Asian Journal of Healthcare Analytics (AJHA)
Vol. 5, No. 1, 2026: 133-144

AJHA
Asian Journal of Healthcare Analytics

Antioxidant Retention and Physicochemical Characterization of Instant Ginger Powder Formulation as a Functional Beverage

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A R T I C L E I N F O

Keywords: Antioxidant, Functional Beverage, IC_{50}, Instant Powder, Zingiber Officinale

Received: 19, March
Revised: 20, April
Accepted: 30, May

A B S T R A C T

This study aims to formulate an instant ginger rhizome extract powder and comprehensively evaluate its physicochemical characteristics and antioxidant retention capacity as a functional beverage. This experimental research employed four variations of ginger powder concentration (0%, 5%, 10%, and 15%) using the wet granulation method. Evaluation results indicated that all formulations met the required standards, with moisture content below 5% and favorable flowability. The 15% formulation (F3) proved to be the most optimal, demonstrating strong antioxidant activity with an IC50 value of 65.50 ppm. Overall, this formulation produces a powdered beverage with excellent physicochemical stability and measurable nutraceutical efficacy, making it a viable candidate for functional food.

DOI: https://doi.org/10.55927/ajha.v5i1.16477
ISSN-E: 2963-9905
https://journal.formosapublisher.org/index.php/ajha

INTRODUCTION

The globally increasing prevalence of degenerative diseases and public health awareness have triggered a high demand for functional foods (Granato et al., 2020). Functional herbal beverages derived from natural plant extracts have proven to be rich in phytochemicals, nutrients, and bioactive compounds essential for the body (Shaik et al., 2023). Functional foods, particularly those with high antioxidant capacity, are urgently needed to scavenge free radicals and mitigate the impacts of oxidative stress, which triggers various metabolic disorders (Forman & Zhang, 2021). In this context, ginger rhizome (*Zingiber officinale*) has long been recognized both empirically and preclinically as a superior herbal commodity. The primary secondary metabolites in ginger, such as gingerol, shogaol, paradol, and zingerone, are reported to exhibit potent antioxidant, anti-inflammatory, and gastroprotective activities (Arcusa et al., 2022; Mao et al., 2019; Sari & Nasuha, 2021). These compounds work synergistically through the activation of cellular signaling pathways (such as Nrf2) to suppress the secretion of proinflammatory cytokines and modulate the immune system (Frontiers, 2024).

The utilization of ginger rhizome as a functional beverage has broad application potential, primarily due to its ability to induce thermogenesis, facilitate digestion, and provide beneficial relaxation effects to alleviate nervous fatigue (Maulana & Syari, 2023; Raudah et al., 2023). However, the daily consumption of fresh ginger is frequently constrained by a relatively short shelf life due to its high moisture content, as well as a lack of preparation practicality in the modern era (An et al., 2022). To overcome these constraints, the development of pharmaceutical formulations in the form of instant powders presents a highly promising technological solution. Instant powder formulations offer advantages such as improved microbiological stability, ease of distribution, effective taste masking, and practicality in oral administration (Sęczyk et al., 2020).

Although powder formulations offer numerous benefits, a critical challenge in their formulation process is the susceptibility of ginger's bioactive compounds to degradation. Thermal processing during manufacturing, along with interactions with binding or bulking agents (excipients), carries a high risk of drastically reducing antioxidant capacity (Daza et al., 2021). Therefore, the selection of carbohydrate excipients such as maltodextrin is crucial; this substance functions as an effective bulking agent (filler) that inhibits the degradation of active ingredients due to thermal exposure during oven drying, encapsulates aroma components, and accelerates the powder's dissolution upon reconstitution (Setiawan et al., 2022). Furthermore, from a pharmaceutical technology perspective, the physicochemical profile of granule or powder formulations—such as flowability, hygroscopicity, moisture content, and dissolution time—must be rigorously evaluated to meet the compendial standards of an ideal oral formulation (Aulton & Taylor, 2021). Formulation optimization is essential to ensure that the resulting instant powder is not only physically stable during storage but also capable of optimally retaining its natural bioactive capacity.

This study contributes to the enrichment of scientific knowledge, particularly in the field of nutraceutical formulation, through an interdisciplinary approach that integrates nutritional science parameters with pharmaceutical technology. The novelty of this study lies in its bidirectional evaluation, which balances the physicochemical characteristics of the granules as a benchmark for formulation stability with the retention level of antioxidant compounds as a measure of nutritional efficacy. This comprehensive approach presents new insights into the measurable quality standardization of herbal-based functional beverage manufacturing, whereas previous literature has tended to isolate these two aspects.

Therefore, this study aims to formulate an instant powder from ginger rhizome extract and comprehensively evaluate its physicochemical characteristics and antioxidant retention capacity. Specifically, this research will examine the intervention of varying ginger extract concentrations across four formulation levels: 0% as the control, alongside additions of 5%, 10%, and 15%. Through this tiered evaluation, the study expects to identify the most optimal formulation percentage that yields an instant powder with superior physicochemical parameters while simultaneously delivering the highest antioxidant retention as a functional food candidate.

LITERATURE REVIEW

Functional Beverages and Ginger (*Zingiber officinale*) Bioactivity

The global shift towards preventive healthcare has significantly accelerated the demand for functional foods and beverages. Functional beverages formulated from plant extracts are increasingly recognized as effective delivery systems for essential phytochemicals and bioactive compounds that help mitigate oxidative stress and prevent metabolic disorders (Granato et al., 2020; Shaik et al., 2023). Among botanical candidates, ginger (*Zingiber officinale* Roscoe) has been extensively documented in both empirical and preclinical studies for its robust therapeutic properties. The pharmacological efficacy of ginger is primarily attributed to its non-volatile phenolic compounds, notably gingerols, shogaols, and paradols (Mao et al., 2019). These secondary metabolites exhibit potent antioxidant and anti-inflammatory activities by acting as free radical scavengers and modulating cellular signaling pathways, thereby protecting tissues from oxidative damage (Arcusa et al., 2022; Forman & Zhang, 2021).

Formulation Technology: Wet Granulation and Encapsulation

While fresh ginger is rich in beneficial compounds, its high moisture content limits its shelf life and complicates its daily consumption in modern lifestyles. Transforming herbal extracts into instant powder formulations offers a viable technological solution, providing enhanced microbiological stability, precise dosing, and ease of reconstitution (Sęczyk et al., 2020). In pharmaceutical and food technology, wet granulation is a preferred method for producing solid dosage forms. This technique effectively addresses the inherent cohesiveness and poor flowability of fine herbal powders by agglomerating

particles, resulting in granules with optimized angle of repose and compressibility (Aulton & Taylor, 2021).

However, a critical challenge in formulating herbal instant powders is the thermal degradation of bioactive compounds during the drying process. To counteract this, the use of carbohydrate-based excipients such as maltodextrin is highly recommended. Maltodextrin functions not only as a bulking agent but also as an effective encapsulating matrix. It forms a protective micro-wall around the thermosensitive phenolic compounds of ginger, preventing oxidation and preserving the sensory attributes (aroma and flavor) during oven drying (An et al., 2022; Daza et al., 2021). Furthermore, maltodextrin's high solubility significantly improves the reconstitution time of the final beverage.

Physicochemical and Antioxidant Evaluation Metrics

The successful development of a functional herbal beverage requires a dual-evaluation approach that balances pharmaceutical stability and nutritional efficacy. Physicochemical characterizations—such as moisture content, flowability, and dissolution time—are critical parameters to ensure the product meets compendial standards. Maintaining a moisture content of less than 5% is particularly vital to prevent powder agglomeration and inhibit microbial proliferation during storage (Aulton & Taylor, 2021). Simultaneously, evaluating the retention of antioxidant capacity is essential to validate the product's functional claims. The DPPH (2,2-diphenyl-1-picrylhydrazyl) radical scavenging assay is widely acknowledged as a highly sensitive and reliable method for determining the *Inhibitory Concentration* 50% (IC_{50}) of plant extracts (Baliyan et al., 2022). By comprehensively assessing both the physical robustness of the granules and the IC50 value, researchers can ensure that the formulated instant ginger powder delivers optimal therapeutic benefits without compromising structural stability.

METHODOLOGY

Materials and Equipment

This study utilized fresh ginger rhizomes (*Zingiber officinale* Roscoe) harvested at 8–10 months of age, obtained from a local traditional market as the primary raw material, considering that this harvesting age provides an optimal accumulation of secondary metabolites (Mao et al., 2019). Supplementary materials included food-grade maltodextrin and sucrose as excipients, as well as distilled water. Chemical reagents for phytochemical screening and antioxidant assays, including 2,2-diphenyl-1-picrylhydrazyl (DPPH) and ascorbic acid (Vitamin C), were of analytical grade. The primary analytical instruments employed included a UV-Vis Spectrophotometer, a temperature-controlled drying oven, an analytical balance, a funnel flowability tester, and compendial standard test sieves (Aulton & Taylor, 2021).

Formulation Design and Raw Material Preparation

This laboratory-based experimental study was designed using four concentration levels of ginger powder (0%, 5%, 10%, and 15%) to progressively evaluate the effect of escalating bioactive ingredient doses on the physicochemical characteristics and functional efficacy of the formulation (Granato et al., 2020). The preparation process commenced with the sorting,

washing, peeling, and slicing of the fresh ginger rhizomes. The rhizome slices were subsequently dried in an oven at 50°C to prevent the degradation of thermolabile compounds such as gingerol (An et al., 2022). The dried ginger simplisia was then ground and passed through a 60-mesh sieve to obtain a homogeneous pure powder. The component ratio design for each treatment group is presented in Table 1.

Table 1. Instant Ginger Powder Formulation Design (in grams)

Ingredients / Excipients	**F0 (Control)**	**F1 (5%)**	**F2 (10%)**	**F3 (15%)**	**Function in Formulation**
Pure Ginger Powder	0	5	10	15	Active Ingredient / Bioactive
Sucrose	30	30	30	30	Sweetener
Maltodextrin	70	65	60	55	Filler / Coating Agent
Total Weight	**100**	**100**	**100**	**100**	

Preparation of Instant Powder Formulation

The formulation was manufactured using the wet granulation method, a solid dosage engineering technique proven effective in enhancing powder compressibility and cohesiveness (Aulton & Taylor, 2021). The pure ginger powder was homogeneously blended with maltodextrin and sucrose according to the designated formulation ratios (Table 1). Distilled water was added slowly (dropwise) as a binding liquid under constant stirring until an ideal, pliable wet mass was formed. This mass was then passed through a 14-mesh sieve to form wet granules. Subsequently, the granules were dried in an oven at 50°C and re-sieved using a 16-mesh screen to uniformize the particle size distribution of the final product (Daza et al., 2021).

Physicochemical and Phytochemical Evaluation

Physicochemical quality evaluation was performed as an indicator of the formulation's pharmaceutical stability, encompassing visual organoleptic assessment (color, odor, and taste), dissolution time in an aqueous medium, and granule flowability evaluation by measuring the flow rate and angle of repose (Sęczyk et al., 2020). Moisture content determination was conducted using the conventional gravimetric method; a specified amount of the sample was accurately weighed and dried in an oven at 105°C until a constant weight was achieved. This gravimetric method guarantees the maximum evaporation of bound water to ensure a final moisture content of ≤5%, a critical threshold to mitigate the risks of agglomeration and microbial proliferation during storage (Aulton & Taylor, 2021). Additionally, qualitative phytochemical screening was performed on the pure ginger extract powder to confirm its constituent secondary metabolite profile, which included the identification of alkaloids, flavonoids, phenolics, saponins, and steroids.

Antioxidant Activity Measurement

The antioxidant retention capacity of the instant powder formulation was quantitatively measured using the DPPH free radical scavenging assay, acknowledged as the most reliable method for detecting the efficacy of

electron/hydrogen-donating compounds (Baliyan et al., 2022). The test samples were reacted with the DPPH reagent and incubated in a dark room for 30 minutes. The absorbance of the solution was then read at a maximum wavelength of 517 nm using a UV-Vis Spectrophotometer. The radical scavenging ability was calculated based on the percentage of inhibition to subsequently determine the Inhibitory Concentration 50% (IC50) value, utilizing pure Vitamin C (ascorbic acid) as the comparative positive control.

Data Analysis

All analytical procedures were performed in experimental triplicates to validate data precision. The obtained quantitative data were presented as mean ± standard deviation and computationally analyzed using the parametric One-Way Analysis of Variance (ANOVA) to test the significance of the effect of escalating active ingredient concentrations on the formulation's quality (Granato et al., 2020). A probability value of $p < 0.05$ was established as the parameter of significance. If significant differences were detected, the analysis proceeded with a Tukey post-hoc test to comprehensively determine the specific differences between treatment groups (An et al., 2022).

RESULTS AND DISCUSSION

The evaluation results of the instant ginger powder formulation demonstrated a significant effect of varying active ingredient concentrations on the physicochemical quality and functional potential of the formulation (Sęczyk et al., 2020).

Physicochemical Characteristics of the Formulation

The evaluation of granule physical properties indicated that all formulations met the standards for solid oral dosage forms required in pharmaceutical compendia (Aulton & Taylor, 2021). The comprehensive data are presented in Table 2.

Table 2. Physicochemical Characteristics of Instant Ginger Powder

Test Parameter	F0 (0%)	F1 (5%)	F2 (10%)	F3 (15%)
Color	White	Yellowish White	Light Yellow	Brownish Yellow
Taste	Sweet	Sweet, Slightly Spicy	Sweet and Spicy	Distinctively Ginger Spicy
Moisture Content (%)	2.15 ± 0.12	2.42 ± 0.08	2.85 ± 0.15	3.12 ± 0.10
Dissolution Time (s)	18 ± 2.5	24 ± 3.1	32 ± 2.8	45 ± 4.2
Angle of Repose (°)	22.4 ± 0.5	25.8 ± 0.8	28.2 ± 0.4	32.5 ± 1.2

Organoleptic testing revealed that color intensity and spicy taste increased linearly with the addition of ginger concentration. Based on gravimetric analysis, all formulations exhibited a moisture content of <5%, indicating excellent formulation stability against the risk of microbial growth or agglomeration (Aulton & Taylor, 2021). Granule flowability (F0-F2) was

categorized as excellent with an angle of repose <30°, whereas F3 demonstrated good flowability (32.5°).

Phytochemical Screening

Phytochemical screening was conducted to identify the presence of secondary metabolites in the ginger powder used as the active ingredient, considering that the phytochemical profile significantly determines the final bioactivity of the formulation (Mao et al., 2019). The qualitative identification results are presented in Table 3.

Table 3. Phytochemical Screening Results of Ginger Powder

Compound Group	Result	Description
Alkaloids	+	Precipitate formed (Mayer/Dragendorff)
Flavonoids	++	Orange color formed (Shinoda Test)
Phenolics	+++	Blackish-green color formed (FeCl3)
Saponins	+	Persistent froth formed
Steroids/Triterpenoids	+	Colored ring formed

These screening results confirmed the rich secondary metabolite profile of the ginger rhizome, particularly the dominance of phenolic and flavonoid compounds (Taufiqurrahman & Syafriana, 2019).

Antioxidant Capacity Evaluation (IC50 Value)

Free radical scavenging activity was measured using the DPPH method and compared with pure Vitamin C, as this method has proven highly sensitive in detecting the activity of hydrogen-donating compounds (Baliyan et al., 2022). The test results are presented in Table 4.

Table 4. IC50 Values and Antioxidant Capacity of Instant Ginger Powder

Sample / Formulation	Ginger Concentration (%)	IC50 Value (ppm)	Antioxidant Category
Vitamin C (Control)	-	12.90 ± 0.15	Very Strong
F0 (Negative Control)	0%	850.25 ± 5.40	Very Weak
F1	5%	178.40 ± 3.25	Weak
F2	10%	115.20 ± 2.80	Moderate
F3	15%	65.50 ± 1.45	Strong

Formulation F3 (15%) demonstrated the best efficacy among the test formulations with an IC50 value of 65.50 ppm (strong category). The IC50 measurement data were subsequently analyzed statistically using the parametric One-Way Analysis of Variance (ANOVA) test. The ANOVA results indicated a significance value of $p < 0.05$, proving a statistically significant effect of varying ginger extract concentrations on the increase in the free radical scavenging capacity of the formulation.

To determine the specific location of differences between treatments, the analysis proceeded with a Tukey post-hoc test. The Tukey test results confirmed that each 5% interval addition of ginger concentration provided a significant decrease in the IC50 value across all formulation groups (F0, F1, F2,

and F3). Although formulation F3 possesses highly potent activity and falls into the strong category, the statistical test also showed that its value still exhibited a significant difference when directly compared to the reactivity of pure Vitamin C (12.90 ppm) as the standard positive control (An et al., 2022).

Referring to the physicochemical characteristics data (**Table 2**), the integration of pharmaceutical parameters and nutritional analysis in this study indicates that the instant ginger powder formulation successfully meets the quality standards of commercial functional beverages. From an organoleptic perspective, the increase in ginger powder concentration provided a positive correlation with color intensity and the formulation's spicy flavor profile. The color change to brownish-yellow in F3 serves as a visual indicator of the high retention of natural pigments and polyphenolic compounds from the ginger rhizome successfully encapsulated within the excipient matrix (Sęczyk et al., 2020).

Furthermore, from a pharmaceutical technology standpoint, the use of the wet granulation method proved highly effective in improving the formulation's flowability. Although a downward trend in flowability occurred in F3 (angle of repose 32.5°) due to the inherently more hygroscopic nature of ginger powder compared to sucrose, the value remained within the compendial requisite limits for granule formulations, which is below 35° (Aulton & Taylor, 2021). This optimal flowability is crucial on an industrial scale to ensure weight uniformity during the packaging process into sachets.

Further evaluation in Table 2 also demonstrated an increase in dissolution time concurrent with the addition of ginger concentration, where F3 required the longest dispersion time (45 seconds). Scientifically, this phenomenon is caused by the high content of insoluble crude fiber and the cellulose structure of the ginger rhizome itself, which requires a longer rehydration time compared to sucrose or maltodextrin crystals (Santos et al., 2021). Nevertheless, this dissolution time remains highly acceptable for an instant beverage product. Concurrently, the use of the gravimetric method with an oven temperature of 105°C ensured the maximum removal of bound water. The moisture content in F3 (3.12%) was maintained well below the critical threshold of 5%. This success affirms that maltodextrin plays a crucial role not only as a filler but also as a coating agent that sterically hinders the hydroxyl groups of ginger components from binding with free water vapor from the surrounding environment (Daza et al., 2021).

The functional efficacy of the formulation relies heavily on the rich secondary metabolite profile within the ginger rhizome, as confirmed by the phytochemical screening results in Table 3. The strong positive detection of phenolic, flavonoid, alkaloid, saponin, and steroid compounds aligns with the phytochemical profile of red ginger rhizome reported by Taufiqurrahman and Syafriana (2019). In the matrix of this functional beverage, saponins not only act as phytonutrients but also function as natural surfactants capable of lowering the surface tension of intestinal epithelial cell membranes, thereby pharmacokinetically facilitating and enhancing the bioavailability (absorption) of phenolic compounds into the bloodstream (Zhang et al., 2022).

The presence of these flavonoid and phenolic compounds is the primary contributor to the formulation's antioxidant activity. Flavonoids operate as highly potent inhibitors through the scavenging mechanism of reactive oxygen species (ROS). Through the release of a single electron from their hydroxyl groups, flavonoids can break the chain reaction of free radicals that trigger oxidative stress at the cellular level (Forman & Zhang, 2021). The stability of the free radical scavenging capacity in the test formulations proves that the wet granulation engineering process was able to preserve the primary non-volatile phenolic compounds of ginger—such as gingerol and shogaol—preventing fatal structural thermal degradation (Mao et al., 2019).

The linear correlation between extract concentration and free radical scavenging efficacy is clearly evident in the evaluation of IC50 values (Table 4). Achieving an IC50 value of 65.50 ppm in formulation F3 solidly places this formulation in the strong antioxidant category. Although this value falls below the extreme reactivity of the pure Vitamin C positive control (12.90 ppm), this achievement is considered highly potent for a complex formulation (mixed matrix). This proves the effectiveness of maltodextrin functioning optimally as an encapsulating agent. Maltodextrin has a high glass transition temperature, enabling it to form a solid micro-wall structure to protect the phenolic bioactive compounds of ginger from thermal oxidation and oxygen exposure during the oven drying process (An et al., 2022).

Overall, this formulation blend produces a powdered beverage product with excellent physicochemical and microbiological stability, while also possessing measurable nutraceutical efficacy. Formulation F3 (15%) represents an ideal balance between pharmaceutical engineering aspects and the fulfillment of nutritional targets, making it a highly prospective candidate to be developed on a massive scale as a functional dietary instrument to suppress the morbidity of degenerative metabolic diseases in society (Granato et al., 2020).

CONCLUSIONS AND RECOMMENDATIONS

This study successfully formulated an instant ginger rhizome powder that integrates pharmaceutical quality standards and nutritional efficacy. Based on the evaluation results, it can be concluded that the increase in ginger powder concentration is directly proportional to the increase in the formulation's free radical scavenging capacity. Formulation F3, with a 15% ginger concentration, is the optimal formula, producing stable physicochemical characteristics with a moisture content of 3.12% and a dissolution time of 45 seconds, while exhibiting strong antioxidant activity with an IC50 value of 65.50 ppm. The use of maltodextrin proved effective as a protective matrix in retaining the secondary metabolites of ginger, such as flavonoids and phenolics, during the manufacturing process.

Based on the findings of this study, conducting long-term stability testing is recommended to determine the product's shelf life under various packaging conditions. Furthermore, *in vivo* clinical trials are required to validate the formulation's effectiveness in reducing oxidative stress markers in human subjects, thereby medically substantiating its claim as a functional food. Future

research could also explore the use of alternative natural sweeteners to broaden the consumer demographic, particularly for individuals with diabetes mellitus.

FURTHER STUDY

This study possesses several limitations that should be considered when interpreting the results. First, the evaluation of antioxidant efficacy was restricted to *in vitro* assessments using the DPPH radical scavenging method. While the formulated IC50 values demonstrate strong antioxidant potential, this *in vitro* metric does not fully encapsulate the bioavailability, absorption kinetics, and metabolic pathways of the formulation within the human gastrointestinal tract. Second, the physicochemical characterizations were exclusively conducted immediately post-production (zero-month baseline). Consequently, the current study lacks long-term and accelerated stability testing required to establish an accurate shelf-life estimate for the product under various environmental conditions.

Future research should prioritize *in vivo* preclinical studies using animal models or direct clinical trials involving human subjects to validate the efficacy of the instant ginger powder in reducing oxidative stress biomarkers in the bloodstream. Furthermore, conducting comprehensive long-term stability testing under varying packaging conditions is highly recommended to ascertain the product's commercial viability. Subsequent studies could also explore the substitution of sucrose with low-calorie natural sweeteners, such as stevia (*Stevia rebaudiana*) extract, to broaden the functional accessibility of the beverage for individuals with metabolic disorders, particularly diabetes mellitus.

ACKNOWLEDGMENT

The authors express their deepest gratitude to the leadership and laboratory staff at STIKES Dirgahayu Samarinda and the Faculty of Public Health, Universitas Mulawarman, for providing the essential research facilities and infrastructure that enabled the successful execution of both the pharmaceutical formulation and nutritional evaluation processes. Sincere appreciation is also extended to our colleagues and fellow researchers who provided constructive feedback and insightful discussions during the data analysis and manuscript preparation phases.

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