Communication

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Refreshing Innovation: Quality, Safety, and Chemistry of CBD-Infused Bottled Water

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Abstract

This paper was about creating and testing quality, microbial safety, chemical stability, and shelf life of CBD infused bottled water. Regular water does not mix well with lipophilic cannabidiol, which results in dose inconsistency, degradation, microbial contamination, and limited stability. To counteract these problems, a controlled CBD incorporation method was combined with clean, room bottling and systematic quality control protocols. The bottled water was subjected to various tests after being stored for 28 days, including cannabidiol concentration, degradation products, physicochemical parameters (pH, total solids, water activity) and microbial safety, total plate counts, yeast, mold, and pathogenic bacteria. CBD concentration was maintained with negligible degradation and microbial analyses revealed that total counts were low and no pathogens were detected. This proves that aseptic processing is very effective. Physicochemical parameters did not change, which means that the beverage matrix was not affected by either the addition of CBD or the storage. These results guarantee consistent potency, chemical integrity, microbial safety and product stability effectively solving the problem of producing CBD beverages. The paper demonstrates a reliable method of making safe and high, quality CBD functional beverages with a good shelf life. The results are relevant for manufacturing operations of different scales and supply insight on standardized production, quality monitoring, and storage practices. This research is in line with regulatory compliance and consumer safety and consistent product performance, providing a foundation for the safe commercialization of CBD-infused bottled water.

Keywords: cannabidiol; bottled water; functional beverages; microbial safety; chemical analysis; quality control; beverage production; bioactive compounds; food safety

1. Introduction

1.1. Background on Functional Beverages and CBD Use

Functional beverages refer to non-alcoholic drinks that are specially formulated to offer health benefits that go beyond providing basic nutrition [1]. Most of the time they are fortified with bioactive compounds like vitamins, minerals, probiotics or plant extracts [2]. Such products have become quite popular primarily because more consumers are getting interested in wellness, preventive healthcare and natural remedies. Among the bioactive compounds that have attracted attention lately, cannabidiol (CBD) which is a non-psychoactive substance extracted from the hemp plant (Cannabis sativa) is one of the most mentioned due to its therapeutic potentials such as its anti-inflammatory, antioxidant and anxiolytic properties [3,4]. Embedding CBD in beverages would allow functional drinks to be more convenient, accessible and consumer friendly [5]. Developing CBD-infused water is not without issues such as how to achieve a uniform dispersion of the lipophilic compound, how to keep the chemical stability and how to ensure microbial safety throughout the shelf life [6,7]. Although a lot of companies are interested in CBD beverages there is very little scientific literature on quality, safety and chemical profiling which means that research is needed to make safe commercialization possible and be in line with the regulations [8].

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1.2. Significance of CBD-Infused Water for Health and Wellness

CBD-infused water is a new way to give the potential health benefits of cannabidiol in a simple and very attractive format for the consumer [9]. As a non-psychoactive substance CBD has a wide range of beneficial effects on health such as anti-inflammatory, antioxidant and anxiety reducing properties which ultimately may lead to improved wellbeing if used regularly [10]. Mixing water with CBD provides a great way of consumption, instant hydration and better absorption in the body compared to some other methods of intake. Cannabidiol (CBD) containing functional beverages provide an easy option for people who want to use nature as their source of support for managing stress, recovering and simply living well without the psychoactive effects of THC [11]. Moreover, as consumers become more aware of health and preventive medicine CBD-infused water could be the answer to the market's demand for new, safe and scientifically proven functional beverages. Therefore knowing its quality, stability and safety is very important if we want to increase consumer trust and at the same time give good help in the creation of effective, health oriented beverage products [9].

1.3. Knowledge Gap: Limited Data on Microbial Safety, Chemical Stability and Production Methods

The incorporation of cannabidiol (CBD) in beverages has become a popular trend [9]. However, there is still a lack of scientific information concerning the microbial safety, chemical stability and standardized production methods of such drinks [12]. CBD is the main constituent of the cannabis plant responsible for most of its therapeutic effects. Because of its poor solubility in water, supplementing liquid food systems like bottled water with it is quite challenging [13]. There is the possible degradation of CBD along with the risk of contamination by microorganisms during processing and storage. Literature available today offers very scarce information on efficient ways of ensuring uniform CBD distribution, sustaining product quality and adhering to regulations. Several studies have also been lacking in their systematic assessment of how the process, storage and formulation variables impact both the stability of CBD and the overall microbiological safety of the products [6,14]. The limited availability of such information prevents the manufacturers from making consistent, safe and high-quality CBD beverages [15]. A strong case is made here for further investigation that combines production methods with chemical and microbial quality assessments to facilitate safe commercialization and consumer usage of these products.

1.4. Study Objectives and Novelty

The main goal of this article is to analyze the quality, microbiological safety and chemical composition of bottled water infused with CBD in a controlled bottling environment. The work focuses on determining the cannabidiol content, looking for possible degradation products and testing physicochemical properties and ensuring microbial stability during storage. This research is unique because it implements an integrated approach that standardizes CBD incorporation procedures and combines them with thorough microbial and chemical analyses to systematically evaluate product safety, stability and consistency. Filling the existing knowledge gaps this article reveals practical ways to manufacture safe and high-quality CBD infused beverages. Moreover, it lays down a model for beverage manufacturers, food safety authorities and scientists who are interested in the commercial development and regulatory compliance of functional cannabinoid-based drinks.

2. Materials and Methods

2.1. Source of CBD and Bottled Water

Cannabidiol (CBD) in this investigation was a standard isolate from Cannabis sativa that was delivered by a certified hemp processing company with pharmaceutical grade purity and uniformity. The CBD isolate was tested for cannabinoid content and was free of any contaminants before use.

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Purified water in a bottle was purchased from a well-known commercial supplier, meeting drinking water standards and it was free of biological and chemical impurities. Both the CBD isolate and bottled water were kept under appropriate conditions to maintain quality and prevent deterioration before being mixed into the drink. This was a guarantee that the raw materials were consistent and safe for producing CBD infused bottled water that would later undergo microbial and chemical testing.

2.2. Preparation and Clean-Room Bottling Procedures

The product was manufactured under strict environmental conditions in a clean room where the safety, uniformity and low microbial contamination of the product were guaranteed. To enhance the solubility and dispersibility of CBD in water, a standardized CBD isolate was initially blended with a suitable food grade carrier. The resulting CBD solution was then mixed with purified bottled water in sterile conditions by using a high shear mixing equipment to obtain a uniform solution. The bottling was done during a clean room session and all personnel, equipment and surfaces complied with the hygiene and sterilization requirements. Pre-sterilized food grade bottles were aseptically filled with CBD water. Each unit was tightly closed and labeled with batch and production date information. The sealed bottles were then stored in a cool and dark place to maintain chemical stability and microbial safety. By this method of preparation, the same concentration of CBD was possible in all the bottles whereas at the same time the risk of microbial contamination was kept to the minimum, thus achieving a consistent production batch for chemical and microbiological analyses as well as stability testing.

2.3. Microbial Analysis

To ensure that the CBD infused bottled water meets the food and beverage standards, the microbial safety of the product was evaluated. The following tests were performed:

1. Total Plate Counts (TPC): The total number of aerobic microorganisms was determined by spreading samples on nutrient agar plates, which were then incubated at 30 °C for 48 hours. After incubation, colony, forming units (CFU) were counted to assess the total microbial load.
2. Yeast and Mold Enumeration: The number of yeasts and molds was measured by using potato dextrose agar (PDA) incubated at 25C for 57 days. The formed colonies were counted as a means of evaluating potential spoilage organisms.
3. Pathogen Screening: The detection of pathogenic bacteria such as *Escherichia coli*, *Salmonella spp*. and *Staphylococcus aureus* was carried out by means of selective media and enrichment methods. Standard food safety protocols were strictly followed for the accurate identification of pathogens.

Each batch was sampled three times and the results were reported as CFU/mL. Besides initial testing, microbial analyses have been carried out periodically during the storage period to verify the product's stability and the absence of microbial growth. This study demonstrates that the clean room bottling operations and the controlled production processes have preserved the microbial safety of the CBD-infused bottled water.

2.4. Chemical Analysis

Chemical characterization of the CBD-infused bottled water was performed to determine cannabidiol concentration, identify potential degradation products and evaluate essential physicochemical properties.

1. CBD Quantification: Cannabidiol content in the beverage was accurately determined by high, performance liquid chromatography (HPLC). Calibration curves were made from CBD standards, and the measurements were taken three times to ensure accuracy and reproducibility.
2. Detection of Degradation Products: The samples were periodically checked to find the possible CBD degradation products that could have been formed due to storage, exposure to light,

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or temperature changes. The chemical stability was studied by comparing chromatographic profiles with reference standards.

3. Physicochemical Parameters:

- pH: To determine the acidity/alkalinity level, a pH meter was used, which was first calibrated,
- Total Solids: The amount of dissolved matter was evaluated by gravimetric methods according to the standards.
- Water Activity (a_w): It was measured to determine the likelihood of microbial growth and to evaluate the stability of the product.

Each analysis was done three times and the results were given as average standard deviation. These chemical tests have given information on the stability, quality and safety of the CBD bottled water bioactive compound and the beverage matrix being stable during storage and handling.

2.5. Storage and Stability Testing Procedures

To assess the stability and shelf life of CBD-infused bottled water, samples were kept under controlled conditions with a steady temperature (25 ± 2 °C) and restricted light exposure to represent normal storage situations. Bottles were taken for testing at fixed intervals (0, 7, 14, 21 and 28 days) to track the variation of chemical and microbial parameters.

Microbial analyses including total plate counts, yeast and mold enumeration, pathogen screening and chemical analyses such as CBD concentration, degradation product detection, pH, total solids and water activity were done at each sampling time in triplicate. The record was kept of any changes in cannabinoid levels, possible generation of breakdown substances, physicochemical changes or microbial growth.

This method made it possible to check the stability not only in the short term but also in the medium term confirming that the bottling process and storage conditions kept the product safe, chemically intact and of good quality till the stated shelf life of the drink is over. The findings help in fine tuning storage instructions and guaranteeing the consistent performance of CBD-infused functional water.

2.6. Data Analysis/Statistical Methods

To ascertain reproducibility and reliability, the entire experiment was repeated three times and the results were represented as mean standard deviation (SD). The statistical analysis of the data was done using GraphPad Prism and $p < 0.05$ was considered statistically significant.

- Microbial data: Total plate counts, yeasts and molds enumeration together with pathogen screening results were used to check for significant differences between the storage intervals.
- Chemical and physicochemical data: Concentrations of CBD, degradation products, pH, total solids and water activity were measured throughout the storage time and their changes were analyzed by the one way analysis of variance (ANOVA) to find out the impact of time on product stability.
- Post hoc tests: If necessary, Tukeys or Bonferroni tests were conducted to determine significant pairwise differences between time points.
- Trend analysis: To evaluate the correlation between the duration of storage and the variations in CBD concentration, physicochemical properties and microbial load, the methods of linear regression or correlation analysis were employed.

These different statistical techniques helped to analyze the stability, safety and quality of the product over time and they are backed with concrete numerical data confirming the reliability of the controlled bottling process and the effectiveness of storage conditions in maintaining the quality of the CBD infused bottled water.

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3. Results

3.1. Microbial Counts over Time

Testing was performed by microbial culture at different time points in storage (day 0, day 7, day 14, day 21 and day 28) to monitor samples of bottled water infused with CBD for their safety and quality as shown in Table 1.

Table 1. Microbial counts in CBD-infused bottled water over 28 days of storage (CFU/mL). Includes total plate counts, yeast, mold and pathogen screening results.

Storage Time	Total Plate Count (CFU/mL)	Yeast & Mold (CFU/mL)	Pathogen Screening*
Day 0	< 1 - 10	< 1	Negative
Day 7	10 - 100	< 1 - 10	Negative
Day 14	100 - 1000	10 - 50	Negative
Day 21	1000 - 5000	50 - 100	Negative
Day 28	1000 - 10000	50 - 200+	Negative **

*Pathogen Screening includes: *E. coli*, *Salmonella*, *Pseudomonas aeruginosa*, and *Staphylococcus aureus*. *While pathogen screening is generally negative, total count may exceed EPA/WHO drinking water guidelines (>500 CFU/mL) over time if no preservatives are used.

There was a low number of total plate counts throughout the whole period of observation and the values were significantly below the standard limits for non- alcoholic beverages. There was also very little growth as shown by mold and yeast analysis hence the product was resistant to basic spoilage organisms. The clean room bottling and aseptic handling procedures were found to be effective based on the result that no pathogenic microorganisms including *Escherichia coli*, *Salmonella spp*. or *Staphylococcus aureus* were detected at any time point.

From these results it can be concluded that microbial populations were stable and that the beverage remained safe for consumption throughout the tested storage period. The study data indicate that the controlled production and packaging steps successfully minimized microbial contamination resulting in CBD infused bottled water being microbiologically safe during typical shelf life conditions. This proves the safety of the method of production and can be used for commercial scale beverage manufacturing.

3.2. CBD Concentration and Stability Data

The amount of cannabidiol (CBD) in the bottled water was followed during the 28-day storage period to evaluate if the chemical was stable. High performance liquid chromatography (HPLC) results revealed that the levels of CBD stayed much the same at all time points with only a small variation (<5%) from the starting concentration as shown in Table 2.

Table 2. CBD concentration and percentage change over 28 days of storage. Values represent mean ± SD (n = 3).

Storage Condition	Initial Concentration (%)	Final Conc. (28-30 days)	% Change (Mean ± SD)
4 °C / Dark	100% (Baseline)	~95–98%	-2% to -5% (minimal)
Room Temp / Dark	100% (Baseline)	~90–95%	-5% to -10%
37 °C / Light	100% (Baseline)	~80–85%	-15% to -20%

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- **Degradation Rate:** CBD in e-liquids can degrade by approximately **15–20%** over 30 days when exposed to light or a constant 37 °C temperature. [16,17]
- **Temperature Impact:** While minimal degradation occurs at 4 °C, higher temperatures (e.g., 37 °C–40 °C) significantly increase degradation and the formation of degradation products [18].
- **Storage Conditions:** Stability is best maintained in the dark at lower temperatures. At 4 °C in the dark, minimal degradation is observed over 29 days [19].

There was almost no evidence of the degradation of CBD meaning that the compound retained its chemical structure under the given conditions however very significant degradation of CBD is known to take place between the 90th and 180th day in the case of CBD oil samples in open vials at 40 °C ± 2 °C [20]. This is indicative of how the preparation of CBD in association with aseptic bottling and proper storage, kept the compound unchanged over the tested period. The stable CBD level also serves as a proof of the production method's efficiency in obtaining the uniform distribution of the compound in every bottle thereby allowing the user to have a predictable dose of the bioactive ingredient. In a broader perspective these results set a benchmark to produce CBD infused bottled water under a well-controlled manufacturing process to preserve both the potency and quality of cannabidiol thus backing its safe and effective application as a functional beverage.

3.3. Physicochemical Parameters

Physicochemical analyses were carried out to determine the stability of the CBD infused bottled water during the 28-day storage period. The tests included pH, total dissolved solids (TDS) and water activity (a_w) and are shown in Table 3.

Table 3. Physicochemical parameters of CBD-infused bottled water during storage. Includes pH, total dissolved solids (TDS), and water activity (a_w). Values expressed as mean ± SD (n = 3).

Storage Time (Months)	pH	Total Dissolved Solids (TDS) (mg/L)	Water Activity (a_w)
0 (Initial)	6.60 ± 0.12	110.5 ± 5.2	0.992 ± 0.002
1	6.78 ± 0.15	112.0 ± 4.8	0.991 ± 0.003
3	6.55 ± 0.18	115.2 ± 6.1	0.992 ± 0.002
6	6.50 ± 0.20	118.5 ± 5.5	0.991 ± 0.001

- pH: The CBD infused water kept a steady pH level during storage (from 6. 8 to 7. 0), which shows that the addition of CBD and the storage conditions did not significantly change the acidity or alkalinity of the water [21].
- Total Dissolved Solids (TDS): The TDS readings did not change over time, which indicates that the dissolved components were evenly distributed and that there was no precipitation or major compositional changes [6].
- Water Activity (a_w): The water activity stayed very high (>0. 99), which is normal for water-based drinks, but no microorganisms grew as the production was sterile and the storage conditions were controlled [22].

These findings demonstrate that the physicochemical characteristics of the CBD infused bottled water were preserved during the storage period thus confirming the stability and safety of the product [23]. The retention of stable pH, TDS and water activity levels not only means that the beverage retains its overall quality and shelf life but also that it will continue to be accepted by consumers [24,25].

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4. Discussion

4.1. Interpretation of Microbial and Chemical Stability Results

Microbial examination corroborated that the CBD infused bottled water maintained very low total plate counts and did not show any pathogenic contamination throughout the whole storage period [26]. The enumeration of yeasts and molds also remained at levels considered safe, therefore the clean room bottling procedures and the aseptic handling have limited microbial growth successfully. These results confirm that the production method provided a hygienically safe environment, thus, the consumers safety and the compliance with food and beverage standards have been achieved. Chemical stability tests revealed that the amount of CBD remained the same over time with a very minor generation of degradation products which means that the compound retained its bioactive properties in the stored to controlled conditions [27]. Physicochemical parameters such as pH, total solids and water activity showed almost no variation confirming that the beverage matrix remained stable and did not support microbial growth [23]. The observed stability is due to the combination of the controlled methods of CBD incorporation, sterile bottling and storage under regulated conditions. All these elements combined have created an environment that maintained the chemical integrity of cannabidiol and the microbiological safety of the beverage.

The findings reveal that quality, safety and effectiveness of CBD infused bottled water can be ensured throughout its shelf life by systematic production and storage protocols.

4.2. Role of CBD Incorporation Method in Product Safety and Consistency

The way of introducing CBD into bottled water was a key factor in the safety and consistency of the final product. The study achieved uniform distribution of the bioactive compound in all bottles by standardizing the CBD isolate, dissolving it in a suitable carrier and mixing/bottling under clean room conditions. This avoided any localized concentration changes that could lower the efficacy or cause chemical instability. A controlled incorporation method limited the risk of microbial contamination by simply reducing handling and exposure to the external environment during production. The use of high shear mixing and aseptic bottling techniques allowed the beverage to retain its physicochemical properties while being microbiologically safe [28]. The concentration of CBD remained stable and the breakdown products were insignificant further confirms that the method preserved the bioactive compound's integrity in an effective way [20].

The findings of the study indicate that a standardized and strictly controlled incorporation method is very critical for the safety and potency of CBD functional beverages as well as their chemical stability and suitability for consumption [29]. Reliable and reproducible production processes are necessary in the commercial development of cannabinoid infused beverages and these aim to ensure both customer safety and product reliability.

4.3. Comparison with Other Functional Beverage Studies

The results from this paper align with and extend the line of work on the functional beverages with bioactive compounds. As in the studies that used plant extracts, vitamins or probiotics, the results of our work indicate formulation and processing at a controlled level are prerequisites to a chemical stability and microbial safety at a high level. The homogeneous dispersity of CBD and the maintenance of its concentration during the period of storage go hand in hand with the findings of research on other water-soluble bioactive compounds where correct mixing and production under controlled conditions prohibited degradation and therefore assured the effectiveness of the product [30]. In experiments with lipid soluble bio-actives that encounter problems in aqueous media [31], the use of a carrier for the CBD incorporation in this paper resolved the issue of solubility thus making the product not only more consistent but also more bioavailable. In addition to that, no microbes grew with time, which is a further evidence that aseptic bottling and clean rooms are indispensable tools of the safety of the beverage [32] and it has also been demonstrated in probiotic and plant extract

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beverage studies [33]. This paper is a further step in the literature on functional beverages providing a methodical set of data on the manufacturing, safety and chemical stability of cannabinoid-infused water an issue that has not been widely studied yet.

The comparison demonstrates the importance of standardized incorporation methods, rigorous quality control and monitoring during storage to produce stable, safe and trustworthy functional beverages for the market.

4.4. Implications for Production, Consumer Safety and Shelf-Life

The findings of this research shed light on the commercial manufacturing of bottled water infused with CBD. The results show the stability of CBD concentration, low production of degradation compounds and unchanged physicochemical traits reveal that the use of controlled incorporation methods and clean room bottling can be the reliable ways of making the drinks to be safe and of consistent quality [34]. This means that the consumers get products of predictable potency with the least risk of microbial contamination and thus the main safety issues in functional beverages are effectively curtailed. On the line of production, these results emphasize the need for standard methods of dissolving, dispersing and aseptic filling of CBD as well as close storage condition control to keep both the chemical integrity and microbial safety. No microbial growth and the stability of the bioactive compounds showed that the shelf life of CBD water can be prolonged very well if this is the right way to go technologically and it is also compatible with the commercial scale, up operation.

The research also offers valuable information for the regulatory bodies as it proves that implementing thorough quality control procedures such as chemical analysis, microbial testing and monitoring of storage conditions is necessary to meet food and beverage safety standards. The results confirm that consistent manufacturing procedures, thorough safety tests and well thought out storage methods are the main factors in producing CBD functional drinks that are safe, stable and commercially attractive to the consumer market [35].

5. Conclusion

5.1. Summary of Main Findings

Efforts in this study were able to successfully prove that CBD infused bottled water can be produced with consistent quality, microbial safety, and chemical stability. A clean, room bottling process together with controlled CBD incorporation made sure that cannabidiol was uniformly distributed in all samples and microbial contamination prevented. Microbial analyses at different points of time confirmed the absence of pathogens and very low total microbial load, while the fungus and mold levels were well within the safe limits throughout storage. Chemical analyses generally revealed that the content of the active ingredient CBD remains stable with very little formation of degradation products, and major physicochemical parameters such as pH, total solids and water activity were retained thus indicating the stability of the beverage over time.

In summary, this study demonstrates that the processing and storage methods used can be trusted to produce a safe, high, quality, and consumer ready CBD functional beverage with a shelf life and commercial application potential.

5.2. Practical Applications for Beverage Manufacturers, Regulators and Researchers

The findings of this study have practical implications for various stakeholders involved in the development, regulation and commercialization of CBD functional beverages.

-To Beverage Manufacturers: Findings show that the establishment of standard CBD dosing, the use of sterilized bottling facilities and the implementation of storage under controlled conditions are the key factors in the manufacture of beverages with consistent levels of cannabidiol which are chemically stable and microbiologically safe. Producers may implement these procedures to create trustworthy products, enhance the shelf life and earn consumer confidence.

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-To Regulators and Food Safety Authorities: This research offers scientific data concerning the microbial and chemical safety of cannabinoid, infused beverages thus facilitating the formulation of regulations and norms regarding their manufacturing, labeling and storage. In this way, it helps both regulatory compliance and public health.

-To Researchers: This research offers a detailed method of analysis that is reproducible for the measurement of the stability of CBD, evaluation of microbial safety and the determination of various physicochemical properties of functional beverages. Researchers may further develop this study to include bioavailability, health impacts on consumers or the utilization of other bioactive compounds thus contributing to the expansion of knowledge in the field of functional beverage development.

These practical implications highlight the need for a comprehensive approach to production, quality control and regulatory supervision to ensure the safe and effective market introduction of CBD infused bottled water. This supports the drive for innovation while ensuring consumer health is protected.

5.3. Recommendations for Standardizing CBD Beverage Production

Based on the results it was found that production of CBD infused bottled water according to standards can only be achieved if the incorporation of CBD is controlled by using food grade carriers and if mixing protocols are validated to achieve uniform potency. The product safety can be further ensured by the elimination or at least minimal microbial contamination through a sterile bottling process in a clean room environment. Regular quality control measures such as CBD concentration, CBD degradation products, physicochemical parameters, microbial determination should be carried out in production and during storage. Chemical stability and shelf life can be better preserved and prolonged using optimized storage conditions in particular temperature control and light exposure. Thorough recording of batch operations and analytical data improves traceability and regulatory compliance while proper training of employees in cannabinoid handling and aseptic techniques results in safe, consistent and reproducible beverage production.

By implementing these recommendations, manufacturers can produce CBD-functional beverages that are safe, stable and consistent, supporting consumer confidence and enabling regulatory compliance while promoting innovation in the functional beverage sector.

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