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KOMBUCHA UNCOVERED: ANCIENT BREW, MODERN WELLNESS

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ABSTRACT

Kombucha has gained popularity in recent years due to its potential health benefits. It is produced by fermenting sweetened tea with a symbiotic culture of bacteria and yeast (SCOBY) over a period of about 7 to 14 days. The incentive and bacteria raise the sugar content in the tea, creating organic acid, probiotics, and other healthy factors. SCOBY is safe to eat and applied for gastronomic value development. The exploration indicates that using the applicable culinary system on the SCOBY, enhances consumer adequacy. The combination culture of bacteria and incentive (SCOBY) used in kombucha manufacturing involves the microbial conditioning engaged in developing biofilm boba are incorporated into product to enhance its nutritive quality. Set up in symbiotic association in the kombucha tea, these microbes help in the conformation of cellulose fibrils extracellularly that forms a biofilm at the air- liquid interface. Kombucha is recognized as a safe and functional drink, offering several health benefits substantially due to its microbial composition. It contains salutary bacteria, particularly from the Acetobacter and Gluconobacter genera, and provocations similar as those from the Saccharomyces rubric. Alongside these microbes, the presence of glucuronic acid also plays a significant part in promoting health. Kombucha has a pungent, slightly sour flavor and generally comes as an effervescent, stimulating drink. Bioactive chemical acting in combination is believed to beget kombucha health benefits. Worth mentioning then that kombucha, which is reported to retain some health benefits like enhanced digestion, vulnerable system strength, and boost in energy position.

KEY WORDS: *Kombucha, SCOBY, Fermentation, Bacteria, Yeast, Gastronomic value.*

I. INTRODUCTION

Kombucha SCOBY is a health-promoting fermented beverage made by culturing a symbiotic mixture of bacteria and yeast in sweetened tea, typically using *Camellia sinensis* leaves along with sugar derived from sugarcane or sugar beet. Often referred to as 'mushroom tea' or 'tea fungus,' kombucha was traditionally brewed at home without the need for specialized equipment. The name 'Kombucha' is believed to originate from the Japanese words 'Kombu' (a type of seaweed once mistakenly linked to the tea) and 'Cha,' meaning tea. This fermented drink is known by various names across Asia—for example, *hongchabeoseo-tcha* in Korea, *shenxian cu* in China, *kochakinoko* in Japan, and *cha-mug* in Thailand. Historical records trace kombucha back to 220 BC in China. It has been consumed for over two millennia and made its way to Western countries around the time of World War I. During World War II, a German physician popularized its use in Europe, claiming it could treat a wide range of ailments, from cancer to diabetes. the drink gained wide acceptance across Europe from the 1950s (3). Kombucha drinks are now being retailed by further than 300 enterprises in the request, furnishing a vast array of brands and flavors. In the once many times, there has been a notable growth in kombucha product and consumption encyclopedically, rendering it one of the most promising requests with several significant profitable trends. To increase their customer reach, companies are introducing a variety of health beverages featuring innovative flavors. Among kombucha products, both the unflavored and fruit- or flower-infused varieties are the most widely consumed. As a result, manufacturers are crafting traditional kombucha using a range of natural raw materials and enhancing them with botanical and fruit-based flavor extracts. Additionally, they are focusing on creative packaging strategies to capture consumer attention and boost the commercial success of kombucha in the market (4). Kombucha is rich in numerous precious ingredients and natural conditioning due to its primary constituents.

That have the eventuality to affect as a common and healthy libation, tea has abundant situations of polyphenols mortal health (5). Also, the multitudinous efficient bioactive provocations rates of kombucha during are turmoil. Result of raw accoutrements phenol content and the cooperation of bacteria and relationship produce By employing substrates in multiple metabolic pathways, the incentive- bacteria a multitude of useful metabolites,

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Kombucha is rich in various beneficial compounds, including organic acids, essential vitamins, polyphenols from tea, amino acids, enzymes that assist in hydrolysis, minerals, and precursors for ethanol production (6). The fermentation relies on a SCOBY culture, typically developed in black tea, which serves as a nutrient-rich medium to support microbial activity. Since the latter part of the 20th century, in recent years, kombucha has attracted growing scientific attention for its potential health benefits. Research indicates that it may contribute to improved immune response and help in reducing the likelihood of chronic diseases such as diabetes, hypertension, and cardiovascular disorders. Additionally, kombucha possesses notable antioxidant activity and has been found to exhibit antimicrobial, anti-inflammatory, and anti-aging effects (7, 8, 9, and 10).

Kombucha has a slightly acidic taste, primarily due to the production of organic acids during fermentation. In addition, several bioactive compounds are formed through natural biochemical processes. Notably, tea-based polyphenols act as potent antioxidants, playing a significant role in reducing the risk of cardiovascular and neurological diseases (5). The microbial population in kombucha—especially specific bacteria—converts glucose and ethanol into various organic acids, including lactic, ascorbic, acetic, gluconic, and glucuronic acids. These compounds are important for several metabolic activities in the human body (11, 12). Therefore, kombucha is classified as a functional beverage with potential health benefits and can serve as a nutritious component of a regular diet. The bioactive profile of kombucha depends largely on the type of tea used, though fermentation generally enhances its antioxidant properties and overall health value.

Recent research directions have focused on evaluating the antioxidant, antibacterial, anti-inflammatory, and anticancer activities of kombucha brewed with various types of tea and alternative substrates, such as sugar beet or sugarcane, instead of the conventional ones. To increase the nutritional value of the beverage, teas like green, oolong, red, and white have been identified as promising alternatives to black tea for kombucha fermentation, offering a wider range of bioactive compounds.

II. KOMBUCHA PREPARATION

This drink is made by stirring tea sugared using a SCOBY (6). It tastes a little sweet and sour contemporaneously, along with having traces of carbon dioxide (13). Oolong, green, or black tea is generally employed to produce kombucha drinks. Five grams of tea leaves for every liter of water can be employed to make it. Sugar is latterly added to the result, serving as a substrate for the provocations and bacteria that raise tea. The ideal quantum of sugar for each liter of water is around 50 g. insure the drink is nearly at 20 °C previous to adding the SCOBY or a small volume of set kombucha. Preparing kombucha demands using sanitized outfit and working in a clean terrain to oversee the origins' growth and help accidental impurity. (14). Also, pH situations should be controlled while stirring kombucha, and immaculately halt this when pH is achieved at position 4.2, as overproduction of acetic acid can be contraindicated (15). To ensure food safety, additional measures include pasteurizing the final product to control the buildup of alcohol and carbon dioxide, adding 0.1% sodium benzoate and 0.1% potassium sorbate as preservatives, and storing the beverage under refrigerated conditions (14).

III. FERMENTATION

The fermentation period for kombucha typically ranges from a minimum of 3 days to a maximum of 60 days, depending on the specific fermentation techniques used (14). It is usually carried out at room temperature to optimize the process. Sucrose is commonly used as the primary carbon source, in concentrations ranging from 5% to 20%, providing essential nutrients for microbial growth. A SCOBY or a 10% inoculum of previously fermented kombucha can be used as a starter culture (16, 17). According to Vīna et al. (2013), key fermentation parameters—such as duration, temperature, and pH—play a critical role in the process. During fermentation, the formation of organic acids decreases the tea's pH, resulting in an acidic and low-oxygen environment. These conditions help suppress the growth of harmful or pathogenic microbes, thereby enhancing the microbiological safety of kombucha as a beverage (14)

IV. SCOBY METABOLISM

Fermentation in kombucha is a biochemical process through which the SCOBY derives energy. This process is primarily influenced by factors such as ambient storage temperature, fermentation duration, and the concentration of sucrose [18–20]. Yeast species present in the SCOBY, including *Brettanomyces*, *Candida*, *Pichia*, *Saccharomyces*, *Saccharomycodes*, and *Zygosaccharomyces*, secrete the enzyme invertase, which facilitates the breakdown of sucrose into glucose and ethanol [21,22]. These fermentation products are subsequently utilized by the microbial community to generate carbon dioxide and other metabolites [22,24]. The primary bacterial strains involved—*Acetobacter* and *Gluconobacter*—converts ethanol into acetic acid through enzymatic actions of alcohol and aldehyde dehydrogenases, thereby lowering the pH of the medium [23]. Acetic acid exhibits antimicrobial properties that help prevent contamination by harmful microorganisms [24]. Elevated ethanol concentrations can disrupt microbial cell membranes, further reducing pathogenic load [22]. Additionally, enzymatic breakdown of certain tea-derived phenolic compounds enhances the antioxidant potential of the drink [23]. The bacterial metabolism also leads to the synthesis of gluconic acid and cellulose, contributing to the formation of biocellulose or microbial biofilm [22].

V. HEALTH BENEFITS

The health goods of kombucha are numerous and encompass detoxification of the blood, lowering of blood pressure, calcification of the feathers, seditious conditions, rheumatism, arthritis, gout pattern, rotundity, menstrual problems, menopausal flashes, wakefulness, stress, and bothered jitters. Kombucha has also been set up to boost the vulnerable system, glandular systems, liver, and interferon situations; regulate intestinal foliage

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and homogenize intestinal function; ameliorate the skin, hair, and nail health; and avoid bladder infections.(6, 25).

5.1 Antioxidant Activity

Antioxidants are compounds that protect cells from oxidative damage caused by free radicals. They achieve this by neutralizing reactive molecules, binding to pro-oxidant metals, or inhibiting enzymes that promote oxidation (26). The antioxidant activity of these compounds is linked to various health benefits, such as reducing the risk of cardiovascular disease and cancer, improving immune function, and relieving inflammation and arthritis (6). Research on the health benefits of kombucha has revealed that it is a rich source of antioxidants, often in higher concentrations than unfermented tea. These antioxidants include polyphenols, catechins, ascorbic acid, and D-saccharic acid-1,4-lactone (DSL).

Polyphenols, renowned for their strong antioxidant effects, help protect cells by neutralizing reactive oxygen species (ROS) and free radicals (2). The polyphenol content in kombucha is influenced by factors such as the type of tea used, fermentation time, and microbial activity during the fermentation process (27). Studies show that kombucha made from green, oolong, and black teas has the highest levels of polyphenols after three days of fermentation, while kombucha from red and white tea reaches its peak polyphenol content after 14 days. Specifically, kombucha brewed with green tea contains more total phenolic compounds than black tea kombucha (28). Prolonging fermentation generally increases polyphenol levels, and the inclusion of additional ingredients has also been shown to enhance the phenolic content and bioaccessibility—the fraction of compounds that becomes available for absorption in the gastrointestinal tract. For example, adding olive leaves or honey improved both phenolic bioaccessibility and antioxidant activity in kombucha (29).

During fermentation, the complex polyphenolic structures are often broken down into smaller, more bioactive molecules due to the acidic conditions and enzymatic activity from the SCOBY microbes. This breakdown leads to increased phenolic concentration and enhanced antioxidant potential (2). Additionally, organic acids produced during fermentation, such as acetic acid, contribute to the drink's antioxidant, antimicrobial, anti-inflammatory, and acidifying properties (28,30). Acetic acid levels were observed to rise with longer fermentation, correlating with increased antioxidant activity. Among various tea bases, black tea kombucha was found to contain higher organic acid concentrations compared to green and oolong teas (27). Under certain conditions, kombucha may also display pro-oxidant activity, which could lead to oxidative cascades that damage cells (31). This pro-oxidant effect may occur due to an overabundance of antioxidants or through specific interactions between antioxidants and certain ions or molecules. For example, substances like catechins, tocopherol, and some organic acids can work together to trigger pro-oxidant effects (32). Additionally, the presence of copper (Cu^{2+}), iron (Fe^{3+}), or hydrogen peroxide (H_2O_2) in combination with phenolic compounds and vitamin C has been shown to exhibit pro-oxidant activity (33).

5.2 Anti-inflammatory and Anticancer Activities

Inflammation is a crucial part of the body's immune response to infections. However, it is also linked to various chronic conditions, including arthritis, asthma, and cardiovascular diseases. Chronic inflammation, in particular, is associated with the development of precancerous lesions that may progress into different types of cancer, one of the leading causes of death worldwide. Consequently, strategies to reduce inflammation have become a key focus in cancer prevention and treatment research.

Recently, kombucha has drawn attention for its potential anti-inflammatory and anticancer properties, largely due to the polyphenols and other bioactive compounds produced through biochemical transformations during fermentation. A study by Četojević-Simin et al. (34) showed that kombucha enhanced with dried pomegranate leaves exhibited significant antigenotoxic effects and antiproliferative activity against various human cancer cell lines, including HeLa (cervical cancer), MCF-7 (breast cancer), and HT-29 (colon cancer), compared to kombucha without supplementation.

Certain components in kombucha, such as vitamin C, glucuronic acid, polyphenols, and lactic acid, have been found to inhibit the growth of stomach cancer cells (35). In another study, Jayabalan et al. (36) observed that kombucha made from black tea demonstrated anticancer effects against several cell lines, including A549 (lung carcinoma), U2OS (osteosarcoma), and 786-O (renal carcinoma). The results indicated that kombucha induced cytotoxic effects in U2OS and 786-O cells and reduced the activity of matrix metalloproteinases (MMP-2 and MMP-9) in 786-O cells and MMP-2 in A549 cells. Additionally, it significantly inhibited cancer cell invasion and motility across all tested types, suggesting that kombucha could be a promising therapeutic option for targeting multiple forms of cancer.

5.3 Antimicrobial Activity

Kombucha is well known for its potent antimicrobial properties, effective against a wide range of both Gram-positive and Gram-negative microorganisms. These antimicrobial effects are mainly attributed to bioactive compounds formed during fermentation, including polyphenols, organic acids, and other metabolites derived from the tea base and microbial activity. Kombucha made from black tea, in particular, has shown significant antibacterial effects against various foodborne pathogens, as well as antifungal activity (37). Likewise, kombucha brewed with green or oolong tea has demonstrated effectiveness against several enteric pathogens, including *Escherichia coli*, *E. coli* O157:H7, *Shigella dysenteriae*, *Salmonella typhi*, and *Vibrio cholerae* (27)

Moreover, it has been observed that the antimicrobial compounds in kombucha remain stable even after heat treatment at 100°C for 20 minutes, indicating good thermal resistance. Most studies have concluded that the antimicrobial potential of kombucha primarily arises from its rich content of organic acids—especially acetic acid—as well as an abundance of phenolic compounds produced during fermentation. Additionally, kombucha may contain

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naturally occurring antibiotic-like substances that contribute further to its antimicrobial activity (38).

5.4 Other Benefits

Kombucha has demonstrated cytotoxic effects, enabling it to target and destroy cancer cells. This action is attributed to the active compounds in tea leaves and the metabolites produced by the SCOBY during fermentation (27). Studies have shown that kombucha made with black tea effectively targets Caco-2 colorectal cancer cells, exhibiting stronger cytotoxic effects on cancer cells than on normal cells. Even boiled black tea kombucha has been found to have significant activity against Caco-2 cells. The presence of organic acids and the low pH of kombucha further enhance its anticancer properties, particularly by aiding in the elimination of Caco-2 cells. Additionally, kombucha has demonstrated anticancer effects on human renal melanoma, osteosarcoma, and lung melanoma cells (36). In animal studies, kombucha reduced cytotoxicity caused by phenols (39). Moreover, kombucha is known to have hepatoprotective effects, helping to reduce liver damage caused by toxic chemicals.

The organic acids in kombucha contribute to various health benefits, such as detoxification, hormonal balance, and improved absorption of phenolic compounds. For example, glucuronic acid, a potent detoxifying metabolite, binds to toxins in the liver and aids in their elimination (40). It also serves as a precursor for vitamin C production and plays a crucial role in glucuronidation, which supports hormonal balance and increases the bioavailability of phenolic compounds. This process helps neutralize free radicals and prevent oxidative damage (41). Additionally, lactic acid in kombucha has beneficial effects on health by improving blood circulation and preventing blood clot formation. The acidity from lactic acid also contributes to kombucha's antimicrobial activity (25). Kombucha has been shown to protect the liver from toxins in animal models (42, 43).

Jung et al. (44) found that kombucha made with black tea positively influenced gut microbiota in mice, alleviating conditions like nonalcoholic fatty liver disease. The microbial communities in SCOBY are considered probiotics, supporting digestion, nutrient absorption, and immune function. Microcellulose in kombucha also aids in the growth of beneficial gut bacteria (45). Furthermore, kombucha has been shown to increase energy, reduce skin inflammation, wrinkles, and acne, alleviate constipation, support weight loss, and reduce arthritis symptoms (46, 47).

5.5 Adverse Effects of Kombucha

Kombucha is generally regarded as a safe fermented drink from the aspect of food safety if duly prepared, handled, and consumed. Nonetheless, in certain cases, primarily home- set kombucha, food safety enterprises must be taken into account because some pitfalls are related to kombucha medication and ingestion. The International Association for Food Protection states that kombucha implicit hazards are represented by natural, chemical, and dislike hazards. Food borne pathogens, for case, can be present anywhere during kombucha medication; hence, altering the implements and holders, using boiled water to prepare the tea, and using good quality SCOBY are judicious. Due to the low pH position of kombucha products, the vessel cattiness employed in stirring and storing them is also able of generating a possible chemical hazard that has serious impacts on mortal health. Its inordinate input may lead to lactic acidosis, which is the excess of lactic acid in the blood and in which individualities with disabled impunity are at threat, alcohol abusers, and women who are pregnant(48,49). Kombucha has also been responsible for causing hyponatremia (50), poisonous hepatitis (51), antiJo 1 myositis (51), and cholestatic hepatitis (52).

CONCLUSION

Kombucha has gained increasing popularity among health-conscious individuals due to its wide range of health benefits. The primary raw materials, particularly tea, and the microbial community within the SCOBY, are crucial for producing a variety of beneficial health compounds, including polyphenols, organic acids, amino acids, vitamins, minerals, and hydrolytic enzymes. Numerous studies, both in vivo and in vitro, have reported various health benefits of kombucha, such as antioxidant, antimicrobial, anti-inflammatory, and anticancer properties, in addition to its role in enhancing the immune system and preventing certain chronic conditions.

Most commercial kombucha is naturally fermented by the microbial community present in the SCOBY, which can vary from batch to batch and is difficult to control. To maintain consistent product quality, the introduction of specific strains of microbes may be necessary, especially in large-scale production. To cater to consumer preferences, additional ingredients are often added to enhance the flavor, aroma, and health benefits of kombucha. However, it is important to assess the health-promoting properties of these final products. While many of kombucha's health benefits have been supported by in vitro and animal studies, human clinical trials are essential to confirm the health impacts of kombucha and its active components (1, 49). Though kombucha is generally considered safe, improper preparation, storage, and handling may lead to negative health effects. Therefore, further research into food safety guidelines, *standardized brewing methods*, *consumer demographics*, *and* consumption recommendations is warranted.

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