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Review

Ultrasonication Effects on Quality of Tea-Based Beverages

Sibel Uzuner

Department of Food Engineering, Faculty of Engineering, Izmir Institute of Technology, Izmir 35430, Turkey; sibeluzuner@iyte.edu.tr

Abstract: Tea is the most popular consumed drink after water. Teas and tea-based beverages have grown in popularity due to bioactive compounds. Tea-based beverages have started to take their place in the market. Extraction is a crucial step for the production of functional tea-based beverages. Compared to conventional methods, ultrasound is attractive due to its lower energy requirements, and shorter extraction time. This review aimed to discuss recent marketing aspects of tea-based beverages as well as the potential and challenges of a novel infusion technique. This review describes the health benefits and technological aspects of tea-based beverages in relation to how to best solve nutritional and microbial concerns. Current and future challenges and opportunities of the novel infusion technique and its scaling-up for the extraction of bioactive compounds are also covered in the present review.

Keywords: tea; ultrasonication; tea beverages; ready-to-drink tea; bio-active compounds

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1. Introduction

Dried tea leaves contain approximately 230 bioactive compounds with relevant nutritional effects on human health [1]. Among these bioactive compounds, polyphenols represent the crucial compounds (30% of total dry weight). The industrial processes during tea production can affect the phenolic content, composition, and antioxidant properties. Tea preparation may lead to quantitative and qualitative changes in the extracted phenolic compounds [2]. Over the years, several studies have shown the antioxidant activities and polyphenol contents of green and black tea [3–5].

Efficient extraction is a vital step in the preparation of tea beverages to extract bioactive compounds with health benefits. To enhance the extraction of tea components, traditional extraction techniques such as heating are carried out [6]. Traditional thermal treatments, such as pasteurization, sterilization, and canning, are widely used in the food industry to produce safe food. However, nutritional properties, such as vitamins, antioxidants, and polyphenols as well as sensorial properties are affected during the thermal treatments [7]. The high energy and time consumption and low extraction yield are caused by conventional thermal treatments [8]. Recently, the use of novel technologies has been preferred and tested in food industries so as to produce microbiologically safe and good-quality products. Among other novel technologies, ultrasound/ultrasonic technology has been explored to enhance preservation, pasteurization, and extraction, and extend shelf life [9]. The main advantages of ultrasonication systems include less extraction time, less energy and solvent consumption, and high extraction yield [10].

There are many studies on ultrasound extraction of polyphenols from yellow tea [11], black tea [12], and green tea [6,13]. However, few studies have focused on the optimization of infusion parameters of green and black teas [5]. These studies have been limited to the health benefits of tea. The effect of ultrasonication on bioactive compounds and viable count for tea-based beverages still remains poorly understood. To deepen these beneficial effects derived from tea-based beverages on the market, it is essential to know how the total polyphenol content varies when novel technologies such as ultrasonication are applied for the infusion of tea-based beverages. This review describes different types of tea-based beverages, their sources, and their producers. This review also focuses on a novel extraction technique (ultrasound) for the infusion of tea-based beverages. Challenges in the industrial setup of ultrasound systems for tea-based beverages are discussed at the end of this review.

2. Tea

Tea (*Camellia sinensis* L.) is a widely consumed beverage by all age groups that belongs to the Theaceae family [14]. Tea production starts with leaf collection, and then tea leaves are subjected to oxidative and hydrolysis processes in leaf cells using endogenous enzymes such as polyphenol oxidase and peroxidase [15]. The tea is categorized as green tea, black tea, white tea, pu-erh tea, and oolong tea based on processing [14] (Figure 1). Based on the degree of enzymatic oxidation, black tea is fully fermented, white tea is lightly fermented, green tea is not fermented, and oolong tea is semi-fermented [16]. The processing of pu-erh tea involves additional microbial fermentation [17].

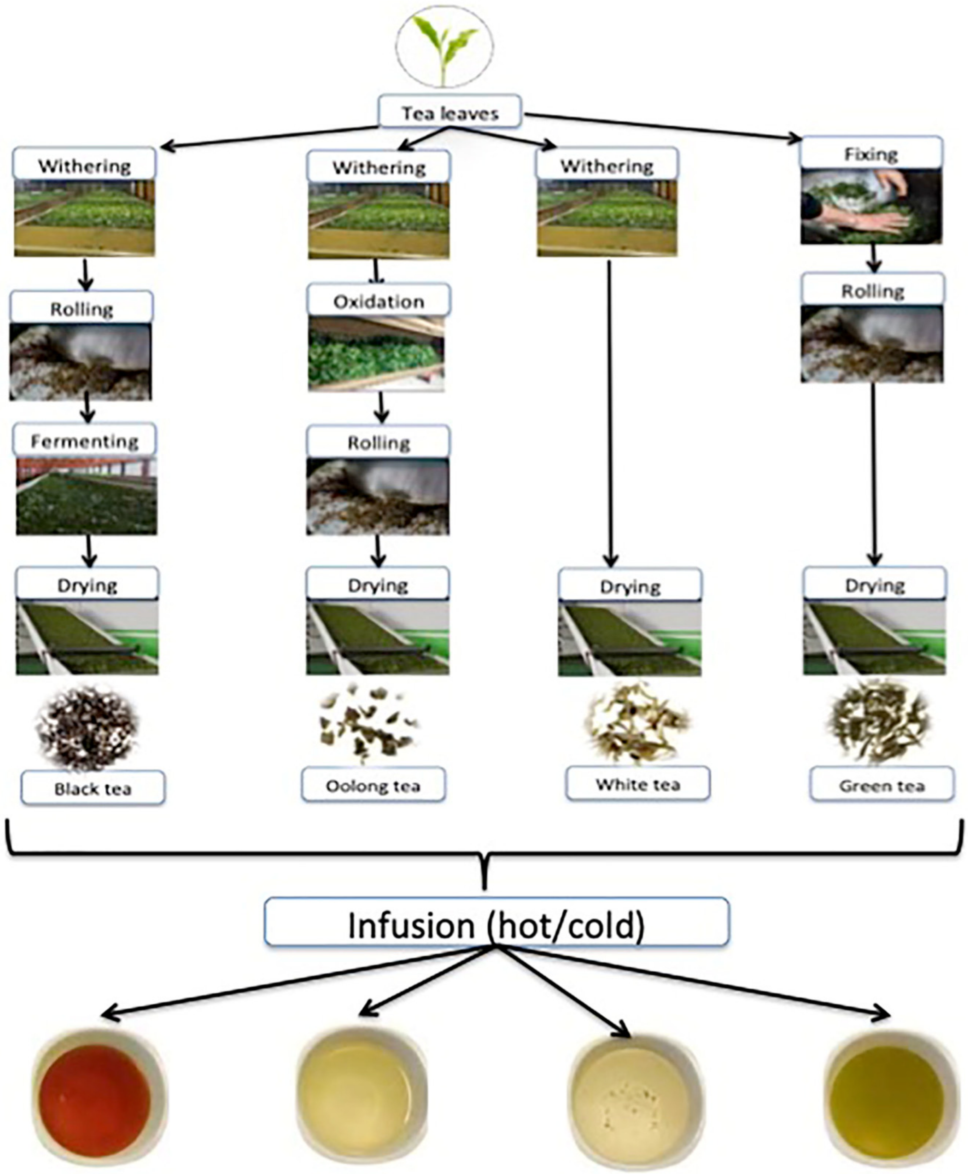

Figure 1. The manufacturing process steps of tea production.

Western countries, especially those in Europe, the United Kingdom, and the United States, consume black tea [18], whereas Far-Eastern countries, especially Japan, Korea, and Northern China consume green tea [19]. Besides, southern China and Taiwan consume oolong tea [20]. Green tea, black tea, and oolong tea are manufactured in the following approximate proportions annually all around the world: 22%, 78%, and 2% [21]. In comparison to black tea and green tea, white tea and pu-erh tea are less well-known. However, the popularity of white tea has been rising in Europe [22]. Tea is mostly consumed after brewing dried tea leaves in hot water (95–100 °C) [23]. Tea consumption may change based on individual preferences. For instance, in Western countries, placing bagged black tea leaves in hot water at 100 °C for a short infusing time (<3 min) is preferred, whereas, in Pakistan, India, and some Middle Eastern countries, black tea leaves are boiled in a pot for longer. In Japan and China, green tea leaves are steeped in hot but not boiling water [24].

In tea processing, the bud and the first few leaves are the most commonly used for high-quality tea production [25]. The bud and the top and the second leaf are used for the production of white tea [26]. The youngest buds of the plant are used to produce white tea, whereas the leaves of the plant and the buds are used for green tea production [27].

Most studies have focused on the health benefits of tea and its components, such as polyphenols and catechins. The polyphenol content of tea changes during the growing conditions and method of leaf processing. The primary polyphenols found in tea are catechins which are (-)-epigallocatechin-3-gallate (EGCG), (-)-epicatechin-3-gallate (EKG), (-)-epigallocatechin (EGC), and (-)-epicatechin (EC) [28]. Green tea (unfermented) has more catechin than black tea (fermented) and oolong tea (semi-fermented) [29]. The catechins are most abundant in green tea, such as epicatechin (EC), (-)-epicatechin-3-gallate (ECG), (-)-epigallocatechin (EGC), (-)-epigallocatechin-3-gallate (EGCG), (+)-catechin, and (+)-gallocatechin (GC). However, a high level of theaflavins is found in black tea [30]. Oolong tea, which is partially fermented, is rich in catechins and theaflavins [31]. The amount of theaflavins and thearubigin increases, whereas catechin content decreases during the fermentation of tea leaves [32].

3. Tea-Based Beverages

Consumers have changed their consumption behaviors in response to emergent food styles, such as the increased consumption of ready-to-drink tea. Especially, young consumers seek out healthy food choices. The health benefits of tea beverages have gained popularity. Then, the global tea market has grown in popularity worldwide due to commercial advertisements and healthier food choices. This has caused producers to develop new forms of tea products. For example, for American and European consumers, mate tea has been mixed with other herbs and ingredients, such as mint, citrus, milk, etc., due to its grassy and smoky taste and aroma [33]. Producers are developing new types of tea by making instant products and ready-to-drink (RTD) teas by combining tea with other ingredients such as soda and juice [33]. So, tea-based beverages and RTD tea have become popular not only in health food stores but also in mainstream supermarkets. Recently, young consumers have become more interested in RTD beverages compared with instant teas [33].

Tea beverages can be categorized as liquid tea beverages (ready-to-drink tea beverages, tea wine, kombucha, and tea concentrate) and solid tea drinks (mainly tea, and solid milk tea) (Figure 2). RTD tea beverages are consumed in bottles or cans [34].

3.1. Instant Tea

The preparation steps for instant tea consist of soaking tea leaves in hot water, concentration, sterilization, and drying [35]. Instant teas have longer shelf life compared with fresh tea. However, it is of lower quality than fresh tea, has a loss of aroma and flavor, and has a high production cost.

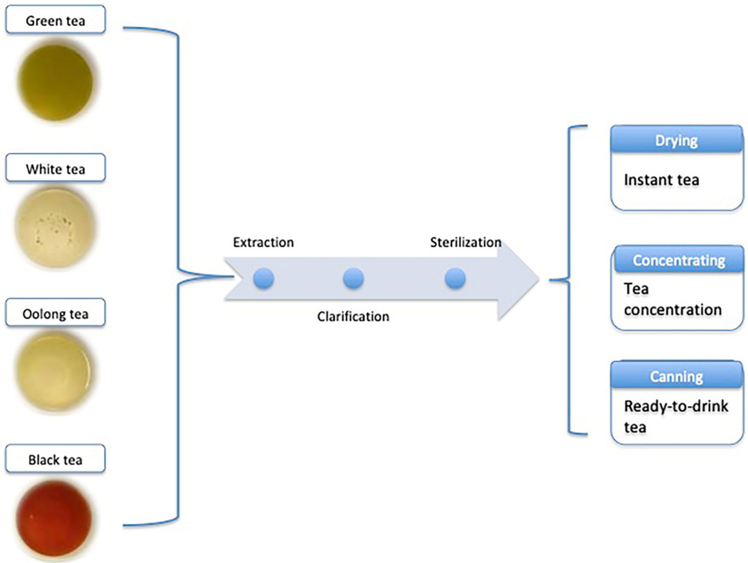

Figure 2. Processing of tea beverages.

3.2. Tea Concentrates

Tea concentrates have become a popular alternative beverage that is of better quality than dried tea. Tea concentrate is derived from concentrated tea extract in liquid or solid form. Concentrates contain up to 35% solids [36]. Concentrates can be used to make tea-based beverages [37]. Tea concentrate is the raw material for RTD tea beverages.

3.3. Ready-to-Drink Tea Beverages

Tea, sugar, and additives are used to prepare RTD tea, which is consumed hot or cold depending on a consumer's choice. RTD iced tea is prepared from mostly black or green tea and consumed cold [38]. RTD iced tea can be made from tea extract (powder or concentrate) or a freshly brewed extract. This tea extract is dissolved in water and combined with other ingredients such as sweeteners, flavors, and acidity regulators [38].

Cold tea beverages such as carbonated teas, iced milk teas, and ready-to-drink (RTD) tea products have started to appear in the market. The RTD tea market size was USD 29.66 billion in 2019 and is estimated to reach USD 38.96 billion by 2027 [39]. The black tea segment was the highest contributor to the market, estimated to reach USD 17.09 billion by 2027. Green tea-related products and cold teas with different fermentation products are also growing in the market [39]. The leading companies for RTD include The Coca-Cola Company, PepsiCo Inc., Pokka Corporation, Nestle S.A., Lucozade Ribena Suntory, Danone SA, Starbucks Corporation, and Unilever. Many types of RTD iced tea such as Lipton (Unilever), pure leaf (Pepsico-Unilever), Nestea (Nestle), Fuze iced tea (The Coca Cola Company), Teavana (Starbucks and Tata) are available in the market [38] (Table 1).

Table 1. Types of tea-based beverages in the market.

Brand Name	Ingredients	Producers/Country	References
Black milk tea	Sri Lankan black tea, whole milk taste, cane sugar	ITO EN/Tokyo, Japan	[40]
Matcha milk tea	Japanese matcha, whole milk taste, cane sugar	ITO EN/Tokyo, Japan	[40]
Tea's tea (Ice-steeped cold brew tea)	Green tea, jasmine or peppermint leaves, water, ascorbic acid	ITO EN/Tokyo, Japan	[40]

Table 1. *Cont.*

Brand Name	Ingredients	Producers/Country	References
Cold brew matcha green tea	Purified water, green tea, Matcha, and ascorbic acid	ITO EN/Tokyo, Japan	[40]
Nestea Instant tea mixes (sweetened and unsweetened)	Black, green, white, and red tea blends and flavors	Nestle/Vevey, Switzerland	[41]
Gold Peak Tea (sweetened and unsweetened)	Brewed green or black tea, cane sugar	The Coca-Cola Company/Atlanta, GA, USA	[42]
Pure leaf (sweetened and unsweetened)	Brewed green/black tea, herbal tea, flavor, and sugar	Pepsico-Lipton/New York, NY, USA	[43]

Milk tea is prepared from a milk and tea infusion, which has become a popular drink among young people [44]. To meet the increasing demand green tea, oolong tea, and black tea are being used [45]. Milk tea is first produced by extracting crushed tea and then mixing the tea infusion with milk [46].

The effect of the particular tea type and bacterial culture on fermented RTD tea beverages is significant [47]. Kombucha tea is produced by the fermentation of black tea leaves or sometimes green tea or oolong tea leaves, which originated in North-Eastern China. Traditional kombucha is prepared by infusing hot black tea, leading to its subsequent fermentation [48]. The other fermented tea beverage is tea wine, which is a combination of tea and baijiu. Tea wine is made by the further fermentation of tea. Wine is made from tea gained from both the wine's taste and the tea's aroma [49]. Research on the production of tea wine has been slow. Tea wine has a significant level of antioxidant activity [50]. There have been few studies on its antioxidant activity [49].

4. Preservation Techniques

The processing steps in extracting tea leaves include fixing, rolling, drying [51], and baking [52]. Moreover, the production steps in making tea beverages consist of extraction, clarification, sterilization, drying, storage [53], enzyme treatment [54], and oxidation [55]. However, the processing of tea beverages has some drawbacks, such as the formation of tea sediment and the degradation of the color and aroma quality. Among the manufacturing steps, extraction is the most crucial step in tea beverage production. To convert raw tea leaves into a beverage, conventional extraction techniques such as heating, boiling, or refluxing need to be carried out [6]. Generally, two types of conventional extraction techniques such as hot and cold extraction are performed [56]. Tea leaves are left to steep in boiled water for a few minutes, then milk and sugar are added [57]. In hot extraction, the loss of aroma and flavor occurs with the increase in temperature. Moreover, hot tea consumption has been associated with an increased risk of stomach cancer compared to warm or cold tea consumption [58]. In cold-brewed tea, tea leaves are steeped in cold or low-temperature water [59]. Lin et al. [60] reported that cold-brewed tea (4 °C/24 h) contains a less astringent and bitter taste than hot tea infusions. Bottled cold-brew tea beverages focus on low-temperature extraction to prevent the thermal degradation of vitamins, catechins, and pigments [61]. However, two major problems, such as long extraction time and low extraction yield, show up in the production of cold brewed tea [6]. In addition, cold brewed tea may have problems preserving against some microorganisms, especially *Salmonella* and *Esherichia coli*, due to its long preparation and storage time [62]. Hence, cold extraction is not suitable for the industrial manufacturing of tea beverages. New preserving methods should be promising to address microbial challenges and extend tea-based beverages' shelf life. Moreover, alternative methods should provide for a high yield, low-cost maintenance, and acceptable quality in less processing time.

4.1. Emerging Technique—Ultrasound

Ultrasonication can be used to overcome some of the restrictions of conventional techniques. Ultrasonication systems can be performed with sound waves at a frequency of 20 kHz using water baths, probes, sonoreactors, and microplate horns [63]. The disruption of the cell walls by ultrasonication penetrates the solvent into the sample to release the target compounds. The mass transfer through the cell membrane is improved to increase the extraction yield with a reduction in time and solvent consumption, and energy saving [64]. In addition, ultrasonication, which is carried out at a low temperature, minimizes thermal damage of extracts and the loss of volatile components [65]. However, an ultrasonication system has its disadvantages, such as being expensive, producing undesirable changes in molecules, and requiring optimization [66].

Ultrasound techniques can improve the extraction yield of value-added substances by reducing time and energy, and increasing shelf life [67]. Two different types of ultrasound devices, ultrasonic baths and ultrasonic probes, are commonly used in the tea industry [68]. Extraction yield can increase during ultrasound processing by disrupting cell tissues [69]. Different methods, such as water-bath shakers, ultrasonic baths, and probes can be used to extract the value-added substances under different temperatures and solvents [67]. The effect of mechanical and thermal energy on the extraction of plant materials was observed during ultrasound processing [12]. The mechanism of ultrasonication based on cavitation phenomena formed micro-channels in the samples to penetrate the solvent [70]. Mechanical effects generate acoustic cavitation while sonic waves are converted to heat [11]. Ultrasonic waves cause cavitation bubbles to form through a series of compression and rarefaction cycles. These bubbles can enlarge in size due to coalescence and collapse during the compression phase, creating hot spots and accelerating biochemical reactions [71]. Pore formation due to sonoporation contributes to the release of bioactive compounds from cellular matrices [72].

4.1.1. Bio-Active Compound Aspects

Extensive studies have been carried out using ultrasonication on different branded teas to enhance the polyphenol content compared to conventional techniques [73] (Table 2). The ultrasonic probe (26 kHz) and ultrasonic bath (40 kHz) were performed in terms of extraction yield and total phenolic content (TPC) for different brands of tea. Among different brands of tea, the maximum TPC in the Haritham brand of tea was found to be 71.13 and 48.88 mg equivalent to gallic/g DW at 40 °C and 40% power, respectively, for 26 and 40 kHz. An ultrasonic probe of frequency at 26 kHz showed better results than an ultrasonic bath of frequency at 40 kHz [73] (Table 2). It might be that the cavitation growth and collapse fared better at a lower frequency due to the fast mass transfer [74]. Xia et al. [6] discovered that the extraction yield of tea polyphenols, caffeine, theanine, and aroma compounds was higher with ultrasonication than with conventional techniques. For instance, Qin et al. [75] investigated a rice-flavored tea wine product made from Anhua black tea using ultrasonic methods. The Anhua black tea and black tea wine products involved two types of probiotics such as *Monascus* and *Eurotium cristatum*, which serve the function of reducing blood lipid levels. Four factors, such as ultrasonic time, solid/liquid ratio, temperature, and power were found to affect the polyphenol content of black tea wine.

Raghunanth and Mallikarjunan [76] evaluated the effect of ultrasonication at different times (10, 20, 30, 40, 50, and 60 min), amplitudes (0%, 10%, 30%, 50%, and 70%), and the solute to solvent ratios (1:25, 1:50, 1:75, 1:100) on the extraction of TPC and the radical scavenging activity from cold-brewed black tea. Raghunanth and Mallikarjunan [76] discovered that the maximum extraction of bioactive compounds for cold-brewed black tea was achieved at 69.9% amplitude with 25 mL solvent volume and 30 min of sonication time at 4 °C. TPC was found to be 78.97 $\pm$ 1.85 mg GAE/g for 30 min in an ultrasonication brewing system, whereas 19.51 $\pm$ 0.76 mg GAE/g for 360 min was found in a conventional brewing system. The extraction of phenolics was increased by four times in comparison to conventional cold brewing. However, brewing time was reduced from 6 h to 30 min by ultrasonication brewing [76].

Table 2. The quality improvement of tea beverages under various ultrasonication conditions.

Beverage Type	Compounds of Interest	Extraction Conditions	Process	Effects	References
Vine tea	Polyphenols	70 °C, 40 min	Thermostatic water bath	Stronger antioxidant activity	[77]
Green tea	Volatile compounds	20 kHz, 100 W, 15–120 min, 20–70 °C	Ultrasound bath and probe	Increased volatile concentrations and polyphenols	[78]
Branded black tea	Polyphenols and antioxidants	26–40 kHz, 40 °C, 40% power at 30 min	Ultrasonic probe and ultrasonic bath	Highest total phenolic flavonoids content and DPPH activity	[73]
Cold-brewed black tea	Total phenolic content and tannin content and antioxidant activity	69.9% amplitude, 30 min, 40 kHz, and 4 °C	Ultrasonic probe	Fourfold increase in TPC and 1.5-fold increase in antioxidant activity	[76]
Instant green tea	Tea polyphenols, aroma compounds, catechins, caffeine	120 W and 49 kHz, 76.2% ethanol, at 15 min, water to tea ratio 1:7	Ultrasonic probe	Promoted the release of main aroma compounds, dissolution of caffeine and theanine; increased the total extraction rate	[79]

Horzic et al. [11] investigated the effect of ultrasound and conventional hot water extraction on the bioactive compounds of yellow tea. The maximum TPC extraction yield was performed at 67 °C and 30 min with 75% aqueous ethanol by an ultrasound probe.

Some herbs, such as non-*Camellia* tea varieties, have been used to form tea-based beverages in China [80]. Vine tea, which is known as *Ampelopsis grossedentata,* is used in health supplements and medicine in China due to its rich polyphenols [77]. Vine tea is consumed by soaking tea leaves in boiling water. A traditional beverage in China, vine tea was treated with ultrasonication to extract polyphenols. The maximum polyphenols were extracted from vine tea with 70% ethanol at 70 °C for 40 min with ultrasonication [77] (Table 2).

4.1.2. Microbial Aspects

Few studies have focused on the microbial inactivation of tea and tea-based beverages. Song et al. [62] investigated the effects of ultrasound on the physicochemical properties, microbial quality, and shelf-life of cold-brew tea. The initial aerobic plate count of (APC) cells was found to be 2.7 $\log_{10}$ CFU/mL and 2.9 $\log_{10}$ CFU/mL for ultrasonic bath-treated cold-brew tea and ultra-probe, respectively. The initial yeast and mold counts were determined as 2.0 $\log_{10}$ CFU/mL and 1.9 $\log_{10}$ CFU/mL for an ultrasonic bath (UB) treated cold-brew tea and ultrasonic-pulverizer (UP) tea, respectively. The APC, yeast, and mold in UB-tea remained in the food safety standard for 8 days, whereas the microbial spoilage was observed well after 8 days for APC, yeast, and mold in UP-tea. Therefore, the shelf-life of tea was indicated as 6 days for UB-tea and UP-tea. Thus, UB-tea and UP-tea showed better microbial stability [62]. Temperature, time, power, and frequency are the main factors affecting microbial inactivation during ultrasonication [81]. Song et al. [62] reported that microbiological safety was ensured under the UB-tea at 150 W and 0 °C for 120 min and UP-tea at 600 W, and 0 °C for 40 min.

4.1.3. Industrial Set-Up Aspects

The design of equipment and usage of novel technologies are vital for industrial applications. The ultrasonication system for tea-based beverages will provide reduced energy consumption and increased extraction yield of bioactive tea compounds to advance the industry. Ultrasonic baths and probes are widely used industrially. Several factors such as instrumentation, batch/flow process, kinetics, economics, and energy consumption have been affected on the industrial scale of extraction techniques [82]. Hielscher (Teltow, Germany) and REUS (Drap, France) developed scaled-up ultrasound extraction systems [71]. The drawback of an ultrasonication system for an industrial setup is the ultrasonic probe, which is limited to a small volume for a quantity of the product [76]. To solve this problem, a continuous system will use an ultrasonication system on an industrial scale, or ultrasound probes will be used on each side of the extractor tank with an agitation system [83]. For this purpose, the Hielscher Company produced a device ranging in power from 50 to 400 W for a lab-scale application and from 500 to 16,000 W for an industrial scale. The REUS Company also developed a range of reactors from pilots (30 to 50 L) to an industrial scale (500 to 1000 L). Moreover, Giotti (Scandicci, Italy) designed four continuous batch systems with ultrasound on each side of the tank and an agitation system [71]. There are few studies that have investigated the effect of an ultrasonication system on an industrial scale in the production of tea beverages. Raghunanth and Mallikarjunan [76] demonstrated that the usage of ultrasound for cold-brewed black tea could increase phenolics extraction four times by reducing the brewing time from 6 h to 30 min. This will help save energy and increase production per day [76].

5. Future Perspectives

The marketing of tea beverages is expected to rise over the next few years, and new types of tea beverages are likely to be produced. Improving the retention of tea compounds during the production of tea-based beverages and the quality control of the process require further research. Healthy functions and organoleptic properties are associated with tea compounds during fermentation. The retention of tea bioactive compounds during fermentation should be enhanced by ultrasonication [49]. The understanding of the effect of ultrasound among tea-based beverages should be clarified. Moreover, the effectiveness of ultrasonication integration in the industry for tea-based beverages should be demonstrated. Therefore, more studies should be conducted to investigate the impact of ultrasound based on the microbial aspects and nutritional benefits of tea-based beverages.

6. Conclusions

Tea-based beverages are healthy products. Based on scientific and technological aspects, alternative processing techniques should be developed to improve energy saving, high efficiency, and low extraction time during the manufacturing process. Further research and development are needed to demonstrate the safety conditions for cold-brewed tea or tea-based beverages of microbial inactivation during ultrasonication. This review will broaden the scope of success at the laboratory and on an industrial scale for the potential application of ultrasonication in the extraction of tea-based beverages.

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