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RESEARCH ARTICLE

Nutritional Analysis and Consumer Acceptability of Tea Formulations with *Morinda citrifolia* leaves, *Tetrapleura tetraptera* and *Zingiber officinale*

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ABSTRACT

The growing demand for functional beverages underscores the necessity of leveraging underutilised plant resources with potential health benefits. Despite their nutritional and medicinal attributes, Morinda citrifolia leaves, *Tetrapleura tetraptera* and *Zingiber officinale* remain underexploited in product development, particularly in Ghana. This study formulated and evaluated herbal tea blends incorporating these plants in varying proportions: BT (50% *Morinda citrifolia* leaves, 25% *Tetrapleura tetraptera*, 25% *Zingiber officinale*), CT (50% *Zingiber officinale*, 25% *Morinda citrifolia* leaves, 25% *Tetrapleura tetraptera*), and DT (50% *Tetrapleura tetraptera*, 25% *Zingiber officinale*, 25% *Morinda citrifolia* leaves). Proximate composition was determined using AOAC methods, and fifty (50) untrained panellists above 16 years of age were randomly recruited from the Takoradi Technical University campus for the acceptance tests. The results revealed that proximate analysis for all parameters were significantly different at $p < 0.05$ with BT having moisture (11.13 %), protein (14.02 %), and ash (6.85 %) content. Fat content demonstrated significant variation, with CT having the highest fat percentage (6.18 %). The fibre content was consistently high (14 %-17 %) across all samples. Carbohydrates were the major component, with the highest concentration in DT (56.17 %). Sensory evaluation using a 7-point hedonic scale revealed that BT and CT received superior ratings for colour (CT =5.82, BT = 5.20), aroma (CT = 5.64, BT = 5.64), taste (CT = 5.88, BT = 5.70), flavour (CT = 5.88, BT = 5.64), and aftertaste (CT = 5.92, BT = 5.88) which indicates they were moderately liked. Overall acceptability was highest for CT (44%) being the most preferred, followed by BT (36%) and DT (20%) as the least preferred. These findings illustrate that the blends, particularly CT and BT, demonstrated favourable nutritional profiles and consumer acceptability, thereby highlighting their potential as functional herbal teas and promoting the utilisation of underexploited plant resources.

Keywords: *Herbal tea, Morinda citrifolia, Tetrapleura tetraptera, proximate composition, consumer acceptability*

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INTRODUCTION

Tea, traditionally prepared from the leaves of Camellia sinensis, is one of the most widely consumed beverages globally (Nair, 2020). This plant produces various types of tea, including green, black, white, oolong, and puerh tea, each with distinct characteristics from different production processes (Kumar et al., 2018; Wong et al., 2022). Aside from the traditionally prepared tea, is herbal tea or tisanes, prepared from leaves, flowers, fruits, and roots of various plants, has gained recognition as an alternative health remedy and is consumed for therapeutic properties (Pathaw et al., 2022). Numerous herbal teas have been widely adopted for their potential role in managing chronic diseases and promoting general health, and their potential effects have been studied on various health conditions, including digestive issues, anxiety, and sleep disorders (Poswal et al., 2019; Yang & Hong, 2013). The growing interest in natural remedies has led to increased research on bioactive compounds present in different herbal teas and their mechanisms of action, which necessitates this research. This research aimed to explore the nutritional profile and acceptability of herbal tea infusion obtained from *Morinda citrifolia* leaves, *Tetrapleura tetraptera* and *Zingiber officinale*. *Morinda citrifolia*, commonly referred to as 'noni', is a herbal ingredient that has gained prominence for its potential health benefits. *Morinda citrifolia* is indigenous to Southeast Asia and the Pacific Islands, where it has been used in traditional medicine for centuries (Nelson & Elevitch, 2006). This plant has recently acquired global commercial relevance, particularly in the production of health and cosmetic products. Freshly dried *Morinda citrifolia* leaves, which have been utilized in products such as juices and drinks, contain significant quantities of vitamin C (ascorbic acid), vitamin B3 (niacin), and vitamin A, according to Nwakanma and Akujuobi (2021), which render them nutritionally beneficial. Almeida et al., (2019)also reported that *Morinda citrifolia* leaves contain significant quantities of minerals such as potassium, calcium, sodium, and selenium, which are essential for human health. The antioxidant properties of *Morinda citrifolia* leaves have also garnered attention in the scientific community, with studies suggesting their potential applications in preventing oxidative stress-related diseases (Salehi et al., 2020). Additionally, some studies have indicated that *Morinda citrifolia* leaf extracts may possess antimicrobial properties, which could be valuable for developing natural alternatives to synthetic antibiotics (Shettima et al., 2023).

Tetrapleura tetraptera, popularly known as prekese in Ghana, and globally 'aidan fruit' is another plant species with considerable potential health benefits.Originating from West Tropical Africa, *Tetrapleura tetraptera*, a species belonging to the Fabaceae family. Its aromatic fruits are extensively utilised in traditional cuisine, particularly in soups, infusions, and ethnomedicine (Adesina et al., 2016). The *Tetrapleura tetraptera* has a diverse chemical composition which varies across the different parts of the fruit with carbohydrate and mineral contents differing among seeds, pulp, and woody coats hence contributing to its nutritional value. It contains various nutrients including fiber, proteins, carbohydrates, vitamins, minerals, and fats (Adadi & Kanwugu, 2020; Dongmo et al., 2022; Oteng et al., 2020).*Tetrapleura tetraptera* has become an increasingly prevalent constituent in health-related products because of its high levels of antioxidants, flavonoids, tannins, steroids, and phenolic compounds, which have traditionally been used in the management of conditions such as type 2 diabetes, reduction of blood glucose levels, and facilitation of weight loss (Adadi & Kanwugu, 2020). *Tetrapleura tetraptera* tea, in particular, has been consumed for its purported ability to promote adipose tissue reduction, regulate blood glucose levels, and alleviate gastrointestinal discomfort such as diarrhoea and emesis (Adesina et al., 2016; Asigbaase et al., 2024; Derkyi et al., 2018).

Zingiber officinale, commonly known as ginger, has been extensively utilised both as a culinary spice and for its medicinal properties. Ginger is consumed in various forms, including fresh, dried, powdered, and paste, and is a fundamental ingredient in numerous global cuisines. In addition to its pungent and spicy flavour, ginger is rich in bioactive compounds such as gingerols, shogaols, and zingerone, which contribute to its anti-inflammatory, antioxidant, and analgesic properties (Poswal et al., 2019). These compounds are responsible for the efficacy of ginger in treating conditions such as motion sickness, arthritis, gastrointestinal disorders, and common cold. In *Zingiber officinale* based tea production, drying plays a critical role in enhancing functional quality. Fresh ginger contains predominantly gingerols, whereas drying converts these compounds into shogaols, which exhibit greater biological activity which enhances its therapeutic (Gao et al., 2024; Osae et al., 2021; Shaukat et al., 2023). Consequently, dried *Zingiber officinale* is commonly preferred in tea formulations due to its higher antioxidant potential, inproved extraction efficiency during infusion, and extended shelf stability (Ofoedum et al., 2025; Shaukat et al.,2023). Nutritionally, on dry basis, ginger is composed of approximately 50% carbohydrates, 9% protein and free amino acids, and 6-8% fatty acids, along with essential micronutrients, such as potassium, magnesium, copper, and manganese. These elements contribute to the capacity of ginger to support cardiovascular health, enhance immune function, and promote skin and hair health (Anh et al., 2020).

Notwithstanding their acknowledged individual health benefits, *Morinda citrifolia* ('noni'), *Tetrapleura tetraptera* ('aidan fruit'), and *Zingiber officinale* (ginger) remain largely underutilised in the beverage industry, particularly within the Ghanaian market. In Ghana, *Zingiber officinale* and *Tetrapleura tetraptera* are commonly used in soups; however, *Morinda citrifolia* leaves are rarely incorporated into everyday culinary practices. Given the increasing consumer demand for health-conscious products, there exists an opportunity to introduce tea formulated from a combination of *Morinda citrifolia* leaves, *Tetrapleura tetraptera,* and *Zingiber officinale.* The scientific rationale for the combination lies in the complementary phytochemical profiles of the plants involved. Specifically, the polyphenols and iridoids present in *Morinda citrifolia*, the aromatic and phenolic compounds found in *Tetrapleura tetraptera*, and the highly bioactive gingerols and shogaols from *Zingiber officinale* may synergistically enhance the antioxidant and functional properties of the final beverage. Such a product would not only offer a convenient and healthful alternative to existing beverages, but would also provide consumers with a beverage rich in bioactive compounds known for their potential health benefits. Therefore, this study formulated a herbal tea blend using underutilized local plants from *Morinda citrifolia*, *Tetrapleura tetraptera*, and *Zingiber officinale* to meet the rising demand for functional beverages and promote their wider use in Ghana.

METHODS

Study Design and Setting

An experimental design was used in this study to ensure the control of variability, supports statistical analysis, and facilitates objective comparison among samples. This approach enhances the efficiency, reproducibility, and scientific credibility of the study.

Sources of Raw Materials

Fresh *Morinda citrifolia* leaves (1 kg) were collected from the researcher's backyard garden in Takoradi, Ghana. The plant material was authenticated by the Department of Herbal Medicine at Kwame Nkrumah University of Science and Technology (KNUST) and given a voucher number KNUST/HM1/2018/L012, while fresh *Zingiber officinale* (3 kg) and *Tetrapleura tetraptera* (2 kg) were purchased from the open market in the Takoradi market, Ghana.

Sample preparation

The 1 kg *Morinda citrifolia* leaves and 2 kg *Tetrapleura tetraptera* were washed thoroughly, rinsed with water, and then wiped with a disposable kitchen napkin and cut into pieces of 1cm each and then dried separately in a food dehydrator (Saachi NL-FD-4935) at 70 °C for 3 h in the case of *Morinda citrifolia* leaves and 4 h for *Tetrapleura tetraptera. Zingiber officinale* (3 kg) was washed, grated, and dried in a dehydrator (Saachi Model NL-FD-4935) at 70 °C for approximately 7 h. The selected drying temperature of 70 ℃ and the corresponding durations were strategically chosen to facilitate rapid moisture removal while minimizing the thermal degradation of heat-sensitive bioactive compounds. Moderate-temperature drying. Ranging from 50℃ to 70℃, has been extensively documented to preserve antioxidant and phenolic content in plant materials (Garcìa et al., 2021). The variations in drying time among the samples was indicative of differences in structure which affect drying kinetics (Bonazzi & Dumoulin, 2011). Following the drying process, the materials were individually milled using an electronic blender (BLG-412, Binatone) for a duration of 10 min per sample. The blender was thoroughly cleaned and dried both prior to and following the milling of each sample. Subsequently, the milled material was passed through a 2 mm aluminum sieve.

Various proportions of the materials were mixed using a mixture design approach, generating nine (9) formulations to systematically explore the effects of ingredient rations on product quality. Subsequently, three (3) formulations were selected based on preliminary screening and optimization criteria, including sensory acceptability, physicochemical properties and functional potential. The selected formulations represented low, intermediate and high inclusion levels, thereby capturing the variability within the design space while reducing the number of samples for detailed analysis as shown in Table 1. Each formulation had samples weighing 2 g, which were placed in rectangular infusion tea bags (5 cm × 4 cm) using an automatic tea-bagging machine (Telesonic ST-101). Commercial green tea (Ahmad tea) was used as the control sample. Ahmad green tea was selected as the control sample due its broad consumer acceptance and established status as a conventrional herbal tea beverage, thus serving as a reference standard for comparison with the formulated tea blends. All the bagged samples were stored in glass jars at temperatures between 28–34°C, away from sunlight. They were properly labeled for later analysis.

Table 1:

Proportions of Materials in Blended Tea Samples

Sample code	*Morinda citrifolia* leaves (%)	*Tetrapleura tetraptera*(%)	*Zingiber officinale* (%)
BT	50	25	25
CT	25	25	50
DT	25	50	25

BT (50% Morinda citrifolia leaves, 25% Tetrapleura tetraptera, and 25% Zingiber officinale), CT (50% Zingiber officinale, 25% Morinda citrifolia leaves, and 25% Tetrapleura tetraptera,), and DT (50% Tetrapleura tetraptera, 25% Zingiber officinale and 25% Morinda citrifolia leaves).

Proximate Analysis

Proximate analysis of the formulated tea samples (BT, CT, and DT) was conducted using the method described by the Association of Official Analytical Chemists (AOAC, 1990). These parameters included the moisture, fat, protein, ash, carbohydrate, and fibre contents. The laboratory protocol was followed to ascertain the results.

Moisture Content Determination

The initial weight of a pre-dried coded pan was recorded. A five-gram portion of the sample was then weighed and spread across the bottom of the coded Petri dish. This dish was subsequently placed in a forced draft oven (BOV-V35F1) set at 105 °C for a duration of 4 hours, after which it was allowed to cool in a desiccator. The weight of the dried sample was then taken, and the moisture content was calculated as the percentage of moisture lost.

Therefore,

$$\%Moisture = \frac{(initial\ weight - final\ weight)}{initial\ weight} \times 100 \text{.................. equation (1)}$$

Fat Content Determination

About 5 g of the sample was measured and placed into a thimble, which was then filled with non-absorbent cotton. This thimble, containing the sample, was inserted into the extractor of a Soxhlet apparatus. A clean and dry Soxhlet flask was weighed, and around 150 mL of petroleum ether was poured into it. The Soxhlet apparatus was then set up. Cold water was circulated through the condenser to facilitate the condensation of the organic solvent. The system was allowed to operate for 6 hours. Afterward, the Soxhlet flask, now containing the extracted fat, was removed and dried in an air oven at 40 - 60 °C for 30 minutes. The mixture was then cooled in a desiccator and weighed. The fat content was calculated as follows:

$$\%Fat = \left(\frac{weight\ of\ oil}{weight\ of\ sample}\right) \times 100 \text{.................. equation (2)}$$

Protein Content Determination

Total nitrogen content was measured via Kjeldahl digestion. Protein content was calculated by multiplying nitrogen content by 6.25, a conversion factor appropriate for general food analysis where specific conversion factors are not established (AOAC, 2019).

$$\text{Kjeldahl Nitrogen } \% = \frac{[(Titre\ of\ sample - Titre\ of\ blank) \times N(HCl) \times 14.01] \times 100}{Weight\ of\ sample \times 10} \text{..........equation (3)}$$

$$\%Crude\ Protein = \%KjeldahlNxF \text{..........equation (4)}$$

Ash Content Determination

The mass of a porcelain crucible, which had already been ignited and cooled, was measured. About 2 g of the sample was placed into the crucible. Using tongs, the crucible was transferred to a Vecstar muffle furnace set at 600 °C and left to ash for 2 hours. Afterward, the ash was cooled to room temperature in a desiccator and then weighed.

Crude Fibre Determination

200 mL of 1.25 % H_2SO_4 was measured and poured over 2 g of defatted sample in a flat-bottom flask and placed over a hot plate for its content to boil for 30 min. To mix the contents in the glass and remove the particles from the side, the mixture was stirred every few minutes by manually rotating the flask. Filtration was then carried out, during which warm distilled water was used to wash the residue. The residue was transferred into the flask, and 200 mL of 1.25 % NaOH was poured over it. This was boiled for 30 min, after which the contents were filtered, and the residue was washed with warm distilled water and 80 % alcohol. The residue was then dried in an air oven at approximately 100°C for 1 h. The weight of the dried sample was measured, and the dried sample was transferred into a crucible. The sample was ashed for 30 min, after which the weight of the ash was measured. The crude fibre content was calculated as

$$\%Crude\ fibre = \left(\frac{dried\ weight - ash\ weight}{initial\ sample\ weight}\right) \times 100 \text{...............equation (5)}$$

Carbohydrate and Energy Determination

The carbohydrate content of the tea samples was determined by difference. The carbohydrate content was calculated as

Carbohydrate(%) = 100 – (% moisture + % fat + % protein + % ash + % fibre)…equation (6)

The Atwater factors were used to calculate the energy content of the tea samples. The energy content was calculated as:

Total energy (kcal/100 g) = [(% available carbohydrates × 4) + (% protein × 4) + (% fat × 9)]…….equation (7)

where "available carbohydrate" refers to the digestible component of carbohydrates that contributes to energy production and is caluculated as carbohydrate in equation (6)

Preparation of infusions

The preparation of tea infusions was conducted using all bagged samples, including the control. Each sample consisted of ten bags, which were submerged in a glass jar containing 1.5 L of boiling water. The infusion process was maintained for a period of 5 min. The selected infusion ratio is equivalent to approximately one tea bag per 150 mL, which corresponds with typical consumer preparation practices, where a single tea bag is generally infused in 150-250 mL of hot water. Moreover, an infusion time of 5 mins is widely recognised as optimal for maxinizing extraction without negatively impacting sensory quality.

Sensory Evaluation

Fifty (50) untrained panellists (41 females; 9 males) above 16 years of age were randomly recruited from the Takoradi Technical University campus for the acceptance tests. The panellists were mostly students aged between 18 and 24 years, with a few university staff members.

Inclusion criteria

- Students and staff of Takoradi Technical University
- Familiarity with tea quality parameters
- Good health and availability
- Willingness and commitment to participate

Exclusion criteria

- Non students and staff of Takoradi Technical University
- Unfamiliarity with tea quality parameters
- Unavailability

Sensory Evaluation Procedure

The 50 panallists who agreed to participate were given a consent form in their preferred language, which outlined the study's objectives. Four sample infusions were coded and served randomly to the panellists. Approximately 30 mL of each infusion was served in a 50 mL transparent cup at approximately 60 – 70 °C at the time of tasting. Panellists were free to analyse the samples in any order of their choice. The panellists were required to clear their palates/mouths with water and slices of cucumber before the commencement of tasting and after tasting each sample, and wait 90 s before tasting the next sample to minimise possible carry-over effects. The panellists were not required to swallow all 30 mL of each sample; however, they were asked to hold approximately 10 mL of the sample in their mouths for 5 s and swallow small quantities to appreciate the full sensory characteristics of the beverage. The panellists were allowed to repeat the tasting when necessary. Panellists had no prior information about the samples they tasted to avoid bias.

The panellists were instructed to score their acceptance of five (5) attributes of the infusions: colour, aroma, flavour, taste, and aftertaste. They were also required to indicate the overall acceptability of the samples. If a panellist did not clearly understand the meaning of a particular attribute, an explanation was provided. The panellists scored their acceptance of the attributes and overall acceptability using a 7-point hedonic scale (1 = dislike very much, 2 = dislike moderately, 3 = dislike slightly, 4 = neither like nor dislike, 5 = like slightly, 6 = like moderately, and 7 = like very much). A 7-point hedonic scale was used for the sensory evaluation because it provides sufficient discrimination among samples while remaining simple and easy to use for untrained panelists. The scale also minimizes respondent fatigue and enhances response reliability (Civille et al., 2024).

Statistical Analysis

Data Analysis was conducted using Statistical Package for Social Science (SPSS) version 22 and statistical significance was established using Analysis of Variance (ANOVA). For all analyses, Tukey Honestly Significant Difference (HSD) at $p < 0.05$ was employed to determine significant differences.The results were presented using bar charts to illustrate comparative trends among samples and interpreted accordingly.

Ethical Clearance

Ethical approval for the study was obtained from the Head of Department of Hospitality Management following a formal request and review of study protocols including sensory evaluation form and consent form by the Ethics Review Committee at Takoradi Technical University with the refernce number TTU/FAS/DHM.STF/24/007.

RESULTS

Proximate Analysis

The proximate composition of the formulated tea samples for moisture, fat, protein, ash, fibre, and carbohydrate is presented in Figures 1a -f.

Moisture Content

The moisture content of the formulated teas ranged from 10 % – 11 %. Specifically, DT exhibited a moisture content of 10.73 %, whereas CT demonstrated a comparable moisture content of 10.52 %. However, BT displayed the highest moisture content of 11.13 %, as illustrated in Figure 1a. Although the differences among the samples were minimal, the data revealed a noticeable trend, wherein BT consistently maintained a higher moisture level than CT and DT. These findings suggest that the proportions of the individual ingredients influenced the moisture content of the blended samples. BT, which contained a higher proportion of *Morinda citrifolia* leaves, retained more moisture. In contrast, CT, which was predominantly composed of *Zingiber officinale*, had a slightly lower moisture content than BT, whereas DT, which contained *Tetrapleura tetraptera* as the primary component, exhibited the lowest moisture content. Overall, the results demonstrated that the moisture content across the samples was relatively uniform, although with slight variations depending on the dominant ingredient in each formulation.

Fat Content

The analysis of the fat content in the tea formulations revealed significant variations among the samples. The DT formulation exhibited the lowest fat percentage, with a recorded value of 3.05 %. In contrast, the CT formulation had the highest fat content (6.18 %), while the BT formulation had an intermediate fat content (5.59 %), as shown in Figure 1b. These findings underscore the distinct variation in fat content among the formulations. Specifically, CT, which primarily comprises *Zingiber officinale*, exhibited the highest fat content, whereas DT, predominantly composed of *Tetrapleura tetraptera*, displayed the lowest. The BT formulation, characterised by a higher proportion of *Morinda citrifolia* leaves, occupied an intermediate position between the two extremes of the study. The results suggest that the fat content of the tea blends was influenced by the proportions of the plant components utilised in the formulations. Altogether, the fat values across the samples remained relatively low compared to other macronutrients, and the differences among the formulations were pronounced.

Protein Content

The results of the protein content analysis indicated that the formulated tea samples contained some proteins, as shown in Figure 1c. Statistical analysis of the results indicated that the protein content of the various tea formulations differed with BT, recording the highest protein content of 14.02 %, followed by CT with 11.39 %, and DT with the lowest protein content of 9.21 %. These results indicate a clear upward trend in protein content from DT to CT to BT. The observed differences suggest that the composition of each formulation significantly influenced the protein content, with BT showing the greatest contribution owing to its higher proportion of *Morinda citrifolia* leaves. In contrast, DT, predominantly composed of *Tetrapleura tetraptera*, contained the least amount of protein. CT, with *Zingiber officinale* as its main ingredient, exhibited an intermediate protein content. Overall, the data underscore the variation in protein levels among the formulations, with BT emerging as the most protein-rich formulation and DT as the least protein-rich.

Ash Content

The ash content, which indicates the mineral content among the formulations, varied from 5 % to nearly 7 %, as shown in Figure 1d. The DT formulation had the lowest ash content of 5.97 %, whereas the CT formulation's ash content was slightly higher at 6.08 %. The BT formulation exhibited the highest ash content (6.85 %). These findings revealed a consistent pattern, with BT containing more ash than the other two formulations. The prominence of minerals in BT suggests a richer supply of inorganic nutrients, making it a suitable choice for consumers seeking tea with a higher mineral profile. Therefore, the results indicated that the ash content of the formulations increased in the order DT < CT < BT.

Fibre Content

The fibre content (Figure 1e) of the tea formulations was consistently high across all samples, ranging from 14 % to nearly 17 %. The DT formulation exhibited the lowest fibre content of 14.86 %, whereas both the CT and BT formulations demonstrated higher fibre levels of 15.79 % and 16.5 %, respectively. These findings suggest that the fibre content was influenced by the specific formulation, with CT and BT showing slightly elevated levels compared to DT. Although the variation among the samples was not substantial, the inclusion of higher proportions of *Morinda citrifolia* leaves and *Zingiber officinale* contributed to an increase in the fibre percentage. In contrast, DT, predominantly composed of *Tetrapleura tetraptera*, contained less fibre.

Carbohydrate Content

Carbohydrates were the most prevalent proximate component across all formulations, with a range of 45 % to almost 57 % (Figure 1f). The DT formulation exhibited the highest carbohydrate content (56.19 %). In contrast, the CT formulation had an intermediate carbohydrate content of 50.04 %, whereas the BT formulation had the lowest carbohydrate content of 45.92 %. These findings indicate a declining trend in carbohydrate content from the DT to CT and BT formulations. The observed variations can be attributed to the primary ingredients of each blend. Specifically, DT, which predominantly contains *Tetrapleura tetraptera*, exhibited the highest carbohydrate content. Conversely, BT, which had a greater proportion of *Morinda citrifolia* leaves, had the lowest carbohydrate content. CT, where *Zingiber officinale* is the main ingredient, was positioned between the two. Overall, carbohydrates were the largest component of the proximate composition of the teas, with DT emerging as the formulation with the highest carbohydrate content.

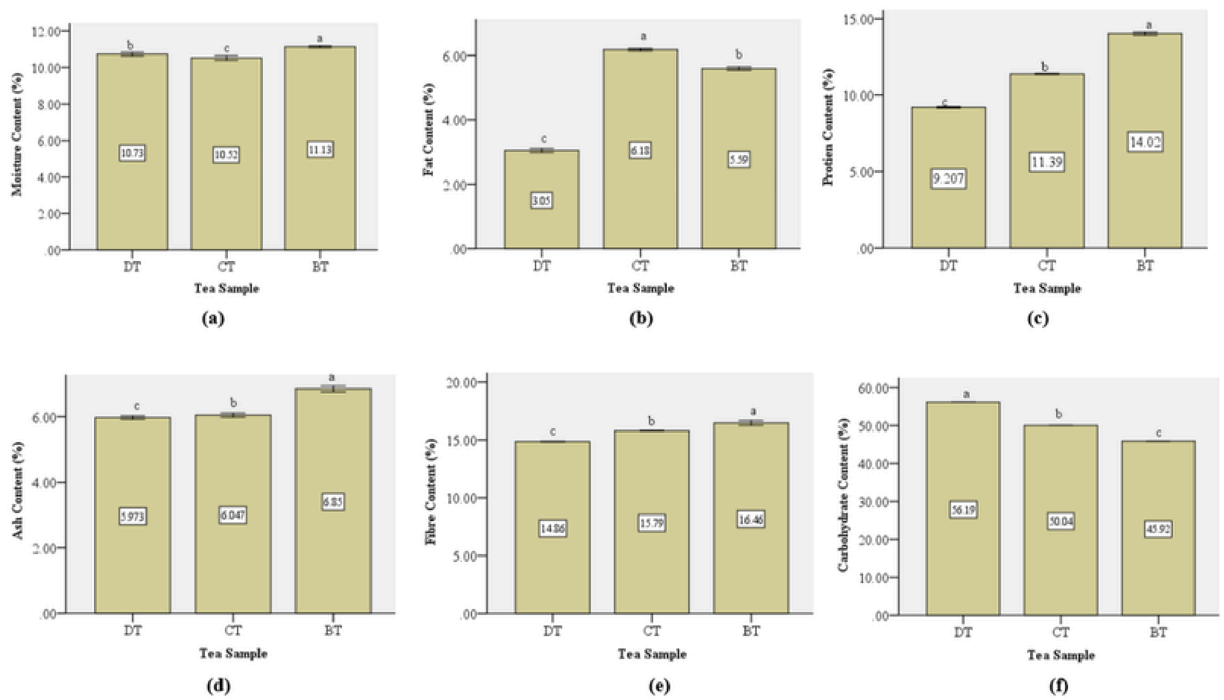

Figure 1: *Proximate Composition of the Formulated Tea Samples – (a) moisture, (b) fat, (c) protein, (d) ash, (e) fibre, and (f) carbohydrate.*

BT (50% Morinda citrifolia leaves, 25% 'aidan fruit', and 25% ginger), CT (50% ginger, 25% Morinda citrifolia leaves, and 25% 'aidan fruit'), and DT (50% 'aidan fruit', 25% ginger, and 25% Morinda citrifolia leaves). Bars with different superscript letters a significantly different ($p < 0.05$) as determined by one-way ANOVA followed by Tukey's HSD test.

Sensory Analysis of Tea Samples

Consumer panellists evaluated the sensory quality attributes (colour, aroma, taste, texture, appearance, and after-taste) by indicating how much they liked or disliked the formulated tea (BT, CT, and DT) samples and a known control brand of green tea (AT) using a 7-point hedonic scale (1 dislike very much, 2 dislike moderately, 3 dislike slightly, 4 neither like nor dislike, 5 like slightly, 6 like moderately, 7 like very much) and overall likeness. Mean scores were calculated for each attribute and overall likeness and presented as a radar chart (Figure 2). The control tea sample (AT) consistently received lower scores across all attributes, generally ranging from 3.0 to 4.0, corresponding to "neither like nor dislike" to "dislike slightly."

In terms of colour, sample CT exhibited the most visual appeal with a score of 5.82, whereas sample AT had the lowest score of 3.6, indicating moderate liking and neither liked nor disliked, respectively. The aroma of samples BT (5.64), CT (5.64), and DT (5.58) was moderately liked; however, the control sample AT (3.56) was neither liked nor disliked. Regarding taste, sample CT recorded the highest (5.88) mean score, indicating that it was liked moderately. Samples DT and BT were also liked moderately, with mean scores of 5.58 and 5.70, respectively. The control sample was neither liked nor disliked, with a mean score of 4. The mean scores for the flavour of the samples ranged from 3.92 to 5.88, with sample CT having the highest score, rating it as being liked moderately. The aftertaste of samples BT, CT, and DT were all liked moderately, with sample CT having the highest (5.92) mean score, followed by sample BT (5.88) and sample DT (5.80). The control sample, AT, was neither liked nor disliked, with a lowest mean score of 3.74. Sample CT was rated as being the overall liked sample in terms of all the attributes, with a mean value of 6.06, meaning it was moderately liked by the panellist.

In summary, the formulated samples BT and CT consistently achieved higher ratings across all sensory attributes, while DT showed moderate acceptance, and the control (AT) was the least preferred sample.

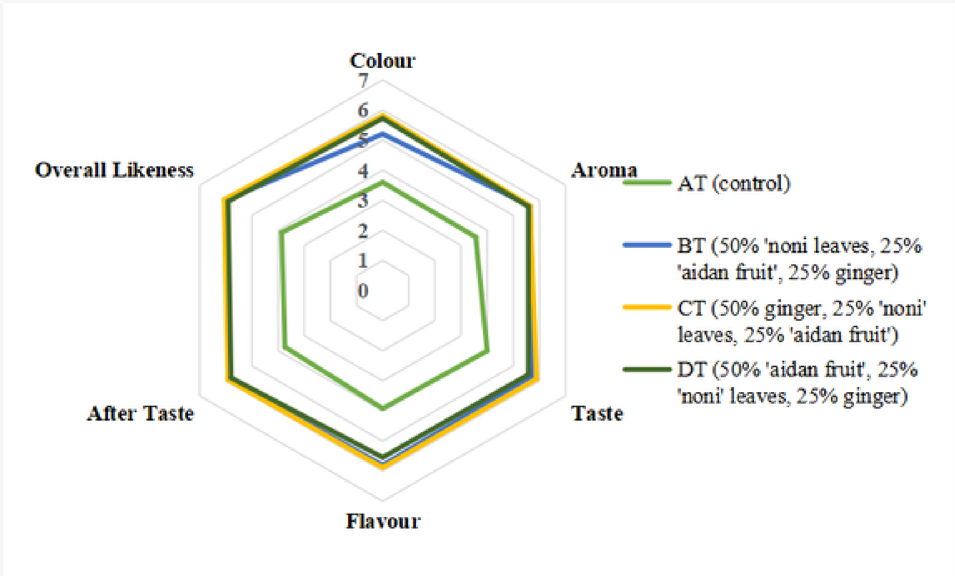

Figure 2: *Panelist Scores of Sensory Attributes*
Scale: *0.1-1.0 (dislike very much), 1.1-2.0 (dislike moderately), 2.1-3.0 (dislike slightly), 3.1 -4.0 (neither like nor dislike), 4.1-5.0 (like slightly), 5.1-6.0 (like moderately) and 6.1-7.0 (like very much)*

Consumer Acceptability of Tea Samples

The acceptability of the formulated herbal tea samples and the control (AT) exhibited significant variations, as illustrated in Figure 3. The control tea sample (AT) demonstrated 0% acceptability, indicating that it was not selected as the preferred option by any of the panellists. Among the formulated samples, CT attained the highest acceptability score, with 44% of the panellists designating it as their most preferred tea. BT followed, achieving an acceptability level of 36%. DT had the lowest preference among the formulated blends, with 20% of the panellists selecting it as their choice. In summary, the data suggest that CT was the most acceptable formulated tea sample among the panellists, followed by BT, whereas DT was the least preferred.

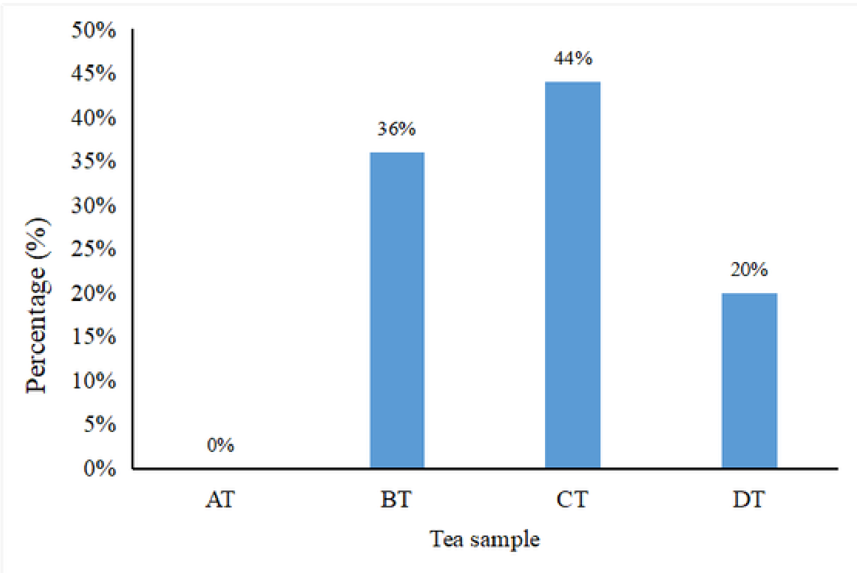

Figure 3: *Acceptability of Tea Samples*
AT (control), BT (50% Morinda citrifolia leaves, 25% Tetrapleura tetraptera and 25% Zingiber officinale), CT (50% Zingiber officinale, 25% Morinda citrifolia leaves, and 25% Tetrapleura tetraptera), and DT (50% Tetrapleura tetraptera, 25% Zingiber officinale, and 25% Morinda citrifolia leaves)

DISCUSSION

Proximate Analysis

Moisture Content

The moisture content of the formulated samples (10 % – 11 %) fell within the anticipated range for dried plant-based tea blends. According to Dongmo et al., (2022), the moisture content of *Tetrapleura tetraptera* ranges from 5.06 % to 8.22 %. Dried *Morinda citrifolia* leaf powders have been reported to contain approximately 11 % moisture, as noted by Almeida et al., (2019). *Zingiber officinale* powders typically exhibit moisture values between 8 % and 10 %, depending on the drying conditions (Anh et al., 2020; Jayashree et al., 2014). The slightly elevated moisture content in BT, which comprised 50 % *Morinda citrifolia* leaves, aligns with the tendency of leafy materials to retain water after drying. Conversely, CT, which contained 50% *Zingiber officinale*, reflected the lower moisture values characteristic of dried rhizomes, whereas DT more closely resembled *Tetrapleura tetraptera*. These findings suggest that the relative proportions of the ingredients dictate the final moisture content, with *Morinda citrifolia* leaves contributing to higher values and *Zingiber officinale* moderating them. The moisture content of herbal tea blends is pivotal to their shelf life and overall quality (Etheridge & Derbyshire, 2020). Elevated moisture levels, as observed in BT, may necessitate more stringent storage conditions to avert microbial growth and preserve product quality. In contrast, the lower moisture content in CT could potentially extend its shelf life, although it may also influence the rehydration properties and flavour release during brewing.

Fat Content

The crude fat content ranged from 3.05 % in DT to 6.18 % in CT, with BT exhibiting an intermediate value. Previous analyses of *Tetrapleura tetraptera* reported fat contents between 11.19 % and 24.71 % (Akintola et al., 2015; Dongmo et al., 2022). In contrast, the *Morinda citrifolia* fruit pulp is characterised by a low-fat content (~3%), with leaf material contributing minimally (Shettima et al., 2023). *Zingiber officinale* contains significant lipid fractions, particularly volatile and essential oils, with dried samples often reporting values between 3 % and 9 % (Oforma et al., 2019; Osae et al., 2021). The elevated fat content in CT is consistent with its 50 % *Zingiber officinale* composition, whereas DT, predominantly composed of *Tetrapleura tetraptera*, exhibited a lower crude fat percentage than anticipated, potentially due to accession differences or loss of extractable oils during processing. BT, containing 50 % *Morinda citrifolia* leaves, presented moderate values, consistent with the low-fat contribution of *Morinda citrifolia* and the partial influence of *Zingiber officinale*. According to Moreira et al. (2024), the variation in fat content among different tea blends underscores the significance of ingredient selection and proportions in determining the nutritional profile of the final product. The higher fat content in CT may contribute to a richer mouthfeel and potentially enhanced flavour retention, whereas DT and BT offer lower-fat alternatives that may appeal to health-conscious consumers.

Protein Content

The protein content was highest in BT (14.02 %), followed by CT (11.39 %) and DT (9.21 %). The literature values for the protein content of *Tetrapleura tetraptera* range from 5.61 % to 6.69 %, with one whole-fruit analysis reporting approximately 15.8 % (Nwafor et al., 2024). In contrast, the fruit *Morinda citrifolia* pulp contains relatively low protein levels (2 – 4 %), whereas *Morinda citrifolia* leaves and 2 % – 4 % of powders exhibit higher values, approximately 11 % or above (Shettima et al., 2023). *Zingiber officinale* powder typically ranges from 4 % to 9 % (Oforma et al., 2019). The elevated protein level of BT can therefore be attributed to the high proportion of leaves, *Morinda citrifolia* which are comparatively protein-rich relative to the fruit pulp and ginger rhizome. CT, composed mainly of *Zingiber officinale*, showed moderate protein levels consistent with the literature, whereas DT exhibited reduced protein content relative to published values for *Tetrapleura tetraptera*, possibly reflecting varietal differences or the effects of blending with other components. The observed gradient in protein levels across the blends underscores the significant influence of noni leaves on the protein content.

Ash Content

The observed ash content range of 5 – 7 % across the formulations indicates a consistent mineral profile despite the varying ingredient compositions. This suggests that all three formulations could potentially contribute to meeting the daily mineral requirements. The higher ash content in BT suggests significant mineral contributions from *Morinda citrifolia* leaves, which are known to accumulate inorganic elements. CT and DT demonstrated similar but slightly lower values, which may reflect the lower mineral density of *Zingiber officinale* and *Tetrapleura tetraptera* compared with *Morinda citrifolia* leaves. Thus, the mineral distribution in the blends aligned with the ingredient composition, with BT showing the strongest contribution from *Morinda citrifolia* leaves.

Fibre Content

The fibre content of the formulated teas was relatively high, ranging from 14 % to 17 %. For *Tetrapleura tetraptera*, crude fibre values are generally reported in the range of 2.8 – 5.3 %, depending on the accession and whether seeds or pods are analysed (Nwafor et al., 2024). *Morinda citrifolia* fruit pulp fibre is moderate (4% – 6 %), whereas the leaves tend to contain higher amounts (Saah & Adu-Poku, 2021). *Zingiber officinale* powders commonly contain 3 –8% fibre (Oforma et al., 2019; Ugwoke & Nzekwe, 2010). The substantially higher fibre content of the formulated teas, especially BT and CT, can be attributed to the dominance of *Morinda citrifolia* leaves and ginger, both of which are more fibrous than *Tetrapleura tetraptera*. Despite containing 50% 'aidan fruit', DT showed elevated fibre content compared to published fruit values, suggesting that blending with fibrous ginger and *Morinda citrifolia* leaves increased the overall proportion.

Carbohydrate Content

Carbohydrates, determined by difference, were the primary component, comprising 45% in BT, 50 % in CT, and 57 % in DT. The elevated carbohydrate content in DT aligns with its 50% *Tetrapleura tetraptera*, indicating the fruit pod's relatively high carbohydrate content, as found in a review study by Mensah et al. (2024). BT exhibited the lowest carbohydrate content, which can be attributed to the increased contributions of protein, fibre, and ash from the *Morinda citrifolia* leaves. CT demonstrated an intermediate value, balancing carbohydrate-rich *Zingiber officinale* with moderate contributions from other components. These findings suggest that the proportions of the ingredients significantly influenced the carbohydrate distribution in the formulations.

Sensory Analysis of Tea Samples

Sensory evaluation revealed distinct differences among the herbal tea formulations. Blends BT (50% *Morinda citrifolia* leaves, 25% *Tetrapleura tetraptera*, 25% *Zingiber officinale*) and CT (50% *Zingiber officinale*, 25% *Morinda citrifolia* leaves, 25% *Tetrapleura tetraptera*) consistently received higher hedonic scores (5.6 – 6.2) across all parameters, whereas DT (50% *Tetrapleura tetraptera*, 25% *Morinda citrifolia* leaves, 25% *Zingiber officinale*) was moderately accepted (5. 0 – 5.4). The control sample scored the lowest (3.0 – 4.0), indicating limited consumer appeal.

The colour was rated highest for BT and CT, suggesting a visually appealing infusion. *Zingiber officinale* is known to impart yellow-golden pigments due to carotenoids, while *Tetrapleura tetraptera* contains polyphenols that enhance colour intensity (Mensah et al., 2024). Blending effects on colour have also been reported in roselle-based herbal teas, where pigment-rich ingredients improved consumer preference for the appearance (Nguyen & Chuyen, 2020). The moderate colour score of DT likely reflects the diminished contribution of *Zingiber officinale* pigments when *Tetrapleura tetraptera* dominated the blend.

Aroma and flavour followed a similar pattern, with BT and CT outperforming DT and the control (AT). *Zingiber officinale's* volatile oils provide pungent and spicy flavours, whereas *Tetrapleura tetraptera* imparts sweet and clove-like aroma compounds (Mao et al., 2019; Mensah et al., 2024). These characteristics appear to complement the leafy aroma of *Morinda citrifolia*, producing a balanced sensory profile in BT and CT. Comparable findings were reported by Makanjuola and Enujiugha (2017), who observed that combining tea and ginger enhanced both aroma and flavour ratings compared with single-ingredient preparations. Similarly, Srisuk et al., (2025) demonstrated that the optimal blending ratios of turmeric and pandan significantly improved sensory scores owing to complementary volatiles. In contrast, the predominance of *Tetrapleura tetraptera* in DT may have overshadowed the contribution of *Zingiber officinale*, leading to relatively lower aroma and flavour ratings.

Taste and aftertaste were also rated more favourably for BT and CT. *Morinda citrifolia* leaves are known to have a bitter undertone (Saah & Adu-Poku, 2021). Still, the addition of *Zingiber officinale's* spicy compounds and *Tetrapleura tetraptera*'s sweet flavour masked this bitterness, improving the overall acceptance. Similar blending effects have been documented in lemongrass–ginger infusions, where complementary taste notes enhanced consumer preference (Dzigbor et al., 2024). The lower taste and aftertaste scores of DT suggest that excessive *Tetrapleura tetraptera* may have altered the flavour balance, reducing palatability.

Overall acceptability was highest for BT and CT, confirming that balanced ingredient proportions yield a synergistic effect on the sensory attributes. This outcome is consistent with previous studies on tea, which showed that strategic blending enhances consumer preference across multiple sensory dimensions (Nguyen & Chuyen, 2020; Srisuk et al., 2025). The consistently low ratings of the control sample underscore the limited appeal of single-component herbal infusions, a finding similar to that noted in prior evaluations of plant-based beverages (Makanjuola & Enujiugha, 2017).

In summary, the sensory data demonstrated that the formulation ratios strongly influenced the consumer acceptance of tea. Formulations with balanced contributions from *Morinda citrifolia* leaves, *Tetrapleura tetraptera*, and *Zingiber officinale* (BT and CT) provided the most favourable outcomes across all attributes, aligning with evidence that complementary ingredient interactions are key to optimising the quality of herbal tea.

Consumer Acceptability of Tea Samples

The acceptability ranking observed in the present study (CT = 44% > BT = 36% > DT = 20% > AT = 0%) indicates a distinct preference among panellists familiar with tea evaluation for the *Zingiber officinale*-dominant formulation (CT). The high acceptability of CT aligns with evidence suggesting that *Zingiber officinale* enhances the palatability of plant-based beverages. Blending ginger with other ingredients typically improves aroma and taste attributes, often resulting in higher hedonic scale scores than single-ingredient beverages (Makanjuola & Enujiugha, 2017). The volatile oil fraction of *Zingiber officinale* contributes to spicy-sweet flavours that are broadly familiar and acceptable to consumers, increasing the likelihood of selection when a single-choice preference is required (Mao et al., 2019).

The intermediate acceptability of the *Morinda citrifolia* -rich formulation (BT) is consistent with prior findings that *Morinda citrifolia* products are acceptable when the pungent aroma and flavour of noni are moderated by complementary ingredients or are limited in concentration. The characteristic off-odour and acrid taste of *Morinda citrifolia* often reduce the acceptance of single-ingredient products; however, inclusion at moderate levels or masking with citrus, spices, or sweet components increases consumer liking (Ni et al., 2025). The BT outcome suggests that a 50% proportion of *Morinda citrifolia* leaves produced a blend that remained acceptable to a substantial minority of panellists but was less preferred than the *Zingiber officinale* -dominated formulation.

The lower preference for the *Tetrapleura tetraptera-dominant* formulation (DT) concurs with the literature, indicating that *Tetrapleura tetraptera*'s intense aromatic profile may be overpowering when used at high proportions in beverages. Studies assessing functional beverages and fermented products incorporating 'aidan fruit have reported improved sensory scores when combined with milder, sweeter bases (e.g. pineapple) or used at moderated levels (Dugbaza, 2021; Mensah et al., 2024). These reports imply that the potent volatile constituents of *Tetrapleura tetraptera* contribute to desirable complexity when balanced but reduce acceptability when they dominate the sensory profile.

The absence of any panellist selecting the control (AT) underscores the importance of formulation in generating consumer appeal; base infusions lacking prominent aroma or flavour constituents are frequently outcompeted by blends containing familiar spices or fruit extracts (Makanjuola & Enujiugha, 2017; Nguyen & Chuyen, 2020). In single-choice tests, consumers tend to prefer beverages that present immediately recognisable and pleasant olfactory and gustatory cues, which likely advantage CT and, to a lesser extent, BT. Similar findings were reported in a study by Opoku et al., (2023), wherein a tea sample with a higher concentration of ginger was identified as the most preferred green tea.

Collectively, these results echo established principles in product formulation: (a) inclusion of ginger tends to enhance immediate sensory appeal through familiar pungent-sweet flavours; (b) functional botanicals with strong or unconventional aromas (*Morinda citrifolia, Tetrapleura tetraptera*) can be acceptable if their intensity is controlled or counterbalanced; and (c) blends optimised for complementary aroma–flavour interactions achieve higher consumer preference than unblended controls (Makanjuola & Enujiugha, 2017; Mao et al., 2019; Ni et al., 2025).

Conclusion

In this study, herbal tea blends were formulated using *Morinda citrifolia* leaves, *Tetrapleura tetraptera*, and *Zingiber officinale* in varying proportions: BT (50% *Morinda citrifolia*, 25% *Tetrapleura tetraptera*, 25% *Zingiber officinale*), CT (50% *Zingiber officinale*, 25% *Morinda citrifolia*, 25% *Tetrapleura tetraptera*), and DT (50% *Tetrapleura tetraptera*, 25% *Zingiber officinale*, 25% *Morinda citrifolia*). Proximate analysis revealed that moisture content ranged from 10% to 11%, with BT exhibiting the highest level. The fat content showed significant variation, ranging from 3.05% in DT to 6.18% in CT. The protein content was highest in BT (14.02 %) and lowest in DT (9.21 %). The ash content varied between 5 % and 7 %, with BT having the highest percentage. The fibre content was consistently high across all samples, ranging from 14% to 17%. Carbohydrates constituted the major component, ranging from 45% to 57%, with the highest concentration in DT. Sensory evaluation, conducted using a 7-point hedonic scale, indicated that BT and CT received higher ratings for colour, aroma, taste, flavour, and aftertaste than DT and the control (AT). The overall acceptability was highest for CT at 44%, followed by BT at 36%, DT at 20%, and AT at 0%. The ginger-dominant CT was the most preferred, whereas the *Tetrapleura tetraptera* -rich DT was less favoured. The sensory appeal was influenced by blending effects and complementary ingredient interactions. In conclusion, the tea formulations with balanced proportions of *Morinda citrifolia, Tetrapleura tetraptera,* and *Zingiber officinale*, particularly CT and BT, demonstrated favourable nutritional profiles and higher consumer acceptability compared to the *Tetrapleura tetraptera* -dominant DT and control. These findings underscore the potential of these blends as functional herbal teas with nutritional benefits and acceptable sensory qualities. Nonetheless, optimising ingredient ratios remains crucial for enhancing consumer appeal.

Recommendations

Further research should evaluate the microbiological safety, physicochemical stability, and retention of bioactive compounds of the tea formulations during storage under varying packaging and environmental conditions. Additionally, these formulations should be examined for potential diversification into other functional food products, such as ready-to-drink beverages or nutraceutical applications, to enhance their utilization and commercial viability.

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Conflict of Interest

The authors declare no conflict of interest.

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