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Optimization of Sinom and Lime Tea Bag Formulation Using D-Optimal Mixture Design: Physicochemical and Sensory Evaluation

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ABSTRACT

Sinom is a traditional beverage composed of turmeric (Curcuma longa) and young tamarind leaves (Tamarindus indica L.), recognized for its phenolic compounds. To address the limited shelf-life of liquid, ready-to-drink Sinom mixed with lime, this study aimed to develop a more practical, dip-type (tea-bag) formulation. A D-Optimal Mixture Design was applied to optimize the ratio of three dry ingredients: young tamarind leaf powder, lime powder, and turmeric powder. The optimization determined an ideal mixture ratio of 48.393 : 18.607 : 33.000 (% w/w), respectively, achieving a desirability value of 0.772. Physicochemical evaluation of the optimized prototype demonstrated a relatively low moisture content (9.572 ± 0.33%), which theoretically supports storability, and an acidic profile (pH 3.33 ± 0.0186). Colorimetry yielded L*, a*, and b* values of 31.9 ± 0.20, 0.9 ± 0.14, and 15.3 ± 0.13. The antioxidant capacity was moderate, indicated by a DPPH IC_{50} value of 238.067 ppm and a total polyphenol content of 14.392 ± 1.12 mg GAE/g. Furthermore, hedonic sensory evaluation revealed a moderate overall consumer acceptance (scored 3.292), with the beverage's color receiving the highest preference rating. In conclusion, the D-Optimal Mixture Design successfully produced a ready-to-brew herbal tea candidate with acceptable physicochemical parameters and moderate functional properties. While this dry formulation presents a practical alternative to liquid preparations, further comprehensive investigations—specifically regarding shelf-life profiling, microbiological safety, and cost evaluations—are essential before establishing definitive claims about its long-term stability or market readiness.

Key Messages:

- While this ready-to-brew format offers a practical approach to modernizing traditional Indonesian herbal beverages, it cannot yet be claimed as commercially durable or widely accepted. Further comprehensive investigations—specifically shelf-life profiling, microbiological safety assessments, and large-scale consumer testing—are necessary prerequisites.

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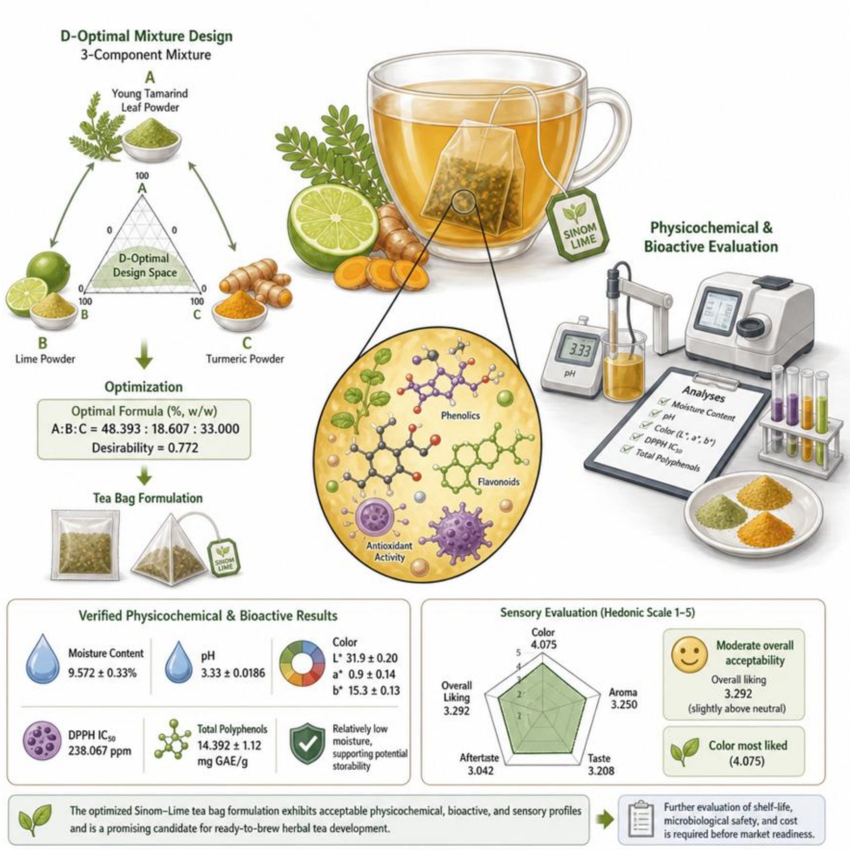
GRAPHICAL ABSTRACT



INTRODUCTION

Plant-based herbal drinks have become influential in the healthcare practices of Indonesian society. According to a 2018 survey published by the Health Research and Development Agency (Riskesdas), approximately 48 percent of Indonesians use traditional remedies to maintain their immune system or manage minor illnesses (1). This indicates substantial market potential for herbal beverage products and supports their development into more practical, standardized, and widely accessible forms. Sinom is one of the popular traditional drinks on the island of Java. Sinom is traditionally prepared as a blend of turmeric rhizomes (*Curcuma longa*) and the leaves or fruit pulp of tamarind (*Tamarindus indica*) (2).

The other researches have showed that Sinom is a source of different bioactive compounds such as vitamin C, B vitamins, unsaturated fatty acids, polyphenols, flavonoids. These substances have been reported to have antioxidant, anti-diabetic, anti-inflammatory, and anti-hyperuricemic properties (3–6). For example, Rizeki & Olivia (4) reported that Sinom beverage intervention significantly reduced uric acid levels in hyperuricemic rats. In contemporary preparations, Sinom is often combined with other natural ingredients such as lime and honey. In this study, the term "Fusi" refers to a formulated Sinom-based mixture consisting of Sinom, lime, and honey (a preparation label used to denote this specific combination rather than a universally established term). Importantly, several claimed benefits of such herbal combinations, such as supporting recovery after illness or alleviating minor complaints (e.g., fever, headache, nausea, and body aches), should be understood primarily as traditional or community-reported uses and should not be interpreted as established clinical outcomes in the absence of controlled human evidence (7).

Although Sinom-based products could be useful, Sinom produced by MSME is mostly offered as ready-to-drink liquid preparations. Liquid products are usually subjected to storage and distribution issues such as low stability thereby affecting the quality and safety of the products (2). Bioactive compounds can be oxidized or degraded during storage, and maybe lose functional capacity (8). Moreover, it is possible to

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alter organoleptic properties (color, taste, aroma) because of microbial contamination or exposure to oxygen, water vapor, light, or pressure during packaging and distribution (9,10).

The MSMEs are also characterized by limited capital and the production equipment that worsen shelf-life and quality problems. Thus, there is a need to innovate more stable forms of dosage that MSMEs can still produce. Liquid products are already known to the consumers but there may be benefits in stability, shelf life and convenience with switching to a dry form of tea bags. According to Jayani et al., (11) moisture, total polyphenols, total flavonoids, and microbiological parameters of the tea (teabag and brewed) of the moringa tea kept within acceptable ranges over a six-month observation time. The process of tea bags is also relatively simple, as it usually requires the process of drying, reduction of size and blending, which do not require the use of costly equipment or complex additives (12). The moisture content, total polyphenols, total flavonoids, and microbiological parameters of the moringa tea (teabag and brewed) were within acceptable levels over a period of six months. The process of producing tea bags is also relatively simple, as it usually implies the process of drying, decreasing size, and combining it with other components- all the processes which do not demand the usage of costly equipment or some complicated additives.

Maintaining bioactivity of the content in the course of processes (drying and formulation modification) is thus a significant issue. As an example, the mass ratio of turmeric rhizomes and tamarind leaves was evaluated and revealed that addition of tamarind leaves may produce a high total phenolic content of the final composition (2)Statistical methods like Design of Experiments (DoE) are very applicable in order to establish optimal proportions of various components of a multi-component formulation in a systematic way. Mixture design is also applicable especially since the independent variables are component proportions as opposed to absolute quantities. According Sahin et al., (13) mixture design can be used in developing a food or beverage where a ratio of ingredients can determine the product characteristics. Applications of D-Optimal Mixture Design in functional/herbal products have also been employed in cases where several responses (multi-characteristics) have to be optimized along with each other (14).

It is appropriate, based on the background above to come up with a sinom-lime compound in the form of tea-bags. This paper seeks to enhance the dry herbal mixture within the tea bag with the concentration on the three key plant-based elements, which include turmeric, tamarind leaves (Sinom base), and lime. Honey is considered to be a supplementary/ optional ingredient that is employed to mirror typical consumption habits. Nevertheless, it is not specified as a mixture-design factor since it is not a dry botanical constituent added to the tea bag and, it being a hygroscopic constituent, could be confounding significant responses associated with stability such as moisture content and shelf-life behavior. The Mixture Design D-Optimal optimization is therefore performed on the three dry ingredients (turmeric, tamarind leaves, and lime). Meanwhile, honey has also been regarded as a fixed accompaniment at the eating point or a complementary component instead of an optimized fraction mix.

Some of the responses considered are the physicochemical properties (moisture content, antioxidant activity, total polyphenols, total color, and pH) and sensory-related responses and consumer preference. The Mixture Design D-Optimal technique is used to do optimization, which allows determining the optimal proportions of components with a relatively fixed number of experimental runs without losing accuracy (15,16). The findings are expected to generate an optimized formulation that is stable, cost-effective, and practically applicable for MSME production.

METHODS

The tools used are a cabinet dryer, analytical balance (Kern ABJ 220-4NM), 40 mesh sieve, water bath shaker (Biobase SHZ-A10), rotary vacuum evaporator (IKA RV 10 digital V), UV-Vis spectrophotometer (Shimadzu UVmini1240), microplate reader (Spectrostar nano), vortex (IKA VM-2000), oven (Memmert Binder BD - 115), pH meter (Biobase PH920), color reader (Konica Minolta CR-10), micropipettes, microplates (Biologix 07-6096), and other supporting glassware. Turmeric and lime fruit, obtained from the Big Market, Badung Market, Denpasar City, Bali; young tamarind leaves obtained from the Klembang area, Tabanan City; mineral water (Tulus brand); mixed lime dip sinom (Elif Tea and Tisane); non-woven PP dip bags; PA methanol; distilled Water; 0.1 mM DPPH reagent in PA methanol; anhydrous gallic acid;

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Folin Ciocalteu reagent; and Na2CO3.

Research Design

The research design for formulating a mixed sinom and lime dip preparation using the Mixture Design D-optimal. The method involved independent variables of turmeric powder, young tamarind leaves, and lime fruit. The optimal variable for the combination of sinom and lime dip preparation, as determined by the Mixture Design D-Optimal method, is presented in Table 1, which includes three main ingredients. The design resulted in 16 runs with responses for powder moisture content, brew pH, and extract DPPH inhibition.

Table 1. Preliminary Screening Ratios and Normalized Mixture Proportions of Young Tamarind Leaf, Lime, and Turmeric Powders for Tea-Bag Preparation

Formulation	Composition	Ratio (parts,w/w)	Normalized mixture (%, w/w)
B1C1	Young tamarind leaf powder: lime: turmeric powder	50: 40: 30	41,67: 33,33: 25
B2C2	Young tamarind leaf powder: lime: turmeric powder	50: 40: 20	45,45: 36,36: 18,18
B3C3	Young tamarind leaf powder: lime: turmeric powder	50: 40: 10	50: 40: 10

Note: Ratios are presented as parts by weight (w/w) for preliminary screening. For mixture-design modeling, all ratios were converted to normalized proportions summing to 100% (w/w).

In the mixture model, component A was young tamarind leaf powder, component B was lime powder, and component C was turmeric powder. The formulations listed in Table 1 represent preliminary screening expressed as parts by weight (w/w). These base ratios were selected to reflect the typical Sinom base (tamarind leaves and turmeric) with lime as an additional component, while allowing an initial variation in turmeric intensity to achieve acceptable sensory characteristics and tea-bag processability. The screening formulations were used to define the feasible formulation region (component constraints) for the subsequent D-Optimal mixture design. Prior to optimization, all component ratios were normalized to a total of 100% (w/w); therefore, the D-Optimal runs and the optimized formulation are reported as decimal percentages (e.g., 48.39%), which may differ from the unnormalized screening ratios shown in Table 1.

Making Sinom

Turmeric and tamarind leaves are sorted and washed. The lime is sliced half a millimeter thick, tamarind leaves are chosen for their light green color with light green stems; the turmeric is thinly sliced. The three materials were sequentially dried by natural drying at 60˚C for 24, 4, and 8 hours, followed by size reduction and sieving (40 mesh) (17,18). The sinom dip preparation was weighed according to the proportions in the formulation, with a total weight of 5 grams, and packaged in filter paper (19). The raw materials for the dip preparation, based on the weight ratio of young tamarind leaf powder: lime and turmeric powder, were stored in bottles as shown in Figures 1. After that, they were ready for testing (20,21).

The raw material powder was extracted by maceration in PA methanol at a ratio of 1:10 for 7 hours at 40˚C and a speed of 70 rpm. The extract was evaporated using a vacuum rotary evaporator at 40˚C. The formulation design for sinom dip preparation and raw materials for polyphenol analysis was extracted by maceration at a ratio of 1:10 with PA methanol for 7 hours at 40˚C and a speed of 70 rpm, according to modifications (20). For optimal formulation of tea bags, brewing is performed with a powder-to-water ratio of 1:100. Water at 95˚C is left to stand for 10 minutes, with 10 dips according to the modified method (22).

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Figure 1. Raw Materials for Sinom Mixed with Lime Juice Dip Preparation

Analysis of Sample Water Content

The initial weight of the sample was 2 g. The sample was oven-dried at 105˚C for 4 hours and then weighed again. This process of oven-drying and weighing was repeated with 1-hour drying intervals until a constant final weight was achieved (difference of 2 mg), according to the modified method SNI 01-2891-1992 (23,24).

Calculation:

Moisture Content = $\frac{W_0}{W_1} \times 100\%$**……………………………………………………………………………………(1)**

Explanation:

W_0: Weight loss after drying (g)

W_1: Weight before drying (g)

Analysis Antioxidant

Antioxidant activity was measured using the DPPH spectrophotometric method (25,26) and a microplate reader (27). The UV-Vis spectrophotometer was used for raw material analysis, with dilutions of 10-50 ppm, and sinom extract from the Design Expert 13 formulation, with a dilution of 200 ppm in PA methanol. The optimal sinom infusion dip preparation was diluted to 25-125 ppm and analyzed using a microplate reader.

Sample addition with DPPH reagent at a 1:1 ratio, homogenization, 30-minute incubation in dark conditions, and absorbance measurement at a wavelength of 517 nm with the following calculation:

% DPPH Inhibition = $\frac{AC-AS}{AC} \times 100\%$ **………………………………………………………………(2)**

Explanation:

AK: Control Absorbance

AS: Sample Absorbance

IC50 = $\frac{50-b}{a}$ **…………………………………………………………………………………(3)**

Explanation:

b: Linear regression constant

a: Linear Regression Coefficient Analysis of pH and Color

Color Analysis

The color of the optimal dip preparation of cinnamon infusion was analyzed using the values of (L*) brightness, (a*) red to green, and (b*) yellow to blue (28). Analysis of brew pH using a pH meter according to SNI 01-2891-1992 (23).

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Total Polyphenol Analysis

The raw material analysis was performed by diluting the turmeric extract 100 times, while the lime leaves and fruit were diluted 25 times with distilled Water. The optimal formulation infusion is not diluted. 0.5 mL of the sample was mixed with 2 mL of 7.5% Na_2CO_3 and 2.5 mL of 10% Folin-Ciocalteu reagent. Incubation was carried out for 1 hour in a dark environment, with absorbance measured at a wavelength of 765 nm, as per modifications (29,30). The calculation of total polyphenols using gallic acid as a standard is as follows:

C (mg GAE/g) = *cc VV mm*..(4)

Explanation:
C: Total polyphenols (mg GAE/g)
c: Concentration based on the standard curve (mg/mL)
V: Extraction volume (mL)
M: Sample mass (g)

Sensory Analysis

Sensory analysis was conducted using a 5-point hedonic test to determine consumer preference for the optimal dip-type sinom brew, following previously reported modifications (31,32). A total of 100 untrained consumer panelists, undergraduate students aged 20–30 years, participated voluntarily. Panelists evaluated color, clarity, turmeric aroma, sour aroma, leaf aroma, bitter taste, sour taste, bitter aftertaste, earthy aftertaste, refreshing sensation, and overall liking using a 1–5 scale (1 = dislike very much; 5 = like very much).

CODE OF HEALTH ETHICS

This research was designed to involve human subjects in a hedonic sensory assessment and was undertaken in compliance with the ethical principles of research involving human subjects. The Research Ethics Committee of Universitas Dhyana Pura (Surat Layak Etik No. 002308/KEP Universitas Dhyana Pura/2025, 11 June 2025) provided the ethical clearance.

RESULTS

Raw Material Characteristics

According to Table 2, the features of the lime sinom mixture raw materials indicate that the three formulations vary in terms of the moisture level, pH, the activity of the antioxidants, and the total polyphenols. The B3C3 formulation had the highest moisture content with 9.28 ± 0.97 and the lowest moisture content with 8.78 ± 0.03. The pH of the materials was different with significant results that were in the range of 2.84 + 0.01 to 6.36 + 0.18 with the highest pH recorded in formulation B3C3 and the lowest in B1C1. Since the percentage of lime was modified equally between formulations, these differences in pH cannot be traced to the amount of lime in the formulation, but rather, these differences may represent the overall formulation effect, the percentage changes in relative proportions of the Sinom base ingredients (turmeric and young tamarind leaf) themselves or some interactions between the ingredients.

Table 2. Characteristics of Raw Materials for the Analysis of Mixed Lime Sinom

Analysis	B1C1	B2C2	B3C3
Moisture Content (%)	8.78±0.03*	8.79±0.30*	9.28±0.97*
pH	2.84±0.01*	2.97±0.04*	6.36±0.18*
Antioxidant Activity (IC50, ppm)	362.78±1.97*	250.64±15.10*	316.19±7.18**
Total Polyphenols (mg GAE/g)	23.512±5.19*	30.545±0.74*	21.225±1.47*

Explanation:
The symbol * indicates the average data from three replications = standard deviation.
the symbol ** indicates the average from the replications = standard deviation

The antioxidant activity test results showed that the B2C2 formulation had an IC50 value of 250.64 ± 15.10 ppm, which was the highest antioxidant activity among the three formulations. A lower IC50 value

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indicates stronger antioxidant capacity. Meanwhile, B1C1 showed the highest IC50 value (362.78 ± 1.97 ppm), indicating that its antioxidant activity was lower than that of the other two formulations. The total polyphenol content was also highest in B2C2 at 30.54 ± 0.74 mg GAE/g, followed by B1C1 (23.51 ± 5.19 mg GAE/g) and B3C3 (21.23 ± 1.47 mg GAE/g). Therefore, B2C2 demonstrates the highest functional-related performance among the tested formulations based on the DPPH IC_{50} assay and total polyphenol content; however, the IC_{50} values (>200 ppm) indicate a moderate antioxidant potency rather than a strong or very strong category.

Antioxidant Activity and Polyphenols of Raw Materials

According to the results of the analysis in Table 3 the range of values of the moisture content of the sinom formulation in the presence of lime is 8.78 to 10.54. This value shows that the moisture content differs depending on the various compositions of the key ingredients, which are turmeric (B1C1), tamarind leaves (B2C2) and lime (B3C3). The pH value is between 3.08 and 3.35, which means that all the samples are acidic in nature, as per the overall nature of the herbal beverages made of natural ingredients. The DPPH inhibition values were between 26.44 and 39.18, meaning that the antioxidant activities of the formulations differ. The lower level of water in a formulation will be more active as an antioxidant, which means that the proportion between the composition of turmeric, tamarind leaves and lime will influence the level of free radicals scavenging and the stability of the beverage itself.

Table 3. Results of the Analysis of the Sinom Formulation Mixed with Lime

Run	Component			Response		
	B1C1	B2C2	B3C3	Moisture Content (%)	pH	DPPH Inhibition (%)
1	47	20	33	8.78	3.32	36.66
2	50	17	33	10.02	3.35	39.18
3	37	23	40	9.79	3.17	29.30
4	36	17	47	10.16	3.15	27.58
5	45	17	38	10.17	3.30	36.23
6	36	17	47	10.48	3.15	28.44
7	33	20	47	10.54	3.13	26.66
8	37	23	40	9.85	3.19	29.40
9	42	22	37	10.30	3.28	31.12
10	50	17	33	10.14	3.34	37.46
11	44	23	33	9.98	3.29	34.25
12	44	23	33	10.11	3.29	34.22
13	30	23	47	9.63	3.08	22.59
14	37	20	44	10.13	3.16	28.65
15	30	23	47	9.46	3.10	23.08
16	40	20	40	10.21	3.24	29.42

Notes: B1C1:B2C2:B3C3 represent the mixture proportions of the three modeled components written as an x:y:z ratio (% w/w), where B1C1 = A (young tamarind leaf powder), B2C2 = B (lime powder), and B3C3 = C (turmeric powder). The three component proportions sum to 100% in each run. *(Honey was treated as a complementary ingredient and was not included as a mixture component in the D-Optimal model.)*

Statistical Analysis and ANOVA Models

Table 4 below shows that cubic is the most suitable model to represent the water content model, linear is the model to represent the pH model and the most suitable model to represent the DPPH inhibition is a quartic model. The p- value of all the models is less than 0.05, which indicates that the response effect is considered to be statistically significant. The proportionate effect of addition of increase in proportion of turmeric (A), tamarind leaves (B) and lime (C) to the moisture content of the infusion of sinom on leaves is significant. The R 2 value of the moisture content is 0.9824 which shows a terrific match between the actual and the predicted data. The pH model has a high R2 of 0.9842 with an adjusted R2 of 0.9797 indicating a strong linear relationship between proportions of ingredients and pH. The DPPH inhibition model has a value of R 2 = 0.9937 and adjusted R 2 = 0.9865 which means that the model captures the majority of the variability in the data. The lack-of-fit p-values of all the responses were larger than 0.05, in which case, it

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was assumed that there is no significant difference between the fitted models and the experimental data. In general, the studied models provide a good description of relationship between ingredient composition, moisture content, pH and antioxidant activity.

Table 4. ANOVA response of Lime Mixed Sinom

Source	Response		
	Moisture Content	**pH**	**DPPH Inhibition**
Model	Cubic P-value=0.0075	Linear P-value<0.0001	Special Quartic P-value<0.0001
Equation	(Actual) Y (Moisture Content) = + 0.981048 A – 41.09571 B + 3.33836 C + 0.726505 AB – 0.061232 AC + 0.612952 BC – 0.005545 ABC – 0.005283 AB(A–B) + 0.000792 AC(A–C) + 0.003270 BC(B–C)	(Actual) Y (pH of infusion) = + 0.040050A + 0.029537B + 0.025735C	(Coded) Y (DPPH inhibition) = 38.32A + 6.46B + 20.49C + 25.97AB + 10.61AC + 31.32BC – 354.33A^2BC + 325.32AB^2C + 41.83ABC^2
Linear Model	P-value=0.0057	P-value<0.0001	P-value<0.0001
Interaction	P-value>0.1	-	A^2BC: *P*-value=0.0047 Other interactions *P*-value < 0.0001
Lack of Fit	P-value=0.6506 F-value=0.2317	P-value=0.6506 F-value=0.2317	P-value=0.6506 F-value=0.2317
Mean	10.05	3.22	30.89
Standard Deviation	0.1194	0.0127	0.5797
R^2	0,9304	0.9824	0.9937
Adjusted R^2	0,8261	0.9797	0.9865
Predicted R^2	Not Available	0.9759	0.9612

A 3D surface plot of the impact of the proportions of turmeric (A), tamarind leaves (B), and lime (C) on the levels of water content (a), pH (b), and antioxidant activity (DPPH) in sinom tea is presented as shown in figure 2. Graph (a) reveals that the higher the lime proportion, the higher the water content; however, turmeric tends to reduce the amount of water content at a high proportion. Graph (b) shows that the relation between the ingredients and pH is linear such that as the content of turmeric increases, the pH also increases because it is a neutral substance. Meanwhile, the leaves of lime and tamarind lower the pH due to the organic acids they contain. Graph (c) indicates that as the proportions of lime and turmeric increase, the antioxidant activity also increases, and the opposite is also true. In general, the conducted results imply that the three ingredients have a synergistic effect on promoting the antioxidant activity and physical properties of sinom infusion.

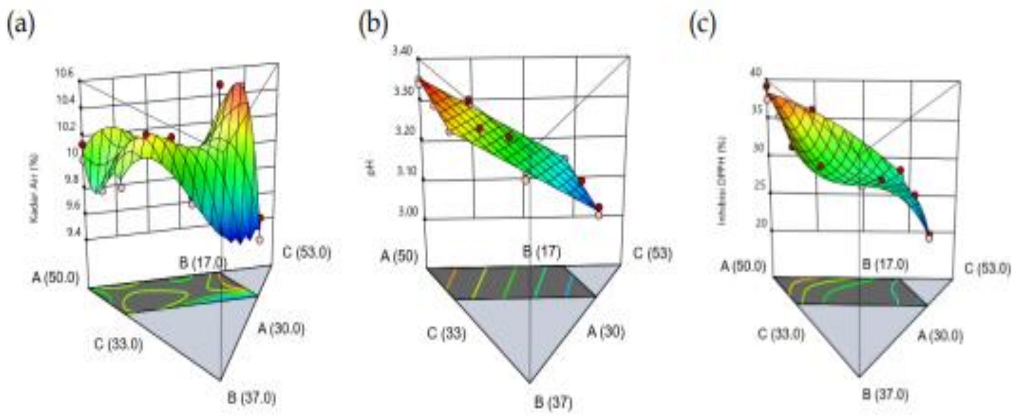

Figure 2. Graph of 30 responses (a) moisture content, (b) pH, (c) DPPH

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Physical and Chemical Characteristics of the Optimal Formula

Table 5 presents the results of the predicting and verifying the optimal formulation for lime juice mixed with sinom. The verified water content value of 9.57 ± 0.33% is close to the predicted value of 9.829%, with a p-value of 0.309, indicating no significant difference between the actual data and the prediction model. The verified pH value of 3.33 ± 0.019 also matches the predicted value of 3.337, with a p-value of 0.481, indicating that the model has good accuracy. The verified antioxidant activity (DPPH inhibition) of 37.23 ± 0.68% was slightly lower than the predicted value of 37.681%, but the difference was not significant (p-value 0.372). Overall, these findings indicate that the model can reliably predict the formulation outcomes within the scope of the three evaluated responses (moisture content, pH, and DPPH inhibition), and can therefore be used to identify an optimal ingredient combination based on these parameters. However, product quality in a broader sense, such as shelf life, safety/toxicity, and cost, was not assessed in this verification and should be evaluated in future work

Table 5. Predicted and Verified Optimal Formulation Values for Lime-Mixed Sinom Dip Preparation

Variable				Response		
Description	**B1C1**	**B2C2**	**B3C3**	**Moisture Content (%)**	**pH**	**DPPH Inhibition (%)**
Prediction	48.393	18.607	33	9.829	3.337	37.681
Verification	48.393	18.607	33	9.572±0.33	3.33±0.019	37.233±0.68
P-value	-	-	-	0.309	0.481	0.372

Sensory Evaluation (Hedonic Test)

According to the hedonic test (Table 6), the best adjustment of sinom tea had moderate overall acceptability on the assessed sensory properties. The best score was received by the color (yellow) with the highest mark of (4.075 ± 0.765) which indicates that the panelists were mainly satisfied with the visual appearance of the product. Transparency was also graded rather positively (3.745 ± 0.829) meaning that the brew was found attractive as far as transparency is concerned. The aroma qualities (turmeric, sour, and leaf) had a relatively low range of 3.038-3.104, which implies that the aspects were perceived as not overly pungent and close to neutral, neutral to slightly liked. The sour taste received the least score (2.991 ± 0.878), meaning that some of the panelists had a tendency not to like this characteristic. Ratings of bitter and earthy aftertaste attributes were neutral-to-acceptable (≈3.23), indicating that the flavor combination was not overwhelmingly negative. In general, the general liking of 3.292 ± 0.915 is more towards the neutral rating (3) than the liked (4-5), which means that the overall acceptability is moderate and that it is possible to maximize consumer preference by refining it further, especially the sourness (33).

Table 6. Hedonic Test Results for Sinom Brew with Optimal Formulation

Sensory Attribute	Hedonic Value of Optimal Formula
Yellow Color	4.075 ± 0.765
Clarity	3.745 ± 0.829
Turmeric Aroma	3.038 ± 1.041
Sour Aroma	3.047 ± 0.999
Leaf Aroma	3.104 ± 0.935
Bitter/Astringent Taste	3.085 ± 0.996
Sour Taste	2.991 ± 0.878
Fresh Sensation	3.321 ± 1.000
Earthy Aftertaste	3.198 ± 0.999
Bitter Aftertaste	3.255 ± 1.070
Overall Liking	3.292 ± 0.915

DISCUSSION

Raw Material Characteristics

Dried herbal products should be properly dried as the level of water in it will greatly affect the final quality of a product. According to SNI 01-3709-1995, the highest concentration of water in the dry herbs

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products is 12%. The percentage of lime water was found to be bigger than that of turmeric in this work and the result was similar to the findings of previous studies (17,18,34,35). Dried herbal products should be properly dried as the level of water in it will greatly affect the final quality of a product. According to SNI 01-3709-1995, the highest concentration of water in the dry herbs products is 12%. The percentage of lime water was found to be bigger than that of turmeric in this work and the result was similar to the findings of previous studies (34,36).

The raw materials also differ in terms of PH, on top of the water content. The tamarind leaves and limes of youth are very acidic in their properties, and the turmeric is nearly neutral. The pH difference may be determined by the oxidation of organic acids during the drying process at lower or higher temperatures (60-70°C) and the differences in the rate of the drying air (37,38). Previous studies also imply that drying can have an influence on the composition of organic acids on the product, and the pH value that may come after the process (39–41).

These materials differ in their functional properties basing on their antioxidant activity as well as content of polyphenols. The antioxidant activity of the fruit of lime is usually moderate, and the antioxidant potential of this fruit has been reported to be less than that of turmeric and tamarind leaves (42–45). Importantly, IC_{50} is inversely related to antioxidant capacity higher IC_{50} values indicate lower antioxidant activity. In the present study, turmeric showed the highest IC_{50} value (the weakest antioxidant activity), whereas lime and tamarind leaves showed lower IC_{50} values (stronger antioxidant activity), with tamarind leaves exhibiting the lowest IC_{50} among the three materials (46). Plant species and variety, extractions method and solvent may also affect differences in IC_{50} and polyphenol (47–50). Secondly, the contents of polyphenols and antioxidant activity may depend on the age of leaves, the stage of maturity of the fruits, and the growing environment (48–51).

Antioxidant Activity and Polyphenols of Raw Materials

Phenolic compounds and flavonoids in the raw materials determine the antioxidant activity of the raw materials. The analysis demonstrated that lime has a lower IC50 value compared to turmeric and tamarind leaves. Such outcomes suggest that Lime has an average level of outstanding antioxidant activity, whereas Turmeric exhibits high antioxidant activity, and tamarind leaves are characterized by weak antioxidant activity (46). Their differences can be attributed to variations in the types of plants, their level of maturity, and the method and solvent used for extraction (47). Antioxidant activity is also dependent on the content of bioactive components of turmeric (*curcumin*), Lime (*hesperidin*), and tamarind leaves (*phenolic acid*) (42,43).

The reason is that the amounts of polyphenols differ between the ingredients. Ripe fruits also have polyphenol buildups because of the development of quinones, and young leaves have high phenol levels because of reacting to physiological stress (50). Rapid weather shifts, such as high temperatures and low rainfall, may affect the quantity of secondary metabolites produced (52). The polyphenol value of turmeric is similar to the report by Singh et al. (53). Conversely, the difference between tamarind and lime leaves depends on the place of growing the material and their maturity degree (48).

The effect of each material is also evident in the relationship between the content of polyphenols and the pH. The high concentration of turmeric in the brew raises its pH, as turmeric is nearly neutral (54). On the other hand, the lime and tamarind leaves reduce the pH because they contain a high concentration of organic acids, such as citric acid and malic acid (55,56). When the three ingredients are combined, a stable acid-base balance is achieved. Turmeric works to alkalinize tamarind leaves and Lime, making the brew more balanced in terms of pH, as well as having a more consistent taste.

ANOVA Models and Statistical Analysis

The findings indicated that the cubic model, linear model, and special quartic model were the best models for water content, pH, and DPPH inhibition activity, respectively. The p-values of the three were less than 0.05, indicating a significant effect between the composition of the ingredients and each of the observed responses (57). Additionally, the value of the lack of fit is more than 0.05, indicating that the model fits the actual data and is successful in explaining the relationship between variables (58). The results

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affirm that the blend of turmeric, tamarind leaves, and lime has a statistically significant impact on the physical and chemical properties of the brew.

The moisture content model presents a variation between 31.41 and 40.48, which is determined by the moisture content of the ingredients, especially the content of organic acid, specifically tartaric acid (4.8-11.4 mg/100g), as well as the content of the amino acid, tryptophan (2.03-3.93mg/g). These compounds are hydrophilic due to the presence of carboxyl, hydroxyl, and amino groups, which readily participate in binding with water (59). The high organic acid content of tamarind, as well as lime leaves, makes it absorb water more readily. In contrast, the curcumin in turmeric is likely to decrease water content due to its hydrophobic properties (60). The findings are consistent with the report by Shaik et al. (61), which states that the interaction of phenolic compounds and organic acids is a key factor in maintaining the stability of water content and physical properties of natural ingredient-based herbal beverages.

Optimisation of Sinom Lime Juice Formula

Optimization of the formula was performed using Mixture Design D-Optimal, which was used to determine the optimal combination of ingredients. The three key response parameters were moisture content, pH, and antioxidant activity (DPPH). The optimization goals were to reduce the moisture content, maintain a constant pH spectrum, and maximize the DPPH inhibiting property. Depending on the analysis findings, the formula was optimal, consisting of B1C1 (48.393%), B2C2 (18.607%), and B3C3 (33%), with a desirability value of 0.772, which is very suitable for the response target (62,63). A good desirability value near 1 indicates that the combination of ingredients yields the optimal ratio of physical, chemical, and functional properties of the product.

The model's results were verified, and it was found that there was no significant difference between the actual and predicted values ($p > 0.05$). The measured moisture content parameter was 9.572 percent, pH 3.33, and DPPH inhibition was 37.233 percent, which were closely correlated with the model simulation results (64). These findings suggest that accurate prediction of the response of the mixture system can be done through the Design Expert 13 model. A functional food based on spices is also frequently examined using D-Optimal Mixture Design, which can reduce the number of experiments without compromising the validity of the received results (65).

This optimization yielded a formulation that balances sensory considerations with antioxidant-related performance. The adjusted proportions of turmeric and young tamarind leaf contributed to an acidic profile with pH maintained within the targeted range, while the inclusion of lime supported the desired citrus aroma. Chen et al. (66) argue that synergistic effects may occur when ingredients with differing phytochemical profiles are combined, potentially supporting color stability, flavor, and antioxidant capacity. Accordingly, the formulation obtained represents the optimal mixture based on the model and the evaluated responses (moisture content, pH, and DPPH inhibition). It can serve as a candidate formulation for developing a lime-based herbal tea product.

Physical and Chemical Properties of the Best Formula

The moisture content of 9.572% obtained by the optimum formulation is less than 12%, which is the maximum limit specified in SNI 01-3709-1995 and international standards for dried spices (67). Low moisture content plays a crucial role in maintaining product stability, preventing microbial growth, and extending shelf life. At 3.33, the pH was high, indicating that the acid was powerful, as evidenced by the presence of young tamarind leaves and lime, which contain citric acid, malic acid, and tartaric acid, predominating (55). This acidic quality facilitates low-oxidation potential storage, as it may inhibit enzyme activities that lead to the degradation of natural pigments.

The color parameters had the values of L 31.9 (bright), a 0.9 (yellowish), and b 15.3 (soft brown)*. The fact that the chlorophyll pigment affects the colour of this brew in young tamarind leaves and the turmeric curcumin characterizes it with a golden yellow colour (68). A combination of these pigments also forms a specific color that is pleasing to the eye, as reported by Yogeswari et al. (69), who established that the intensity of the color of herbal drinks has a positive correlation with consumer preference. The IC50 of 238.067 ppm represents moderate antioxidant activity, whereas the total polyphenols of 14.392 mg Ae/g

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are low. The correlation between total polyphenols and IC50 is negative, which means that the lower the level of polyphenols, the weaker the free radical scavenging agent (70).

Variations in the content of flavonoids and curcuminoids may explain the difference in antioxidant activity. Obulesu and Bhattacharya (49), claim that heating and drying lead to degradation of certain phenolic compounds and carotenoids. Nevertheless, a tamarind leaf mixture with turmeric and lime can still exhibit moderate antioxidant effects, which are sufficient to classify it as a functional beverage. In this way, this formulation is fulfilled not only in terms of standard physical and chemical factors but also with a functional value added as a natural source of antioxidants.

Sensory Evaluation (Hedonic Test)

The hedonic test revealed that the color attribute received the highest rating, with a score of 4.075 (liking). The yellow color, acquired as a result of the combination of turmeric and tamarind leaves, created a fresh and natural impression that the panelists admired (68). The clarity of the brew received a score of 3.745 (somewhat like) and was based on the infusion time and the amount of soluble solids dissolved. Polat et al. (71), argue that prolonged brewing periods enhance the extraction of phenolic compounds but may decrease the level of clarity as a result of an increment in the colloidal particles. Optimal brewing conditions to achieve the desired balance in color intensity and clarity are 95 °C for 10 minutes.

The typical smell of turmeric and lime had a score of 3.038-3.104 (somewhat liked). Unstable ingredients, such as ar-turmerone, b-turmerone, a-curcumene, and limonene, contribute to the development of the typical aroma (72,73). The preponderance of the sour flavor of the lime, however, caused a slight inclination of preference among the panelists. The bitter/astringent taste was 3.085 (somewhat liked), which is also acceptable because the amount of curcumin and organic acids is balanced (74). In the meantime, the pure sour was rated at 2.991 (dislike), due to the lack of sacrose to neutralize the acidity (75,76).

The novelty of the refreshing sensation was rated 3.321 (slightly liked), which may be related to the brew's citrus aroma and bright color. The earthy and bitter aftertaste attributes were also rated in the acceptable range (3.198–3.255), which may be associated with volatile compounds such as α-phellandrene, γ-terpinene, and turmerone. In addition, brewing at high temperatures for 10 minutes may reduce certain polyphenolic compounds that contribute to bitterness (77). The overall liking score of 3.292 indicates moderate acceptability and is only slightly above the neutral point (3.0). Although color was clearly liked, the lowest score was observed for sour taste (2.991), suggesting that perceived sourness is a key sensory limitation of the current formulation. Therefore, the results do not yet strongly demonstrate market acceptability; instead, they indicate that further sensory refinement is needed, particularly to improve taste balance (reducing excessive sourness and/or optimizing the aroma–taste profile) before broader consumer adoption can be inferred.

CONCLUSION

The article was able to determine an optimized equation of a sinom-based citrus tea-bag beverage using D-Optimal Mixture Design method. The best formulation was B1C1 (48.393%), B2 C2 (18.607%), and B3 C3(33.000%), and the desirability was 0.772. The verification of the model showed that the prediction was satisfactory ($p > 0.05$). The confirmed answers were moisture content 9.572, pH 3.33, DPPH inhibition 37.233 and total polyphenols 14.392 mg GAE/g, showing that the physicochemical features were good and the antioxidant performance was moderate according to the experiments performed. Even though the moisture content is rather low, which can be taken as one of the indicators of the possible stability, overall product stability is not achievable due to the lack of shelf-life tests and microbial safety tests. The hedonic test was moderately accepted with the panelists showing a strong preference towards color and clarity. In general, the optimized lime-sinom formulation has a potential as a convenient ready-to-brew herbal tea product, whereas additional research and shelf life and microbiological quality are suggested to support the stability assertions.

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DECLARATION OF THE USE OF AI

The authors declare that no artificial intelligence (AI), AI-assisted technologies, or large language models (LLMs) were used in the conception of the study, data analysis, or the drafting, writing, and editing of this manuscript

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CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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