

Research article

EFFECT OF DEHYDRATION PROCESS OPTIMIZATION ON PHENOLIC CONTENT AND ANTIOXIDANT ACTIVITY OF GUYABANO (*ANNONA MURICATA* L.) LEAF TEA

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Abstract

Guyabano (*Annona muricata* L.) leaves are used in herbal infusions, but dehydration conditions can alter phenolic retention, radical-scavenging activity, and sensory quality. This study evaluated the effects of forced-air dehydration temperature and time on guyabano leaf tea using an I-optimal response surface design over 55-75 degrees C and 2-6 h. Independent processing batches were analyzed for proximate composition, total phenolic content (TPC), and DPPH radical-scavenging activity, while selected high-temperature formulations were evaluated for sensory acceptability and microbiological quality. Formulation significantly affected all testable proximate and bioactive responses ($p < 0.05$). GT12 showed the highest observed TPC (119.39 ± 2.52 mg GAE/100 g dried sample), whereas GT04 and GT11 showed the highest DPPH inhibition group, with GT12 showing moderate DPPH activity ($56.61 \pm 1.21\%$). The TPC RSM model showed strong fit and predictive performance ($R^2 = 0.977$; predicted $R^2 = 0.856$), while the DPPH model was statistically significant but less predictive ($R^2 = 0.788$; predicted $R^2 = 0.325$). Multi-response desirability identified 75 degrees C for 6 h as the model-predicted optimum, with predicted TPC of 125.99 mg GAE/100 g dried sample and DPPH inhibition of 61.39%. Sensory testing of GT10-GT12 showed acceptable hedonic scores, with GT12 numerically highest in overall acceptability. The selected formulations tested for microbiological quality met the referenced criteria. The optimum represents a model-predicted condition requiring independent confirmation.

1. Introduction

Guyabano (*Annona muricata* L.) leaves are used locally as a herbal infusion and are valued

because soursop leaves contain phenolic compounds and other phytochemical constituents associated with antioxidant

potential (Hasmila et al., 2019; Santos et al., 2023). For a dried-leaf tea product, however, infusion quality depends not only on the plant material but also on the processing conditions used before storage and brewing (Nhi et al., 2020).

Forced-air dehydration is necessary to lower product moisture and support handling stability; in this study, ASEAN tea moisture guidance was treated only as an analogous benchmark for the dried herbal-infusion product (ASEAN, 2014; Liu et al., 2022). Thermal exposure can alter bioactive quality. Moderate heating may improve phenolic extractability through tissue disruption and enzyme inactivation, whereas excessive temperature or prolonged drying can promote oxidation, polymerization, or degradation of heat-sensitive compounds (Antony & Farid, 2022; Duan et al., 2021; ElGamal et al., 2023). Similar drying-parameter effects have been reported for herbs and tea leaves (Roslan et al., 2020; Thamkaew et al., 2021).

Although guyabano leaf tea and related soursop-leaf products have been studied as herbal infusions or processed extracts, limited evidence is available on how forced-air dehydration temperature and time jointly affect phenolic retention, DPPH radical-scavenging activity, sensory acceptability, and microbial quality under controlled processing conditions (De Castro et al., 2018; Nhi et al., 2020). This distinction is important because total phenolic content and DPPH inhibition are related but not interchangeable measures of antioxidant behavior (Dobrinás et al., 2021; Platzer et al., 2022).

The present study tested the hypothesis that dehydration temperature and time exert significant linear, interaction, and nonlinear effects on the bioactive quality of guyabano leaf tea. The study aimed to identify a process condition that balances phenolic retention, DPPH activity, product moisture, sensory acceptability, and microbiological quality within the tested dehydration region.

Specifically, the study sought to: (1) quantify proximate composition, TPC, and DPPH radical-scavenging activity across the I-

optimal design runs; (2) model the effects of dehydration temperature and time using response surface methodology; (3) evaluate sensory acceptability and microbiological quality for selected high-temperature formulations; and (4) identify a model-predicted optimum for future independent validation.

2. Materials and Methods

2.1. Gathering of raw materials

Guyabano leaves were collected during rainy season from approximately five source tree(s) within the vicinity of Calamba, Laguna. Leaves used for the experiment were obtained from multiple trees and pooled before allocation to the experimental batches. Visually immature or overly mature leaves, as well as leaves showing yellowing, browning, physical damage, or apparent disease, were excluded. The selected leaves were transported to the processing area under clean handling conditions before preparation.

2.2. Preparation of Guyabano Leaves

The leaves were washed repeatedly with running water to remove dust, soluble impurities, and adhering dirt. The petiole and midrib were removed using clean kitchen scissors, and each leaf was cut into smaller pieces to improve drying uniformity. The prepared leaves were patted dry with clean absorbent material before loading into the dehydrator.

2.3. Preparation of Dehydrated Guyabano Leaves

The trimmed guyabano leaves were dried using a forced-air cabinet dehydrator (LJ Industrial Fabrication, Model CFD-12T, Philippines) at the temperature-time combinations specified in the I-optimal response surface design. Before each run, the dehydrator was preheated for 30 min, and chamber temperature was verified using an independently calibrated digital thermometer placed at the center tray. Fresh leaves were loaded at 250 g per tray, equivalent to 0.69 kg/m², with two trays used per experimental batch for a total loading of 500 g. The leaves were arranged in a single

layer with minimal overlap; leaf-layer thickness was not independently quantified. The internal fan operated continuously at a fixed setting, with an average air velocity of 1.2 ± 0.1 m/s. Relative humidity within the drying chamber was not independently controlled or recorded. Each run was terminated after the dehydration time specified by the experimental design rather than at a predetermined final-moisture endpoint. Initial moisture content was $68.4 \pm 1.9\%$ wet basis, determined from triplicate 5 g subsamples oven-dried at 105°C to constant weight, while final moisture content was subsequently determined for each dried formulation. After

dehydration, samples were cooled in a desiccator for 30 min, ground using an Osterizer 10-speed blender (Model BLSTMG-W00, 450 W), passed through a 20-mesh stainless-steel sieve, packed in food-grade laminated aluminum pouches, protected from light, and stored at $25 \pm 2^\circ\text{C}$ until analysis within 7 days.

The I-optimal response surface design used for the dehydration runs is summarized in Table 1. The duplicated low-temperature point and triplicated mid-region point were retained to support model estimation, pure-error assessment, and lack-of-fit evaluation.

Table 1. I-optimal response surface design for guyabano leaf dehydration

Run	Formulation	Temperature ($^\circ\text{C}$)	Time (h)	Design Note
1	GT01	55	4.54	Replicated low-temperature point
2	GT02	55	4.54	Replicated low-temperature point
3	GT03	55	5.98	High-time boundary
4	GT04	58	2.00	Low-time interior point
5	GT05	62	6.00	High-time interior point
6	GT06	66	2.00	Low-time interior point
7	GT07	67	3.72	Replicated mid-region point
8	GT08	67	3.72	Replicated mid-region point
9	GT09	67	3.72	Replicated mid-region point
10	GT10	75	2.00	High-temperature boundary
11	GT11	75	3.68	High-temperature interior point
12	GT12	75	5.42	High-temperature, near-optimum point

Note. The design comprised 12 design runs representing 9 unique temperature-time points. Runs at 55 degrees C for 4.54 h and 67 degrees C for 3.72 h were duplicated or triplicated within the design to support model estimation.

I-optimality was selected because the study emphasized prediction across the specified temperature-time region while maintaining an efficient number of experimental runs and replicated design points for estimation of pure error. Unlike fixed geometric response surface designs such as central composite and Box-Behnken designs, the I-optimal approach allowed the experimental points to be allocated within the defined factor region to improve prediction precision. The experimental design and response surface analyses were performed using Design-Expert software version 23.1, and the statistical outputs and model diagnostics were independently cross-checked using Python.

2.4. Evaluation of Dehydrated Guyabano Leaves

The proximate composition of the dehydrated guyabano leaf tea samples was determined following AOAC methods (AOAC, 2016). Moisture, ash, crude fat, protein, and fiber were measured for each formulation, and nitrogen-free extract (NFE) was treated as a calculated descriptive value rather than as an independently replicated analytical response.

$$\text{Moisture (\%)} = \frac{W_1 - W_2}{W_1} \times 100 \quad (1)$$

Where:

W₁: weight (g) of Guyabano tea leaves sample before drying

W₂: weight (g) of Guyabano tea leaves sample after drying

$$\text{Total ash (\%)} = \frac{W_1}{W} \times 100 \quad (2)$$

Where:

W: weight (g) of the dried Guyabano tea leaves sample

W₁: weight (g) of the ash Guyabano tea leaves sample after drying

$$\text{protein (\%)} = \frac{(A-B) \times N \times 1.4007 \times F}{W} \quad (3)$$

Where:

A = volume (ml) of 0.2 N HCl used in the sample
B = volume (ml) of 0.2 N HCl used in the blank titration

N = Nitrogen of HCl

W = weight (g) of sample

14.007 = atomic weight of nitrogen

F = the protein-nitrogen conversion factor

$$\text{Fat (\%)} = \frac{W_{fat}}{W_{GT}} \times 100 \quad (4)$$

Where:

W_{fat}: weight (g) of fat present in the Guyabano tea leaves

W_{GT}: weight (g) of Guyabano tea leaves sample

Nitrogen-free extract was calculated by difference from the measured proximate components following the food-composition approach described by FAO (2003). Because NFE was calculated by difference and showed no within-formulation variation, it was reported descriptively and excluded from inferential comparison.

$$\text{Total Carbohydrates} = 100 - (\text{protein} + \text{fat} + \text{water} + \text{ash} + \text{alcohol}) \quad (5)$$

2.4.5. Sample preparation for determination of total phenolic content and antioxidant activity

For TPC and DPPH analysis, 3 g of dried guyabano leaf tea sample was infused in 100 mL of boiling deionized water and held for 20 min following the adapted extraction procedure used for tea antioxidant assessment (Tong et al., 2019). The extract was cooled, filtered, and analyzed under the same extraction conditions for all formulations.

2.4.6. Determination of total phenolic content

Total phenolic content was determined using the Folin-Ciocalteu method. The Folin-Ciocalteu approach remains widely used for estimating total phenolics in tea matrices, although it measures Folin-reactive reducing capacity rather than individual phenolic compounds (Sun et al., 2022). Absorbance was measured at 760 nm using a Shimadzu UV-1900i UV-Vis spectrophotometer with 1 cm quartz cuvettes. Gallic acid working standards of 0, 20, 40, 60, 80, and 100 mg/L were used to generate the calibration curve (absorbance = 0.0087 concentration + 0.021, R² = 0.997). Results were expressed as mg gallic acid equivalent per 100 g dried sample.

2.4.7. Determination of antioxidant activity

DPPH radical-scavenging activity was measured using a procedure adapted from antioxidant-assay protocols for food extracts (Tong et al., 2014). Freshly prepared 0.1 mM DPPH in methanol was protected from light. The DPPH control absorbance at 517 nm was accepted when between 0.700 and 0.900. Absorbance was measured after 30 min of dark incubation, and results were expressed as percent inhibition. Each formulation was produced in three independent processing batches; each batch was extracted once and read in triplicate, and triplicate absorbance readings were averaged to produce one batch-level value for statistical analysis.

$$\% \text{ inhibition} = \left[\frac{(Abs_0 - Abs_1)}{(Abs_0)} \right] \times 100 \quad (6)$$

Where:

Abs₀: absorbance without samples

Abs₁: absorbance in the presence of the sample

2.4.8. Sensory and microbiological evaluation of selected formulations

GT10, GT11, and GT12 were selected for sensory acceptability and microbiological quality assessment because they represented high-temperature formulations near the response surface optimum region. The 75°C for 6 h condition was treated as a model-predicted

numerical solution rather than an independently confirmed treatment condition.

The selected high-temperature formulations evaluated for sensory acceptability and microbiological quality are listed in Table 2. These formulations represented the observed high-temperature treatments nearest to the predicted optimum region.

Table 2. Selected high-temperature formulations evaluated for sensory and microbiological quality

Formulation	Temperature (°C)	Time (h)
GT10	75	2.00
GT11	75	3.68
GT12	75	5.42

Sensory acceptability was evaluated using complete responses from 35 analyzable raters on a 9-point hedonic scale (Heymann & Ebeler, 2016; Yang & Lee, 2019). Microbiological assessment for the selected formulations included aerobic plate count, coliform, *E. coli*, *Salmonella*, and yeast and mold count.

2.5. Statistical Treatment of Data

Data were summarized as mean $\pm$ standard deviation. Formulation effects on proximate composition, TPC, and DPPH radical-scavenging activity were evaluated using one-way analysis of variance followed by Tukey HSD post-hoc comparison at $\alpha = 0.05$. ANOVA assumptions were assessed using residual diagnostics, the Shapiro-Wilk test for residual normality, and the Brown-Forsythe test for homogeneity of variance. Variance homogeneity was supported for all analyzed responses, while a modest departure from residual normality was observed for TPC. NFE was treated as a derived descriptive variable because it was calculated by difference rather than measured as an independent analytical response.

Response surface models were fitted using coded factors for temperature (A) and time (B), where $A = (\text{Temperature} - 65)/10$ and $B = (\text{Time} - 4)/2$. A quadratic model was fitted for TPC,

while a two-factor interaction model was fitted for DPPH inhibition. Model adequacy was evaluated using R^2 , adjusted R^2 , predicted R^2 , RMSE, lack-of-fit testing, observed-versus-predicted plots, and residual diagnostics. Numerical optimization was performed by simultaneously maximizing predicted TPC and DPPH inhibition within the experimental ranges of 55-75°C and 2-6 h. Individual response desirabilities were combined into an overall desirability score ranging from 0 to 1, with higher values indicating better simultaneous attainment of the two response goals. Candidate conditions were ranked according to overall desirability.

3. Results and Discussion

Results are presented by proximate composition, bioactive response, response surface modeling, numerical optimization, sensory acceptability, and microbiological quality.

Proximate Composition and Bioactive Responses

The proximate composition of the dehydrated guyabano leaf tea formulations is summarized in Table 3. This table reports the measured composition by formulation and separates NFE as a calculated descriptive value.

Table 3. Proximate composition of guyabano leaf tea formulations

Formulation	Moisture (%)	Ash (%)	Crude Fat (%)	Protein (%)	Fiber (%)	NFE (%)
GT01	1.10 ± 0.08	8.39 ± 0.17	8.53 ± 0.72	32.96 ± 0.73	21.65 ± 2.11	28.47 ± 0.00
GT02	3.02 ± 0.01	7.86 ± 0.24	11.05 ± 0.02	37.05 ± 0.33	37.36 ± 0.89	6.68 ± 0.00
GT03	1.09 ± 0.05	7.92 ± 0.28	7.70 ± 0.13	37.17 ± 3.32	25.53 ± 2.33	21.67 ± 0.00
GT04	1.26 ± 0.09	8.16 ± 0.16	9.33 ± 0.31	34.56 ± 2.14	19.94 ± 1.57	28.00 ± 0.00
GT05	0.76 ± 0.08	7.06 ± 0.11	7.63 ± 0.21	39.55 ± 0.25	23.09 ± 3.20	22.66 ± 0.00
GT06	0.68 ± 0.06	7.10 ± 0.20	7.82 ± 0.20	36.14 ± 1.37	21.51 ± 1.41	27.43 ± 0.00
GT07	1.04 ± 0.07	8.24 ± 0.08	8.88 ± 0.46	34.87 ± 2.38	18.22 ± 1.83	29.79 ± 0.00
GT08	1.84 ± 0.05	7.89 ± 0.51	8.83 ± 0.47	37.15 ± 1.76	20.36 ± 1.05	25.77 ± 0.00
GT09	2.15 ± 0.13	8.19 ± 0.28	10.01 ± 0.23	30.91 ± 1.16	17.70 ± 0.52	33.18 ± 0.00
GT10	1.20 ± 0.02	7.05 ± 0.34	8.87 ± 0.53	36.47 ± 1.57	30.38 ± 2.93	17.23 ± 0.00
GT11	1.78 ± 0.06	7.44 ± 0.74	8.92 ± 0.37	37.72 ± 0.77	19.74 ± 1.05	26.19 ± 0.00
GT12	1.40 ± 0.06	7.83 ± 0.10	8.98 ± 0.10	38.48 ± 1.65	25.79 ± 2.10	18.92 ± 0.00

Note. Values are mean ± SD from three independent processing batches (n = 3). NFE was calculated by difference and was analyzed descriptively.

The bioactive responses for TPC and DPPH inhibition are presented in Table 4. The table also shows Tukey groupings so that numerical

differences can be distinguished from statistically supported differences.

Table 4. Bioactive-response values with Tukey groupings

Formulation	TPC (mg GAE/100 g dried sample)	TPC Tukey Group	DPPH (% Inhibition)	DPPH Tukey Group
GT01	81.69 ± 2.13	c	41.43 ± 1.32	e
GT02	78.16 ± 1.29	c	37.07 ± 1.35	f
GT03	79.46 ± 2.17	c	35.50 ± 0.09	f
GT04	98.89 ± 4.08	b	69.51 ± 1.10	a
GT05	106.26 ± 6.64	b	45.49 ± 0.58	d
GT06	108.19 ± 6.59	b	59.43 ± 0.45	b
GT07	107.12 ± 1.63	b	55.75 ± 1.12	c
GT08	102.39 ± 0.70	b	47.69 ± 2.32	d
GT09	105.06 ± 5.16	b	56.29 ± 1.21	bc
GT10	116.69 ± 1.45	a	53.97 ± 0.63	c
GT11	114.62 ± 1.19	a	68.12 ± 0.49	a
GT12	119.39 ± 2.52	a	56.61 ± 1.21	bc

Note. Values are mean ± SD from three independent processing batches (n = 3). Within each response, formulations sharing the same Tukey letter are not significantly different at $\alpha = 0.05$.

The inferential summary for formulation effects is provided in Table 5. Table 5 summarizes formulation effects and indicates

which responses were eligible for inferential comparison.

Table 5. ANOVA and post-hoc summary

Response	df	F-value	p-value	Interpretation Boundary
Moisture	11, 24	274.69	< 0.0001	Formulations differed significantly; report results as mean $\pm$ SD.
Ash	11, 24	6.66	0.0001	Formulations differed significantly; interpret as a quality and mineral-content indicator.
Crude Fat	11, 24	21.10	< 0.0001	Formulations differed significantly; avoid unsupported claims regarding storage stability.
Protein	11, 24	6.16	0.0001	Formulations differed significantly; protein functionality was not directly measured.
Fiber	11, 24	26.26	< 0.0001	Formulations differed significantly; discussion should be limited to compositional differences.
NFE	Not valid	Not valid	Not valid	Derived value with zero within-formulation standard deviation; ANOVA could not be validly performed.
TPC	11, 24	47.93	< 0.0001	Significant differences were observed; GT12, GT10, and GT11 belonged to the highest Tukey group.
DPPH	11, 24	284.08	< 0.0001	Significant differences were observed; GT04 and GT11 belonged to the highest Tukey group, whereas GT12 was not among the strongest DPPH-performing formulations.

Note. Statistical significance was assessed at $\alpha = 0.05$. NFE was excluded from inferential analysis because it was calculated by difference.

The final moisture content of the dried samples ranged from $0.68 \pm 0.06\%$ in GT06 to $3.02 \pm 0.01\%$ in GT02, indicating low residual moisture across all formulations (ASEAN, 2014; Liu et al., 2022). Ash, crude fat, protein, and fiber also differed among formulations, but these compositional differences should be interpreted descriptively because the study did not directly measure mineral speciation, protein functionality, or shelf-life stability.

The bioactive-response table corrects the previous omission of GT08 TPC and DPPH values and applies consistent units. GT12 had the highest numerical TPC (119.39 ± 2.52 mg GAE/100 g dried sample) and shared the top Tukey group with GT10 and GT11. DPPH inhibition showed a different pattern: GT04 and GT11 shared the highest Tukey group, whereas GT12 showed moderate DPPH activity ($56.61 \pm 1.21\%$). The divergence between TPC and DPPH responses indicates that antioxidant behavior cannot be inferred from total phenolic

concentration alone. DPPH inhibition depends on the chemical structure of reducing compounds, phenolic transformation during radical neutralization, extractability, and possible interactions with non-phenolic antioxidants (Olszowy-Tomeczyk & Typek, 2023; Platzer et al., 2022; Zeb, 2020). Therefore, GT12 is best described as a high-TPC and multi-response desirability candidate, not as the strongest DPPH formulation.

NFE was treated as a derived descriptive variable because it was calculated by difference and showed no within-formulation variation. Consequently, NFE was excluded from inferential comparison.

Response Surface Modeling and Model-Predicted Optimization

The ANOVA for the fitted quadratic TPC response surface model is shown in Table 6. The model terms provide the statistical basis for interpreting the effects of temperature, time, interaction, and curvature on phenolic retention.

Table 6. ANOVA for the quadratic TPC response surface model

Source	Sum of Squares	df	Mean Square	F-value	p-value
Model	2213.79	5	442.76	51.35	< 0.0001
A – Temperature	1721.83	1	1721.83	199.70	< 0.0001
B – Time	0.4846	1	0.4846	0.0562	0.8205
AB	61.70	1	61.70	7.16	0.0368
A ²	67.14	1	67.14	7.79	0.0316
B ²	114.77	1	114.77	13.31	0.0107
Residual	51.73	6	8.62	—	—
Lack of Fit	34.21	3	11.40	1.95	0.2983
Pure Error	17.52	3	5.84	—	—
Cor Total	2265.53	11	—	—	—

Note. Model terms with $p < 0.05$ were considered statistically significant.

For TPC, the quadratic model was statistically significant ($F = 51.35$, $p < 0.0001$), with significant temperature, temperature-time interaction, and curvature terms. The non-significant lack-of-fit result ($p = 0.2983$) supports the model's adequacy within the tested design region.

The DPPH response was fitted using a two-factor interaction model, and the corresponding ANOVA is shown in Table 7. This table should be read together with the weaker predicted R^2 reported in Table 8.

Table 7. ANOVA for the two-factor interaction DPPH response surface model

Source	Sum of Squares	df	Mean Square	F-value	p-value
Model	1061.02	3	353.67	9.91	0.0045
A – Temperature	188.26	1	188.26	5.28	0.0507
B – Time	273.78	1	273.78	7.67	0.0243
AB	263.52	1	263.52	7.39	0.0263
Residual	285.39	8	35.67	—	—
Lack of Fit	229.48	5	45.90	2.46	0.2444
Pure Error	55.91	3	18.64	—	—
Cor Total	1346.41	11	—	—	—

Note. Model terms with $p < 0.05$ were considered statistically significant.

Table 8. Coded response surface equations and model diagnostics

Model	Coded Equation	R ²	Adjusted R ²	Predicted R ²	RMSE	Interpretation
TPC Quadratic	TPC = 102.347 + 16.939A + 0.316B + 4.827AB – 5.465A ² + 7.021B ²	0.977	0.958	0.856	2.94 mg GAE/100 g	Strong model fit with good predictive performance within the experimental design region. Statistically significant model, but limited predictive capability; results should be interpreted with caution.
DPPH 2FI	DPPH = 53.572 + 5.563A – 7.265B + 9.522AB	0.788	0.709	0.325	5.97% inhibition	

The DPPH model was statistically significant ($F = 9.91$, $p = 0.0045$), with significant time and temperature-time interaction effects. However, the model's predicted R^2 was weak, so DPPH predictions should be interpreted more cautiously than TPC predictions.

The coded model equations and diagnostic indices for both response surface models are consolidated in Table 8. This table provides the main basis for comparing the stronger TPC model with the less predictive DPPH model.

The TPC response was well described by a quadratic model, with $R^2 = 0.977$, adjusted $R^2 = 0.958$, predicted $R^2 = 0.856$, and $RMSE = 2.94$ mg GAE/100 g dried sample. In contrast, the DPPH model was statistically significant but less reliable for prediction, with $R^2 = 0.788$, adjusted $R^2 = 0.709$, predicted $R^2 = 0.325$, and $RMSE = 5.97\%$ inhibition. These results indicate that the DPPH model is useful for describing observed trends within the design region but should be used cautiously for

prediction outside the observed experimental support.

Figure 1 shows the response-surface contour plots for TPC, DPPH inhibition, and overall desirability. The TPC surface increases toward the high-temperature, longer-time region of the tested design space, whereas the DPPH surface is less uniform because DPPH inhibition was affected by the temperature-time interaction. The desirability surface therefore identifies 75 degrees C for 6 h as the best model-predicted compromise within the studied range. The response-surface pattern is consistent with the dual role of heating in plant matrices. Thermal treatment can improve release of bound or compartmentalized phenolics, but excessive exposure may accelerate oxidation and degradation of thermolabile compounds, causing nonlinear or interaction effects between temperature and time (Antony & Farid, 2022; Duan et al., 2021; ElGamal et al., 2023; Taokaenchan et al., 2021).

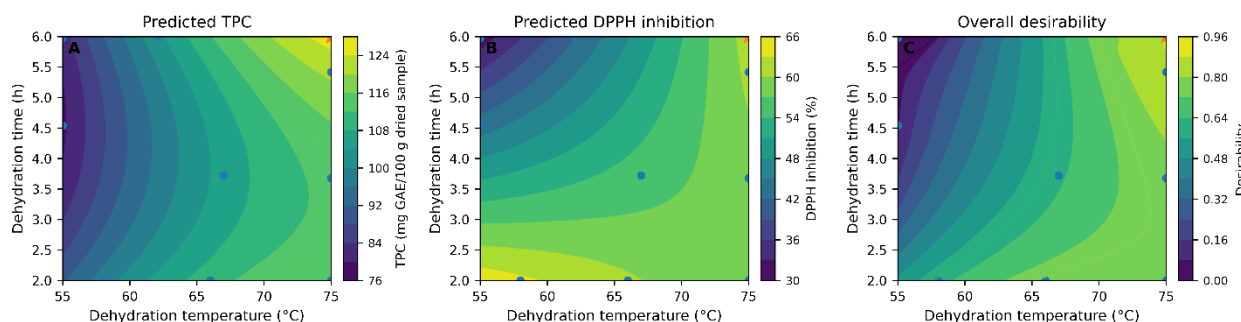


Figure 1. Response-surface contour plots for (A) total phenolic content, (B) DPPH inhibition, and (C) overall desirability. Points represent the I-optimal design runs; the marked boundary point indicates the model-predicted optimum at 75°C for 6 h.

Model agreement between observed and predicted responses is shown in Figure 2. Figure

2 compares observed and predicted values for the TPC and DPPH response mode

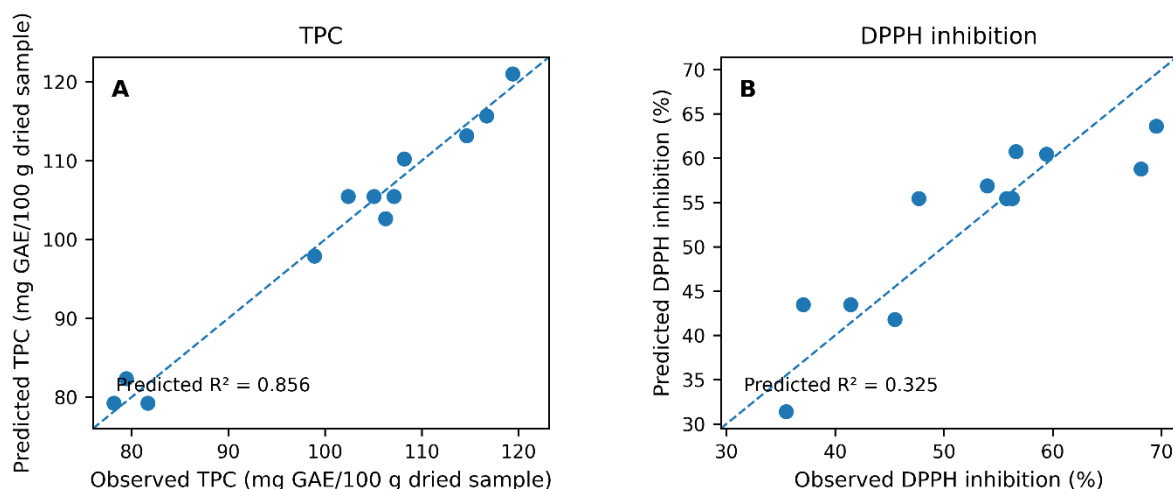


Figure 2. Observed-versus-predicted plots for (A) total phenolic content and (B) DPPH inhibition. The diagonal line represents perfect agreement between observed and predicted values.

The observed-versus-predicted plots support the different levels of confidence assigned to the two response models. TPC observations clustered more closely around the diagonal reference line, consistent with the strong predicted R^2 . DPPH observations showed greater dispersion, which supports the cautious interpretation of DPPH predictions and

reinforces the need for independent confirmation of the predicted optimum.

The numerical desirability solutions generated from the fitted models are listed in Table 9. These solutions rank candidate temperature-time combinations by combined desirability for TPC and DPPH responses.

Table 9. Model-predicted numerical solutions from multi-response desirability optimization

Solution	Temperature (°C)	Time (h)	Predicted TPC (mg GAE/100 g dried sample)	Predicted DPPH (% Inhibition)	Desirability
1	75.0	6.0	125.99	61.39	0.886
2	75.0	5.8	124.54	61.22	0.883
3	75.0	5.7	123.44	61.08	0.881
4	74.7	6.0	125.70	60.99	0.880
5	75.0	5.2	119.73	60.54	0.873
6	71.4	2.0	114.59	58.28	0.781
7	71.4	2.0	114.55	58.31	0.781
8	71.6	2.0	114.65	58.23	0.781
9	71.3	2.0	114.50	58.36	0.781
10	72.0	2.0	114.85	58.07	0.781
11	74.9	2.0	115.69	56.92	0.773

The numerical optimization identified 75 degrees C for 6 h as the highest-desirability condition within the tested design region, with predicted TPC of 125.99 mg GAE/100 g dried sample and predicted DPPH inhibition of 61.39%. This condition is interpreted as a

model-predicted optimum requiring experimental confirmation. The weaker predictive performance of the DPPH model further supports cautious interpretation of the numerical optimum.

The difference between TPC and DPPH responses indicates that total phenolic concentration alone did not determine radical-scavenging performance (Dobrinas et al., 2021; Olszowy-Tomczyk & Typek, 2023; Platzer et al., 2022). Figure 3 shows the formulation-level relationship between mean TPC and mean DPPH inhibition. The moderate positive correlation (Pearson $r = 0.716$, $p = 0.0088$) supports the interpretation that phenolic content contributes to radical-scavenging activity but

does not fully determine it, explaining about 51% of the formulation-level variation in DPPH. This pattern suggests that dehydration affected not only the amount of Folin-reactive phenolics but also phenolic composition, extractability, oxidation state, and possible interactions with non-phenolic antioxidants. The result also explains why GT12 had the highest observed TPC but did not show the highest observed DPPH inhibition.

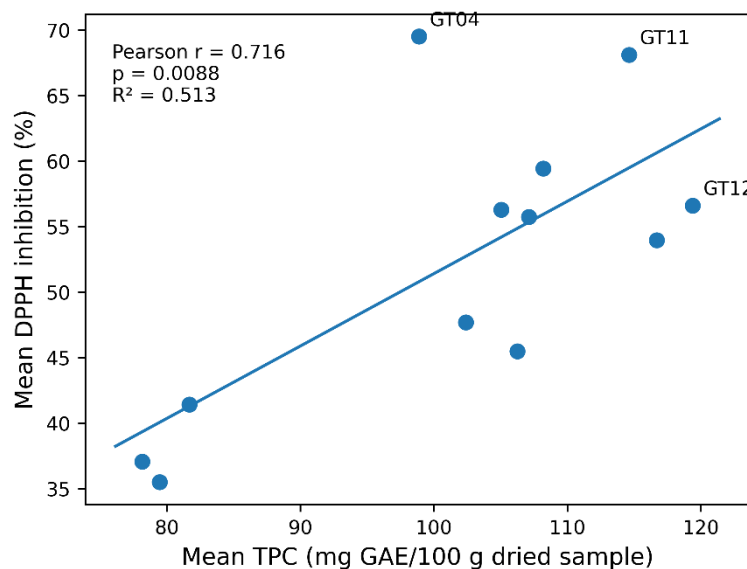


Figure 3. Relationship between formulation-level mean total phenolic content and DPPH inhibition (Pearson $r = 0.716$, $p = 0.0088$; $R^2 = 0.513$).

Sensory Acceptability and Microbiological Quality

The sensory mixed-model results for the selected high-temperature formulations are summarized in Table 10. This table reports consumer acceptability scores and the omnibus formulation effect for each sensory attribute. GT12 had the highest numerical flavor and overall acceptability scores, but no Holm-adjusted pairwise contrast remained significant. The sensory results therefore support comparable acceptability among GT10-GT12, with GT12 numerically favorable for overall acceptability rather than statistically preferred.

The sensory findings should be interpreted as consumer acceptability data rather than trained descriptive profiling. The absence of significant adjusted pairwise contrasts indicates that GT10-GT12 were broadly comparable in liking, while individual preference variation may explain why numerical differences did not translate into robust pairwise significance (Feeney et al., 2024; Heymann & Ebeler, 2016; Yang & Lee, 2019).

The microbiological quality results for the selected tested formulations are shown in Table 11. It reports the microbiological status of GT10-GT12 under the assays performed.

Table 10. Sensory mixed-model summary for selected high-temperature formulations (n = 35 analyzable raters)

Attribute	GT10 (Mean $\pm$ SD)	GT11 (Mean $\pm$ SD)	GT12 (Mean $\pm$ SD)	Wald χ^2	p-value	Interpretation
Color	6.34 $\pm$ 1.63	7.03 $\pm$ 1.12	6.86 $\pm$ 1.14	8.002	0.0183	Significant omnibus formulation effect; however, no Holm-adjusted pairwise comparison was significant.
Aroma	6.31 $\pm$ 1.32	6.74 $\pm$ 1.22	6.66 $\pm$ 1.31	4.732	0.0939	No significant differences among formulations.
Taste	5.74 $\pm$ 1.72	6.06 $\pm$ 1.41	6.03 $\pm$ 1.01	1.911	0.3845	No significant differences among formulations.
Flavor	5.77 $\pm$ 1.73	6.00 $\pm$ 1.39	6.06 $\pm$ 1.28	1.546	0.4618	No significant differences among formulations.
Overall Acceptability	6.00 $\pm$ 1.55	6.40 $\pm$ 1.38	6.43 $\pm$ 1.04	6.031	0.0490	Borderline significant omnibus effect; however, no Holm-adjusted pairwise comparison was significant.

Table 11. Microbiological quality results for selected tested formulations

Formulation	Aerobic Plate Count (CFU/g)	Coliform (MPN/g)	<i>E. coli</i> (MPN/g)	<i>Salmonella</i>	Yeast and Mold Count (CFU/g)
GT10	30,000	79	< 1.8	Absent	< 10
GT11	96,000	240	< 1.8	Absent	10
GT12	62,000	240	< 1.8	Absent	20

The selected formulations tested for microbiological quality (GT10-GT12) met the referenced microbiological criteria under the assays performed (Tea & Herbal Infusions Europe [THIE], 2021). This interpretation applies only to GT10-GT12. The low final moisture values are also consistent with the general principle that moisture reduction supports microbial-risk control in low-moisture foods, although shelf-life testing remains necessary for storage claims (Liu et al., 2022).

4. Conclusion

Within the tested forced-air dehydration range of 55-75 degrees C and 2-6 h, temperature and time significantly influenced the physicochemical and bioactive properties of guyabano leaf tea. GT12 showed the highest observed TPC and acceptable DPPH radical-scavenging activity, while GT04 and GT11 showed stronger observed DPPH inhibition. The multi-response desirability analysis identified 75 degrees C for 6 h as the best model-predicted condition within the design space, but this optimum should not be treated as experimentally

validated until independent confirmation runs are completed.

Sensory evaluation showed that GT10-GT12 were generally acceptable, with GT12 numerically highest in overall acceptability, although adjusted pairwise differences were not significant. Microbiological findings apply only to the selected tested formulations. Future work should validate the predicted optimum using independent processing batches and assess storage stability and phenolic-profile changes during shelf life.

5. Study Limitations and Recommendations

The model-predicted optimum of 75°C for 6 h was not independently validated, and the DPPH model showed lower predictive performance than the TPC model. Sensory and microbiological assessments were limited to GT10-GT12, and sensory evaluation focused on hedonic acceptability rather than descriptive profiling. Individual phenolic compounds and changes during storage were also not characterized.

Future studies should confirm the predicted optimum using independent processing batches, evaluate shelf-life stability, and characterize phenolic-profile changes associated with dehydration and storage. Quantitative descriptive analysis may also be used to extend the sensory characterization of guyabano leaf tea.

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