beverages

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Review

Current Trends in Kombucha: Marketing Perspectives and the Need for Improved Sensory Research

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Abstract: Kombucha is a fermented functional beverage that started as a homemade beverage and grew into a commercial product in the U.S. by the turn of this century. The number of companies producing kombucha, as well as the variety of kombucha products, is increasing rapidly. The scientific research on kombucha also got active along with the growth in the market. The topics of kombucha research can be grouped into the substrate used in fermentation, the microbial composition of the cultures, processing methods, chemical composition, the health benefits and health risks associated with consumption, the utilization of symbiotic cultures of bacteria and yeasts (SCOBYs), etc. There are several already published in-depth scientific reviews covering these topics. Even with the sensory characteristics of kombucha being a critical aspect of the beverage, there are not many publications covering the sensory and consumer research on this beverage. This review paper aims to provide the current market status of kombucha and to show a need for scientific sensory and consumer research studies to help the kombucha researchers and industry working on this fast-growing beverage.

Keywords: kombucha; functional beverage; market status; consumer research

1. Introduction

The Wall Street Journal called 2018 the year of "Fancy water and kombucha" [1]. Before 2016, the carbonated soft drink was the largest beverage category by volume in the United States [2]. After finding the association of soft drink intake with obesity and related health problems due to the high sugar content, many states in the United States banned the sales of soft drinks in schools [3]. Additionally, in a recent study with the European population, it has been found that not only the sugar-sweetened but also artificially sweetened soft drinks are associated with all-cause mortality rates [4]. These results are considered the motivation for public health campaigns of limiting soft drink consumption [5]. Consumers are actively looking for alternative beverages to replace soft drinks. Their need for healthy and functional beverages beside simple hydration has led to the growth of the flavored water market [6].

The functional beverage market is one of the fastest-growing segments in the functional food market [7,8]. Consumers' demand for "healthy" food and beverages is considered as a driving force behind the growth of the functional foods sector [9]. Despite the current growth and trend of functional food and beverages in the U.S. market, there are no specific definitions or regulations for functional foods by law. These are referred to as "conventional" foods which must be safe to be marketed as foods, and the ingredients must be "generally recognized as safe" (GRAS) or approved as food additives by the Food and Drug Administration (FDA) [10,11]. Functional Food Center/Functional Food Institute (Dallas, TX, USA) have suggested a new definition of functional food as 'Natural or processed foods that contain biologically-active compounds; which, in defined, effective non-toxic amounts, provide a clinically proven and documented health benefit utilizing specific biomarkers, for the prevention, management, or treatment of chronic disease or its symptoms' [12]. The Institute of Food Technologists (IFT) expert report on science related to functional foods and its regulatory environment defined functional food and food components as products 'that provide a health benefit beyond basic nutrition (for the intended population)' [13]. In 1999, the American Dietetic Association (currently Academy of Nutrition and Dietetics) defined functional food as 'including whole foods and fortified, enriched, or enhanced foods, have a potentially beneficial effect on health when consumed as part of a varied diet on a regular basis, at effective levels' [14]. Additional definitions of functional food/beverages are listed in Table 1. Within the functional food category, beverage is considered as a most effective and active sector due to (1) convenience and the possibility to meet consumer demands for container contents, size, shape, and appearance, (2) ease of distribution and better storage for refrigerated and shelf-stable products, and (3) the great opportunity to incorporate desirable nutrients and bioactive compounds [9,15,16]. Functional beverages include (1) sport drinks, (2) energy drinks, (3) fortified juice, (4) dairy and non-dairy (dairy alternative) drinks, and (5) others (including enhanced water, ready-to-drink tea, and coffee) [9,17].

Table 1. Definition of 'Functional food/beverage' from literatures.

Definition and Types of Functional Beverage	Reference
Functional beverages are nonalcoholic drink containing non-traditional ingredients, such as minerals, vitamins, amino acids, dietary fibers (DFs), probiotics, added raw fruits, etc.	[18]
In the U.S., there is not a separate category or a set of regulations for functional foods. These products fall under the regulations for conventional foods. They must be safe to be marketed as foods, and the ingredients must be "generally recognized as safe" (GRAS) or approved as food additives [19]. Regarding product claims, these can be categorized into 3 categories: (1) health claims, (2) nutrient content claims, and (3) structure/function claims.	[9]
Functional foods can be considered to be those whole, fortified, enriched or enhanced foods that provide health benefits beyond the provision of essential nutrients (e.g., vitamins and minerals), when they are consumed at efficacious levels as part of a varied diet on a regular basis.	[19]
Foods and food components that provide a health benefit beyond basic nutrition.	[20]
Functional foods are those that have scientifically proven their beneficial effects in the organism, in one or more of its functions, providing optimal health and well-being, regardless of their nutritional value	[21]

Kombucha is a fermented beverage that has caught consumers' attention very recently and is generally considered to be a functional beverage. The kombucha industry has reported rapid growth in recent years and the research related to kombucha is flourishing. The objective of this review paper is to provide overall information of kombucha such as the definition, history, and fermentation process of kombucha along with the commercial and sensory research status of kombucha.

2. Kombucha

2.1. Definition and History of Kombucha

From the Merriam-Webster dictionary [22], kombucha is defined as 'a gelatinous mass of symbiotic bacteria (as *Acetobacter xylinum*) and yeasts (as of the genera *Brettanomyces* and *Saccharomyces*) grown to produce a fermented beverage held to confer health benefits'. It is also defined as 'a somewhat effervescent beverage prepared by fermenting kombucha with black or green tea and sugar.' Various kombucha-related publications have cataloged their understanding of kombucha [21,23–33] and if all their definitions/descriptions are synthesized, we can arrive at the following common characteristics or features:

(1) it is a beverage produced by the fermentation of tea and sugar source;
(2) mainly black tea is used, but green tea, oolong tea and other teas can be used as well;
(3) using sugar as a substrate in a traditional method but also other carbon sources can be used;
(4) a symbiotic culture of bacteria and yeasts (SCOBY) is used;
(5) is characterized by slight sweetness and sourness with carbonation.

While kombucha was defined by researchers rather recently, there is literature mentioning kombucha consumption since 220 B.C. where it was prized as "Divine Che (Remedy of Immortality)" for detoxifying and energizing purposes [26,28]. Other records mention that the kombucha was brought to Japan from Korea to cure the digestive problems of the Emperor Inkyo by Doctor Kombu in 414 [28,34]. From as early as Tsin Dynasty in Manchuria, kombucha is believed to have traveled to Russia and Eastern Europe by trade routes that extended beyond the Far East [26]. Kombucha was utilized as an effective folk medicine in Russia in the 1800s [34]. The first distinct record of Kombucha from Russia is from the end of the 19th century. During World War I (WWI) kombucha began to spread to other countries through Russian and German prisoners. Kombucha became popular as a home and folk remedy in Germany by the 1920s. Later, kombucha spread from Germany to western European countries such as France and to their colonial countries in North Africa [34,35]. While kombucha was distributed to various countries, there were various names to call this beverage (Table 2).

Table 2. Other names of kombucha in literatures.

Other Names of Kombucha	Reference
Tea Fungus, Kargasok Tea, Manchurian Mushroom, and Haipao	[26]
In Russia—Grib (mushroom), tea kvass", or plainly "kvass" In Japan—"Tea Mushroom" or "Tea Kvass" Kombucha Fungus, Gout Jelly-fish Manchurian Tea, Russian Jelly-fish, Remedy of Immortality, Fungus Japonicus, Fungajapon Kombucha, Combucha, Kambotscha, Koucha Kinoko, Tea Mold, Indian Tea Fungus, Manchu Fungus, Kombucha Mushroom, Hongo Japanese Tea Fungus, Manchu Fungus, Kombucha Mushroom, Mushroom of Charity, The Divine Che, Miracle Fungus, Tea Mushroom, Mo-Gu, Russian Tea-Vinegar, Tea Cider, Volga-Spring, Teakwass, Tea Beer, and Kargasok Tea	[34]

Traditionally, kombucha was spread by sharing the culture material with others. In the U.S., this provoked the safety concern for the kombucha processing and consumption in 1995 [36]. In 2013, Nummer [37] published the risk analysis and processing guidance manual to safely make kombucha under the Food and Drug Administration Model Food code. This report includes kombucha hazard analysis (biological hazards and chemical hazards), controlling food safety (critical control points, critical limits, monitoring, corrective actions, and record keeping), and good manufacturing practices (standard operating procedure, packaging). Due to much of kombucha's history being spread by word of mouth, there are widespread health-promoting beliefs among kombucha consumers that are mostly unfounded [33,38]. Together with health benefits, some health risks or side effects have been associated with kombucha consumption as shown in Table 3. These are usually related to overconsumption, consumption of highly acidic kombucha, potential contamination of heavy metals that leached out from containers or consumption of kombucha by people with pre-existing health conditions or diseases [36–38]. There have been research studies that have tried to prove the health benefit of kombucha. Most of the studies are in vitro studies and some in vivo studies in rodents, small animals, and human peripheral blood lymphocytes [38]. We could not find any in vivo clinical trials that used human subjects to understand the health benefits of kombucha.

Table 3. Example of potential health benefits and health risks of kombucha consumption [38].

Potential Health Benefits
Antioxidant
Antimicrobial
Anti-tumor properties
Detoxification
Helps normal central nervous system function
Immune stimulation
Inhibiting the development and progression of cancer, cardiovascular disease, diabetes, and neurogenerative diseases
Liver and gastrointestinal function
Potential Health Risks
Acute renal failure
Allergic reaction
Hyponatremia
Jaundice
Lactic acidosis
Lead poisoning from ceramic brewing pot
Metabolic acidosis
Myositis
Nausea
Toxic hepatitis
Vomiting

Starting from the small batch-to-batch scale of kombucha production, nowadays there are high numbers of kombucha companies producing commercialized kombucha. These products are distributed through the retail distribution and to the restaurants or kombucha taproom. Fresh kombucha from the tap where consumers can enjoy freshly brewed kombucha is getting popular worldwide. Currently, people still brew homemade kombucha at home in a small scale to consume by themselves. The small to mid-size farm industry also make kombucha as a value-added product using their crops. These kombucha products are mainly sold at local farmers' markets. The industrialization of kombucha in the U.S. first started in the California area around the 1990s. After kombucha gained its popularity among consumers, a large number of kombucha companies were established all over the U.S. over a few decades, making finding commercial kombucha products easy even in the local retail stores. As the kombucha industry grows, in 2014 a non-profit organization called Kombucha Brewers International (KBI) was established to help with regulations and legislations related to kombucha [39]. Currently, as of November of 2019, there are 235 companies worldwide that are enrolled as a member of this organization (Table 4) [40]. KBI claims to have kombucha companies representing over 90% of commercial kombucha products in stores and/or on tap as members. North America (U.S. and Canada), has the largest number of registered kombucha companies in the organization. In the U.S., the West leads the pack with 58 companies (Table 5). Mexico in Latin America, Spain in Europe and Australia in Asia-Pacific are the countries having the highest number of registered kombucha companies in each region. In the U.S., the western region has the most registered kombucha companies. California in the west, New York in the northeast, Florida in the south are the states with the highest number of registered kombucha companies. KBI members share information, such as the best practice for kombucha manufacturers, how to measure alcohol, Hazard Analysis and Risk-Based Preventive Controls (HARPC), etc.

Table 4. Number of kombucha companies registered as a member of Kombucha Brewers International (KBI). This data represents the member states as of November 2019.

Number of KBI Registered Kombucha Companies in Total (*n* = 235)		
	Country (Number of Companies)	
Asia Pacific (*n* = 31)	Australia (15) China (3) Hong Kong (1) India (1)	Japan (1) New Zealand (7) South Korea (2) Thailand (1)
Europe (*n* = 30)	Belgium (1) Finland (2) France (1) Germany (2) Iceland (1) Ireland (2) Netherlands (2)	Portugal (1) Slovenia (1) Spain (9) Switzerland (1) Turkey (2) United Kingdom (5)
Latin America (*n* = 12)	Brazil (3)	Mexico (9)
North America (*n* = 162)	Canada (28)	United States (134) —Midwest (22) —Northeast (22) —South (31) —West (58) —Other US Territory (1)

Table 5. Types and examples of flavoring of commercial kombucha products.

Type	**Flavors**
Fruits	Lemon, Blueberry, Raspberry, Strawberry, Lime, Mango, Cherry, Pineapple, Pomegranate, Apple, Orange, Grape, Passionfruit, Peach, Blackcurrant, Grapefruit, Asian Pear, Blood Orange, Coconut, Cucumber, Citrus, Elderberry, Guava, Watermelon, Aronia, Coffee, Cranberry, Dragon Fruit, Tangerine, Yumberry, Almond, Bilberry, Camu Camu, Green Apple, Habanero Pepper, Hawthorn Berry, Honeysuckle, Juniper, Kiwi, Kumquat, Mangosteen, Maqui Berry, Sea Buckthorn, Yuzu
Herb	Mint, Basil, Lavender, Sage, Peppermint, Rosemary, Spearmint, Echinacea, Guayusa, Holy Basil (Tulsi), Lemongrass, Red Clover, Rhodiola
Spice	Ginger, Turmeric, Vanilla, Cayenne Pepper, Cinnamon, Clove, Black Pepper, Nutmeg, Spice, Szechuan Pepper
Vegetables	Carrot, Rhubarb, Beet, Burdock, Chicory, Jalapeno, Kale, Maca Root, Spinach
Flower	Hibiscus, Hops, Rose, Jasmine
Tea	Green Tea, Yerba Mate, White Tea
Algae	Spirulina, Algae, Chlorella
Others	Lemonade, Oak, Cola, Root Beer, Bitters, Caramel, Chai, Molasses, Sorghum Molasses, Wheatgrass

Taprooms to enjoy this fermented beverage fresher and near the consumer is gaining popularity in the fermented beverage industry that includes beer and hard cider. Along with the trend with other mainstream fermented beverages, the kombucha taproom also started to open and grow its business. Based on a web search of 'kombucha taprooms' in the U.S., currently in November 2019, there are 65 kombucha taprooms in business, with the West and South combining for 44 taprooms. This result only includes kombucha companies where they serve kombuchas they brewed by the company and are served on tap. Many kombucha taprooms were expanded from their kombucha brewery facilities. Some of the beer breweries expanded their products to other fermented beverages such as kombucha or apple cider. Several kombucha companies are distributing their kombucha products to local beer breweries, restaurants, distilleries, wellness centers, etc., as a draft on tap. In a number of cases, the kombucha is being marketed as a good alternative to non-alcoholic beverages to enjoy.

2.2. Kombucha Fermentation Process

Kombucha is fermented by acid-tolerant species of a symbiotic culture of bacteria and yeasts (SCOBY) [25] traditionally mainly using black tea and sugar as an ingredient but nowadays with various variations [21,28,30]. Kombucha is generally fermented in the food-grade glass or stainless-steel containers [37]. The fermentation vessels and utensils must be sterilized to avoid possible spoilage or contamination [26]. The recipe for making kombucha varies in details such as the amount of tea or added sugar and starter culture, the time and temperature required for the fermentation, etc. However, the main process is quite similar. First, the tea is brewed by steeping tea for the required amount of time (~5–10 min) and sugar is added and dissolved while the tea base is still hot. Typically, 50 to 150 g/L (5–15%) of sugar is added [26–28]. Afterward, the sweetened tea must be cooled down to room temperature. The cellulose-pellicle-formed SCOBY is added to the sweetened tea with 100–200 mL of previously fermented kombucha or vinegar [26,28]. This lowers the pH of the mixture to inhibit the growth of undesirable microorganisms [27]. The top of the vessel is covered with materials such as a clean cotton cloth or a paper towel. This prevents air-borne mold and dust from entering and keeps insects, such as fruit flies, out [26,27]. The incubation happens at room temperature (18–30 °C) for 7 to 10 days [26].

As the fermentation proceeds, the disc-shaped gel-like cellulose pellicle called the 'daughter SCOBY' forms on the top surface and the composition of the liquid phase changes with the sugar level and the pH decreases and the acidity increases due to the symbiotic action of starter bacteria and yeast. The kombucha mixture will start to have fermented vinegary notes and visible gas bubbles will form [26,27]. The yeast hydrolyzes sucrose into glucose and fructose, which is catalyzed by invertase. Additionally, the yeast produces ethanol by using fructose as a preferred substrate via glycolysis [27,28]. Various yeast genera, such as *Brettanomyces/Dekkera*, *Candida*, *Kloeckera/Hanseniaspora*, *Kluyveromyces*, *Pichia*, *Saccharomyces*, *Saccharomycodes*, *Saccharomycoides*, *Shizosaccharomyces*, *Torulaspora*, and *Zygosaccharomyces*, are reported to be present in kombucha SCOBYs [23–25,28,29,41–45]. *Acetobacter* and *Gluconobacter* genera, both of which are in the Acetic acid bacteria (AAB) family, are the most abundant bacteria of the kombucha SCOBY. AAB converts glucose to gluconic acid and uses ethanol to produce acetic acid [25,27]. *Acetobacter xylinum* [27] now reclassified as *Komagataeibacter xylinus* [46,47] is a species that biosynthesizes the cellulose pellicle [48]. The acetic acid produced by AAB stimulates the yeast, and the ethanol produced by the yeast promotes AAB to produce acetic acid [28,44]. Other organic acids, such as acetic, gluconic, glucuronic, tartaric, malic, and citric acid, are also produced during the kombucha fermentation. These products decrease the pH of kombucha. The antimicrobial activity of ethanol and acetic acid combined with the decreased pH during kombucha fermentation prevents the contamination from pathogenic bacteria or mold [25,27,28,44,49].

The taste of kombucha changes from sweet to fruity, sour, and slightly sparkling to a mild vinegar-like taste as the fermentation progress [28]. The sweetness of the kombucha decreases while the sour taste increases due to the SCOBY using the sugar as a substrate to produce organic acids [25,27]. There is no clear endpoint of the kombucha fermentation. The acidity, however, may increase up to a potentially harmful level for consumption after 10 days [26]. The pH endpoint of >2.5 is recommended for the safe consumption of kombucha [37]. After the fermentation is over, both 'mother' and 'daughter' SCOBYs are removed from the fermentation vessel. The liquid is filtered and stored in a capped food-grade container for consumption [27,28,30].

2.3. Commercial Kombucha Status

After the first launch in the 1990s in the U.S., the kombucha industry has kept growing. The value of the global kombucha market is estimated to be USD 1.5 billion in 2018. In the period of 2014–2018, the market grew at a compound annual growth rate (CAGR) of 23% [50]. The market is forecasted to continue its growth, reaching between USD 3.5 to 5 billion by 2025 [50–52]. As mentioned earlier, currently there are 134 kombucha companies based in the U.S., which are registered members of KBI. This number does not include a total number of kombucha companies in business in the U.S., however, it gives an estimate of the size of kombucha industry. Until recently, most of the kombucha companies were independent companies. From the late 2010s, multinational beverage companies started to show their interest in the kombucha market. Starting with Pepsi Co. (Harrison, NY, USA) acquiring one California-based kombucha company in November 2016 [53], Molson Coors Brewing Co. (Denver, CO, USA) has also acquired a California-based kombucha company in June 2018 [54]. Coca-Cola Co. (Atlanta, GA, USA) has invested $20 million in a California-based kombucha company since 2014 [55,56] and has acquired an Australian-based kombucha company in 2018 [57].

To understand the commercial kombucha products currently on the market, data of 201 products from 16 kombucha companies were collected. Since the U.S. is one of the main produces of kombucha, we focused our attention on the products available on the U.S. market. The product information was collected from the kombucha companies' website or the website of retailers. Most of the commercial kombucha products have the following characteristics: (1) bottled in a glass bottle, (2) requires refrigerated distribution and storage, (3) flavored, and (4) unpasteurized. A few exceptions do not have all the characteristics mentioned above. Most of the currently distributed commercial kombucha products, however, have these characteristics due to the nature of kombucha as a fermented beverage. Kombucha itself has a natural, mild carbonation due to the fermentation process and it is highly likely to go under the second fermentation if the product is not refrigerated after bottling. Glass bottling allows the products to endure the generated pressure inside the container to a certain point. However, after a certain amount of carbon dioxide is generated, which increases the pressure; there is a risk of rupturing the glass bottle. In order to minimize this hazard, the products need to be refrigerated to slow down the second fermentation.

The majority of kombucha products on shelves are flavored kombucha. The examples of kombucha flavors are listed in Table 5. The flavors of fruits and herbs, such as ginger, lemon, blueberry, raspberry, strawberry, lime, mint, and mango, were the common flavoring option in kombucha products. Rather than having one single flavor, most of the kombucha products have complex flavors having several flavors in one product (Table 6). With the current trend of Cannabidiol (CBD) application in the U.S. food industry, some kombucha companies are launching a CBD-infused kombucha into the market. Some products mentioned using real fruit juice to flavor or color the products, while other products add flavoring or coloring.

Table 6. Number of flavorings of commercial kombucha produced in the U.S. (n = 201).

Number of Flavors	Number of Products
Without flavoring (original)	8
1 type of flavor	41
2 types of flavors	91
3 types of flavors	48
4 types of flavors	8
5 types of flavors	4
6 types of flavors	1

When looking at kombucha products available on the market, statements such as 'USDA organic', 'natural' 'healthy for your gut', 'live culture', 'raw', 'non-dairy probiotics', 'non-Genetically Modified Organism(GMO)', and 'Kosher' are commonly used. A large number of kombucha companies do not pasteurize their product to keep the beverage's natural microbes. They claim the product being raw and unpasteurized as a reason for their kombucha product having pre/probiotic function. In order to fulfill the claim of probiotics, few companies pasteurize their products and inoculate with known probiotics, such as *Bacillus coagulans*, *Bacillus coagulans GBI-30 6086*, *Bacillus subtilis*, *Saccharomyces boulardii*, and *Lactobacillus rhamnosus*.

The common size of the kombucha products was 335–355 mL (12 fl oz.), 414–415 mL (14 fl oz.), 449–450 mL (15.2 fl oz.), and 473–480 mL (16 fl oz.). Some of the products have uncommon sizes, such as 250 mL (8.4 fl oz.), 1.4 L (48 fl oz.), and 1.9 L (64 fl oz). The calories per 100 mL, sugar content per 100 mL, and the price per 100 mL showed a difference among brands (Table 7). The average serving size of kombucha was 352 mL ranging from 207 mL to 480 mL. The calorie per serving ranged from 15 to 100. The calorie per 100 mL ranged from 3.6 to 29.2. The sugar content per serving ranged from 1 to 24 g. The sugar content per 100 mL ranged from 0.2 to 6 g. Some kombucha companies used artificial sweetener or sugar alcohol such as stevia extract or erythritol to lower the calorie and sugar content in their kombucha. The price of kombucha products in the market ranged from $0.79 to $14.99. The price per 100 mL ranged from $0.22 to $2.07. Compared to the glass-bottled kombucha from the same company with the same flavor, canned kombucha have less calories per 100 mL, sugar per 100 mL, and price per 100 mL.

From 2018, the kombucha industry started using aluminum can as a packaging material. Out of 16 brands in the U.S., 10 brands were selling their kombucha in glass bottles. Four companies produced both glass and canned packaged kombucha (Table 7). Two companies produce kombucha only in cans. One of the Georgia-based kombucha company stopped glass bottling their kombucha products and switched to aluminum cans. The convenience of carrying, the availability to bring out to outdoor activities, ease and capability of recycling, and the possibility of decreasing the current market price of kombucha are considered as advantages of using the can as a bottling material [58]. Based on an interview with a Georgia-based kombucha company, they had to install the whole line of kombucha canning equipment in their facility. They tried to rent the canning machine from other breweries and rental companies. However, due to a concern about cross-contamination between different fermented beverages, such as craft beer and hard cider, they had to put a big investment in installing their own specifically for kombucha. Kombucha is traditionally bottled and distributed in a glass container; there is no known consumer feedback on the can-packaged kombucha thus far.

Table 7. Details of commercial kombucha products in the U.S.

Brand	Company	Packaging	Calorie Per 100 mL (kcal)	Sugar Per 100 mL (g)	Price Per 100 mL
BREW DR. KOMBUCHA	BREW DR. KOMBUCHA	all (n = 21) glass (n = 16) canned (n = 5)	13.62 13.84 12.89	2.77 2.80 2.69	$$ * $$ $
búcha®	New Age Beverages Corporation	glass (n = 5)	11.84	2.71	$$
Buchi	Asheville Kombucha Mamas, LLC	glass (n = 9)	20.66	4.44	$$$$$
Clearly Kombucha	Clearly Kombucha	glass (n = 6)	6.04	0.97	$
Golda Kombucha	Golda Kombucha	canned (n = 6)	5.30	0.85	$$$
Classic Kombucha, Classic Synergy Kombucha, Enlightened Kombucha, Enlightened Synergy Kombucha	GT's Living Foods	glass (n = 49)	12.67	3.23	$$
HEALTH-ADE KOMBUCHA	Health-Ade	glass (n = 18)	16.17	2.58	$$$
Humm Kombucha	Humm Kombucha, LLC	all (n = 18) glass (n = 13) canned (n = 5)	15.13 14.61 16.48	3.51 3.41 3.76	$$$ $$$ $$
KÖE kombucha	Stratus Group	canned (n = 5)	9.86	2.25	$$
Live Kombucha	LIVE soda	glass (n = 9)	9.86	2.25	$$$$
Master Brew Kombucha	KeVita (Pepsi Co., Inc.)	glass (n = 13)	13.95	3.46	$$
Organic Simply balanced Kombucha	Target corporation	glass (n = 4)	15.00	3.61	$$
Revive Kombucha	Revive Kombucha	all (n = 11) glass (n = 7) canned (n = 4)	10.10 12.66 5.63	2.58 3.16 1.41	$$ $$ $$
Simple truth organic	The Kroger Co.	glass (n = 5)	17.14	3.96	$$
Suja Kombucha	Suja Life, LLC	glass (n = 9)	13.61	3.05	$$
Wonder Drink Kombucha	Wonder drink	all (n = 13) glass (n = 5) canned (n = 8)	23.35 26.67 21.28	5.06 5.75 4.62	$$ $$ $$$
Total		all (n = 201)	14.12	3.17	$$
Coca-Cola	The Coca-Cola Company		39.44	10.99	$

* $ (<$0.5), $$ ($0.5–$1.0), $$$ ($1.0–$1.5), $$$$ ($1.5–$2.0), $$$$$ ($2.0–$2.5).

In the U.S., kombucha is considered as and sold under the non-alcoholic beverage category. Under federal law, the non-alcoholic beverages should not contain more than 0.5% alcohol by volume (ABV) at any time during production, during or after bottling. The non-alcoholic beverages are subject to the Food and Drug Administration (FDA) agency of the United States Department of Health and Human Services regulations. The alcoholic beverages, which are at or above 0.5% ABV at any time during production, bottling, or after bottling are subject to the Alcohol and Tobacco Tax and Trade Bureau (TTB) of the United States Department of the Treasury regulations [59]. Based on the nature of kombucha as a fermented beverage, the production of alcohol is inevitable. A large number of commercial kombucha products include statements such as 'contains less than 0.5% alcohol by volume', 'Kombucha is a fermented tea that has naturally occurring alcohol. Do not consume if you are avoiding alcohol due to pregnancy, allergies, sensitivities, or religious beliefs', 'If you are pregnant or breastfeeding, please consult with your doctor before consuming. Due to natural fermentation, this product may contain a trace amount of alcohol and small pieces of culture.' In June of 2010, there was a nationwide voluntarily recall by suppliers of kombucha and Whole Foods after finding the product contained over 0.5% ABV [60]. Kombucha companies had to find a method to lower the alcohol content in their products below 0.5%. Examples of such a method include diluting the beverage, heat pasteurization, the microfiltration of a specific alcohol-producing yeast strain and the distillation of alcohol using a spinning cone column. This provoked questions among kombucha consumers and industry whether the kombucha beverage going through these modifications can still be considered as kombucha. A kombucha brewery based in Texas adopted a patent pending kombucha fermenter, which produces kombucha below 0.5% ABV by increasing the bacterial content and reducing the yeast content. One of Oregon-based kombucha companies developed a patent-pending process to produce kombucha that keeps the alcohol level below 0.5% without refrigeration. On the other hand, some kombucha companies created a new category of alcoholic beverage 'hard kombucha' or 'kombucha beer' containing more than 0.5% ABV.

2.4. Kombucha Research Status

The earliest research on kombucha published in English was done in 1945 by Homburger and Reed [61]. Along with the popularity of kombucha, related scientific work also started from the late 1990s. The number of publications, such as research papers, review papers, book chapters, conference papers, meeting abstracts, magazine articles, etc., related to kombucha jumped covering various topics related to kombucha (Figure 1). A total of 354 publications were identified through scientific databases searched with the keyword 'kombucha', 'tea fungus', and 'tea mushroom' after removing duplication and retracted publications. Only the publications published in English were included in the counts. SCOPUS and Web of Science (WOS) were used as a scientific database-searching source. The topics can be broadly divided into preparation/fermentation process, substrates, microbiological characteristics, chemical composition, cellulose biomass (application), sensory and consumer analysis, health benefits, and the harmful effect of kombucha.

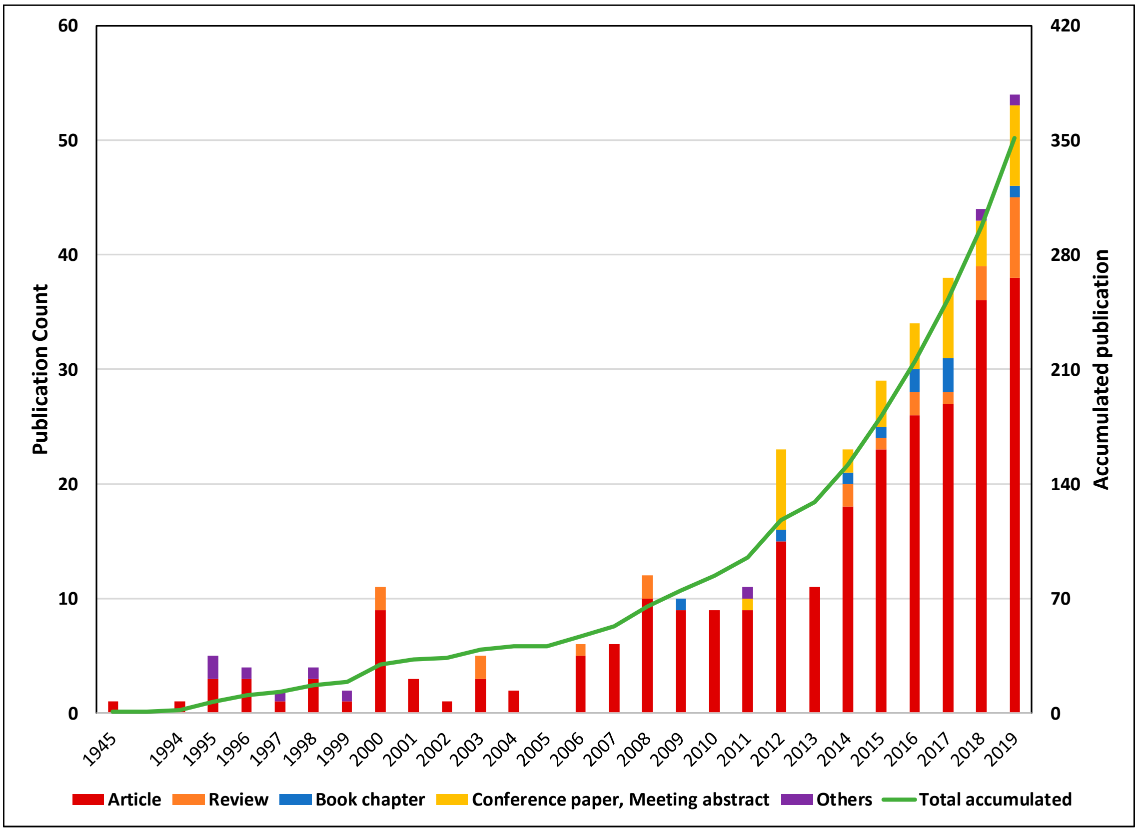

Figure 1. Kombucha publication trend. Kombucha publication types and their counts are shown with accumulated publication number per year from 1945 to 2019.

There have been several review papers covering kombucha that have been published recently. After filtering the 'review'-type papers from database search results, 21 publications were collected. After removing review papers whose focus was not primarily kombucha, only eight articles were left (Table 8). All eight review articles covered the preparation and fermentation process of kombucha. Depending on the objectives of the papers, the topic of kombucha that was covered varied.

Table 8. Topics covered by comprehensive review papers on kombucha.

Preparation /Fermentation	Substrate	Microbiology	Chemical Composition	Health Benefits	Harmful Effects	Cellulose Biomass	Reference
X *	X	X	X	X	X		[26]
X		X	X	X	X		[28]
X	X	X	X	X	X	X	[27]
X		X	X	X	X		[33]
X	X	X	X	X	X	X	[25]
X		X	X	X		X	[62]
X				X	X		[38]
X	X	X	X			X	[63]

* X indicates that the topic was covered in the paper.

Consumer awareness and popularity are considered as a reason behind the current trend of the flourishing market and active research on kombucha. One of the recognized characteristics of kombucha is its sensory characteristics commonly described as sweet, vinegary sour, and carbonated. Nevertheless, there is no research publication that solely worked on the sensory or consumer area of kombucha. There are very limited publications covering sensory and consumer research as one of their research objectives. The earliest paper that mentioned having sensory research work is from 2008 [64].

From 2010, few kombucha researchers started to include sensory or consumer work in their projects. A total of 20 research articles have sensory or consumer research data: seven consumer evaluation studies, eight descriptive analysis studies, and five studies without enough information to categorize them into specific testing type (Table 9).

Sample attributes, such as appearance, color, odor, taste, and overall acceptability, were evaluated in the consumer tests [65–68]. The number of participants for the consumer test varied from 8–30 which is a very low number of consumers for affective tests. Moreover, none of these publications provided detail about the screening of the participants. One of the papers used the 5-point intensity scale to evaluate aroma for their consumer test with the anchor '1—no typically kombucha at all', '2—no typically kombucha', '3—slightly typically kombucha', '4—typically kombucha', and '5—extremely typically kombucha' [68]. The researchers did not define what typical 'kombucha aroma' is. Without the consumer screener information, it is difficult to know whether participants were regular kombucha consumers or individuals who knew the characteristics of the kombucha beverage. Even if they were, it is not known whether participants were able to understand and evaluate the aroma of the samples properly with the provided scale. Moreover, this paper interpreted the average score of 2–3 when using the 5-point hedonic scale as 'acceptable', which is not the right way to interpret the result.

The number of participants for the descriptive analysis varied from 7–30. Most of the descriptive analysis studies were lack of detail on panelists [69–75]. In some cases, untrained consumers were included together with trained panels [70]. Attributes such as aroma (tea, lemon, acetic, yeast, sour, other), taste and flavor (tea, lemon, acetic, yeast, sour, acidic, bitter, storage-stale, other), color, clarity, and consistency were covered [69–76]. However, none of the publications included the definition of the terms used in their descriptive testing. The majority of descriptive works asked panels to evaluate the acceptability of the samples [71–75] that is not a question targeted for the descriptive testing but rather for the acceptability testing. Three papers that claimed to have descriptive analysis used a hedonic scale to evaluate each attribute [71,74,75]. They all mentioned using trained panelists and hedonic scales/acceptability scores. It is not known whether they did not understand the meaning of the 'hedonic/acceptability' scale or proper usage of the scale for specific testing methods. Two of the papers evaluated the quality of kombucha by making a single complex indicator 'sensory mark' [70,76]. According to them, the coefficients of attributes and quality parameters were calculated as follows: appearance—1 point, color—2 points, odor—3 points, consistency—4 points, and flavor—10 points. The scores were added, and the overall sensory quality was calculated as a percentage of the maximum quality out of 20 points.

Few publications were unable to categories the type of testing due to the lack of information provided for panelist details, replication, and the scale used for the evaluation, result, etc. [64,77–79]. Two publications mentioned using qualified evaluators with consumers [64,77]. There were no details on the panelists or the scale used during evaluations. The result did not mention whether it was from qualified evaluator or consumers. From the result, the researcher summed up the scores and calculated the acceptability of each sample. One research paper used the trained evaluators in the consumer study as well [80]. No additional information regarding sensory testing, such as panelist details or the scales used were found in the publication. One of the paper used qualified evaluators [78], but no details on either panel training or scaling instruments were provided. The authors wrote evaluators assessed appearance, consistency, odor, and taste. In the result, however, they stated one of the samples had mild and refreshing characteristics. There was no reasoning behind this conclusion nor detail on such descriptor in the Materials and Methods section. Lastly, one other paper did not have any details regarding the panel [79]. By mentioning three replications during the evaluations, it seems like the researcher's intention was to use descriptive analysis method. However, the scale they used was a 5-point acceptability scale and the descriptors, such as 'CO_2 content', 'alcoholic taste', and 'ferment smell', needed defining.

Table 9. Sensory evaluation details of kombucha and the sensory and consumer research available in the literature.

Sensory Evaluation Method	Participant Type (No.)	Attributes	Scale Used	Reference
Consumer	Consumer (6)	defect (deviation)	3-point category scale	[81]
	Customers (25)	-	Triangle test	[82]
	untrained panelists (15)	N/A	9 point (lowest to highest)	[83]
	untrained panelists (30)	color, aroma and taste	5 point hedonic	[65]
	N/A (10)	appearance, color, odor, sourness and sweetness	9-point hedonic scale	[66]
	N/A (8)	appearance, color, odor, and taste	9-point hedonic scale	[67]
	untrained panelists (15)	taste, aroma and total acceptability	5-point hedonic scale for acceptability and 5-point intensity scale for taste and aroma	[68]
Descriptive analysis	Panels (16)	smell discriminants (tea, lemon, acetic, yeast, sour, other), taste discriminants (tea, lemon, acetic, yeast, sour, bitter, storage-stale, other), color tone, clarity	unstructured scales (0–10 c.u.)	[69]
	Qualified evaluators (4) and untrained consumers (3)	N/A	5-point category scale	[70]
	semi-trained panels (30)	odor, acidity, taste, color, overall acceptability	10-point hedonic scale	[71]
	Trained panel (10)	odor, sweetness, acidity, taste, color, overall acceptability	9-point scale	[72]
	Trained panel (14)	acceptability, consistency, clarity, color, taste and aroma	unstructured hedonic scale for acceptability, consistency, clarity and unstructured intensity scale for color, taste and aroma	[73]
	Trained panel (20)	aroma intensity, sweetness, acidity, color and overall acceptability	9-point hedonic scale	[74]
	Trained panel (10)	color, consistency, odor, taste, and general acceptance	5-point hedonic scale	[75]
	Trained panel (10–15)	appearance, color, flavor, consistency, and taste	5-point scale	[76]
Limited information	Qualified evaluators together with untrained consumers (N/A)	appearance, color, consistency, odor and taste	appearance (0–1), color (0–1), consistency (0–4), odor (0–2) and taste (0–12)	[64]
	Qualified evaluators together with untrained consumers (N/A)	appearance, color, consistency, odor and taste	appearance (0–1), color (0–1), consistency (0–4), odor (0–2) and taste (0–12)	[77]
	Qualified evaluators	not available	5-point scale	[78]
	Qualified evaluators with common consumers (N/A)	appearance, color, consistency, odor and taste	appearance (0–1), color (0–1), consistency (0–4), odor (0–2) and taste (0–12)	[80]
	N/A (16)	CO_2 content, sugar taste, acidic taste, alcoholic taste, ferment smell, transparency	5-point hedonic scale	[79]

3. Conclusions on the Kombucha Market and Research Status

Even though the commercialized market history of kombucha is as recent as a little over 20 years, its market size and product variety are growing fast. Kombucha is considered an alternative beverage for the consumer to choose over traditional soft drinks with functional features along with a basic hydration purpose. A traditional soft drink, such as coke, has an average calorie content of 39.5 kcal per 100 mL, and an average sugar content of 10% by weight. Based on the commercial kombucha products currently on the market, the average calorie content per 100 mL is 14.12 kcal, and the average sugar content per 100 mL is 3.17 g. Kombucha has a lesser caloric and sugar content profile compared to regular soft drinks. The average price of kombucha per 100 mL was $0.87, while coke per 100 mL in retail stores costs about $0.15. The kombucha industry has started introducing canned packaging for kombucha products. This not only reduced the price of commercial kombucha products but also gave the product portability, the capability of being recycled, and sustainability.

The research publications also got active along with the growth of the kombucha market. In most of the research, the focus was on substrate, processing, chemical composition, microbial activity, the health benefit and risk of kombucha consumption, and utilizing the cellulose byproduct. There is no work solely on the sensory or consumer evaluation of kombucha. From the few publications found to have some sensory or consumer research done, we were not able to find any publication with proper or right research details. There has been an increase of using sensory or consumer evaluation in kombucha research projects. With this trend, the number of sensory and/or consumer research on kombucha is expected to increase. To promote this trend and to help future kombucha researchers and the industry, the researchers who use sensory and/or consumer research on kombucha should use an appropriate methodology, conduct research properly, and interpret the results correctly.

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