Rasayely
Membrane Science International
https://rasayely-journals.com/index.php/msi
Vol 2(1); 18–28, 2023

Review Article
Open Access

Polymeric Membranes and Tea Polyphenols: A Perspective

Mayank Saxena[1,2] **and Amit Bhattacharya**[1,2,*]

[1] *Membrane Science and Separation Technology Division, Council of Scientific & Industrial Research-Central Salt and Marine Chemicals Research Institute (CSIR-CSMCRI), Bhavnagar-364002, Gujarat, India*

[2] *Charotar University of Science and Technology, Changa-388421, Anand, Gujarat, India*

[*] Author to whom any correspondence should be addressed; e-mail: bhattacharyaamit1@rediffmail.com

Received: 06 July 2023; Revised: 24 August 2023; Accepted: 03 September 2023; Published: 11 Oct 2023

Academic Editor: Sami Sayadi, Qatar University, Qatar

Abstract

Tea, derived from the cured leaves of the *Camellia sinensis* plant, is the most popular beverage. It has gained significant attention for its beneficial health properties, including antioxidant, antitumor, anti-inflammatory, and metabolic regulation effects. The main components of tea are tea polyphenols, namely theaflavins and catechins. Tea is categorized into black, green, and oolong tea, with black tea being widely consumed worldwide. Ensuring access to a high-quality life is important, and health and nutritional care play essential roles in human well-being. In tea processing, various clarification methods such as solvent ultrasound-assisted and microwave-assisted extraction are employed. This review examines the features and limitations of these techniques. Membranes have emerged as a prominent factor in this field, offering natural and additive-free ready-to-drink (RTD) tea. The use of membranes for clarifying extracts from black tea, along with their relative advantages and limitations, is discussed. Additionally, this study highlights the connection between tea polyphenols and membranes.

Keywords

Tea-polyphenols; membrane; separation; extraction

1. Introduction

Tea is considered the most extensively consumed beverage in the world. The popularity road map spreads to China, Japan, Europe, India, Sri Lanka, and presently signatures worldwide. The projected black tea consumption will grow at a rate of 3% per annum, reaching 4.14 million tonnes in 2023 [1]. The presence of high antioxidant tea polyphenols and tea flavonoids highlights the health benefits (as antibiotics, anti-diarrheal, anti-ulcer, and anti-inflammatory agents) of this beverage. It can also help treat heart disease, hypertension, vascular fragility, radical scavenging, allergies, and hypercholesterolemia. Perceptions about how human health relates to tea can influence production and tea research. It can be seen as a means to enhance human well-being through enriching diet and nutrition. One of the studies confirmed that drinking oolong tea increases CO_2 exhalation as a substance in the tea operative oxygen inhaling in the mitochondria system [2].

Polyphenols, naturally occurring organic compounds, are derived from the leaves of *Camellia sinensis* [3]. There are reports of two primary botanical varieties, i.e. Chinese tea shrub (*Camellia sinensis*), and Indian tea tree (*Camellia assamica*) [4,5]. Tea is grown in many countries, mainly China, India, Japan, and Sri Lanka [6]. The most aromatic, top-grade teas are obtained from the undeveloped leaves and young leaflets of the top twigs, collected during the spring season [5]. In 2012, the global tea production reached 4,625 million kg [7]. Tea is primarily classified into three categories: green, oolong, and black [8]. The categories are mainly based on leaf harvesting, leaf maturation, botanical varieties, geographical origin, and agricultural practice. Green tea is processed by drying the leaves, after chopping them, in the sun or with a steam of hot air. In this case, few polyphenols are oxidized as polyphenol oxidases enzyme does not activate properly. Major constituents of green tea include epicatechin (EC), epicatechin-3-gallate (ECG), epigallocatechin (EGC), and epigallocatechin-3-gallate (EGCG), while minor constituents include caffeine, theobromine, theophylline, and phenolic acid (gallic acid) **(Figure 1)**. Oolong tea, on the other hand, undergoes enzyme inactivation through heating after a specific time interval.

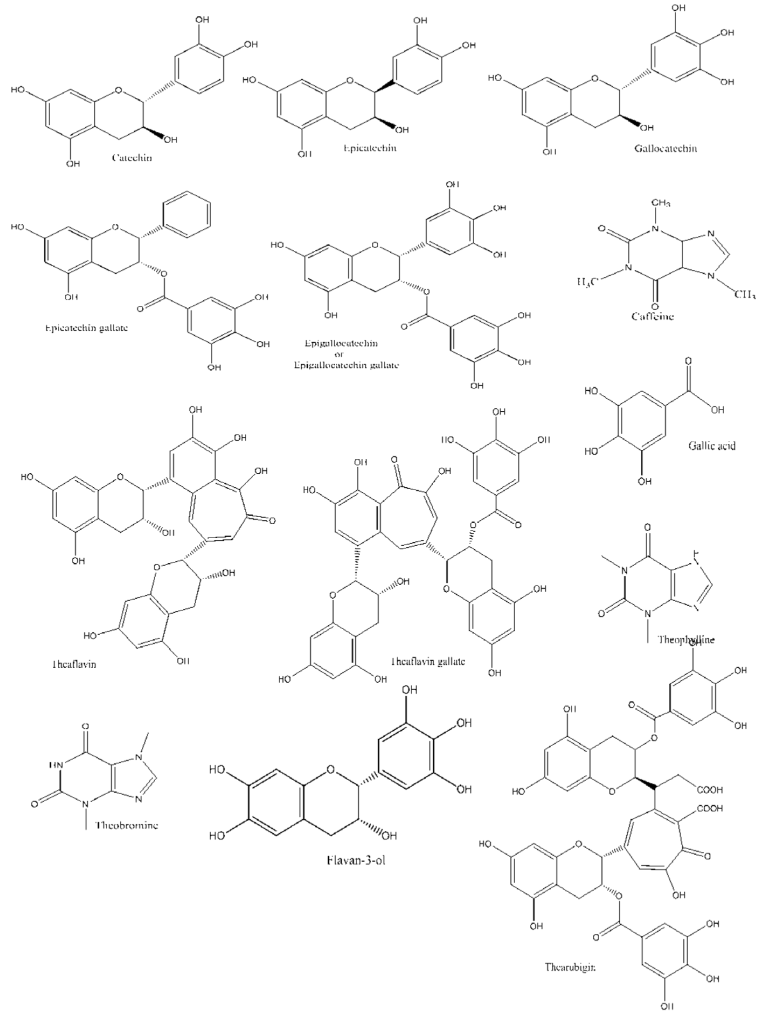

Figure 1: Some chemical structures of tea polyphenol constituents.

Black tea is a fermented product of green tea. The enzyme oxidizes during a period of 3-6 hours after chopping the leaves. The colorless catechins form a complex mixture of polyphenols, mainly the orange-yellow to red-brown i.e. theaflavin-gallate and thearubigins compounds. In this case, 15% of catechins remain unchanged, 10% are transformed into bisflavanols, theaflavins, and other oligomers with a molecular weight of 500–3000 Da, and 75% are transformed into colored theaflavin-gallate and thearubigins compounds having a molecular weight ranging from 700–40000 Da [3]. It is reported that black tea consumption is significantly higher (78%) compared to other tea varieties [9]. Sarkar *et al.* reported that black tea catechin extracts are more effective in scavenging superoxide anions than green tea [10]. Tea production involves various processes such as quantifying polyphenols in natural sources, extraction, and concentration [11–27]. In this context, membrane technology offers a broader range of solutions and effects. As the popularity of Ready-to-drink (RTD) or iced tea gains, the spray-dried tea powder demand increases [28]. The formation of insoluble material termed "tea cream" and haze occurring depends on physical parameters such as temperature, pH, and temperature/time history of the liquor [29]. Thus, removing haze and tea cream-originating compounds from tea is essential. In the fermentation process during black tea production, monomeric flavan-3-ol undergoes an enzymatic polymerization to a series of colored chemical compounds, viz. theaflavins (TFs) and thearubigins (TRs). These polyphenols tend to interact with proteins and haze. However, the tendency of these polyphenols to interact with proteins leads to haze formation [30]. The decreaming methods are based on the removal of the precipitating complexes. It includes clarification by centrifugation/filtration and a combination of the methods. One of the approaches increases solubility by adding chemicals and enzymes [31].

Membrane processes could be a better alternative for the separation and concentrating process, with potential advantages such as better separation efficiency, high purity, mild operation parameters, temperature independence, and reduced or avoided use of solvents. There are various options such as ultrafiltration and nanofiltration are available [3]. Moreover, it can be flexible to result in hybrid techniques. The separation science and membrane technology coming together is a moment bristling with possibilities and challenges.

2. Determination of Polyphenol Content

The well-acquainted few methods with their features and limitations for the determination of polyphenol content are summarized in **Table 1** [32].

Table 1: Different analytical methods for determining polyphenol content.

Analytical Methods	Features	Limitations
Titration method (oxidation by permanganate) [33]	Simple process and easy to do anywhere	Other compounds (viz. non-polyphenols) may participate in the oxidizing reaction Endpoint detection
Spectrophotometry [34–36] a) Ferrous tartrate method [37] b) Folin–Ciocalteu method [38]	Widely used, the right selection of the chromogenic agent, and good accuracy	Different polyphenols show differences in color formation ability (especially Fe(III) compounds) which makes it difficult to monitor the right conversion coefficient for the measurement It needs extensive pretreatments
Infrared spectroscopy	Non-destructive and no need for chemical reagents. Rapid detection abilities	It needs reliable calibration
Electrochemical analysis [39]	High precision and sensitivity, quick analysis, make-in miniature scale, and on-site detection	It needs electrodes of high precision [40]
Liquid Chromatography [41]	Good separation performance and better sensitivity	Simultaneous determination of individual polyphenols and separation of individual tea phenols is difficult from the complex systems [42,43]
Liquid Chromatography with Mass spectrometry (LC-Mass) [44,45]	Sensitivity, precision, and better resolution [46]	It needs the expertise to analyze the spectra

2.1. Potentiality of Black Tea

Tea components possess antioxidant, antimutagenic, and anticarcinogenic effects. Black tea catechins provide some protection against degenerative diseases. They have antiproliferative activity on hepatoma cells (i.e., cancer-liver cells) and hypolipidemic activity in hepatoma-treated rats. Catechins could prevent hepatoxicity and mammary cancer post-initiation [47]. Consuming black tea can counter many types of cancer, including lung, colon, esophagus, mouth, stomach, small intestine, kidney, pancreas, and mammary glands [48]. Meydani *et al.* reported that black tea could protect against cancer from environmental agents [49]. Several studies and clinical trials showed that black and green tea (Oolong tea to a lesser extent) could reduce the risk of many chronic diseases [50]. Black tea may lower blood pressure and thus reduce coronary heart disease risk. An interesting observation based on animal studies is that it reduces blood glucose levels and body weight, thus protecting against coronary heart disease [51]. Mukhtar *et al.* reported the inhibitory effects of black tea leaves against tert-butyl hydroperoxide-induced lipid peroxidation [52]. A similar antioxidant impact on the kidney is observed after oral administration of the significant tea polyphenol EGCG. The formation of peroxides is reduced more effectively by crude catechins compared to dl-α-tocopherol [53]. The chemopreventive effect of black tea among cigarette smokers is also reported [54].

Black tea is associated with increased bone mineral density and protects against hip fractures [55]. It strengthens the immune system's action by protecting it from oxidants and radicals. It is helpful for insect stings due to its anti-inflammatory effects and capacity to stop bleeding [56,57]. It reduces the risk of kidney stone formation [58]. The catechins in black tea have an inhibitory effect on *Helicobacter pylori* infection [59]. Black tea can counter the influenza virus, especially in its earliest stage, and the *Herpes simplex* virus [60–62]. Mukoyama *et al.* observed the *in vitro* inhibition of adenovirus infection by black tea catechins [63].

Green tea catechins show their behavior as antitumorigenic agents and immune modulators in transplanted tumors of carcinogen treatment [64]. Green tea extracts effectively prevent oxidative stress and neurological problems [65,66]. Green tea can counter diarrhea and typhoid [67–69]. Hirasawa *et al.* observed the positive effects of green tea extracts and green tea polyphenols (GTPs) on the proliferation and activity of bone cells [70]. The proliferation of hepatic stellate cells is closely related to the progression of liver fibrosis in chronic liver diseases. EGCG has a potential inhibitory effect on the proliferation of these cells [71,72]. Recent studies suggested that GTPs might counter Parkinson's and Alzheimer's diseases, and other neurodegenerative diseases [73,74]. Gupta *et al.* reported that green tea preserved the lens antioxidant defense system in an experimental cataractogenesis model [75]. It shows a beneficial effect of green tea on alcohol intoxication [76].

2.2. Extraction of Tea Polyphenol

Tea polyphenol extraction is the art of restoring volatile compounds, avoiding biodegradation, and maximizing recovery [77–79]. In this area, a few methods are explored including solvent extraction, microwave-assisted extraction, ultrasound-assisted extraction, high-pressure processing, supercritical fluid extraction, and subcritical extraction [80]. Some of the methods are summarized below.

2.2.1. Solvent Extraction

This method is based on the relative solubilities of the compounds in a particular solvent. Phytochemicals are recovered from tea polyphenol using different solvents (e.g. water, alcohol, acetone, and dimethyl formamide) [81].

Mostly soxhlet, maceration (softening by soaking in a liquid), reflux, and hydrodistillation techniques are employed [82].

Features

- Simple method
- Not location specific

Limitations

- Chances of thermal degradation of active components
- Using organic solvents is not environmentally friendly [83]

2.2.2. *Ultrasound-Assisted Extraction*

The tea polyphenol solution mainly propagates ultrasound pressure waves (high frequency ~20 kHz). It forms bubbles that generate microturbulence, disrupt cell membranes, and promote solvent dissolution [84]. Different influencing factors are extraction efficiency, time, solvent composition, and input power [85,86].

Features

- Low-temperature extraction
- Time-saving
- Minimizes solvent use
- Can be coupled with other extraction techniques

Limitations

- Needs sophisticated arrangement
- Energy consumption relates to process efficiency
- Restricted to a definite volume

2.2.3. *Microwave-Assisted Extraction*

Microwaves form energy by ionic conduction and dipole rotation, resulting in internal water vaporization that disrupts the biomass cell wall and plasma membrane. It uses microwave energy to heat solvents and partition components from the natural sample matrix into the solvent accordingly. The permeability of solvents to the cell matrix is enhanced, allowing the dissolution of molecules. The efficiency of the process depends on the polarity and volume of extracting solvent, volume, temperature, time, and microwave power [87]. Li *et al*. experimented with different parameters in this aspect and reported the irradiation time > intensity > tea/water ratio > number of times for irradiation [88].

Features

- Clean process
- Efficiency relates to the optimization of parameters
- Applicable to thermally unstable substances

Limitations

- Restricted to organic solvents
- Energy consumption relates to the efficiency of the process
- Restricted to a definite volume
- Risk of bio-component degradation

2.2.4. *High-Pressure Processing*

This method is based on adiabatic heating, which increases solvent permeability and extracts solubility. It is used for the extraction of tea polyphenol from plant materials at high pressures of 100–800 MPa or <1000 MPa. It is a fast and effective method [89].

Features

- Non-thermal process [90]
- The time of extraction can be minimized
- High extraction efficacy
- Variable options like ultrahigh and high hydrostatic pressure [91]
- Energy consumption is low in mild extraction conditions [92]

Limitations

- Possibility of structural changes of the bio-components [93]
- Potential undesirable sensory changes in foods [94]

2.2.5. *Supercritical Fluid Extraction*

This method separates extracts from the matrix using supercritical fluids as the extracting solvent. It is based on supercritical fluid (viz. CO_2). It results in lower viscosity and higher diffusivity above its critical temperature. A packed bed adsorption column with the help of fluidized CO_2 by high pressure is used for the extraction.

Features

- Green solvent
- Time consumption can be minimized
- Heating and evaporation can be avoided [95,96]
- Avoidance of toxic organic solvents [97]
- The supercritical fluid (CO_2) has a lower critical point, abundant in nature, and can be recycled
- Can use co-solvent and modifiers to enhance extraction yield [97]

Limitations

- Unavoidable loss of tea catechins [98]
- Possibilities of structural changes of the components

2.2.6. *Membrane*

Membrane clarification of green tea extract is a promising step to improving its quality. Membranes of different ranges (micro to reverse osmosis) are used in the tea polyphenol arena. Membranes have the ability to separate particles into organics depending on their pore size. Micro and ultrafiltration separate particles and large macromolecules whereas nanofiltration and reverse osmosis separate organics of different sizes. Tea polyphenol is composed of different organics, as discussed earlier. There is the possibility of formation of complexes as well as oligomers. The features and limitations of different membrane processes in this arena are in the ensemble (**Table 2**).

Table 2: Different membrane processes with their features for tea polyphenol separation.

S.N.	Membranes	Pore size range (nm)	Features
1	Microfiltration (MF)	100 - 1000	It has the ability to separate suspended solids or colloidal particles, bacteria, oligomers, thearubigins, and turbidity. It needs low operating pressure and thus requires low energy.
2	Ultrafiltration (UF)	10 - 100	Suspended solids and solutes of high molecular weight (viz. caffeine, gallocatechin (GC), epigallocatechin gallate(EGCG), polyphenols, carbohydrates, catechin in oxidized form, polysaccharides together with oxidized polyphenols, polymerized intermediates, and other complexes, proteins are separated in clarification [27,99].
3	Nanofiltration (NF)	1 - 10	It has the ability to separate organic compounds (viz. pectins, proteins, chlorophylls, thearubigins, theaflavins, and other oxidative products that form complexes with residual metal ions, catechins in oxidized form, amino acids) along with higher valent salts effectively [99].
4	Reverse Osmosis (RO)	0.1- 1	Loose Reverse Osmosis membranes are capable of separating organics (in their non-oxidized form) along with salts.

Membrane technology can overcome some disadvantages inherently associated with the conventional decreaming methods, i.e., removal of precipitating complexes. Membrane separation processes are better alternatives for concentration and separation processes with potential advantages of greater separation efficiency, high purity bioactive phenolic compounds from the respective streams due to their flexibility and mild operating conditions, and avoidance or reduced use of solvent. Different polymeric materials (viz. cellulose, polysulfone, polyamide thin film composite membrane) are used for membrane preparation.

Chandini *et al*. experimented broad range of MF (200 and 450 nm pore size) and UF (25, 50, 100, and 500 kDa) membranes [100]. The rejection of tea components increased with the decrease in pore size. The clarity of membrane-processed extracts was excellent 4 NTU (Nephelometric Turbidity Units). UF-500 and MF membranes showed better retention and more significant recovery of tea solids, including polyphenols in the clarified extract. The rejection (%) of catechin and caffeine with different UF membranes (viz. Polysulfone, flat sheet (GR51pp, DDS (Dow Danmark A/S), polyether sulfone, flat sheet PTHK, Nihon Millipore, Ltd., PTTK, spiral, Nihon Millipore, Ltd.) is promising though they are small molecules [101]. The pore size range is 0.014 to 0.008 µm. The separation (viz. $R(\%)_{\text{Catechin}}$ 3.6 to 10.8) increases with the decrease in the pore size of the membranes.

Evans *et al.* experimented with the performance of fluoropolymer (from Alfa Laval Nakskov) and regenerated cellulose (from Microdyn-Nadir) membranes having MWCO 30KDa [101]. Two membranes could remove 21% and 27% tea solids having flux 23 and 32.1 LMH respectively at 1.0 bar. The permeate lightness and yellowness increased, and thus haze decreased. The concentration polarization resistance was significantly higher for regenerated cellulose membrane compared to fluoropolymer membrane.

The clarification performance of black tea depends on the physical features (hydrophobicity, surface charge, and surface roughness) and the chemical properties of the membranes [102]. In this regard, they have investigated regenerated cellulose (RC) and fluoropolymer (FP) membranes supplied by Microdyn-Nadir. The fouling increased on the rougher, more hydrophobic FP membrane surfaces. It showed the order FP30 (59nm) > FP10 (27nm) > FP100 (11nm). The foulants were significantly entrapped on the rougher surface of the membrane. It also correlated with the negative charge. FP membranes were rougher compared to RC membranes. Thus, less deposition occurred on the RC membranes. The membranes with the isoelectric points at the pH of the liquor showed a higher fouling tendency. The fouling mechanism resulted in cake deposition on the membranes. The total fouling resistance depended on the ionic strength and increased concentration polarization. Adding calcium to the black tea feed solution resulted in polar group–calcium complexation (bridging). It increased irreversible fouling [103].

Cross-linked polyvinyl alcohol was coated on asymmetric polysulfone (PS) support (MWCO 6 kDa), showing the potential for separating tea polyphenol [104]. The cross-linking between poly(vinyl alcohol, PVA) and dibasic acid (maleic acid, MA) was done for the coating. **Figure 2** depicts the schematic diagram of the coated membrane. The membranes showed 70-90% polyphenol retention having a flux 15-20 LMH at 500 psi for various coating and support types. The modified membrane develops the reduction in fouling, and at the same time, the pore size decreases compared to the support membrane, without much compromising productivity flux. It showed steady performance in water or methanol at pressurized conditions. The variation of flux with time showed that all the membranes are steady with no loss in flux during a methanol exposure time of 250h.

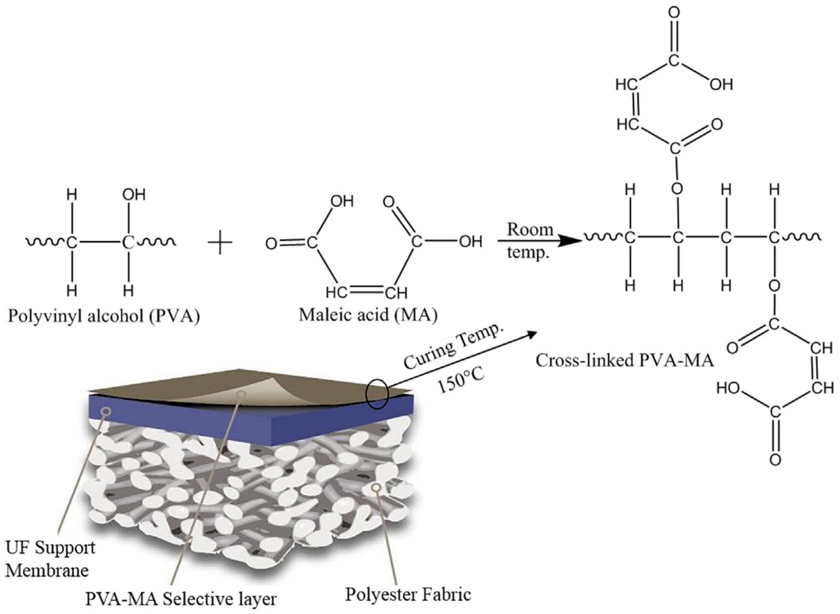

Figure 2: Schematic diagram of the coated membrane (PVA-MA).

The efficiency of the hollow fiber microfiltration membrane to enrich the epigallocatechin gallate (EGCG) from green tea aqueous extract was reported **[105]**. The particle size distribution of the raw and hollow fiber microfiltered (av pore diameter 0.1μm) green tea extract is observed that the range of particles in the extract was 40-100nm suggesting that the membrane passes the smaller-sized solutes (≤100nm) **[105]**.

The flux decline of membranes was quantified with simple resistance in the series model. The study showed that the growth of the fouling layer with the time of filtration is fitted with the first-order kinetic model.

$$R_F = R_F^S[\,1 - \exp(-kt)]$$

Where k designates the proportionality constant and represents the growth rate of the fouling layer. Larger 'k' features a rapid increase of RF to the steady state, and small 'k' signifies slow growth of fouling resistance.

The fouling resistance of the membrane improves with transmembrane pressure (TMP) drop and declines with Reynolds number.

Wu *et al.* studied the filtration characteristics of model solutions containing tea proteins, theaflavins (TFs), thearubigins, and caffeine through PS UF membranes (MWCO 30kD, GE Osmonics, Minnetonka, MN) **[106]**. The permeate flux declines rapidly i.e. > 60% of the initial flux was lost within 15 min. Pure TF filtration creates concentration polarization. The mixture of protein or protein mixed with polyphenol with caffeine reduces normalized filtration fluxes significantly.

The adsorptive fouling of polyphenolic compounds on UF membranes was also seen **[107]**. It mainly depends on membrane–solute interactions and membrane–solute–solute interactions. It might be through H-bonding, hydrophobic interactions, benzene ring interaction by p–p stacking, and changes in water structure at the membrane polymer surface. The nature of membranes (chemistry on the surface and pore size) and the nature of feed (pH and salt content) control the adsorptive fouling. Due to the fouling, the water flux reduction takes place. The impact of water flux reduced due to polyphenolic compound (PPC) adsorptive fouling was higher than protein fouling. Ethanol treatment of polymeric membranes to improve the performance of multiple foul-clean cycles is also explored **[108]**. It facilitates better transmission of polyphenolic compounds and surface charge of the membranes, though reducing the negative surface charge following treatment resulted in detrimental performance. The performance of the nanofiltration membrane (NF 270 (MWCO 270) and NTR-7450 (MWCO 700)) was analyzed. NF 270 membrane showed 90% rejection, whereas NTR 7450 membrane experienced 94% rejection **[109]**.

The combination of ultrafiltration and reverse osmosis treatment for the clarification and concentration of tea extracts is explored **[99]**. The catechin content was high in the retentate >100KPa pressures in all types of filtration processes studied compared to the original content of fresh green leaves. Rao *et al.* developed a hybrid technique consisting of ultrafiltration, silica gel, and chitosan treatment for clarification **[110]**. The silica gel and chitosan treatment decreased haze-active protein significantly. The post-treatment through ultrafiltration (10 kDa regenerated cellulose membrane, Shanghai Mosu Instrument Co., Ltd. (Shanghai, China)) reduced the protein content considerably from 11.36 to 5.85 mg/100 mL. The regenerated cellulose commercial membranes were used.

3. Future Directions

The convergence of tea polyphenols and membranes presents a pivotal moment brimming with possibilities and challenges in the health sector. These two factors stand as the primary catalysts for rapid advancements in this field. The continuous improvement of membrane technology to enhance performance is an ongoing endeavor. One of the key areas of focus is the mitigation of fouling on the membrane. Researchers have been diligently orchestrating the overall direction, particularly in terms of hybrid technologies. However, a systematic approach is required to fully exploit this potential.

4. Conclusions

Perceptions regarding the relationship between human health and natural resources can significantly influence the direction of research. Leveraging natural resources has the potential to promote well-being and prevent diseases. By combining these resources with advanced technologies, greater benefits can be achieved for individuals. In this context, the quest for improved methods of tea clarification has been discussed, including their unique features and limitations. Membrane techniques have emerged as a prominent solution, as they enable the production of natural and additive-free ready-to-drink (RTD) tea. Additionally, specific membrane types such as ultrafiltration and nanofiltration, along with their respective performance capabilities, have been highlighted.

Authors' Contributions

Mayank Saxena: Literature survey and writing. A. Bhattacharya: conceptualization, drafting, editing, and communication.

Funding

This work was supported by the Council of Scientific & Industrial Research (CSIR) for a research fellowship [grant number 31/28(0261)/0291-EMR-I].

Conflict of Interest

The authors declare no conflicts of interest.

References

[1] Chang K. World tea production and trade Current and future development 2015.

[2] Rumpler W, Seale J, Clevidence B, Judd J, Wiley E, Yamamoto S, *et al*. Oolong tea increases metabolic rate and fat oxidation in men. The Journal of Nutrition 2001;131:2848–52. https://doi.org/10.1093/jn/131.11.2848.

[3] Sun L, Wang H, Wang Z, He S, Chen S, Liao D, *et al*. Mixed lineage kinase domain-like protein mediates necrosis signaling downstream of RIP3 kinase. Cell 2012;148:213–27. https://doi.org/10.1016/j.cell.2011.11.031.

[4] Balentine DA, Wiseman SA, Bouwens LCM. The chemistry of tea flavonoids. Critical Reviews in Food Science and Nutrition 1997;37:693–704. https://doi.org/10.1080/10408399709527797.

[5] Chu D-C, Juneja L. General chemical composition of green tea and its infusion. In: Yamamoto T, Juneja L, Chu D-C, Kim M, editors. Chemistry and Applications of Green Tea, New York: CRC Press LLC; 1997, p. 13–22.

[6] Mira L, Fernandez MT, Santos M, Rocha R, Florêncio MH, Jennings KR. Interactions of flavonoids with iron and copper ions: a mechanism for their antioxidant activity. Free Radic Res 2002;36:1199–208. https://doi.org/10.1080/1071576021000016463.

[7] 59th Annual tea report. India: Tea Board; 2012.

[8] Harbowy ME, Balentine DA, Davies AP, Cai Y. Tea chemistry. Critical Reviews in Plant Sciences 1997;16:415–80. https://doi.org/10.1080/07352689709701956.

[9] Zheng J-S, Yang J, Fu Y-Q, Huang T, Huang Y-J, Li D. Effects of green tea, black tea, and coffee consumption on the risk of esophageal cancer: a systematic review and meta-analysis of observational studies. Nutrition and Cancer 2013;65:1–16. https://doi.org/10.1080/01635581.2013.741762.

[10] Sarkar A, Bhaduri A. Black tea is a powerful Chemopreventor of reactive oxygen and nitrogen species: comparison with its individual catechin constituents and green tea. Biochemical and Biophysical Research Communications 2001;284:173–8. https://doi.org/10.1006/bbrc.2001.4944.

[11] Chavan UD, Shahidi F, Naczk M. Extraction of condensed tannins from beach pea (Lathyrus maritimus L.) as affected by different solvents. Food Chemistry 2001;75:509–12. https://doi.org/10.1016/S0308-8146(01)00234-5.

[12] Goli AH, Barzegar M, Sahari MA. Antioxidant activity and total phenolic compounds of pistachio (Pistachia vera) hull extracts. Food Chemistry 2005;92:521–5. https://doi.org/10.1016/j.foodchem.2004.08.020.

[13] Zuo Y, Chen H, Deng Y. Simultaneous determination of catechins, caffeine and gallic acids in green, Oolong, black and pu-erh teas using HPLC with a photodiode array detector. Talanta 2002;57:307–16. https://doi.org/10.1016/S0039-9140(02)00030-9.

[14] Sun T, Ho C-T. Antioxidant activities of buckwheat extracts. Food Chemistry 2005;90:743–9. https://doi.org/10.1016/j.foodchem.2004.04.035.

[15] Filip R, Ferraro GE. Researching on new species of "Mate": Ilex brevicuspis. Eur J Nutr 2003;42:50–4. https://doi.org/10.1007/s00394-003-0399-1.

[16] Khokhar S, Magnusdottir SGM. Total phenol, catechin, and caffeine contents of teas commonly consumed in the United Kingdom. J Agric Food Chem 2002;50:565–70. https://doi.org/10.1021/jf010153l.

[17] Larger PJ, Jones AD, Dacombe C. Separation of tea polyphenols using micellar electrokinetic chromatography with diode array detection. Journal of Chromatography A 1998;799:309–20. https://doi.org/10.1016/S0021-9673(97)01062-5.

[18] Lee B-L, Ong C-N. Comparative analysis of tea catechins and theaflavins by high-performance liquid chromatography and capillary electrophoresis. Journal of Chromatography A 2000;881:439–47. https://doi.org/10.1016/S0021-9673(00)00215-6.

[19] Liang Y, Lu J, Zhang L, Wu S, Wu Y. Estimation of black tea quality by analysis of chemical composition and colour difference of tea infusions. Food Chemistry 2003;80:283–90. https://doi.org/10.1016/S0308-8146(02)00415-6.

[20] Obanda M, Okinda Owuor P, Mang'oka R. Changes in the chemical and sensory quality parameters of black tea due to variations of fermentation time and temperature. Food Chemistry 2001;75:395–404. https://doi.org/10.1016/S0308-8146(01)00223-0.

[21] Pomilio AB, Trajtemberg S, Vitale AA. High-performance capillary electrophoresis analysis of mate infusions prepared from stems and leaves of Ilex paraguariensis using automated micellar electrokinetic capillary chromatography. Phytochemical Analysis 2002;13:235–41. https://doi.org/10.1002/pca.647.

[22] Del Pero Martínez MA, Pelotto JP, Basualdo N. Distribution of flavonoid aglycones in Ilex species (Aquifoliaceae). Biochemical Systematics and Ecology 1997;25:619–22. https://doi.org/10.1016/S0305-1978(97)00054-9.

[23] Wang H, Helliwell K. Determination of flavonols in green and black tea leaves and green tea infusions by high-performance liquid chromatography. Food Research International 2001;34:223–7. https://doi.org/10.1016/S0963-9969(00)00156-3.

[24] Yao LH, Jiang YM, Shi J, Tomas-Barberan FA, Datta N, Singanusong R, *et al*. Flavonoids in Food and Their Health Benefits. Plant Foods Hum Nutr 2004;59:113–22. https://doi.org/10.1007/s11130-004-0049-7.

[25] Opie SC, Robertson A, Clifford MN. Black tea thearubigins—their HPLC separation and preparation during in-vitro oxidation. Journal of the Science of Food and Agriculture 1990;50:547–61. https://doi.org/10.1002/jsfa.2740500412.

[26] Zhou K, Yu L. Effects of extraction solvent on wheat bran antioxidant activity estimation. LWT - Food Science and Technology 2004;37:717–21. https://doi.org/10.1016/j.lwt.2004.02.008.

[27] Subramanian R, Kumar CS, Sharma P. Membrane clarification of tea extracts. Critical Reviews in Food Science and Nutrition 2014;54:1151–7. https://doi.org/10.1080/10408398.2011.628424.

[28] Todisco S, Tallarico P, Gupta BB. Mass transfer and polyphenols retention in the clarification of black tea with ceramic membranes. Innovative Food Science & Emerging Technologies 2002;3:255–62. https://doi.org/10.1016/S1466-8564(02)00046-2.

[29] Tolstoguzov V. Thermodynamic aspects of biopolymer functionality in biological systems, foods, and beverages. Critical Reviews in Biotechnology 2002;22:89–174. https://doi.org/10.1080/07388550290789478.

[30] Hagerman AE, Riedl KM, Jones GA, Sovik KN, Ritchard NT, Hartzfeld PW, *et al*. High molecular weight plant Polyphenolics (Tannins) as biological antioxidants. J Agric Food Chem 1998;46:1887–92. https://doi.org/10.1021/jf970975b.

[31] Chandini SK, Rao LJ, Gowthaman MK, Haware DJ, Subramanian R. Enzymatic treatment to improve the quality of black tea extracts. Food Chemistry 2011;127:1039–45. https://doi.org/10.1016/j.foodchem.2011.01.078.

[32] Sun M-F, Jiang C-L, Kong Y-S, Luo J-L, Yin P, Guo G-Y. Recent advances in analytical methods for determination of polyphenols in tea: a comprehensive review. Foods 2022;11:1425. https://doi.org/10.3390/foods11101425.

[33] Yong Y, Su-Fang Z, Shao-Min S, Chuan D. Determination of tea polyphenols in tea by 1.10-phenanthroline-iron( ) indicator. Food Science 2008;29:403.

[34] Ren G, Xue P, Sun X, Zhao G. Determination of the volatile and polyphenol constituents and the antimicrobial, antioxidant, and tyrosinase inhibitory activities of the bioactive compounds from the by-product of Rosa rugosa Thunb. var. plena Regal tea. BMC Complement Altern Med 2018;18:307. https://doi.org/10.1186/s12906-018-2374-7.

[35] Hidayat MA, Puspitaningtyas N, Gani AA, Kuswandi B. Rapid test for the determination of total phenolic content in brewed-filtered coffee using colorimetric paper. J Food Sci Technol 2017;54:3384–90. https://doi.org/10.1007/s13197-017-2757-7.

[36] Paiva L, Lima E, Motta M, Marcone M, Baptista J. Variability of antioxidant properties, catechins, caffeine, L-theanine and other amino acids in different plant parts of Azorean Camellia sinensis. Current Research in Food Science 2020;3:227–34. https://doi.org/10.1016/j.crfs.2020.07.004.

[37] Turkmen N, Sari F, Velioglu YS. Effects of extraction solvents on concentration and antioxidant activity of black and black mate tea polyphenols determined by ferrous tartrate and Folin–Ciocalteu methods. Food Chemistry 2006;99:835–41. https://doi.org/10.1016/j.foodchem.2005.08.034.

[38] Obanda M, Owuor PO, Taylor SJ. Flavanol composition and caffeine content of green leaf as quality potential indicators of Kenyan black teas. Journal of the Science of Food and Agriculture 1997;74:209–15. https://doi.org/10.1002/(SICI)1097-0010(199706)74:2<209::AID-JSFA789>3.0. CO;2-4.

[39] Saikrithika S, Senthil Kumar A. Electrochemical detections of tea polyphenols: a review. Electroanalysis 2020;32:2343–60. https://doi.org/10.1002/elan.202060061.

[40] Jiang H, Xu W, Chen Q. Determination of tea polyphenols in green tea by homemade color sensitive sensor combined with multivariate analysis. Food Chemistry 2020;319:126584. https://doi.org/10.1016/j.foodchem.2020.126584.

[41] Goto T, Yoshida Y, Kiso M, Nagashima H. Simultaneous analysis of individual catechins and caffeine in green tea. Journal of Chromatography A 1996;749:295–9. https://doi.org/10.1016/0021-9673(96)00456-6.

[42] Perumalla AVS, Hettiarachchy NavamS. Green tea and grape seed extracts — Potential applications in food safety and quality. Food Research International 2011;44:827–39. https://doi.org/10.1016/j.foodres.2011.01.022.

[43] Vural N, Algan Cavuldak Ö, Akay MA, Anlı RE. Determination of the various extraction solvent effects on polyphenolic profile and antioxidant activities of selected tea samples by chemometric approach. Food Measure 2020;14:1286–305. https://doi.org/10.1007/s11694-020-00376-6.

[44] Wu C, Xu H, Héritier J, Andlauer W. Determination of catechins and flavonol glycosides in Chinese tea varieties. Food Chemistry 2012;132:144–9. https://doi.org/10.1016/j.foodchem.2011.10.045.

[45] Zhao F, Lin H-T, Zhang S, Lin Y-F, Yang J-F, Ye N-X. Simultaneous determination of caffeine and some selected polyphenols in Wuyi rock tea by high-performance liquid chromatography. J Agric Food Chem 2014;62:2772–81. https://doi.org/10.1021/jf4056314.

[46] Motilva M-J, Serra A, Macià A. Analysis of food polyphenols by ultra high-performance liquid chromatography coupled to mass spectrometry: An overview. Journal of Chromatography A 2013;1292:66–82. https://doi.org/10.1016/j.chroma.2013.01.012.

[47] Crespy V, Williamson G. A review of the health effects of green tea catechins in in vivo animal models. The Journal of Nutrition 2004;134:3431S-3440S. https://doi.org/10.1093/jn/134.12.3431S.

[48] Koo MWL, Cho CH. Pharmacological effects of green tea on the gastrointestinal system. European Journal of

Pharmacology 2004;500:177–85. https://doi.org/10.1016/j.ejphar.2004.07.023.

[49] Meydani M. Vitamin E and atherosclerosis: beyond prevention of LDL oxidation. The Journal of Nutrition 2001;131:366S-368S. https://doi.org/10.1093/jn/131.2.366S.

[50] Zaveri NT. Green tea and its polyphenolic catechins: Medicinal uses in cancer and noncancer applications. Life Sciences 2006;78:2073–80. https://doi.org/10.1016/j.lfs.2005.12.006.

[51] Tsuneki H, Ishizuka M, Terasawa M, Wu J-B, Sasaoka T, Kimura I. Effect of green tea on blood glucose levels and serum proteomic patterns in diabetic (db/db) mice and on glucose metabolism in healthy humans. BMC Pharmacology 2004;4:18. https://doi.org/10.1186/1471-2210-4-18.

[52] Mukhtar H, Wang ZY, Katiyar SK, Agarwal R. Tea components: Antimutagenic and anticarcinogenic effects. Preventive Medicine 1992;21:351–60. https://doi.org/10.1016/0091-7435(92)90042-G.

[53] Sano M, Takahashi Y, Yoshino K, Shimoi K, Nakamura Y, Tomita I, *et al.* Effect of tea (Camellia sinensis L.) on lipid peroxidation in rat liver and kidney: a comparison of green and black tea feeding. Biological & Pharmaceutical Bulletin 1995;18:1006–8. https://doi.org/10.1248/bpb.18.1006.

[54] Hara Y. Advances in food science and Technology. Nippon Shokuhin Kogyo Gakkai, Korin, Tokyo 1990:21–39.

[55] Yam TS, Hamilton-Miller JM, Shah S. The effect of a component of tea (Camellia sinensis) on methicillin resistance, PBP2' synthesis, and beta-lactamase production in Staphylococcus aureus. Journal of Antimicrobial Chemotherapy 1998;42:211–6. https://doi.org/10.1093/jac/42.2.211.

[56] Pan T, Jankovic J, Le W. Potential therapeutic properties of green tea polyphenols in Parkinson's disease. Drugs Aging 2003;20:711–21. https://doi.org/10.2165/00002512-200320100-00001.

[57] Sagesaka-Mitane Y, Miwa M, Okada S. Platelet aggregation inhibitors in hot water extract of green tea. Chemical & Pharmaceutical Bulletin 1990;38:790–3. https://doi.org/10.1248/cpb.38.790.

[58] Ishizuka H, Eguchi H, Oda T, Ogawa S, Nakagawa K, Honjo S, *et al.* Relation of coffee, green tea, and caffeine intake to gallstone disease in middle-aged Japanese men. Eur J Epidemiol 2003;18:401–5. https://doi.org/10.1023/A:1024237927985.

[59] Wu C-H, Lu F-H, Chang C-S, Chang T-C, Wang R-H, Chang C-J. Relationship among habitual tea consumption, percent body fat, and body fat distribution. Obesity Research 2003;11:1088–95. https://doi.org/10.1038/oby.2003.149.

[60] Takabayashi F, Harada N, Yamada M, Murohisa B, Oguni I. Inhibitory effect of green tea catechins in combination with sucralfate on Helicobacter pylori infection in Mongolian gerbils. J Gastroenterol 2004;39:61–3. https://doi.org/10.1007/s00535-003-1246-0.

[61] Yee Y-K, Koo MW-L, Szeto M-L. Chinese tea consumption and lower risk of Helicobacter infection. Journal of Gastroenterology and Hepatology 2002;17:552–5. https://doi.org/10.1046/j.1440-1746.2002.02718.x.

[62] Toda M, Okubo S, Hiyoshi R, Shimamura T. The bactericidal activity of tea and coffee. Letters in Applied Microbiology 1989;8:123–5. https://doi.org/10.1111/j.1472-765X.1989.tb00255.x.

[63] Mukoyama M, Nakao K, Hosoda K, Suga S, Saito Y, Ogawa Y, *et al.* Brain natriuretic peptide as a novel cardiac hormone in humans. Evidence for an exquisite dual natriuretic peptide system, atrial natriuretic peptide and brain natriuretic peptide. J Clin Invest 1991;87:1402–12. https://doi.org/10.1172/JCI115146.

[64] Ivanov V, Roomi MW, Kalinovsky T, Niedzwiecki A, Rath M. Anti-atherogenic effects of a mixture of ascorbic acid, lysine, proline, arginine, cysteine, and green tea phenolics in human aortic smooth muscle cells. Journal of Cardiovascular Pharmacology 2007;49:140. https://doi.org/10.1097/FJC.0b013e3180308489.

[65] Anandh Babu P, Sabitha K, Shyamaladevi C. Green tea extract impedes dyslipidaemia and development of cardiac dysfunction in streptozotocin-diabetic rats. Clinical and Experimental Pharmacology and Physiology 2006;33:1184–9. https://doi.org/10.1111/j.1440-1681.2006.04509.x.

[66] Unno K, Takabayashi F, Yoshida H, Choba D, Fukutomi R, Kikunaga N, *et al.* Daily consumption of green tea catechin delays memory regression in aged mice. Biogerontology 2007;8:89–95. https://doi.org/10.1007/s10522-006-9036-8.

[67] Shim JS, Kang MH, Kim YH, Roh JK, Roberts C, Lee IP. Chemopreventive effect of green tea (Camellia sinensis) among cigarette smokers. Cancer Epidemiol Biomarkers Prev 1995;4:387–91.

[68] McKay DL, Blumberg JB. The role of tea in human health: an update. Journal of the American College of Nutrition 2002;21:1–13. https://doi.org/10.1080/07315724.2002.10719187.

[69] Fang MZ, Wang Y, Ai N, Hou Z, Sun Y, Lu H, *et al.* Tea polyphenol (-)-epigallocatechin-3-gallate inhibits DNA methyltransferase and reactivates methylation-silenced genes in cancer cell lines. Cancer Res 2003;63:7563–70.

[70] Hirasawa M, Takada K. Multiple effects of green tea catechin on the antifungal activity of antimycotics against Candida albicans. Journal of Antimicrobial Chemotherapy 2004;53:225–9. https://doi.org/10.1093/jac/dkh046.

[71] Muraki S, Yamamoto S, Ishibashi H, Horiuchi T, Hosoi T, Suzuki T, *et al.* Green tea drinking is associated with increased bone mineral density among elderly women. Journal of Bone and Mineral Research 2003;18:S241.

[72] Park H, Ko S, Kim J, Kim S. Effects of green tea extracts and polyphenols on the proliferation and activity of bone cells. Journal of Bone and Mineral Research 2003;18:S342.

[73] Dorchies O, Wagner S, Waldhauser K, Buetler T, Ruegg U. Anti-fibrotic properties of green tea catechins on mouse muscle cell cultures, 2003, p. 639–639.

[74] Sakata R, Ueno T, Nakamura T, Sakamoto M, Torimura T, Sata M. Green tea polyphenol epigallocatechin-3-gallate inhibits platelet-derived growth factor-induced proliferation of human hepatic stellate cell line LI90. Journal of Hepatology 2004;40:52–9. https://doi.org/10.1016/S0168-8278(03)00477-X.

[75] Gupta SK, Halder N, Srivastava S, Trivedi D, Joshi S, Varma SD. Green tea (Camellia sinensis) protects against selenite-induced oxidative stress in experimental cataractogenesis. Ophthalmic Research 2002;34:258–63. https://doi.org/10.1159/000063881.

[76] Skrzydlewska E, Ostrowska J, Farbiszewski R, Michalak K. Protective effect of green tea against lipid peroxidation in the rat liver, blood serum and the brain. Phytomedicine 2002;9:232–8. https://doi.org/10.1078/0944-7113-00119.

[77] Xia T, Shi S, Wan X. Impact of ultrasonic-assisted extraction on the chemical and sensory quality of tea infusion. Journal of Food Engineering 2006;74:557–60. https://doi.org/10.1016/j.jfoodeng.2005.03.043.

[78] Su X, Duan J, Jiang Y, Shi J, Kakuda Y. Effects of soaking conditions on the antioxidant potentials of oolong tea. Journal of Food Composition and Analysis 2006;19:348–53. https://doi.org/10.1016/j.jfca.2005.02.005.

[79] Wang L, Qin P, Hu Y. Study on the microwave-assisted extraction of polyphenols from tea. Front Chem Eng China 2010;4:307–13. https://doi.org/10.1007/s11705-009-0282-6.

[80] Banerjee S, Chatterjee J. Efficient extraction strategies of tea (Camellia sinensis) biomolecules. J Food Sci Technol 2015;52:3158–68. https://doi.org/10.1007/s13197-014-1487-3.

[81] Turkmen N, Velioglu YS, Sari F, Polat G. Effect of extraction conditions on measured total polyphenol contents and antioxidant and antibacterial activities of black tea. Molecules 2007;12:484–96. https://doi.org/10.3390/12030484.

[82] John K, Vijayan D, Kumar R, Premkumar R. Factors Influencing the Efficiency of Extraction of Polyphenols from Young Tea Leaves. Asian J Plant Sci 2006;5:123–6. https://doi.org/10.3923/ajps.2006.123.126.

[83] Both S, Chemat F, Strube J. Extraction of polyphenols from black tea – Conventional and ultrasound assisted extraction. Ultrasonics Sonochemistry 2014;21:1030–4. https://doi.org/10.1016/j.ultsonch.2013.11.005.

[84] Shirsath SR, Sonawane SH, Gogate PR. Intensification of extraction of natural products using ultrasonic irradiations—A review of current status. Chemical Engineering and Processing: Process Intensification 2012;53:10–23. https://doi.org/10.1016/j.cep.2012.01.003.

[85] Chemat F, Rombaut N, Sicaire A-G, Meullemiestre A, Fabiano-Tixier A-S, Abert-Vian M. Ultrasound assisted extraction of food and natural products. Mechanisms, techniques, combinations, protocols and applications. A review. Ultrasonics Sonochemistry 2017;34:540–60. https://doi.org/10.1016/j.ultsonch.2016.06.035.

[86] Iskalieva A, Yimmou BM, Gogate PR, Horvath M, Horvath PG, Csoka L. Cavitation assisted delignification of wheat straw: A review. Ultrasonics Sonochemistry 2012;19:984–93. https://doi.org/10.1016/j.ultsonch.2012.02.007.

[87] Kataoka H. Pharmaceutical analysis | sample preparation. In: Worsfold P, Poole C, Townshend A, Miró M, editors. Encyclopedia of Analytical Science (Third Edition), Oxford: Academic Press; 2019, p. 231–55. https://doi.org/10.1016/B978-0-12-409547-2.14358-6.

[88] Li D-C, Jiang J-G. Optimization of the microwave-assisted extraction conditions of tea polyphenols from green tea. International Journal of Food Sciences and Nutrition 2010;61:837–45. https://doi.org/10.3109/09637486.2010.489508.

[89] Shouqin Z, Junjie Z, Changzhen W. Novel high pressure extraction technology. International Journal of Pharmaceutics 2004;278:471–4. https://doi.org/10.1016/j.ijpharm.2004.02.029.

[90] Knorr D. Effects of high-hydrostatic-pressure processes on food safety and quality. Food Technol (Chic) 1993;47:156–61.

[91] Xi J, Shen D, Zhao S, Lu B, Li Y, Zhang R. Characterization of polyphenols from green tea leaves using a high hydrostatic pressure extraction. International Journal of Pharmaceutics 2009;382:139–43. https://doi.org/10.1016/j.ijpharm.2009.08.023.

[92] Xu R, Ye H, Sun Y, Tu Y, Zeng X. Preparation, preliminary characterization, antioxidant, hepatoprotective and antitumor activities of polysaccharides from the flower of tea plant (Camellia sinensis). Food and Chemical Toxicology 2012;50:2473–80. https://doi.org/10.1016/j.fct.2011.10.047.

[93] Jun X. Caffeine extraction from green tea leaves assisted by high pressure processing. Journal of Food Engineering 2009;94:105–9. https://doi.org/10.1016/j.jfoodeng.2009.03.003.

[94] Prasad KN, Yang E, Yi C, Zhao M, Jiang Y. Effects of high pressure extraction on the extraction yield, total phenolic content and antioxidant activity of longan fruit pericarp. Innovative Food Science & Emerging Technologies 2009;10:155–9. https://doi.org/10.1016/j.ifset.2008.11.007.

[95] Kim W, Kim J, Oh S. Supercritical carbon dioxide extraction of caffeine from Korean green tea. Separation Science and Technology 2007;42:3229–42. https://doi.org/10.1080/01496390701513008.

[96] Kim W-J, Kim J-D, Kim J, Oh S-G, Lee Y-W. Selective caffeine removal from green tea using supercritical carbon dioxide extraction. Journal of Food Engineering 2008;89:303–9. https://doi.org/10.1016/j.jfoodeng.2008.05.018.

[97] Herrero M, Cifuentes A, Ibañez E. Sub- and supercritical fluid extraction of functional ingredients from different natural sources: Plants, food-by-products, algae and microalgae: A review. Food Chemistry 2006;98:136–48. https://doi.org/10.1016/j.foodchem.2005.05.058.

[98] Park HS, Lee HJ, Shin MH, Lee K-W, Lee H, Kim Y-S, *et al.* Effects of cosolvents on the decaffeination of green tea by supercritical carbon dioxide. Food Chemistry 2007;105:1011–7. https://doi.org/10.1016/j.foodchem.2007.04.064.

[99] Ramarethinam S, Anitha G, Latha K. Standardization of conditions for effective clarification and concentration of green tea extract by membrane filtration. Journal of Scientific & Industrial Research 2006;65:821–5.

[100] Chandini SK, Rao LJ, Subramanian R. Membrane clarification of black tea extracts. Food Bioprocess Technol 2013;6:1926–43. https://doi.org/10.1007/s11947-012-0847-0.

[101] Evans PJ, Bird MR. Solute-membrane fouling interactions during the ultrafiltration of black tea liquor. Food and Bioproducts Processing 2006;84:292–301. https://doi.org/10.1205/fbp06030.

[102] Evans PJ, Bird MR, Pihlajamäki A, Nyström M. The influence of hydrophobicity, roughness and charge upon ultrafiltration membranes for black tea liquor clarification. Journal of Membrane Science 2008;313:250–62. https://doi.org/10.1016/j.memsci.2008.01.010.

[103] Evans PJ, Bird MR. The role of black tea feed conditions upon ultrafiltration performance during membrane fouling and cleaning. Journal of Food Process Engineering 2010;33:309–32. https://doi.org/10.1111/j.1745-4530.2008.00276.x.

[104] Saxena M, Chaudhri SG, Das AK, Singh PS, Bhattacharya A. Cross-linked thin poly(vinyl alcohol) membrane supported on polysulfone in tea polyphenol separation. Separation Science and Technology 2019;54:343–59. https://doi.org/10.1080/01496395.2018.1519579.

[105] Mondal M, De S. Enrichment of (−) epigallocatechin gallate (EGCG) from aqueous extract of green tea leaves by hollow fiber microfiltration: Modeling of flux decline and identification of optimum operating conditions. Separation and Purification Technology 2018;206:107–17. https://doi.org/10.1016/j.seppur.2018.05.057.

[106] Wu D, Bird MR. The fouling and cleaning of ultrafiltration membranes during the filtration of model tea component solutions. Journal of Food Process Engineering 2007;30:293–323. https://doi.org/10.1111/j.1745-4530.2007.00115.x.

[107] Susanto H, Feng Y, Ulbricht M. Fouling behavior of aqueous solutions of polyphenolic compounds during ultrafiltration. Journal of Food Engineering 2009;91:333–40. https://doi.org/10.1016/j.jfoodeng.2008.09.011.

[108] Argyle IS, Pihlajamäki A, Bird MR. Black tea liquor ultrafiltration: Effect of ethanol pre-treatment upon fouling and cleaning characteristics. Food and Bioproducts Processing 2015;93:289–97. https://doi.org/10.1016/j.fbp.2014.10.010.

[109] Sun L, Li BMH, Khojah E, Arcot J. Membrane application for polyphenols concentration from black tea solution. Chemeca 2011: Engineering a Better World: Sydney Hilton Hotel, NSW, Australia, 18-21 September 2011, 2020, p. 2871–3. https://doi.org/10.3316/informit.194182435686712.

[110] Rao L, Hayat K, Lv Y, Karangwa E, Xia S, Jia C, *et al*. Effect of ultrafiltration and fining adsorbents on the clarification of green tea. Journal of Food Engineering 2011;102:321–6. https://doi.org/10.1016/j.jfoodeng.2010.09.007.

How to Cite
Saxena M, Bhattacharya A. Polymeric Membranes and Tea Polyphenols: A Perspective. Membrane Sci Int 2023;2(1):18–28.