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Next-Generation Tea Beverages: Innovations in Formulation and Processing

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Abstract This study explores the significant innovations and trends shaping the future of the tea beverage industry, focusing on novel ingredients, advanced processing technologies, and emerging consumer demands. The importance of innovation in tea beverages is evident in the shift of consumer preferences towards healthier and more sustainable choices. New ingredients such as functional additives and innovative extraction methods and processing technologies are fundamentally changing tea drink formulations, not only enhancing their health benefits but also improving sensory quality. Technological progress is the key to this transformation, with modern extraction, brewing, and fermentation technologies, as well as advancements in preservation and packaging, playing a crucial role. This study further discusses the integration of automation and digital technologies in tea production, showcasing successful innovations through case studies and lessons learned from market failures. It offers strategic recommendations and forecasts future directions for tea beverage innovation to meet evolving consumer expectations. This study provides a roadmap for future research and development in the tea beverage industry.

Keywords Tea beverages; Functional formulations; Advanced processing technologies; Consumers; Innovation

1 Introduction

The tea beverage industry has witnessed significant transformations over the past few decades, driven by the increasing consumer demand for health-oriented and functional beverages. Innovations in tea formulations and processing techniques have played a crucial role in meeting these demands. The introduction of next-generation tea beverages, which incorporate a variety of bioactive compounds, has not only enhanced the health benefits of tea but also diversified its flavor profiles and applications. These advancements are essential in maintaining the relevance and competitiveness of tea in the global beverage market (Nurmilah and Utama, 2022).

Several key trends are driving innovation in tea formulations. There is a growing consumer preference for natural and health-promoting ingredients. This has led to the incorporation of various herbs, leaves, berries, seeds, and roots into tea formulations, resulting in beverages rich in bioactive compounds such as carotenoids, flavonoids, phenolic acids, and terpenoids (Nurmilah and Utama, 2022). Microbial fermentation technology enriches tea beverages with functional health properties and unique flavors, making them highly appealing to consumers (Morales-de et al., 2023). Moreover, the rise of the "new-tea" industry, characterized by novel marketing strategies and the use of e-commerce platforms, has further fueled innovation. The adoption of tools like SWOT, PEST and AISAS analyses has enabled companies to better understand market dynamics and consumer preferences, thereby facilitating the development of innovative tea products (Lu, 2022; 2024).

This study aims to explore the significance of bioactive compounds in enhancing the health benefits of tea and analyze the impact of consumer trends and market dynamics on tea innovation. The study discusses tea processing techniques that aid in the development of new tea products and identifies future directions and potential challenges for the tea beverage industry. By integrating recent research findings, this study hopes to provide

valuable insights and references for the evolving landscape of the tea beverage industry and highlight the potential for future innovations.

1 New Ingredients and Formulations

1.1 Exploration of novel ingredients in tea beverages

The exploration of novel ingredients in tea beverages has been a significant focus in recent research. Next-generation teas are being formulated with a variety of bioactive compounds derived from herbs, leaves, berries, seeds, and roots. These components not only enhance flavor but also offer health benefits. For instance, the inclusion of carotenoids, flavonoids, phenolic acids, alkaloids, coumarins, polyacetylene, terpenoids, and saponins has been shown to offer multiple biological functions such as anticarcinogenicity, antimutagenicity, and antiaging effects (Mahdavi-Roshan et al., 2020; Deka et al., 2021). This diversification in ingredients is aimed at creating tea beverages that are not only enjoyable but also contribute to overall well-being.

1.2 Health-oriented formulations

Health-oriented formulations in tea beverages are becoming increasingly popular as consumers seek healthier alternatives. One of the key trends is the reduction of sugar content in tea beverages to cater to the growing demand for low-calorie drinks. Additionally, the incorporation of functional additives such as botanic extracts is gaining traction. These extracts are used for their potential health benefits, including weight control, slimming, and various beauty applications (Nurmilah and Utama, 2022). The focus on health-oriented formulations is driven by the need to provide consumers with beverages that support their health goals while still offering a pleasurable drinking experience.

1.3 Case studies of successful new formulations

Several case studies highlight the success of new formulations in the tea beverage industry. For example, the use of herbal teas that incorporate a wide range of bioactive compounds has been well-received in the market. These teas are produced using fresh or dried herbs and other plant materials, which are either infused or boiled to extract their beneficial properties. The resulting beverages are rich in natural compounds that offer antibacterial, antioxidant, and antiviral properties, making them a popular choice among health-conscious consumers (Figure 1) (Nurmilah, and Utama, 2022). The success of these formulations demonstrates the potential of next-generation tea beverages to meet the evolving preferences of consumers while providing significant health benefits.

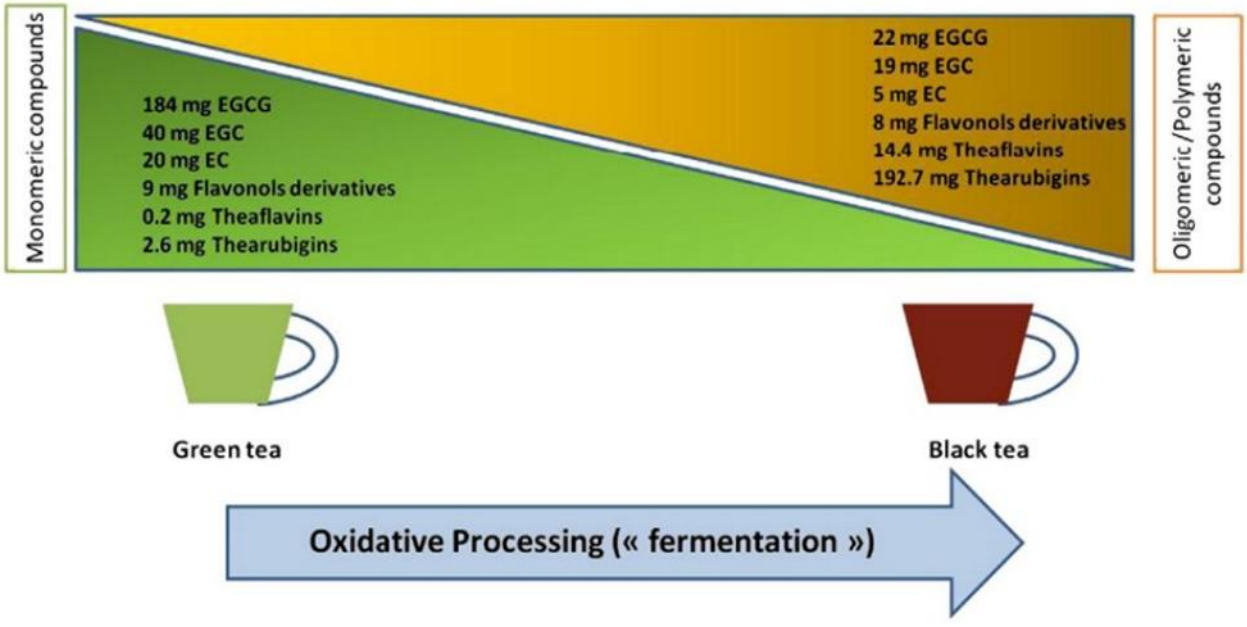

Figure 1 Major compounds change in green and black teas on fermentation (Adopted from Nurmilah and Utama, 2022)

Oxidative processing of tea leaves significantly changes its chemical composition, from high levels of monomeric compounds in green tea to high levels of oligomeric/polymeric compounds in black tea. This process is critical for the development of the characteristic pigments and flavors of different tea types. Nurmilah and Utama (2022) compared the chemical composition of green tea (minimally processed) and black tea (fully oxidized). Green tea contained higher levels of monomeric compounds (such as 184 mg EGCG and 40 mg EGC) compared to black tea. Black tea contained higher levels of oligomeric/polymeric compounds such as theaflavins (14.4 mg) and thearubigins (192.7 mg), which were significantly increased by complete oxidation. The oxidation process causes the conversion of flavan-3-ols in green tea to theaflavins (dimeric form) and thearubigins (oligomeric/polymeric structures) in black tea.

2 Technological Advancements in Tea Processing

2.1 Innovations in extraction and brewing techniques

Innovations in extraction and brewing techniques have played a crucial role in the development of next-generation tea beverages. These techniques focus on maximizing the extraction of bioactive compounds from tea leaves and other botanical sources. Next-generation teas are rich in natural bioactive compounds, including carotenoids, flavonoids, phenolic acids, alkaloids, coumarins, polyacetylene, terpenoids, and saponins, which contribute to their health benefits (Nurmilah and Utama, 2022). The use of advanced brewing methods ensures that these compounds are effectively extracted, providing consumers with beverages that offer various health benefits, such as anticarcinogenic, antimutagenic, antibacterial, antioxidant, and antiviral properties (Nurmilah and Utama, 2022).

2.2 Innovations in tea fermentation methods

The innovation in tea fermentation technology is a pivotal factor driving the enhancement of quality and optimization of flavor in tea beverages. Specifically, advancements in microbial screening and utilization techniques have bolstered the health benefits and flavor profiles of fermented tea beverages. Kombucha, a low-alcohol fermented tea beverage, is produced through symbiotic fermentation of sweet tea by bacteria and yeast (Figure 2) (Nyhan et al., 2022). As one of the globally renowned functional fermented beverages, kombucha is widely consumed for its abundant metabolic health products (Kim et al., 2022; Jakubczyk et al., 2023). Additionally, fermentation of tea products with *Saccharomyces cerevisiae* produces high-alcohol tea beverages, which gradually gain consumer favor due to their combination of tea's flavor and quality with that of wine. Current research has focused on developing a new generation of functional tea-flavored alcoholic beverages by fermenting anthocyanin-rich “Ziyan” tea and black tea, which are known for their potential in reducing the risk of metabolic syndrome, preventing cardiovascular diseases, and managing hypertension (Xu et al., 2023; 2024). These findings underscore the emerging trend of functional fermented tea beverages that integrate health benefits with refined flavor profiles in future tea product development.

2.3 Advances in preservation and packaging technologies

Preservation and packaging technologies have also seen significant advancements, ensuring that tea products maintain their quality and freshness over extended periods. These technologies include innovative packaging materials and methods that protect the tea from environmental factors such as light, moisture, and oxygen, which can degrade its quality (Cacciotti et al., 2018). The development of such technologies is crucial for maintaining the bioactive compounds in tea, thereby preserving its health benefits. Additionally, the use of sustainable packaging materials aligns with the industry's move towards environmentally friendly practices.

2.4 Automation and digitization in tea production

The automation and digitization of tea production processes have revolutionized the industry, leading to increased efficiency and consistency in tea quality. Automation technologies, such as robotic systems and automated processing lines, have streamlined various stages of tea production, from harvesting to packaging. Digitization, including the use of data analytics and smart technologies, has enabled producers to monitor and optimize production processes in real-time, ensuring high-quality output and reducing waste (Xia et al., 2020; Lu, 2022).

These advancements not only improve the overall efficiency of tea production but also allow for the customization of tea products to meet specific consumer preferences (Lu, 2022).

The next-generation tea beverages are a result of significant technological advancements, innovative extraction and brewing techniques, microbial fermentation technology, advanced preservation and packaging technologies, and the automation and digitization of production processes. These innovations have collectively contributed to the development of high-quality, health-promoting tea products that cater to the evolving needs and preferences of consumers.

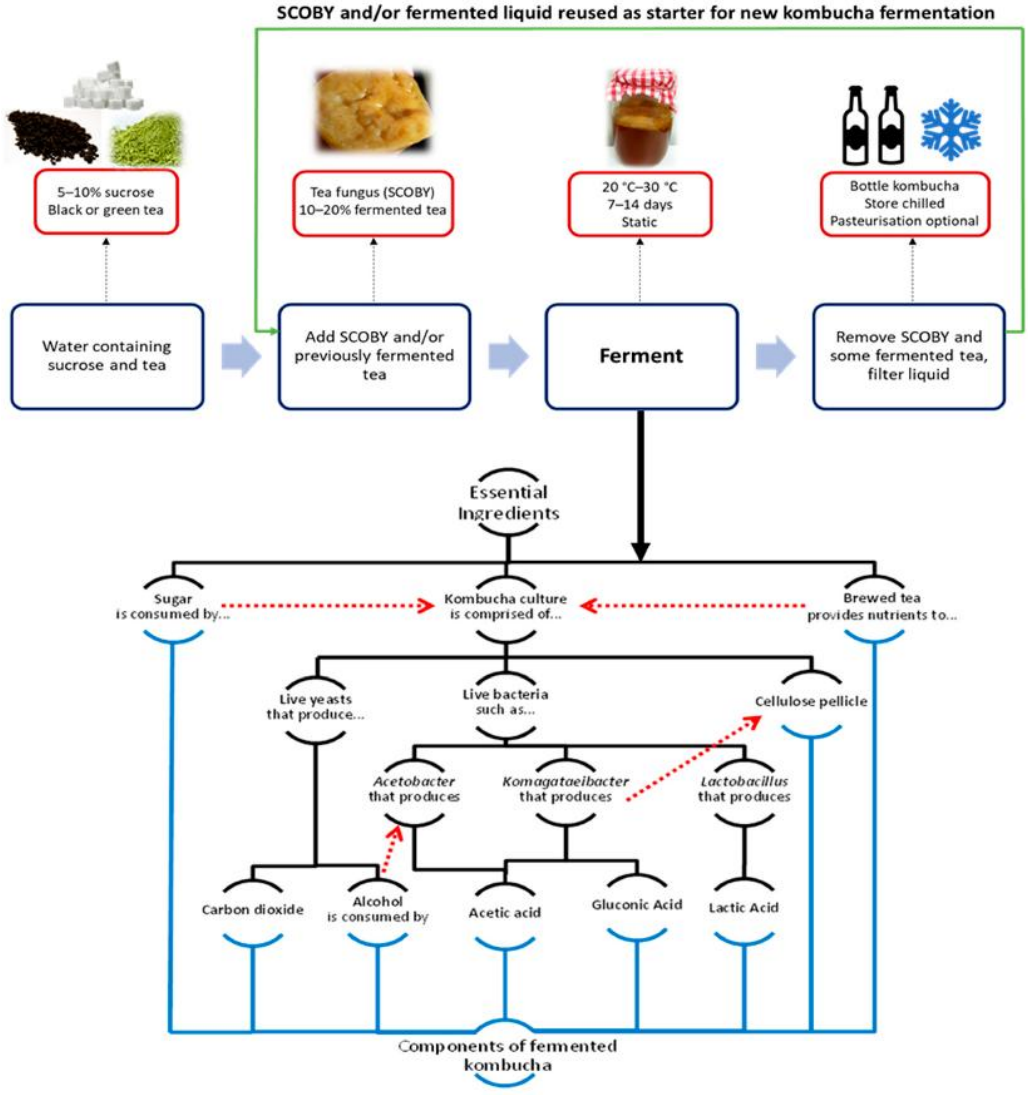

Figure 2 An overview of kombucha preparation and fermentation (Adopted from Nyhan et al., 2022)

3 Sustainability and Ethical Sourcing

3.1 Sustainable sourcing of tea and other ingredients

Sustainable sourcing is a critical aspect of the tea industry, aiming to balance economic, environmental, and social objectives. Several studies have highlighted innovative techniques and approaches for sustainable sourcing in tea production. Green extraction techniques such as ultrasonic-assisted extraction and microwave-assisted extraction have been shown to significantly reduce the consumption of raw materials, solvents, and energy while maximizing the extraction yield of bioactive molecules from tea species. This approach not only protects the environment but also improves the quality of human life by providing safer dietary supplements and pharmaceutical formulations (Figure 3) (Koina et al., 2023).

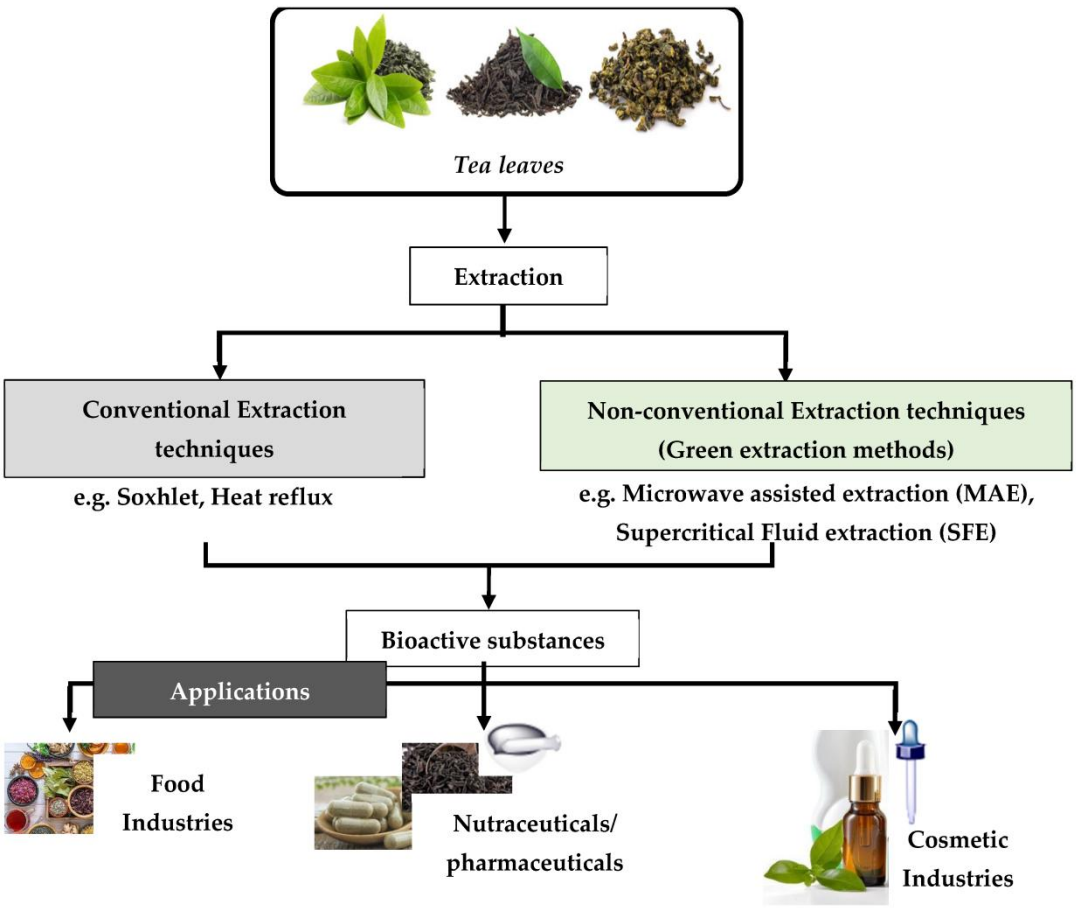

Figure 3 Extraction of biologically active compounds from tea leaves and their application (Adopted from Koina et al., 2023)

Koina et al. (2023) demonstrated the extraction technology and application of bioactive substances in tea. Tea extraction can be carried out by traditional extraction technology or non-traditional extraction technology (green extraction method). Traditional extraction techniques include Soxhlet extraction and hot reflux method, while non-traditional extraction techniques (green extraction methods) include microwave-assisted extraction (MAE) and supercritical fluid extraction (SFE). Through these extraction methods, bioactive substances in tea can be obtained, including polyphenols, polysaccharides, amino acids, alkaloids, organic acids, proteins and volatile components.

High-quality tea extracts, produced through green and efficient extraction technologies, meet the growing demand for natural plant drinks with health benefits. These technologies also address safety concerns related to pesticide residues, heavy metals, and organic solvents, ensuring the stability and safety of tea products (Wei et al., 2023).

3.2 Environmental impact of new tea production processes

The environmental impact of tea production processes has been a significant concern, with studies indicating various methods to mitigate negative effects. A comprehensive analysis of China's green tea production revealed that local tea is more environmentally damaging compared to exported tea, primarily due to lower yields and higher greenhouse gas (GHG) emissions. Improving fertilizer use efficiency, adopting new tea varieties, and utilizing renewable energy are effective measures to reduce environmental impacts (Xu et al., 2021).

Life cycle assessment (LCA) of tea production highlights the substantial CO_2 emissions from traditional tea preparation methods. Shifting to powdered or boxed tea products, coupled with biogas utilization from tea waste, can significantly reduce these emissions. Moreover, the adaptation of tea production to climate change is crucial.

Climate change impacts have led to changes in tea cultivation areas and practices to optimize environmental conditions, ensuring sustainable tea production in the face of global warming (Zhao et al., 2022).

3.3 Ethical considerations in the global tea market

Ethical considerations in the global tea market encompass fair labor practices, equitable trade, and responsible sourcing. The Rainforest Alliance certification has been instrumental in promoting sustainable tea production practices. This certification process has driven tea producers in Kenya to adopt environmentally and socially responsible farming methods to maintain market access (Archer and Elliott, 2021). Furthermore, the economic sustainability of organic tea cultivation among small-scale growers in Assam, India, has shown that organic practices can provide better income and long-term viability compared to conventional methods. However, stable yields and resource optimization are critical for maximizing economic benefits (Deka and Goswami, 2021).

Sustainable sourcing, minimizing environmental impacts, and addressing ethical considerations are essential for the advancement of next-generation tea beverages. These practices not only ensure the sustainability of the tea industry but also promote health, environmental protection, and social equity.

4 Consumer Preferences and Market Trends

4.1 Changing consumer demographics and preferences

Consumer demographics and preferences are continuously evolving, which has a profound impact on the tea beverage market. Studies indicate that consumers of different ages and social backgrounds have significantly different preferences for tea products. For example, college students show a preference for milk tea made with tea bases from well-known tea companies and have a negative attitude towards non-dairy creamers (Lin et al., 2023). Additionally, different demographic groups exhibit significant differences in their knowledge and attitudes towards herbal tea, with highly educated individuals being more inclined to choose herbal tea (Hussain et al., 2023).

4.2 Analysis of market trends in different regions

The development trends of the global tea market vary across different regions. For example, the tea market in China has experienced significant growth in recent years, especially with the rapid recovery of the new tea beverage market after the pandemic (Tan, 2022). In India, despite challenges such as rising production costs and climate change, the tea industry still shows strong growth potential (Hajra, 2021). Additionally, Sri Lanka's tea industry focuses on enhancing environmental and social sustainability while facing global market challenges (Kamalakkannan et al., 2020).

4.3 Case studies of market adaptation and consumer engagement

In terms of market adaptation and consumer engagement, several successful case studies provide valuable insights for tea companies. For example, China's "HEYTEA" has successfully captured a significant share in the competitive tea beverage market through co-branding and diversified sales strategies (Zhao, 2023). Another case is "Xiao Guan Cha" which quickly gained market recognition through brand culture positioning and differentiated packaging (Yang, 2020). Furthermore, research has found that in Sri Lanka, consumer loyalty to branded tea is significantly influenced by income and education levels. Tea brands can increase their market share by developing product-oriented marketing strategies (Bandara et al., 2021).

5 Regulatory Challenges and Opportunities

5.1 Overview of global regulations affecting tea beverages

The global tea beverage market is subject to a complex web of regulations that vary significantly across different regions. These regulations encompass aspects such as food safety, labeling, health claims, and the use of additives. For instance, in many Asian countries where tea consumption is deeply rooted in culture, regulations are often stringent to ensure the safety and authenticity of tea products. The European Union and the United States also have rigorous standards that govern the permissible levels of contaminants, the use of bioactive compounds, and the claims that can be made about the health benefits of tea beverages (Lovrek et al., 2011). These regulations are

designed to protect consumers but can also pose significant challenges for manufacturers looking to innovate and introduce next-generation tea beverages.

5.2 Opportunities in regulatory changes

Despite the challenges, regulatory changes can also present opportunities for the tea beverage industry. For example, the increasing recognition of the health benefits of bioactive compounds found in next-generation teas could lead to more favorable regulations that allow for specific health claims on product labels (Debnath et al., 2021). Additionally, harmonization of regulations across different regions could simplify the process of international trade, making it easier for manufacturers to expand their markets. The shift towards more transparent and science-based regulatory frameworks can also encourage innovation by providing clear guidelines on the use of new ingredients and processing methods (Lovrek et al., 2011).

5.3 Challenges in compliance and international trade

Compliance with diverse and often stringent regulations remains a significant challenge for the tea beverage industry. Manufacturers must navigate a labyrinth of requirements that can vary not only by country but also by region within countries. This complexity can lead to increased costs and delays in bringing new products to market (Nurmilah and Utama, 2022). Furthermore, the lack of harmonization in regulations can create barriers to international trade, as products that meet the standards in one region may not be compliant in another. This is particularly challenging for next-generation tea beverages that incorporate novel ingredients and processing methods, which may not be covered by existing regulations (Lovrek et al., 2011). The need for continuous monitoring and adaptation to regulatory changes adds another layer of complexity, requiring significant resources and expertise.

6 Case Studies in Innovation

6.1 Innovative products that reshaped the market

Innovative products have played a crucial role in reshaping the tea market. For instance, the Japanese tea industry has transformed the perception of green tea from a commodity to a branded luxury good through technological innovations and strategic marketing. This repositioning has allowed Japanese green tea to penetrate international markets and appeal to a luxury segment of consumers (Xia and Donzé, 2023). Another example is the success of "Sexy Tea", a Chinese brand that integrated traditional Chinese aesthetics into its product innovation and marketing strategies. This approach has significantly enhanced the brand's market share and consumer recognition by leveraging cultural elements to create a unique and appealing brand image (Da et al., 2023).

6.2 Start-ups and new business models in tea industry

Start-ups and new business models have also contributed to the dynamic evolution of the tea industry. Nayuki, for example, has utilized innovative marketing strategies, such as the "third space" concept and a close-loop management system via e-commerce platforms, to distinguish itself in a competitive market. These strategies have enabled Nayuki to attract a broad customer base and secure a significant market position (Lu, 2022). In India, small tea growers have adopted branding strategies to market fresh tea leaves as high-quality, differentiated products rather than bulk commodities. This shift has improved market competitiveness and increased the earnings of smallholders by tapping into new consumer markets and enhancing product value through branding and marketing support (Raj, 2021).

6.3 Lessons learned from failed product launches

Learning from failed product launches is essential for future success. For example, some products failed to gain market traction due to a lack of understanding of consumer preferences and market conditions. The case of PT. Sinar Sosro Medan in Indonesia illustrates this point. Despite efforts in product innovation, the company faced challenges due to insufficient market research and a mismatch between product offerings and consumer expectations, leading to limited consumer interest and market performance (Sinaga et al., 2021). Another example is the experience of Nayuki, which, despite having high-quality products, struggled with imperfect marketing strategies compared to competitors like Luckin Coffee. The need for continuous innovation in marketing

approaches and the importance of expanding sales channels were highlighted as critical factors for sustaining competitiveness in the evolving tea market (Huang and Yao, 2023).

7 Future Directions

7.1 Predictions for the next wave of tea beverage innovations

Driven by consumer demands and technological innovations, the future of tea beverages is poised for significant progress. One major trend is the development of functional teas, which, in addition to providing basic nutrition, also offer health benefits. These next-generation teas are expected to be rich in bioactive compounds such as flavonoids, phenolic acids, and catechins, which have been shown to possess antioxidant, anti-inflammatory, and anticancer properties (Williamson et al., 2011; Kim et al., 2020). Additionally, there is growing interest in herbal teas made from a variety of plants, which can provide a wider range of bioactive compounds compared to traditional teas derived solely from the tea plant (Nurmilah and Utama, 2022).

7.2 Technological integration and future product developments

Technological advancements will play a key role in the formulation and processing of next-generation tea beverages. Innovations in genomics and biotechnology are expected to enhance the quality and health benefits of tea by cultivating tea plants optimized for bioactive compound features. Moreover, advancements in food processing technologies such as high-pressure processing and packaging can improve the stability and bioavailability of these compounds, ensuring maximum health benefits for consumers (Ferruzzi, 2010). The integration of digital technologies like blockchain and the Internet of Things can revolutionize the tea industry by enhancing traceability and ensuring the authenticity and quality of tea products. This helps to build consumer trust and meet the growing demands for transparency in food sourcing and production (Xia et al., 2020).

7.3 Strategic recommendations for stakeholders

For stakeholders in the tea industry, several strategic recommendations can be made to capitalize on these future directions. Continued investment in R&D is essential to discover new bioactive compounds and develop innovative tea formulations that cater to health-conscious consumers. Employ advanced processing technologies to improve the stability and bioavailability of bioactive compounds in tea beverages. This can help create products with superior health benefits (Ferruzzi, 2010). Use genomic and biotechnological tools to cultivate tea plants rich in beneficial compounds. This can produce premium teas with specific health benefits (Xia et al., 2020). Implement digital technologies such as blockchain to improve traceability and ensure the authenticity of tea products. This can help build consumer trust and meet regulatory requirements. Educate consumers on the health benefits of next-generation tea beverages and the importance of bioactive compounds. This can drive demand and create a loyal customer base (Kim et al., 2020). Work with healthcare providers to promote the health benefits of tea and include tea drinking in dietary recommendations for disease prevention and health promotion (Kim et al., 2020; Mahdavi-Roshan et al., 2020). Identify and target new segments, such as functional beverages for specific health conditions or demographic groups, to expand the market for tea products. Prioritize sustainability and ethical sourcing practices to meet growing consumer demand for environmentally and socially responsible products (Xia et al., 2020). By following these strategic recommendations, stakeholders can capitalize on emerging trends and innovations in the tea beverage industry and ensure long-term growth and success.

8 Concluding Remarks

This study discusses the innovations in the formulation and processing of next-generation tea beverages and explores their impact on the tea industry from multiple perspectives. The advancements in extraction, brewing techniques, and microbial fermentation technology have enhanced the nutritional content and flavor of tea beverages. Processing technologies that focus on both health benefits and flavor are pivotal directions for the future development of functional tea beverages. The application of green extraction techniques and efficient extraction methods significantly reduces the consumption of raw materials and energy while enhancing the safety and quality of tea products. Consumer preferences for tea beverages are changing, with significant differences in tea product preferences among consumers of different ages and backgrounds. Successful brands like "SexyTea"

and "Nayuki" have stood out in the competitive market through cultural positioning and innovative marketing strategies.

The tea industry faces several challenges: climate change significantly impacts tea cultivation, requiring adaptive measures to ensure sustainable production. Global market competition is intense, and China and other major tea-exporting countries must improve product quality and market strategies to maintain their competitive edge. Small farmers need more training and technical support to promote organic farming and sustainable agricultural practices. Meanwhile, there are numerous opportunities: the development of e-commerce platforms has brought new growth points to the tea market, allowing tea products to reach a broader consumer base through online sales and digital marketing. As consumer concern for health and environmental protection increases, the market for organic tea and functional tea beverages has a promising future.

The tea industry is undergoing a rapid transformation, shifting from traditional production and sales models to modern, sustainable, and innovation-driven approaches. In the future, the tea industry will play a more significant role in addressing climate change, improving product quality, and meeting diverse consumer demands. Through technological innovation, marketing strategies, and global cooperation, the tea industry will continue to thrive and contribute significantly to the global economy and cultural exchange.

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Conflict of Interest Disclosure

The authors affirm that this research was conducted without any commercial or financial relationships that could be construed as a potential conflict of interest.

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