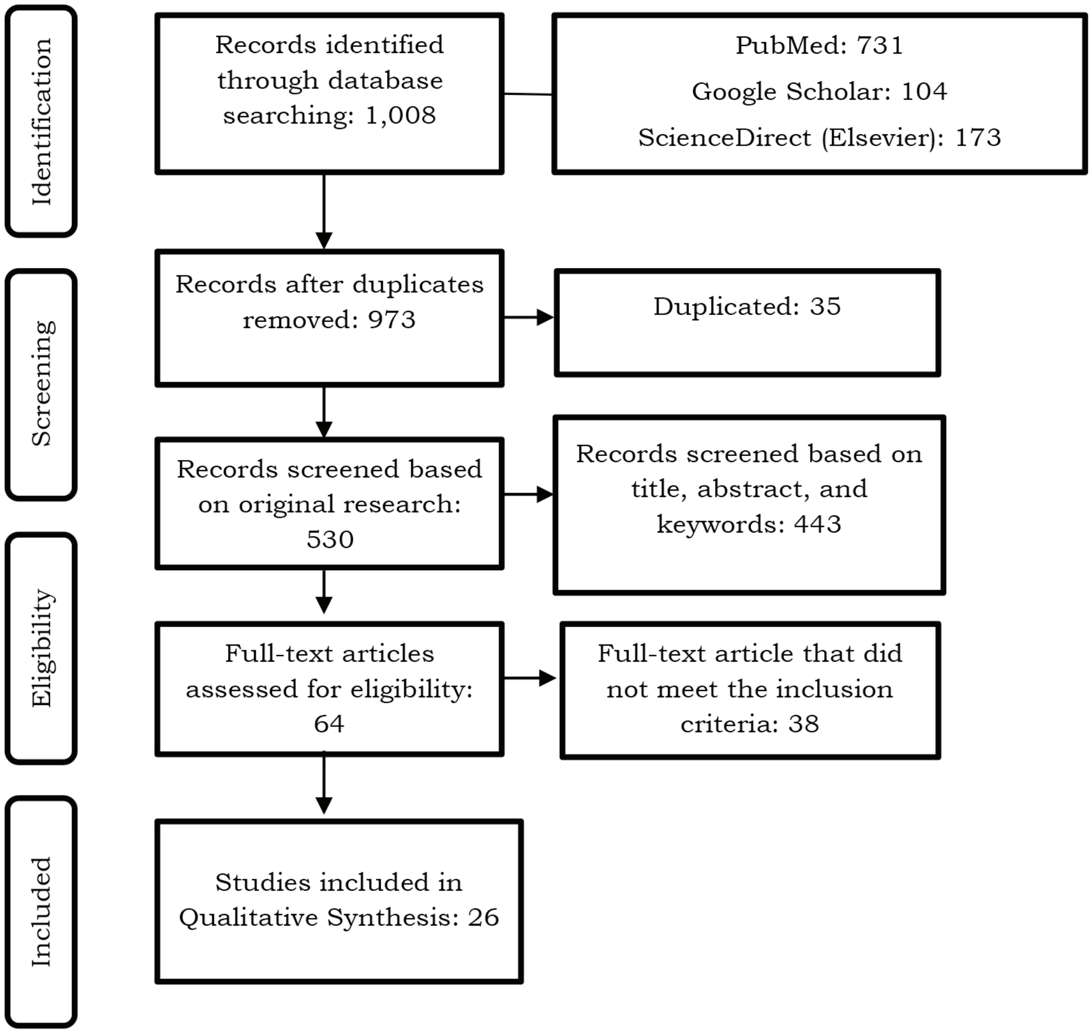


Figure 1. Flow chart of PRISMA method

tea clones, such as "*Big White*", "*Small White*", and "*Narcissus*", characterised by their large fleshy buds, were selected as the primary raw material for various white tea varieties, including "*Silver Needles*" (Sanlier, Atik & Atik, 2018). The name "white tea" is derived from the silky white feathers that cover the unopened leaves and buds. It offers a delicate and sweet taste distinct from the unparalleled flavour of green tea (Damiani *et al.*, 2014).

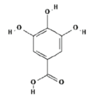
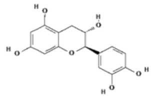
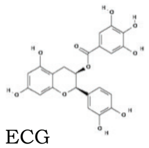
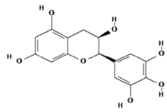
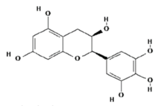
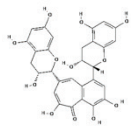
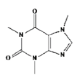
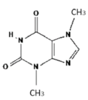
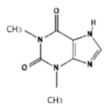
White tea production

White tea, harvested annually in early spring, undergoes minimal processing compared to other tea varieties, lacking fermentation stages like oolong or black tea or enzyme deactivation like green tea (Tan *et al.*, 2017). The white tea sample, harvested during summer and withered for 23 hours, exhibits the highest antioxidant activity (Paiva *et al.*, 2021). White tea is made from young buds and occasionally young leaves from

Table 1. Brewing methods and characteristics of white tea from different countries

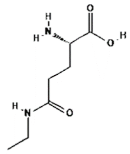
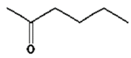
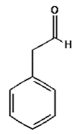
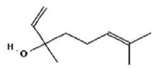
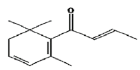
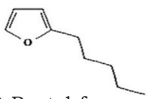
No.	*Family/type of white tea*	*Product Country*	*Appearance*	*Method of brewing*	*Infusion accessory*	*Quantity*	*Temperature*	*Length of infusion*	*Suggestion*	*References*
1	Bai Hao Yin Zhen, Yu Xue Ya	China	Non-rolled, delicate, needle-shaped buds covered in white down.	*Gaiwan*	Small teapot or a *gaiwan*	1/10 (3 g) tea to 1 cup (250 ml) water (2 teaspoons per cup/10 ml per 250 ml)	149 to 167 °F (65 to 75 °C)	5-7 minutes	White teas should be steeped in a small amount of water (such as in a *gaiwan*) to enhance their delicate flavours fully.	Gascoyne *et al.*, 2011
2	Bai Mu Dan, Hong Xue Ya		Unrolled, delicate buds shaped like needles coated with a layer of white fuzz.				167 to 176 °F (75 to 80°C)		These teas hold up well with more water, allowing to brew larger quantities without losing their delicate flavours.	Gascoyne *et al.*, 2011
3	Avongrove Darjeeling. Malawi Satemwa	India (Darjeeling region), Malawi (Satemwa Estate)	Silver and slightly blackish leaves.	*Gaiwan*	Teapot, *gaiwan*, or tea infuser		176 to 194 F (80 to 90 °C)		These can take a larger volume of water.	Gascoyne *et al.*, 2011
4	Gamboeng	Indonesia	Light, silvery-white tea buds, often covered in fine white hairs.	Traditional teapot	Teapot or infuser	2 g/200 ml	75–85 °C (167–185 °F)	5-10 minutes	Brew in small pots to preserve delicate flavours.	Hadiansyah *et al.*, 2023
5	Bai Hao Oolong (Oriental beauty)	Taiwan	The leaves are twisted, featuring dark brown to green colors with golden tips, and the tea has a fragrant aroma.	The gong fu cha	A teapot, tea infuser, or tea filter	2 grams of tea per cup (200 ml)	195°F 80 °C to 100 °C	3-5 minutes	Multiple infusions with short times; increase steeping time gradually.	Gascoyne *et al.*, 2011
6	White tea	Japan	Delicate buds, silver hue, light green liquor.	The *senchado*, *gaiwan*, or *kyusu*	The *kyusu* or small teapot	2-3 grams	70–80 °C (158–176 °F)	1–3 minutes	Infuse gently to appreciate its delicate and fresh flavour profile.	Gascoyne *et al.*, 2011

Table 2. The bioactive compounds and health benefits of white tea

Category	*Compounds*	*Chemical structure*	*Effects and mechanism*	*References*
Flavonoid	Four major epicatechins and gallic acid esters: (-) epicatechin (EC), (-) epicatechin gallate (ECG), epigallocatechin (EGC), and (-) epigallocatechin gallate (EGCG)	 Gallic acid  EGCG  ECG  EGC  EGCG	• Modulates metabolic syndrome by improving lipid metabolism. Strong antiradical activity, especially against methoxy radicals. Reduces triglyceride accumulation in adipogenesis. EGCG reduces MITF production and suggests that reduced tyrosinase activity by hinokitiol explains their synergistic effect on melanogenesis. • Against methoxy radical are those with the gallate group, EGCG, EC, EGC, and ECG. • Accountable for causing astringency. • Exhibiting antioxidant properties through hydroxyl groups, which perform antioxidant functions. • Enhances lipid metabolism via AMP-activated protein kinase. Demonstrating antidiabetic and insulinotropic effects.	Kim *et al.*, 2004; Söhle *et al.*, 2009; Azman *et al.*, 2014; Alves *et al.*, 2015; Pastoriza *et al.*, 2017; Luo *et al.*, 2020; Samanta, 2022
	Theaflavin	 Theaflavin	• Contributes to tea colour and astringency. Inhibits tyrosinase activity, reducing melanogenesis.	Heck & Gonzalez de Mejia, 2009; Yamaoka *et al.*, 2009
Methylxanthines	Caffeine	 Caffeine	• Enhances cardiac activity and smooth muscle relaxation via phosphodiesterase inhibition.	Paiva *et al.*, 2021
	Theobromine and theophylline (Bitter taste)	 Theobromine  Theophylline	• Theobromine is a bitter-tasting compound that contributes to the distinctive flavour profile of the tea. • Theophylline is used to treat chronic respiratory diseases by relaxing the muscles in the airways, thereby widening the air passages and making breathing easier.	Jeon *et al.*, 2017

to be continued...

Table 2. The bioactive compounds and health benefits of white tea (continued)

Category	*Compounds*	*Chemical structure*	*Effects and mechanism*	*References*
Amino acid	Theanine	 Theanine	• Enhances tea aroma (crispy-rice, chestnut notes). Linked to neurochemical effects on brain relaxation.	Bryan, 2008; Guo *et al.*, 2019; Li *et al.*, 2022
Volatile compounds	2-Hexanone, benzeneacetaldehyde, trans-linalool oxide, linalool, trans-β-damascenone, 2-Pentyl-furan, trans-α-ionone and trans-β-ionone	 2-Hexanone  Benzeneacetaldehyde  Linalool  trans-β-damascenone  2-Pentyl-furan	• 2-Hexanone, benzeneacetaldehyde, trans-linalool oxide, and linalool imparted a floral aroma. It can help reduce stress and promote relaxation. • trans-β-damascenone contributed sweetness. • 2-Pentyl-furan provided a roasted scent. • trans-α-ionone and trans-β-ionone contributed a woody aroma.	Lin *et al.*, 2021; Wu *et al.*, 2024

Chemical structures of bioactive compounds found in white tea, sourced from PubChem and visualised in Microsoft PowerPoint.

the *Camellia sinensis* plant. These are typically hand-plucked to ensure that only the finest buds are used (Guo *et al.*, 2024). White tea undergoes minimal oxidation of 5% in its production process, thus ensuring the retention of high levels of antioxidant compounds (Yılmaz & Acar-Tek, 2023). Briefly, the production process of white tea involves only withering and drying without fermentation (Samanta, 2022).

During withering, tea leaves and buds are spread out in natural sunlight or under controlled indoor conditions for up to 93 hours (Maulana *et al.*, 2020). Withering reduces the moisture content of freshly harvested, thick, and glossy tea leaves by approximately 60–70%, preserves the enzyme PPO (polyphenol oxidase) crucial for tea production, stabilises most evaporating organic compounds, and catalyses the oxidation of epicatechin (Zhang *et al.*, 2019; Samanta, 2022).

After withering, drying is crucial for removing moisture and preserving the tea's delicate flavour. The drying process eliminates residual moisture, typically reducing it to 3-5%, vital for long-term storage (Samanta, 2022). The drying temperature significantly impacts the transformation of flavonoid glycosides in tea. Drying at 60°C enhances taste acceptability by reducing bitterness and

Table 3. Therapeutic applications of white tea for health

Therapeutic applications	*Sample*	*Study type*	*Subject*	*Dose*	*Results*	*References*
Body-weight management	Polyphenols of white tea (EGCG and EGC)	*in vitro*	HepG2, HL-7702, and 293 T cell lines	10 g of white tea leaves were milled and extracted with 150 mL of 90% ethanol	Improves lipid metabolism in metabolic syndrome	Luo *et al.*, 2020
	Polyphenols and methylxanthines (EGCG of white tea)	*in vitro*	Human adipocytes	A liquid leaf extract of tea (50 µM)	↓ triglyceride accumulation, ↑ glycerol release, ↓ sirt1 expression	Söhle *et al.*, 2009
Antidiabetic and metabolic-syndrome effects	Extract water from white tea	*in vivo*	57BL/6 mice	2 g/100 mL of water	↓ blood glucose, ↑ glucose tolerance, improved metabolic health	Xia *et al.*, 2020
	Infuse white tea	*in vivo*	Wistar rats	1 g/100 mL	↑ glucose tolerance, ↑ insulin sensitivity in prediabetic rats, ↑ cardiac acetate, ↑ alanine contents, ↑ and protein oxidation levels.	Alves *et al.*, 2015
	White tea extract and the mixture of white tea and kelor	Post-test control group design	Sprague-Dawley rats	100 mg/kg	Pancreatic histopathology showed increased Langerhans islet diameter.	Martini *et al.*, 2019
	0.5% white tea extract water	*in vivo*	C57BL/6 mice	-	↓ oxidative stress levels, ↓ adipose tissue, and ↓ circulating triacylglycerols	Teixeira *et al.*, 2012
Anticancer effects	White tea aqueous extract	*in vitro*	Hela and liver cancer (BEL-7402) cells	2 g of tea leaf powder in 100 mL water	↓ cancer cell growth, IC50: 0.05 mg/mL (HeLa), 0.1 mg/mL (BEL-7402)	Liu *et al.*, 2018

to be continued...

Table 3. Therapeutic applications of white tea for health (continued)

Therapeutic applications	*Sample*	*Study type*	*Subject*	*Dose*	*Results*	*References*
Hepatic effects	White tea and Epigallocatechin gallate (EGCG)	*in vivo* and *in vitro*	Rats	EGCG and WT (10–300 mg/ml)	↓ inflammation, ↓ oxidative stress, ↑ hepatic protection	Rangi *et al.*, 2018
	White tea extract	*in vivo*	C57BL/6 mice		↓ lipid synthesis genes, ↑ energy expenditure genes	Li *et al.*, 2022
Antiaging and anti-melanogenic effects	Water of white tea	*in vitro*	Melan-A cells	600 g	↓ Tyrosinase activity, ↓ Melanin production	Kim, Choi & Park, 2015
	White tea extracts were applied to topical cream	*in vivo*	Human	-	White tea is recognized as an effective photoprotective agent.	Camouse *et al.*, 2009
Neuroprotective effects	Water of white tea	*in vitro*	PC-12 neuronal cells,	50-150 µg/mL	White tea demonstrated a distinctive anti-aggregatory effect by modifying Aβ into an amorphous and punctate aggregate morphology	Li *et al.*, 2019
Cardiovascular effects	Mix 100 g of white tea powder and 1 L of 70% ethanol	*in vivo*	Wistar rat	5% extract white tea	↑ neovascularization protection, ↓ atherosclerosis risk	Kouhihabibidehkordi *et al.*, 2021
	Water of white tea extract and the other of black and green tea	*in vivo*	C57/BL6J mice	1.6% White tea extract	↓ hypertension onset, ↑ endothelial function	Muñoz *et al.*, 2022
	White tea powder and ethanol solution	*in vivo*	*Rattus Novergicus* rats	-	↓ IL-6, ↓ foam cell count, ↓ intima-media thickness	Faustin *et al.*, 2023

Note: ↓: decrease; ↑: improve

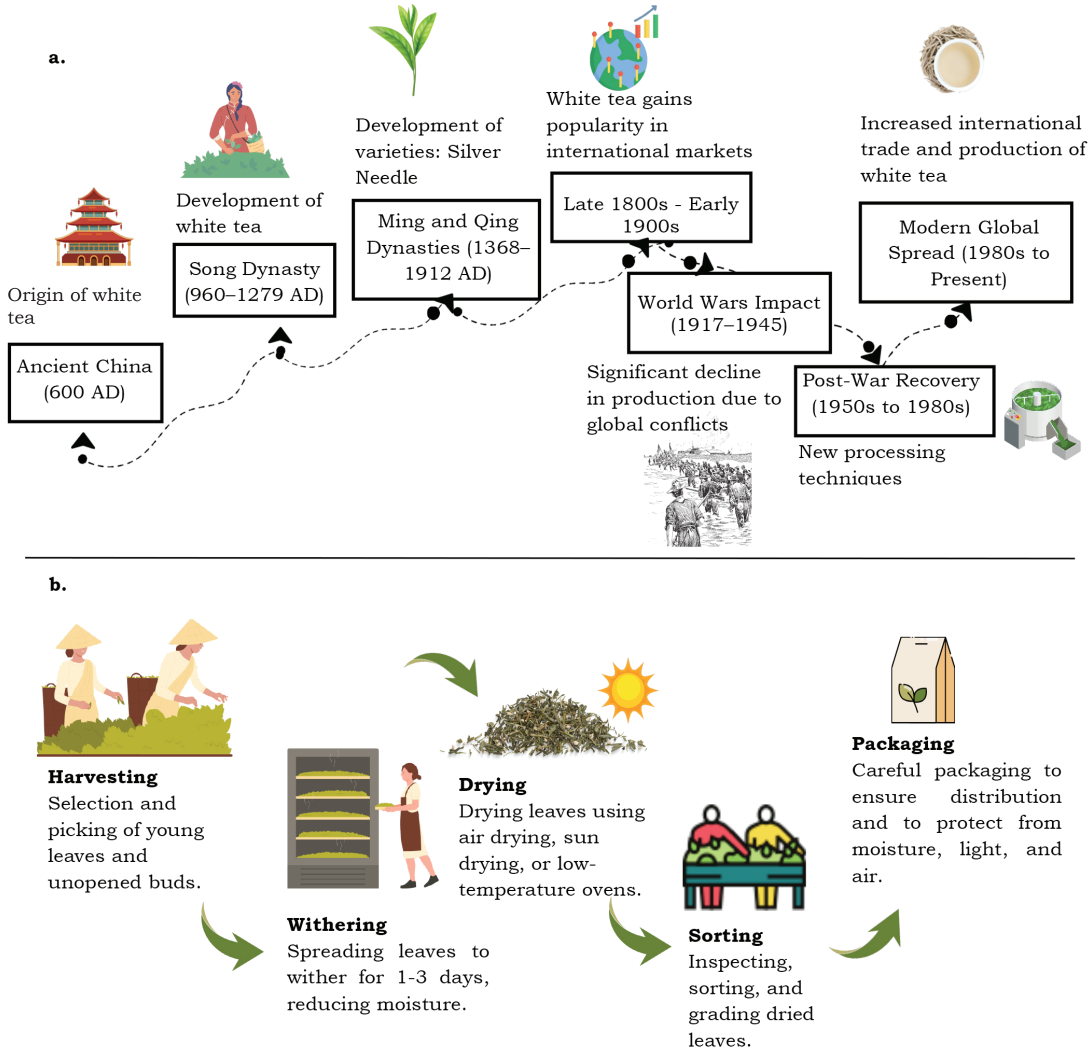


Figure 2 a. The development of white tea; **b.** Stages of white tea production.

astringency while preserving sweetness and umami (Wang *et al.*, 2024).

The next step involves removing broken leaves and debris, retaining only intact buds and leaves. This process uses sieves of various sizes, while branches are removed manually or mechanically (Gascoyne *et al.*, 2011). Finished teas are then meticulously packaged in plywood or double-textured aluminium foil boxes to prevent moisture absorption and ensure safe distribution (Figure 2b) (Samanta, 2022). White tea should be stored in cool, dry conditions away from light and oxygen to preserve its antioxidant properties and freshness (Hazra *et al.*, 2020). Exposure to environmental factors like heat, moisture, oxygen, and light can degrade tea quality through various chemical reactions (Lv *et al.*, 2023).

Figure 3 a. Infusion accessory; **b.** Appearance types of white tea

Optimal brewing and daily intake of white tea

White tea, originating from China, is gaining popularity worldwide due to its unique flavour and health benefits. A vital tool in enhancing its delicate characteristics is the *gaiwan*, a traditional Chinese tea container with a saucer, bowl, and lid. Since the Ming dynasty, the *gaiwan* has infused delicate teas like white and green effectively. The process begins by heating the *gaiwan*, adding tea leaves, and pouring them into water at the appropriate temperature. After a brief steeping period, the liquid is carefully poured into a separate container while the lid holds back the leaves. This method allows tea enthusiasts to enjoy the rich, subtle aromas and highlights the complex flavours that emerge with each infusion, making the tea-drinking experience truly special (Gascoyne *et*

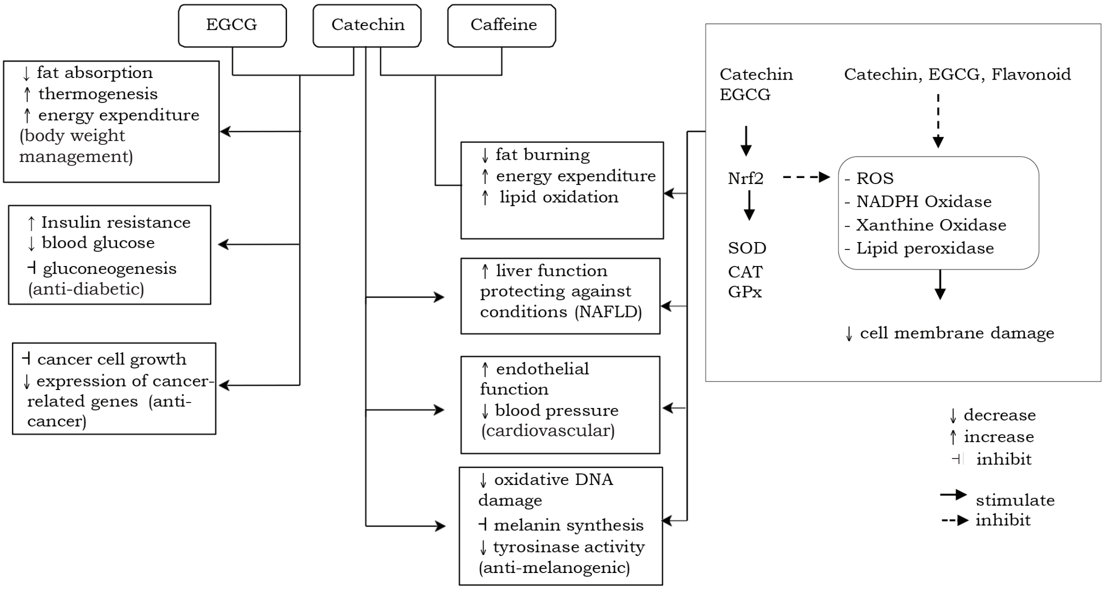


Figure 4. Mechanisms underlying the therapeutic effects of bioactive components in white tea (Note: ↓: decrease; ↑: improve; ⊣: inhibit)

al., 2011). The brewing methods for white teas vary by country and specific tools are used to enhance their unique flavours (Table 1 and Figure 3).

On the other hand, white tea is rich in polyphenols, including flavonoids and phenolic acids, and contains catechins, such as epigallocatechin gallate (EGCG), epicatechin (EC), epicatechin gallate (ECG), and epigallocatechin (EGC), which are potent antioxidants with potential health benefits (Dias *et al.*, 2013). Catechins neutralise reactive oxygen species (ROS) and free radicals by donating hydrogen atoms or electrons, preventing oxidative damage to biomolecules such as lipids, proteins, and DNA (Pereira & Cotas, 2023). White tea consumption raises plasma flavan-3-ol levels but does not significantly impact antioxidant capacity or oxidative stress markers in the short term (Müller *et al.*, 2010). However, regular tea consumption has been associated with health benefits (Yi *et al.*, 2019).

A comprehensive review of meta-analyses found that drinking 2-3 cups of tea daily was linked to reduced risks of total mortality, cardiovascular diseases, stroke, and type 2 diabetes (Yi *et al.*, 2019). The average daily intake of EGCG from tea infusions in general among adults ranges from 90 to 300 mg, while higher consumption levels can reach up to 866 mg of EGCG per day. Food supplements containing green tea catechins deliver EGCG in dosages ranging from 5 to 1000 mg daily for the adult population (Younes *et al.*, 2018). White tea's caffeine content per cup (200 mL) is 49 mg (Shannon *et al.,* 2018). The consumption of single doses of caffeine up to 200 mg, which corresponds to approximately 3 mg/kg body weight for a 70-kg adult, is generally considered safe and does not raise safety concerns (EFSA, 2015).

Bioactive compounds in white tea

Natural polyphenols are the predominant

antioxidants found in human diets, with their radical scavenging activities attributed to substituting hydroxyl groups in the aromatic rings of phenolics (Zhang *et al.,* 2015). White tea's total phenolic contents (TPC) were detected using the Folin-Ciocalteu assay, yielding 68.38±12.44 mg GAE (Gallic Acid Equivalent)/g DW (Zhao *et al.,* 2019).

Flavonoids, a subclass of polyphenols, are significant components of tea leaves. These include flavanols (flavan-3-ols), flavonols, flavones, flavanones, and anthocyanidins such as cyanidin, pelargonidin, delphinidin, and tricetinidin (Pinto *et al.*, 2020; Vastrad *et al.*, 2022). Flavonoid compounds, particularly catechins, constitute the primary tea polyphenols (60%-80%) and 12%-24% of the tea's dry weight. Flavonoids enhance cardiovascular health by improving endothelial function and reducing inflammation (Liang *et al.*, 2017).

Catechins, a group of flavan-3-ols, are the primary bioactive compounds in fresh tea leaves. Among these, EGCG, EGC, ECG, EC, gallocatechin, and gallocatechin gallate are the major polyphenolic compounds found in white tea (Khan & Mukhtar, 2018). A study reported the extraction of catechins from white tea, including EGCG, ECG, EGC, and EC, with concentrations of 29.6±10.6, 5.40±2.09, 5.04±0.20, and 2.48±1.10 mg/100 g, respectively (Peiró *et al.*, 2014). Catechins are potent antioxidants that scavenge free radicals, which can damage cells and contribute to various health problems, and inhibit oxidative damage at the cellular level (Table 2) (Khan & Mukhtar, 2018; Zhao *et al.*, 2019; Vastrad *et al.*, 2022; Hasan *et al.*, 2024). EGCG, characterised by the most phenolic hydroxyl groups, exhibits the most potent antioxidant activity among phenolic compounds, potentially rendering it the most bioactive (Hinojosa *et al.*, 2021).

Therapeutic applications

White tea, due to its rich content of bioactive compounds, such as catechins, caffeine, and EGCG, has been the subject of numerous studies highlighting its potential therapeutic effects (Dias *et al.*, 2013). These include body weight management, anti-ageing and anti-melanogenic properties, anti-diabetic benefits, and positive effects on cardiovascular and hepatic health (Dias *et al.*, 2013; Pérez-Burillo *et al.*, 2018; Hinojosa *et al.*, 2021). Table 3 and Figure 4 detail several mechanisms underlying the therapeutic properties of white tea's bioactive components.

Body weight management

The compounds in white tea may inhibit fat absorption, potentially reducing fat accumulation (Yang *et al.*, 2016). White tea has a higher catechin content than other types of tea due to minimal processing (Yılmaz & Acar-Tek, 2023). Studies suggest consuming 3-4 cups of tea daily (600-900 mg tea catechins) can reduce body weight and alleviate metabolic syndrome. The beneficial effects of tea consumption on weight management are attributed to decreased absorption of lipids and proteins in the intestine and the activation of AMP-activated protein kinase in various tissues (Yang *et al.*, 2016).

White tea, particularly at doses around 0.22 mg, as observed in a rat study, appears to aid in weight loss and maintenance by accelerating fat burning and enhancing energy expenditure. Catechins in white tea contribute to this effect by reducing fat absorption via the inhibition of micelle formation and pancreatic and gastric lipase enzymes, which are crucial for fat digestion, as well as sugar absorption via inhibition of alpha-glucosidase activity (Mahmud, Setyaningtyas & Rachmah, 2022). Additionally, white tea may increase thermogenesis and prevent triglyceride accumulation, supporting its potential for long-term obesity prevention and weight management (Mahmud *et al.*, 2022; Yilmaz *et al.*, 2022). EGCG further supports weight management by stimulating thermogenesis in brown fat tissue through its interaction with noradrenaline and modulating lipid metabolism enzymes, as well as enhancing energy expenditure by influencing cyclic adenosine monophosphate (cAMP) levels (Murase *et al.*, 2009).

Anti-ageing and anti-melanogenic

Beyond its traditional use as a brewed beverage, white tea has gained attention as a topical application in skincare and dermatological formulations. White tea extract is increasingly incorporated into cosmetic and dermatological products due to its photoprotective, anti-ageing, and anti-melanogenic properties. Research indicates that white tea leaf extract can absorb ultraviolet (UV) radiation, thus protecting against its detrimental effects on skin (Mishra, Mishra & Chattopadhyay, 2011).

White tea is recognised as an effective photoprotective agent, prolonging the ageing process while enhancing lifespan (Koch *et al.*, 2019; Somavanshi *et al.*, 2021). In a study by Camouse *et al.* (2009), skin samples from volunteers were treated with white or green tea after UV irradiation. The tea extracts were applied topically using a specialised cosmetic vehicle. Results showed that both teas reduced CD1a+ staining by 22% and 35%, respectively, which suggests a decrease in epidermal Langerhans cells involved in immune responses and potentially related to skin ageing. Additionally, both teas significantly reduced oxidative DNA damage caused by UV radiation. Despite having a sun protection factor (SPF) of 1, their photoprotective effects were not solely due to direct UV absorption or traditional sunscreen effects. White tea is considered more suitable for topical facial use due to its lighter colour (Camouse *et al.*, 2009).

White tea has emerged as a promising agent in combating melanogenesis due to its efficacy in inhibiting melanin synthesis and tyrosinase activity. Compared to other tea varieties, white and black teas have shown elevated levels of anti-melanogenic activity (Kim *et al.*, 2015). Furthermore, white tea and other tea extracts have exhibited the ability to impede tyrosinase activity by sequestering essential copper ions vital for enzymatic function. Notably, white tea has exhibited the most pronounced inhibition of intracellular tyrosinase activity. The reduction in tyrosinase protein expression corroborates this inhibitory effect, indicating a post-translational mechanism of action (Kim *et al.*, 2015; Korkmaz *et al.*, 2019). EGCG in tea with hinokitiol also decreases MITF (microphthalmia-associated transcription factor) production, indicating that the collaborative inhibition of tyrosinase activity by hinokitiol may contribute to their synergistic impact on melanogenesis (Kim *et al.*, 2004).

Anti-diabetic and metabolic syndrome effects

EGCG has been identified as having potential anti-diabetic properties (Liu, Kang & Yan, 2021). In a study conducted on diabetic rats, the administration of White Tea Extract (WTE) for 14 days resulted in a decrease in fasting blood glucose levels. Among the doses tested, 100 mg/kg body weight of WTE exhibited the most significant effect in reducing fasting glucose levels compared to the negative control group (Ardiana, Sauriasari & Elya, 2018). White tea consumption improved the overall metabolic condition of rats at risk of diabetes by enhancing glucose and insulin handling, protecting against adverse effects on the heart. It increased the levels of lactate and acetate in the heart while reducing the expression of glucose transporters GLUT1 and GLUT3 mRNA in cardiac tissue (Alves *et al.*, 2015). In another study with diabetic mice induced by a high-fat diet and streptozotocin, intervention with white tea water extract activated the AMPK pathway. This activation led to the inhibition of G6P expression, effectively suppressing gluconeogenesis and improving insulin resistance (Xia *et al.*, 2020). Tea and its extracts have demonstrated the ability to reduce the expression of critical enzymes involved in gluconeogenesis, such as PEPCK, G6P, and FBP. Moreover, they boost the expression of GSK, facilitating glycogen synthesis and leading to decreased blood glucose levels observed in both *in vivo* and *in vitro* studies (Li *et al.*, 2024).

A study on white tea samples processed from leaves at different stages showed that white tea effectively addresses aspects of metabolic syndrome associated with diabetes. The results demonstrated that white tea significantly reduced glucose and cholesterol absorption and increased LDL receptor binding activity by 40% (Tenore *et al.*, 2013). Another study found that white tea aged 1, 3, and 5 years displayed potent antioxidant properties and inhibited essential enzymes associated with type 2 diabetes, such as α-amylase and α-glucosidase (Xu, Chen & Wang, 2019).

Cardiovascular effects

Flavonoids present in tea have been proposed as potentially beneficial for cardiovascular health (Cao *et al.*, 2019; Chung *et al.*, 2020), showing promising effects. These compounds exhibit antioxidant properties, protecting the endothelium from oxidative damage and improving endothelial function (Grassi *et al.*, 2013). A study found that white tea treatment improved cardiac glycolytic and heart antioxidant capacity in prediabetic rats (Alves *et al.*, 2015). Additionally, EGCG was shown to protect human umbilical vein endothelial cells from oxidative stress injury, which is associated with certain cardiovascular diseases. The antioxidant effects of EGCG in white tea are primarily mediated by activating the p38 MAPK and ERK1/2 signalling pathways. This activation leads to upregulating of the Nrf2/HO-1 pathway, which plays a crucial role in cellular defence against oxidative stress (Pullikotil *et al.*, 2012; Yang *et al.*, 2015). By enhancing Nrf2 activation, EGCG promotes the expression of antioxidant enzymes like HO-1 (heme oxygenase-1), which helps protect cells from oxidative damage and supports overall cellular homeostasis. This mechanism contributes to the antioxidant properties of white tea, offering protective effects against various diseases associated with oxidative stress (Yang *et al.*, 2015).

Anti-cancer effects

White tea contains the highest amount of catechin, previously found to enhance anti-cancer activity (David *et al.*, 2021). Some studies indicate the effect of white tea administration on the development of colorectal cancer. EGCG exhibits potent anti-cancer effects through multiple mechanisms, including antioxidants, reducing oxidative stress, and preventing DNA damage (Bondarian *et al.*, 2020; Khanafer, 2020; David *et al.*, 2021).

Assay results revealed that white tea extract (WTE) at concentrations of 150, 500, and 1000 μg/ml exhibit a notable inhibitory effect on the growth of colorectal cancer cells. Treatment with these concentrations of WTE for 8, 16, and 24 hours resulted in significant decreases in the expression of MMP2 and K-ras after 24 hours (Bondarian *et al.*, 2019, 2020). EGCG inhibits cancer cell proliferation by modulating key signalling pathways, including PI3K/AKT and MAPK. It also induces apoptosis in cancer cells by activating caspases and regulating the balance between pro-apoptotic and anti-apoptotic proteins (Yang & Wang, 2016). EGCG's anti-inflammatory properties contribute to its anti-cancer effects by inhibiting NF-κB signalling (Min & Kwon, 2014).

Neuroprotective effects

The pathology of Alzheimer's disease is marked by the aggregation of Aβ proteins and the accumulation of senile plaques in the brain (Hardy & Selkoe, 2002). White tea demonstrates potential in treating Alzheimer's disease due to its ability to protect against neurotoxicity induced by Aβ, the hallmark protein associated with Alzheimer's disease. While white tea and other teas do not mitigate oxidative stress-induced toxicity, they significantly preserve cell viability following Aβ exposure. Analysis showed that white tea inhibits Aβ aggregation and uniquely modifies Aβ aggregates into an amorphous and punctate morphology. Chemical analysis revealed higher levels of catechin derivatives, flavonol or flavone glycosides, and amino acids like GABA and Gln in white tea compared to other teas. These compounds have known neuroprotective effects, suggesting that the unique chemical composition of white tea contributes to its efficacy in treating Alzheimer's disease (Das *et al.*, 2016; Li *et al.*, 2019).

A study by He *et al.* (2018) reported the partial inhibition effects of catechin polyphenols and their free radical scavenging activity. It demonstrated that EGCG and its derivatives can protect neurones from oxidative stress-induced neurodegeneration. EGCG was identified as the most effective polyphenol against H_2O_2-induced stress in HT22 cells, showing a solid capacity to reduce ROS production and scavenge radicals (He *et al.*, 2018). In another study using cell cultures, the neuroprotective effect of white tea was observed, demonstrating a reduction in oxidative stress associated with brain damage (Almajano, Vila & Gines, 2011). This effect was credited to its content of catechins and other flavonols. Oxidative stress, a consequence of ROS production, is recognised as a significant factor in ageing and neurodegenerative conditions like Alzheimer's, Parkinson's, or Huntington's disease (Wang & Michaelis, 2010).

Hepatic effects

White tea and its primary component, EGCG, demonstrate significant hepatoprotective effects. Studies showed that WTE and EGCG can alleviate NAFLD by regulating lipid metabolism, thus reducing fat accumulation and enhancing energy expenditure (Li *et al.*, 2022). These compounds exhibit potent antioxidant properties, effectively reducing oxidative stress and inflammation in liver cells (Tipoe *et al.*, 2010; Rangi *et al.*, 2018). EGCG has been found to mitigate liver fibrosis by inhibiting pro-fibrogenic markers and reducing collagen deposition (Tipoe *et al.*, 2010). Additionally, EGCG shows promise in treating NAFLD through multiple mechanisms, including promoting lipid and glucose metabolisms, anti-lipid peroxidation, and anti-inflammatory activities (Chen *et al.*, 2018). In a study investigating the inhibition of hepatic dysfunction induced by the procarcinogenic compound benzo(a) pyrene (BaP), the effectiveness of EGCG was examined. It was found that both EGCG and white tea extract exhibited antioxidative properties, suggesting the potential use of white tea extract as a preventive measure to mitigate oxidative damage to hepatocytes and red blood cells (RBCs) caused by BaP (Rangi *et al.*, 2018).

Future perspective of white tea

White tea, the least processed tea variety, is gaining attention for its potential health benefits and commercial opportunities (Dias *et al.*, 2013). However, several challenges must be addressed to fully realise its potential. One significant gap arises from the inconsistencies of extraction and processing techniques, which result in variations of bioactive compound concentrations. Establishing standardised methods is crucial to ensuring the optimal health benefits of white tea and improving its efficacy in functional applications (Samanta, 2022). Despite its promising health properties, white tea remains less widely consumed than green and black teas. Limited consumer awareness of its benefits, coupled with a lack of strategic marketing, has hindered its broader acceptance in the market. Nevertheless, as health consciousness rises alongside economic and educational growth, white tea holds immense potential as a functional beverage alternative (Linnarto *et al.*, 2019; Yılmaz & Tek, 2023).

Future research directions include exploring white tea's potential in personalised nutrition, integrative medicine, and the development of functional foods and nutraceuticals (Zhou *et al.*, 2023). Advances in nutrigenomics could enable tailored dietary recommendations based on genetic profiles, optimising its health benefits. Additionally, innovations in extraction and processing techniques could further improve the stability, accessibility, bioavailability, and efficacy of white tea's active compounds, enhancing its therapeutic applications (Gopi *et al.*, 2024; Guo *et al.*, 2024).

CONCLUSION

White tea, derived from the *Camellia sinensis* plant, offers a unique profile of bioactive compounds with numerous potential health benefits. The health-promoting effects of white tea are mediated through several mechanisms: it supports weight management by enhancing fat metabolism and reducing oxidative stress, offers anti-ageing and photoprotective benefits through its antioxidant properties, and exhibits anti-diabetic potential by modulating glucose metabolism. Additionally, white tea demonstrates potential in cancer prevention, particularly in inhibiting colorectal cancer cell proliferation, and provides cardiovascular protection through its antioxidant effects. These findings underscore the potential of white tea as a functional food and dietary supplement, as well as for use in skincare formulation. Public health initiatives can be carried out to promote its benefits for disease prevention and overall well-being. However, as this review compiled existing findings, further research is necessary to clarify the underlying mechanisms by which white tea exerts its health effects.

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Authors' contribution

Anjani G, funding acquisition, supervision, validation, writing-reviewing, and editing; Ayustaningwarno F, conceptualisation, investigation, project administration, resources, supervision, writing-reviewing, and editing; Khasanah AN, conceptualisation, investigation, writing original draft, and visualisation.

Conflict of interest

The authors declare no conflict of interest.

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