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Effect of nanonization on physicochemical, sensory, and nutritional properties of Ginger (Zingiber officinale) and Sappan Wood (Caesalpinia sappan) powdered drink

Efek nanonisasi terhadap sifat fisikokimia, sensorik dan kandungan gizi pada minuman serbuk jahe (Zingiber officinale) dan kayu secang (Caesalpinia sappan)

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Abstract

Ginger and sappanwood contain high levels of antioxidants with recognized immunomodulatory and antidiabetic properties; however, their bioavailability is limited. Nanonization has the potential to enhance absorption by reducing the particle size. This study evaluated the differences in the physicochemical, sensory, and nutritional properties of nano and non-nano ginger–sappanwood powdered drink formulations. A completely randomized design (CRD) with four ratios (F1:50:40, F2:60:40, F3:70:30, and F4:80:20) was applied, and the formulations were processed into powders and powdered drinks. Sensory evaluation was conducted using semi-trained panelists. The proximate composition and antioxidant activity were determined. Statistical differences were analyzed using two-way analysis of variance (ANOVA) ($\alpha = 0.05$). Nano-milling improved sensory attributes in the powder form, particularly color and texture ($p < 0.05$). Differences in flavor were observed only in the drink form, whereas taste and overall acceptability were not significantly affected. Formula 4 (80:20) achieved the highest hedonic and organoleptic ratings. Antioxidant activity was generally low across all formulations; however, the nano-milled powders exhibited slightly higher values than their non-nano counterparts. In conclusion, nanonization enhanced selected sensory qualities and modestly improved antioxidant performance, particularly in the powdered form.

Keywords: Antioxidant, bioavailability, ginger-sappan wood, nanotechnology, powdered drink

Abstrak

Jahe dan kayu secang yang kaya akan antioksidan memiliki sifat imunomodulator dan antidiabetes, namun bioavailabilitasnya masih terbatas. Proses nanonisasi berpotensi meningkatkan bioavailabilitas dengan memperkecil ukuran partikel. Penelitian ini bertujuan menganalisis perbedaan sifat fisikokimia, sensori, dan kandungan gizi pada formulasi minuman serbuk jahe dan kayu secang dengan metode non-nano dan nano. Penelitian eksperimental ini menggunakan rancangan acak lengkap dengan empat formulasi rasio bahan, yaitu F1 (50:40), F2 (60:40), F3 (70:30), dan F4 (80:20). Analisis sensori dilakukan pada panelis semi-terlatih. Analisis proksimat dan antioksidan dilakukan pengukuran. Analisis statistik dilakukan dengan uji two way ANOVA (α=0,05). Hasil menunjukkan bahwa formulasi nano meningkatkan atribut sensori pada bentuk bubuk, terutama warna ($p<0.001$) dan tekstur ($p=0.05$). Flavor menunjukan atribut yang bermakna pada bentuk minuman ($p=0.015$), namun tidak berpengaruh signifikan terhadap rasa dan penerimaan keseluruhan. Formula terbaik berdasarkan uji hedonik dan organoleptik adalah F4 (80:20). Aktivitas antioksidan pada formulasi nano sedikit lebih tinggi dibanding non-nano, meskipun keduanya tergolong lemah. Kesimpulan, nanonisasi pada minuman serbuk jahe dan kayu secang terbukti dapat memperbaiki karakteristik sensori serta meningkatkan aktivitas antioksidan, khususnya pada bentuk serbuk.

Kata Kunci: Antioksidan, bioavailabilitas, jahe-kayu secang, minuman serbuk, nanoteknologi

Introduction

The consumption of natural antioxidants has therapeutic and preventive benefits in diabetes mellitus and hypertension. Moreover, it may reduce the risk of severe complications of COVID-19 in individuals with comorbidities (Fatima et al., 2023). Studies have demonstrated that antioxidants are effective in mitigating oxidative stress and inflammation (insert reference). Additionally, they can help regulate blood pressure and act as immunomodulators, enhancing the body's response to infection (Ardalan & Rafieian-Kopaei, 2014; Handayani et al., 2017; Kamyshnyi et al., 2020). Therefore, the intake of antioxidant-rich foods is highly recommended to maintain immunity, particularly in individuals with hypertension and diabetes mellitus (Amponsah-Offeh et al. 2023).

Ginger contains bioactive compounds such as gingerol and shogaol, whereas sappanwood contains brazilin and brazilein, which are potent natural antioxidants (Bak et al., 2012; Promdam & Panichayupakaranant, 2022; Yusuf & Rusli, 2019). Shogaol exhibits antidiabetic activity, whereas 6-gingerol functions as an immunomodulator (Hasanah et al., 2020; Yi et al., 2019).

Previous research has developed instant drinks from ginger and sappanwood using two drying methods: crystallization and conventional drying. The conventional drying method produced a more desirable texture and exhibited an antioxidant activity of 2040.86 mg/kg per 100 g (Srimiati et al., 2023). However, a major limitation is the low solubility and bioavailability of antioxidants from plant products, which may reduce their efficacy in the body (Zagórska et al. 2023). Hence, strategies are needed to enhance the activity and absorption of these antioxidants (Mao et al., 2019).

One promising strategy is nanonization, a technology that reduces particle size to the nanoscale (100–1000 nm), thereby increasing the surface area, improving the bioavailability of active compounds, and potentially extending the product shelf life (Moshcwitzer, 2010; Srimiati et al., 2021, 2022). Ginger nanoparticles have been widely applied in herbal medicine and have been shown to reduce therapeutic doses by up to 50% without compromising the treatment efficacy (Abd El Wahab et al., 2021; Bakr et al., 2020).

Despite its potential, the application of nanonization in food products, particularly in herbal drinks, remains relatively limited. Therefore, this study aimed to evaluate the physicochemical, sensory, and nutritional properties, as well as the antioxidant content, of nano and non-nano ginger–sappanwood powdered drink formulations.

Methods

Study Design and Ethical Approval

This experimental study employed a completely randomized design (CRD) and was conducted from July to August 2024 at Binawan University in East Jakarta. Sample testing was performed at the Dietetic Laboratory of Binawan University, East Jakarta and PT Saraswanti Indo Genetech, Bogor. The study protocol was reviewed and approved by the Ethics Committee of Binawan University, Jakarta (ethical clearance no. 165/KEPK-UBN/VIII/2024). Written informed consent was obtained from all participants before their inclusion in the study.

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Materials

The primary ingredients used to prepare the powdered drinks were Java ginger (*Zingiber officinale* var. *amarum*) and sappanwood (*Caesalpinia sappan*). The ratios and drying methods were determined based on the preliminary research conducted by Srimiati et al. (2023).

Ginger, sappanwood, and stevia sugar were purchased online in Bogor. The ginger samples exhibited light to brown-golden skin and bright yellow flesh, with a mature, firm, and smooth texture. Sappanwood has a rich red to reddish-brown color, woody fragrance, dense texture, and hard consistency. Equal amounts of ginger were dried in a microwave for 3 h, combined with sappanwood and sugar, and ground using a food processor.

Nanonization Procedures

Nanoflour production from ginger and sappanwood was conducted at the Nanocenter in Tangerang using planetary ball milling. Prior to nanonization, dried ginger and sappan wood were pulverized into coarse powders using a conventional grinder and sieved to obtain uniform particle sizes.

Milling was performed intermittently, consisting of 10 min of milling followed by 10 min of rest to prevent excessive heat accumulation. The total milling duration was 12 h, with a rotational speed ranging from 300 to 700 rpm. The milling duration was determined through trial and error based on modifications of previous methods (Pohshna & Mailapalli, 2023; Srimiati et al., 2022). The resulting nanoflour was collected and stored in airtight containers before characterization.

Characterization

Previous studies conducted in 2023 identified optimal drying methods for ginger and sappanwood powder based on organoleptic properties and antioxidant activity (Srimiati et al., 2023). In this study, nanonization was applied to ginger and sappanwood, which influenced their organoleptic attributes and nutrient content. The formulations of powdered ginger and sappanwood drinks are presented in Table 1.

Table 1. Ginger and sappanwood drink formulation

Ingredients	F1	F2	F3	F4
Ginger (g)	1	1.2	1.4	1.6
Sappan woord (g)	1	0.8	0.6	0.4
Sugar (g)	2	2	2	2

Chemical analysis

Macronutrient content was determined using proximate analysis according to the AOAC (2005) standards (AOAC, 1990). The analyses were conducted by PT Saraswanti Indo Genetech. SNI 01-2891-1992 guidelines were followed for the water (point 5.1), ash (point 6.1), protein (point 7.1), and fat (point 8) content. Fat content was measured using the gravimetric method, and the protein content was determined using the Kjeldahl method. The carbohydrate content was calculated by difference, as described in SNI 01-3775-2006 (Appendix B.6).

Antioxidant activity was evaluated using a modified DPPH (2,2-diphenyl-1-picrylhydrazyl) radical cation assay. The DPPH reagent was prepared by dissolving 8 mg of DPPH in 100 mL of methanol, resulting in a final concentration of 80 µM. For the assay, 100 µL of DPPH reagent was mixed with 100 µL of the sample in a 96-well microplate and incubated at room temperature for 30 min. Absorbance was measured at 514 nm using an ELISA reader (TECAN, Gröding, Austria), with methanol as the control. Radical scavenging activity (RSA) was calculated as follows:

$$\%\text{DPPH RSA} = \frac{A\ control - A\ sample}{A\ control} \times 100\%$$

Note: RSA = Radical Scavenging Activity; A control = absorbance of the DPPH solution without sample; A sample = absorbance of the DPPH solution with sample.

IC50 values (concentration required to inhibit 50% of DPPH radicals) were determined via regression analysis. Antioxidant activity was determined based on the IC50 values.

Sensory Evaluation

The instant nano-ginger and sappanwood beverages were organoleptically evaluated for color, aroma, taste, and texture/consistency. Samples were tested in both powder and liquid forms (after dissolving the powder in warm water at 70 °C for 5 min). The purpose of this evaluation was to identify the formula preferred by the panelists.

Sensory evaluation was conducted under controlled conditions in a sensory room with neutral lighting and an ambient temperature. Evaluations were performed individually during the morning sessions to minimize sensory fatigue. Samples were served in identical cups and labeled with randomized three-digit codes (Lawless & Heymann, 2010). The serving order was randomized for each panelist, and the panelists were instructed to cleanse their palate with plain drinking water between samples.

Thirty trained panelists participated, all of whom were undergraduate students with prior coursework in food technology or sensory evaluation, aged ≥18 years, and reported no sensory impairments or food allergies related to the products tested. This sample size was considered sufficient for hedonic and organoleptic tests (Lawless & Heymann, 2010). The tests were performed at the Organoleptic Laboratory of Binawan University.

Statistical Analysis

The data distribution was assessed using the Kolmogorov–Smirnov test. Hedonic and organoleptic data were analyzed using two-way ANOVA, followed by Duncan's multiple range test for post hoc comparisons.

Result and Discussion

Characterization and Sensory Properties Evaluation

The hedonic test results for the nano ginger–sappanwood drink formulations (F1–F4), evaluated in both powdered and reconstituted (liquid) forms, assessed various sensory attributes, including color, flavor, texture (powder), taste (liquid), consistency (liquid), and overall acceptability. Ratings ranged from 1 (Strongly Dislike) to 7 (Strongly Like), with scores reported as mean ± standard deviation.

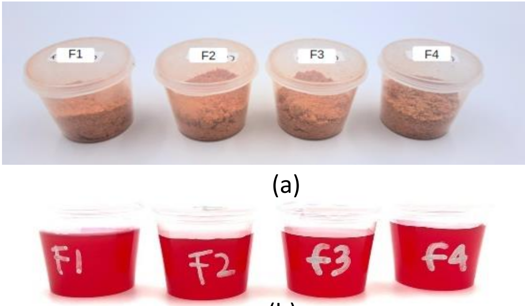

Figure 1. Product formulation: (a) Nano Ginger and Sappanwood powder; (b) Nano Ginger and Sappanwood powdered drink.

In non-nano formulations, no significant differences were observed among the formulations for most sensory attributes of the ginger–sappanwood powder, with scores ranging from 4.6 to 5.1, indicating generally favorable acceptance, particularly for F4. An exception was color, for which higher scores were observed in the F1. For the powdered drink, taste scores were relatively low (3.8–4.3), whereas consistency was comparable across all the formulas. These results suggest that flavor compounds may be reduced during processing, as heat and dilution can diminish the volatile constituents responsible for the aroma and taste of ginger (Starowicz, 2021).

A significant difference in flavor preference was observed, with F4 receiving the highest score. In this formulation, ginger was the primary factor influencing flavor and aroma perceptions. Ginger contains volatile compounds such as gingerol, shogaols, and zingiberene, which strongly contribute to its aroma and pungency (Pang et al., 2017). This finding aligns with previous evidence indicating that higher concentrations of ginger increase the content of gingerols, shogaols, and essential oils, thereby intensifying the aroma and taste perception (Dalsasso et al., 2022).

Table 2. Hedonic test of nano ginger and sappanwood drink formulation

	Powder				Powdered drink				
	Color	Flavor	Textures	Overall	Color	Flavor	Taste	Consistency	Overall
Non-Nano									
F1	5.1 ± 0.9^{a}	4.7 ± 0.8^{a}	4.6 ± 0.8^{a}	4.9 ± 0.7^{a}	4.7 ± 0.8^{a}	4.2 ± 0.7^{a}	3.8 ± 0.7^{a}	4.4 ± 1.0^{a}	4.4 ± 0.9^{a}
F2	5.0 ± 0.9^{a}	4.9 ± 0.8^{a}	4.6 ± 0.9^{a}	5.0 ± 0.7^{a}	4.8 ± 0.7^{a}	4.4 ± 0.5^{ab}	4.0 ± 1.0^{a}	4.5 ± 0.7^{a}	4.4 ± 0.7^{a}
F3	4.9 ± 0.9^{a}	4.8 ± 0.8^{a}	4.8 ± 1.0^{a}	4.9 ± 0.7^{a}	4.5 ± 0.6^{a}	4.5 ± 0.6^{ab}	4.2 ± 0.7^{a}	4.5 ± 0.7^{a}	4.4 ± 0.7^{a}
F4	4.6 ± 1.1^{a}	5.0 ± 1.0^{a}	4.9 ± 1.0^{a}	5.0 ± 0.8^{a}	4.4 ± 0.8^{a}	4.7 ± 0.7^{b}	4.3 ± 1.0^{a}	4.6 ± 0.8^{a}	4.6 ± 0.8^{a}
p-value	0.295	0.652	0.523	0.920	0.215	0.026*	0.227	0.764	0.533
Nano									
F1	5.0 ± 0.9^{b}	4.4 ± 0.9^{a}	4.7 ± 0.6^{a}	4.8 ± 0.,8^{a}	4.6 ± 0.8^{b}	4.3 ± 0.7^{a}	4.3 ± 1.4^{a}	4.8 ± 1.0^{ab}	4.3 ± 0.8^{a}
F2	4.7± 0.8^{ab}	4.6 ± 0.9^{a}	4.8 ± 0.8^{a}	4.8 ± 0.6^{a}	4.5 ± 0.6^{b}	4.3 ± 0.6^{a}	4.3 ± 0.9^{a}	4.7 ± 1.0^{ab}	4.2 ± 0.5^{a}
F3	4.6± 0.8^{ab}	4.8 ± 0.8^{a}	4.9 ± 0.9^{a}	5.0 ± 0.8^{a}	4.5 ± 0.6^{b}	4.6 ± 0.7^{a}	4.5 ± 1.5^{a}	4.9 ± 1.2^{b}	4.4 ± 0.6^{a}
F4	4.4 ± 1.3^{a}	4.8 ± 0.8^{a}	5.1 ± 0.8^{a}	4.9 ± 0.6^{a}	4.1 ± 0.6^{a}	4.4 ± 0.7^{a}	3.9 ± 1.0^{a}	4.3 ± 0.7^{a}	4.3 ± 0.7^{a}
p-value	0.106	0.352	0.341	0.736	0.029*	0.21	0.379	0.134	0.807

Ginger and sappan wood powders were mixed at ratios of 50:40 (F1), 60:40 (F2), 70:30 (F3), and 80:20 (F4). The attributes ranged from 1 (Strongly Dislike) to 7 (Strongly Like). Different letters above the standard deviation indicate a significant difference between the formulations ($p < 0.05$), as determined by (*). Analysis was performed using Two-way ANOVA.

Table 2 presents the hedonic scores for the ginger–sappanwood powder and powdered drink formulations (F1–F4) in both nano and non-nano forms, evaluating sensory attributes such as color, flavor, texture (powder), taste (liquid), consistency (liquid), and overall acceptability. Scores ranged from 1 (Strongly Dislike) to 7 (Strongly Like) and are reported as mean ± standard deviation. Different letters above the SD indicate statistically significant differences between the formulations ($p < 0.05$), as determined by two-way ANOVA.

In the nano formulations, the color preference for the powdered drink differed significantly across formulations ($p = 0.029$). Formulations F1, F2, and F3 received higher scores (approximately 4.5–4.6), whereas F4 received a lower score (4.1). The reduced color acceptance in F4 may be attributed to the higher concentration of sappanwood pigments (brazilin and brazilein), which deepens the hue and produces darker tones at higher concentrations (Ngamwonglumlert et al., 2020).

The flavor did not differ significantly between the formulations in powder ($p = 0.352$) or powdered drink ($p = 0.21$), with scores consistently ranging from 4.3 to 4.8. Previous studies have shown that nanoprocessing or superfine grinding can improve solubility, flowability, and textural uniformity by reducing particle size and increasing homogeneity (Duguma et al., 2023).

The texture (powder) and consistency (powdered drink) did not vary significantly among the formulations. The powder texture received the highest score in F4 (5.1), while the powdered drink consistency ranged from 4.3 to 4.9. The taste of powdered drink formulations also showed no significant differences ($p = 0.379$), although F3 achieved the highest score (4.5) and F4 the lowest (3.9). Overall acceptability did not differ significantly between the powders and powdered drinks ($p = 0.807$).

Nanoparticles, defined as materials with one or more dimensions between 1 and 100 nm, can be organic, inorganic, or carbon-based, and exhibit enhanced surface properties compared to larger particles (Egbuna et al., 2022). Nano-formulation slightly improved some sensory attributes, particularly color and flavor; however, the differences were minor. Nanoparticles enhance functional properties owing to their small size, including increased reactivity, surface area, mechanical strength, and stability. They are often incorporated into food to improve flavor, color, stability, and shelf life (Egbuna et al., 2022).

Interestingly, flavor scores were higher in non-nano formulations, particularly in F4, whereas nano F4 showed a decrease in the flavor rating. This suggests that nanoprocessing may influence the sensory perception of flavor, potentially by altering the release of volatile aromatic compounds. Overall, both nano and non-nano formulations were moderately liked by the panelists, although improvements in the flavor and consistency of powdered drinks remain possible.

Table 3. Sensory attributes of nano ginger and sappanwood drink formulation

	Powder			Powdered drink			
	Color	Flavor	Textures	Color	Flavor	Taste	Consistency
Non-Nano							
F1	2.5 ± 1.6[a]	4.3 ±1.4[a]	4.7 ± 1.4[a]	3.5 ± 1.8[a]	4.2 ± 1.2[a]	4.5 ± 1.1[a]	3.6 ± 1.1[a]
F2	3.9 ± 1.9[b]	4.7 ± 1.2[ab]	5.1 ± 1.0[a]	3.4 ± 1.8[a]	4.2 ± 1.1[a]	4.9 ± 0.7[a]	3.3 ± 0.9[a]
F3	4.5 ± 1.7[b]	4.9 ± 1.0[ab]	4.9 ± 1.2[a]	3.3 ± 1.7[a]	4.5 ± 1.4[ab]	4.9 ± 1.1[a]	3.4 ± 1.1[a]
F4	5.8 ± 1.3[c]	5.1 ± 1.4[b]	5.2 ± 1.3[a]	2.8 ± 1.6[a]	5.0 ± 1.3[b]	5.5 ± 1.2[b]	3.3 ± 1.3[a]
p-value	0.000	0.102	0.452	0.520	0.057	0.002*	0.724
Nano							
F1	3.6 ± 1.9[a]	4.4 ± 1.0[a]	5.3 ± 0.8[a]	3.5 ± 1.8[a]	4.2 ± 1.0[a]	4.7 ± 1.2[a]	3.5 ± 1.3[a]
F2	4.6 ± 1.6[b]	4.6 ± 1.0[ab]	5.5 ± 0.7[a]	3.6 ± 1.7[a]	4.4 ± 0.8[ab]	4.7 ± 1.0[a]	3.3 ± 1.0[a]
F3	5.4 ± 1.7[bc]	4.9 ± 1.2[ab]	5.3 ± 1.0[a]	3.3 ± 1.6[a]	4.9 ± 1.0[b]	5.0 ± 1.1[a]	3.3 ± 1.3[a]
F4	5.7 ± 1.5[c]	5.2 ± 1.3[b]	5.4 ± 1.1[a]	3.1 ± 1.6[a]	5.0 ± 1.3[c]	5.1 ± 1.3[a]	3.1 ± 1.2[a]
p-value	0.000*	0.054*	0.904	0.601	0.015*	0.418	0.612

Ginger and sappan wood powder and powdered drink at ratios of 50:40 (F1), 60:40 (F2), 70:30 (F3), and 80:20 (F4). Different letters above the standard deviation indicate a significant difference between formulations (p< 0.05), as determined by (*). Analysis was performed using Two-way ANOVA. Specific scales for the sensory quality of powder assessment were defined as follows: color ranged from 1 (bright orange) to 7 (dull orange), aroma from 1 (Strongly Unfragrant) to 7 (Strongly Ginger Fragrant), taste from 1 (bland) to 7 (Strongly Spicy), and texture from 1 (strongly coarse) to 7 (strongly smooth). Specific scales for the sensory quality of powdered drink assessment were defined as follows: color ranged from 1 (red) to 7 (maroon); aroma extended from 1 (Strongly Unfragrant) to 7 (Strongly Ginger Fragrant); taste varied from 1 (bland) to 7 (Strongly Spicy); and consistency ranged from 1 (watery) to 7 (viscous).

Organoleptic tests provided insights into the sensory characteristics, including color, flavor, texture (powder), taste (powdered drink), and consistency. Ratings for each attribute ranged from 1 (Strongly Dislike) to 7 (Strongly Like).

Significant differences in color perception were observed among the powder formulations (p = 0.000). Formulation F4 (80:20) received the highest score (5.7 ± 1.5), indicating a dull orange appearance, whereas F1 (50:40) received the lowest score (3.6 ± 1.9), corresponding to a brighter orange hue. The flavor perception of the powder was nearly significant (p = 0.054), with F4 scoring the highest (5.2 ± 1.3), suggesting a more pronounced ginger aroma. The texture did not differ significantly among the formulations (p = 0.904), with all scores between 5.3 and 5.5, indicating a smooth texture.

In the powdered drink form, color perception did not differ significantly across the formulations (p = 0.601), with scores ranging from 3.1 to 3.6, indicating a generally reddish hue. The flavor differed significantly (p = 0.015), with F4 showing the highest rating, indicating a stronger ginger aroma. No significant differences were observed in taste or consistency (p > 0.05), suggesting that variations in the ginger-to-sappanwood ratio predominantly affected the aroma rather than the taste or mouthfeel.

The powder formulations exhibited noticeable color differences, with higher ginger ratios (F4) resulting in a duller orange, likely due to the increased concentration of ginger pigments. This visual difference can influence consumer appeal. The nearly significant flavor improvement in F4 indicates that increasing the ginger content enhances the aromatic profile of the powder. The texture remained smooth across all powders, suggesting that the ginger-to-sappanwood ratio did not substantially affect the mouthfeel.

For powdered drinks, while the color and consistency were uniform, the stronger flavor in F4 demonstrates that higher ginger ratios enhance aromatic intensity and potentially consumer acceptance. The taste and consistency were largely unaffected by the formulation ratios, indicating that the primary sensory impact of ginger concentration was on flavor. Bioactive compounds in ginger, which contribute to its flavor and color, are retained during processing and influence the sensory quality of the product (Laelago Ersedo et al., 2023). Enhancing the color and ginger fragrance in the lower-ginger formulations (F1 and F2) could improve the overall product appeal and broaden consumer preference.

Ginger content was a key determinant of sensory perception in both nano and non-nano formulations. Higher ginger ratios (F4, 80:20) improved the flavor and taste, particularly in powdered drinks. Nanonization slightly enhanced the color and improved the flavor consistency, making the nanoformulations marginally more appealing. The texture remained consistent across both nano and non-nano forms, with no significant differences observed.

Nutrient Evaluation

Table 4. Macronutrient composition of nano ginger–sappanwood powdered drink (F4) per 100 g

Component	Formulation 4
Energy (kcal)	7.44
Protein (g)	0
Fat (g)	0
Carbohydrate (g)	0.1
Water content (%)	98.12
Ash content (%)	0.02

Macronutrient analysis of the selected nano ginger–sappanwood drink (F4, 80:20) indicated that it was extremely low in energy and macronutrients. The beverage provides only 7.44 kcal per 100 g, contains no measurable protein or fat, and contains a negligible amount of carbohydrates (0.1 g). Water constitutes the majority of the drink (98.12%), and the ash content is minimal (0.02%), suggesting a very low mineral content.

According to beverage classifications, including low-calorie beverages (LCB), sugar-sweetened beverages (SSB), 100% fruit juices (FJ), tea, coffee, water (TCW), milk, and alcoholic beverages (Gibson et al., 2016), this formulation falls under the low-calorie beverage category. Its minimal macronutrient content renders it primarily suitable for hydration rather than as a source of energy or protein. The potential health benefits of this nano-ginger and sappanwood beverage are likely derived from its bioactive compounds, particularly antioxidants, rather than its macronutrient profile.

Table 5. Antioxidant activity (IC50 μg/mL) of nano ginger–sappanwood drink

Method	Powder	Powdered drink
Non-Nano	269.76	476.84
Nano	220.24	372.33

The antioxidant activities of nano-ginger–sappanwood were evaluated in two forms: powder and powdered drink. The IC50 value represents the concentration required to inhibit 50% of free radicals, with lower IC50 values indicating higher antioxidant activity (Akullo et al., 2023; Martinez-Morales et al., 2020).

The non-nano powder exhibited an IC50 of 269.76 μg/mL, whereas the powdered drink exhibited a significantly higher IC50 of 476.84 μg/mL. These results indicate that the powder form exhibits stronger antioxidant activity than the powdered drink. This reduction in antioxidant potential may result from processing and dilution, which can decrease the concentration or stability of the bioactive compounds.

Nanoprocessing enhanced the antioxidant activity of both powders and powdered drinks. The nanopowder had the lowest IC50 (220.24 μg/mL), indicating the highest antioxidant potency among all the formulations. The antioxidant activity of the nano-powdered drink was improved (IC50 = 372.33 μg/mL), which, although lower than that of the nano powder, was higher than that of the non-nano powdered drink. These findings suggest that nanonization effectively improves antioxidant activity by increasing the surface area and potentially enhancing the bioavailability of active compounds.

Overall, the powder form, particularly in nanoformulations, demonstrated the strongest ability to neutralize free radicals. The reduced efficacy observed in powdered drinks may be attributable to the processing, dilution, or partial degradation of antioxidant compounds. These results underscore the potential of nano powders to serve as potent functional beverages or dietary supplements, emphasizing the importance of formulation and processing methods in preserving bioactivity.

This study has several limitations. First, the sensory evaluation involved a relatively small number of semi-trained panelists, which may limit the generalizability of the hedonic findings to broader consumer populations. Second, antioxidant activity was assessed using a single in vitro assay (DPPH), which does not fully replicate the in vivo antioxidant behavior. Third, although this study discussed potential improvements in bioavailability via nanonization, no direct measurements of bioavailability were performed. Future research should include in vivo studies to confirm the functional efficacy of nanoformulated beverages.

Conclusion

This study demonstrated that ginger–sappanwood powdered drink formulations exhibit acceptable sensory characteristics. Nano-processing led to modest improvements in selected sensory attributes and slightly enhanced antioxidant activity, particularly in the powdered form. The nano powdered drink can be considered a low-calorie beverage suitable for hydration, with the added benefit of its antioxidant content.

Future studies should further evaluate consumer acceptability using larger and more diverse panels, incorporate additional assays to assess antioxidant activity and product stability, and employ in vitro digestion models to better understand the functional implications of nanofunctionalized formulations. Moreover, investigating product stability under various storage and processing conditions is warranted to optimize the formulation performance and shelf life.

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