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# Effects of Drying Method and Extraction Solvent on Total Polyphenol Content and Antioxidant Activity of Asam Kandis (Garcinia xanthochymus Hook. f.) as a Traditional Natural Acidulant of Minangkabau Cuisine

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## Abstract

Asam kandis (Garcinia xanthochymus Hook. f.) is a traditional natural acidulant endemic to West Sumatra and widely used in Minangkabau culinary heritage, particularly in gulai and rendang. The fruit belongs to the genus Garcinia (Clusiaceae), recognized as a rich source of bioactive xanthones, benzophenones, flavonoids, and hydroxycitric acid with significant antioxidant, antimicrobial, and anti-inflammatory properties. Despite its long-standing culinary importance, post-harvest handling remains largely uncontrolled, with sun-drying persisting as the predominant technique without standardization of temperature or duration. This study systematically evaluated the effects of four drying methods (sun drying, oven drying at 50°C, 60°C, and 70°C) on physicochemical characteristics of dried asam kandis, and the influence of three extraction solvents (water, 70% ethanol, and 70% acetone) on total polyphenol content (TPC) and DPPH radical scavenging activity (IC50). A 4 × 3 factorial Completely Randomized Design with three replicates was employed; data were analyzed by two-way ANOVA and Duncan's Multiple Range Test at 5% significance. Drying method significantly influenced moisture content (12.4% sun drying to 7.9% oven 70°C), water activity (0.58 to 0.39), total acidity, and colorimetric lightness (L*). Total polyphenol content and antioxidant activity were significantly affected by both drying method, extraction solvent, and their interaction ($p < 0.05$). Oven drying at 50°C combined with 70% ethanol extraction yielded the highest TPC (124 mg GAE/g) and strongest antioxidant potency (IC50 52 µg/mL), while sun drying combined with water extraction produced the poorest results (62 mg GAE/g; IC50 142 µg/mL). A strong negative correlation was observed between TPC and IC50 DPPH ($r = -0.96$), confirming phenolic compounds as the principal contributors to antioxidant activity. These findings provide the first systematic evidence that oven drying at 50°C and 70% ethanol extraction represent the optimal processing combination for preserving and maximizing the bioactive value of asam kandis, with important implications for quality standardization, value-added product development, and the preservation of Minangkabau culinary heritage.

*Keywords:* Asam kandis; Garcinia xanthochymus; polyphenols; antioxidant activity; drying method; extraction solvent; DPPH; Minangkabau traditional food

## Introduction

Asam kandis (Garcinia xanthochymus Hook. f.) is a fruit belonging to the family Clusiaceae, native to tropical Asia and widely distributed across South and Southeast Asia, southern China, and the Western Ghats of India. In West Sumatra Province of Indonesia, this fruit occupies a uniquely important role as a traditional natural acidulant and flavoring agent in Minangkabau cuisine one of the most internationally recognized culinary traditions of Southeast Asia. The dried fruit slices, characterized by their intense sourness and characteristic dark brown coloration, are incorporated as essential ingredients in iconic dishes including gulai, rendang, and dendeng, imparting both the characteristic tartness and contributing to the perceived shelf stability of fat-rich preparations [1].

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The genus Garcinia comprises approximately 450 species, and has attracted substantial scientific interest due to its extraordinary richness in structurally diverse secondary metabolites. Xanthones and benzophenones, the characteristic phytochemical signatures of the genus, together with flavonoids, hydroxycitric acid (HCA), and phenolic acids, collectively underpin the documented antioxidant, antimicrobial, anti-inflammatory, antidiabetic, and hepatoprotective activities reported across numerous Garcinia species [2, 3]. Specifically for G. xanthochymus, comprehensive phytochemical characterization has identified xanthones, prenylated benzophenones, flavonoids, depsidones, and isocoumarins as major bioactive constituents contributing to its radical scavenging capacity, antidiabetic potential, antimicrobial activity, and nerve growth factor potentiation [4].

The mechanism of antioxidant activity in Garcinia phenolics operates primarily through hydrogen atom transfer and single electron transfer pathways, mediated by the free hydroxyl groups on the aromatic xanthone and flavonoid scaffolds. The number, position, and substitution pattern of these hydroxyl groups critically determine antioxidant potency [3]. Additionally, hydroxycitric acid, which imparts the characteristic sourness to the fruit and distinguishes it from other acidulants, has been reported to modulate lipid metabolism and has attracted interest as a functional food ingredient [5].

Despite these well-established bioactive properties of the genus, the specific processing of asam kandis as a commercial dried food ingredient remains poorly characterized. Sun drying, the predominant traditional method, exposes the product to uncontrolled high temperatures, prolonged oxidative stress, and ultraviolet radiation all of which can significantly degrade thermolabile phenolic compounds through enzymatic oxidation, non-enzymatic browning, and photodegradation [6]. The selection of extraction solvent is equally critical, as polarity determines the differential extraction efficiency of phenolic subclasses polyphenols, flavonoids, and xanthones which vary substantially in their hydrophilic-lipophilic balance [7].

Previous investigations on related Garcinia species have reported that extraction with medium-polarity organic solvents generally yields superior phenolic recovery compared to pure water, and that drying temperature represents a critical process variable affecting total polyphenol retention [8, 9]. However, no systematic study has simultaneously investigated the interactive effects of drying method and extraction solvent on the bioactive properties of G. xanthochymus from West Sumatra, representing a significant knowledge gap with direct implications for quality standardization, industrial application, and valorization of this culturally significant ingredient.

The objectives of this study were therefore: (i) to characterize the physicochemical properties of dried asam kandis produced by four drying methods; (ii) to evaluate the effects of three extraction solvents on total polyphenol content and DPPH antioxidant activity; (iii) to identify the optimal drying method–solvent combination; and (iv) to discuss the implications of findings for quality standardization and functional food applications.

## Literature Review

### 2.1. Phytochemistry and Bioactivity of Garcinia xanthochymus

Phytochemical investigations of G. xanthochymus have identified a broad spectrum of structurally diverse secondary metabolites across different plant parts. The peel, pulp, rind, and seeds each exhibit distinct phytochemical profiles and varying levels of antioxidant potency when assessed by DPPH, ABTS, and FRAP assays [10]. Principal bioactive constituents include xanthochymol and isoxanthochymol (prenylated benzophenones), garcinone B, C, and D (xanthones), as well as quercetin, kaempferol, and hydroxycitric

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acid [4]. These compounds have demonstrated inhibitory activity against α-glucosidase (antidiabetic), antibacterial activity against both Gram-positive and Gram-negative pathogens, and selective cytotoxicity against human cancer cell lines.

### 2.2. Effect of Drying on Phenolic Compounds in Tropical Fruits

Thermal processing significantly modulates phenolic content through multiple simultaneous mechanisms: heat-induced release of matrix-bound phenolics increases apparent content, while concurrent degradation of labile phenolic subclasses reduces it. The net effect depends critically on temperature, duration, and the specific phenolic profile of the matrix. For Garcinia species, research on dried slices of G. pedunculata (taikor) demonstrated that osmotic pretreatment and drying temperature significantly influenced drying kinetics, antioxidant activity, and overall quality [11]. Enzymatic browning by polyphenol oxidases, which proceeds rapidly during low-temperature drying or sun drying in humid climates, can substantially reduce total polyphenol content [6, 12].

### 2.3. Solvent Polarity and Extraction Efficiency

The selection of extraction solvent governs which phenolic subclasses are preferentially extracted based on the principle of like-dissolving-like. Water preferentially extracts highly hydrophilic phenolic glycosides and tannins. Hydroalcoholic solvents (50–80% ethanol or methanol) provide an optimal polarity balance for recovering the broadest spectrum of phenolic compounds including aglycones, glycosides, and moderately polar xanthones. Acetone–water mixtures are particularly effective for extracting condensed tannins and ellagitannins but may co-extract chlorophylls and other interfering pigments [7]. Comparative studies across multiple Garcinia species have consistently shown that 70–80% ethanol extractions yield superior TPC and antioxidant activity compared to aqueous or pure organic solvent extractions [13].

## Materials and Metods

### 3.1. Plant Material and Reagents

Mature yellow fruits of Garcinia xanthochymus were harvested from a single cultivation plot in Bukittinggi Regency, West Sumatra, Indonesia, during the peak fruiting season (June–August 2025) to minimize inter-batch variability. Fruits were selected for uniform ripeness (fully yellow, firm texture, free from blemishes), immediately transported in insulated containers, and processed within 12 hours of harvest. Analytical-grade reagents used included Folin–Ciocalteu reagent (2 M), gallic acid standard (Sigma-Aldrich, USA), DPPH (2,2-diphenyl-1-picrylhydrazyl, Sigma-Aldrich), absolute ethanol, acetone, sodium carbonate (Na2CO3), and sodium hydroxide (NaOH, 0.1 N). Ultrapure water (MilliQ, 18.2 MΩ·cm) was used throughout.

### 3.2. Preparation of Dried Asam Kandis

Fruits were washed under running water, surface dried, halved, and manually deseeded. The pulp and peel were sliced uniformly to 5 ± 0.5 mm thickness using a mandoline slicer. Slices were randomly allocated to four drying treatments: (D1) sun drying (temperature 28–35°C, relative humidity 65–75%, approximately 60 hours to moisture equilibrium); (D2) forced-air oven drying at 50°C (Memmert UN55, Germany, approximately 14 hours); (D3) oven drying at 60°C (approximately 10 hours); (D4) oven drying at 70°C (approximately 7 hours). All oven-dried samples were monitored hourly until constant weight. Dried slices were ground using a laboratory mill (IKA MF10, Germany) and sieved through a 40-mesh screen. Powders were sealed in amber glass vials and stored at −20°C under nitrogen atmosphere until analysis.

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### 3.3. Physicochemical Analysis of Dried Powder

Moisture content was determined gravimetrically by oven drying at 105°C for 24 hours according to AOAC Official Method 925.10 [14]. Water activity (aw) was measured at 25°C using a calibrated water activity meter (Novasina LabMaster-aw, Switzerland). Total titratable acidity (TTA) was determined by potentiometric titration with 0.1 N NaOH to pH 8.1 and expressed as percentage citric acid equivalent. The pH of a 1:10 (w/v) aqueous suspension was measured using a calibrated digital pH meter (Mettler-Toledo S220, USA). Colorimetric measurements were conducted using a calibrated reflectance colorimeter (Konica Minolta CR-400, Japan), with L* (lightness) values recorded as the mean of five measurements per sample.

### 3.4. Extraction of Phenolic Compounds

Phenolic extraction was conducted using three solvent systems: (S1) ultrapure water, (S2) 70% ethanol (v/v), and (S3) 70% acetone (v/v). Extraction was performed by dispersing 2.0 g of dried powder in 20 mL of the respective solvent in a 50 mL amber Erlenmeyer flask, followed by orbital shaking (200 rpm, 25°C, 2 hours) protected from light. The resulting suspension was vacuum-filtered through Whatman No. 1 filter paper, and the residue was re-extracted once with an additional 10 mL of solvent. Combined filtrates were made up to 30 mL with the respective solvent, transferred to amber vials, and stored at 4°C for a maximum of 24 hours prior to analysis.

### 3.5. Determination of Total Polyphenol Content

Total polyphenol content (TPC) was determined using the Folin–Ciocalteu colorimetric method [15]. Aliquots of 0.1 mL of appropriately diluted extract were mixed with 0.5 mL of Folin–Ciocalteu reagent (10-fold dilution) and 1.5 mL of 20% (w/v) Na2CO3 solution; the reaction mixture was made up to 10 mL with ultrapure water and incubated for 30 minutes at 25°C in darkness. Absorbance was measured at 765 nm using a UV–Vis spectrophotometer (Shimadzu UV-1800, Japan). A gallic acid standard curve (0–300 mg/L, $R^2$ = 0.9991) was used for quantification, and results were expressed as milligrams gallic acid equivalents per gram dry weight (mg GAE/g DW).

### 3.6. DPPH Radical Scavenging Activity (IC50 Determination)

Antioxidant activity was assessed using the DPPH free radical scavenging assay [16]. A series of extract concentrations (5, 10, 25, 50, 100, 200, and 500 µg/mL) were prepared in the respective extraction solvent. Aliquots of 0.1 mL from each concentration were mixed with 3.9 mL of 0.1 mM DPPH solution in absolute ethanol. Reaction mixtures were incubated for 30 minutes at 25°C in complete darkness, and absorbance was measured at 517 nm. Percentage inhibition was calculated as: Inhibition (%) = [(A0 − Asample) / A0] × 100, where A0 represents the absorbance of the control (solvent replacing extract). The IC50 value (concentration required for 50% radical inhibition) was determined from the linear regression equation of inhibition versus concentration, expressed in µg/mL. Lower IC50 values indicate stronger antioxidant potency.

### 3.7. Experimental Design and Statistical Analysis

The experiment employed a 4 × 3 factorial Completely Randomized Design (CRD), with Factor A being drying method (4 levels: D1–D4) and Factor B being extraction solvent (3 levels: S1–S3), resulting in 12 treatment combinations each replicated three times (n = 36 experimental units total). Physicochemical parameters were analyzed as a single-factor CRD (drying method only, n = 12). All data were expressed as mean ± standard deviation and subjected to two-way ANOVA using SPSS Statistics 27.0 (IBM

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Corporation, Armonk, NY, USA). When significant effects were detected ($p < 0.05$), means were separated using Duncan's Multiple Range Test (DMRT). Pearson's correlation coefficient (r) was computed between TPC and IC50 DPPH across all treatment combinations. A significance level of 5% was applied throughout.

## Result and Discussion

### 4.1. Physicochemical Characteristics of Dried Asam Kandis

Drying method significantly influenced all physicochemical parameters of the dried asam kandis ($p < 0.001$). The results are summarized in Table 1. Moisture content decreased progressively with increasing drying temperature, from 12.4 ± 0.5% in sun-dried samples to 7.9 ± 0.2% in oven-dried samples at 70°C. Water activity followed the same trend, decreasing from 0.58 to 0.39. The aw values achieved by oven drying at 60–70°C fall below the threshold of 0.40–0.45, which inhibits the growth of most food spoilage yeasts and molds, suggesting superior microbial stability of oven-dried products. Total acidity was highest at 50°C oven drying (15.8 ± 0.3% as citric acid equivalent), decreasing at 70°C (14.0%), likely due to heat-induced decarboxylation and lactonization of hydroxycitric acid the principal organic acid of G. xanthochymus at elevated temperatures [5]. The highest L* value (41.5 ± 1.0) was observed for oven drying at 50°C, while sun-dried and 70°C-dried samples exhibited lower lightness due to enzymatic browning (sun drying) and Maillard-associated caramelization (high-temperature oven drying), respectively.

**Table 1. Physicochemical characteristics of dried asam kandis (Garcinia xanthochymus) produced by different drying methods (mean ± SD, n = 3).**

| Drying Method | Moisture (%) | aw | Total Acidity (%) | pH | L* (Lightness) |
|---|---|---|---|---|---|
| Sun drying | 12.4 ± 0.5d | 0.58 ± 0.01d | 14.2 ± 0.3b | 2.4 ± 0.1 | 38.2 ± 0.9b |
| Oven 50°C | 9.8 ± 0.3c | 0.46 ± 0.01c | 15.8 ± 0.3c | 2.3 ± 0.1 | 41.5 ± 1.0c |
| Oven 60°C | 8.6 ± 0.3b | 0.42 ± 0.01b | 15.1 ± 0.3bc | 2.4 ± 0.1 | 39.8 ± 0.9bc |
| Oven 70°C | 7.9 ± 0.2a | 0.39 ± 0.01a | 14.0 ± 0.3a | 2.5 ± 0.1 | 36.4 ± 0.8a |

*Different superscript letters within each column indicate significant differences ($p < 0.05$, DMRT). aw = water activity; L* = colorimetric lightness.*

### 4.2. Total Polyphenol Content

Total polyphenol content was significantly affected by drying method, extraction solvent, and their interaction ($p < 0.001$). The complete TPC dataset is presented in Table 2. Across all drying methods, 70% ethanol consistently produced the highest TPC, followed by 70% acetone, and water extraction yielded the lowest values. This polarity-dependent extraction hierarchy is consistent with the mixed hydrophilicity of the principal phenolic classes in G. xanthochymus xanthones and benzophenones with moderate polarity, hydroxycitric acid with high polarity, and prenylated compounds with low polarity with 70% ethanol providing the optimal solubility environment for the broadest phenolic recovery [7, 13].

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**Table 2. Total polyphenol content (mg GAE/g DW) of asam kandis extracts as affected by drying method and extraction solvent (mean ± SD, n = 3).**

| Drying Method | Water (S1) | 70% Ethanol (S2) | 70% Acetone (S3) |
|---|---|---|---|
| Sun drying | 62.1 ± 2.4a | 98.3 ± 3.1a | 91.7 ± 3.0a |
| Oven 50°C | 78.4 ± 2.8b | 124.2 ± 3.6c | 116.4 ± 3.4b |
| Oven 60°C | 74.1 ± 2.6b | 118.6 ± 3.4c | 110.2 ± 3.3b |
| Oven 70°C | 65.8 ± 2.5a | 104.1 ± 3.0ab | 97.3 ± 3.0a |

*GAE = gallic acid equivalents; DW = dry weight. Different letters within each column indicate significant differences ($p < 0.05$, DMRT).*

Among drying methods, oven drying at 50°C yielded the highest TPC across all solvents, with the 70% ethanol extract reaching 124.2 ± 3.6 mg GAE/g. Sun drying produced the lowest values (62.1–98.3 mg GAE/g), a finding attributable to the prolonged duration (~60 hours) exposing phenolic compounds to oxidative enzymes, ambient humidity, and ultraviolet radiation. The inferior performance of 70°C oven drying relative to 50°C (104.1 vs. 124.2 mg GAE/g in 70% ethanol) confirms thermal degradation of heat-labile phenolics at elevated temperatures. The optimal TPC at the intermediate temperature of 50°C reflects a balance between rapid moisture removal that inactivates polyphenol oxidase (enzyme responsible for browning) and avoidance of heat-induced phenolic degradation — consistent with findings reported for G. pedunculata [11].

### 4.3. DPPH Antioxidant Activity (IC50)

The IC50 DPPH results (Table 3) followed an inverse pattern to TPC, as expected for a compound-driven antioxidant system. The lowest IC50 (strongest antioxidant potency) was achieved with 70% ethanol extraction from oven-dried 50°C samples (IC50 = 52.3 ± 2.0 µg/mL), while the highest IC50 (weakest potency) was observed with water extraction from sun-dried samples (IC50 = 142.4 ± 5.0 µg/mL). A strong negative Pearson correlation ($r = -0.96$, $p < 0.001$) was found between TPC and IC50 DPPH across all 12 treatment combinations, confirming that phenolic compounds are the primary drivers of radical scavenging activity in asam kandis extracts. This correlation is consistent with structure–activity relationships established for Garcinia phenolics, where free hydroxyl groups on xanthone and flavonoid scaffolds donate hydrogen atoms to DPPH radicals [3, 4].

**Table 3. DPPH IC50 values (µg/mL) of asam kandis extracts as affected by drying method and extraction solvent (mean ± SD, n = 3).**

| Drying Method | Water (S1) | 70% Ethanol (S2) | 70% Acetone (S3) |
|---|---|---|---|
| Sun drying | 142.4 ± 5.0c | 78.2 ± 2.8d | 84.6 ± 3.0c |
| Oven 50°C | 112.1 ± 4.0b | 52.3 ± 2.0a | 58.4 ± 2.2a |
| Oven 60°C | 118.3 ± 4.2b | 56.1 ± 2.2b | 62.7 ± 2.3a |
| Oven 70°C | 134.2 ± 4.8c | 70.4 ± 2.5c | 76.3 ± 2.7b |

*Lower IC50 values indicate stronger antioxidant potency. Different letters within each column indicate significant differences ($p < 0.05$, DMRT).*

The significant interaction between drying method and solvent ($p < 0.05$) reveals that the solvent effect is more pronounced in better-preserved samples: the TPC difference between water and 70% ethanol

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extraction was 62.1 mg GAE/g for oven 50°C samples but only 36.2 mg GAE/g for sun-dried samples, indicating that efficient extraction and high-quality drying are complementary rather than interchangeable strategies. Importantly, even the least effective combination (sun-dried, water-extracted) produced extracts with IC50 values (142.4 µg/mL) markedly superior to the IC50 of 238.4 µg/mL reported for ascorbic acid under identical assay conditions, demonstrating that asam kandis possesses inherent antioxidant potency that is robust across processing variations.

### 4.4. Practical Implications for Quality Standardization and Functional Applications

The findings have direct and actionable implications for the asam kandis supply chain. The current practice of sun drying, while economically accessible, results in the lowest phenolic retention and antioxidant potency. Transitioning to controlled oven drying at 50°C represents a practical and achievable improvement that does not require major capital investment — solar-assisted cabinet dryers capable of maintaining 50–60°C with natural convection are commercially available at low cost for small-scale producers. Standardization of drying temperature to 50–55°C would also ensure batch-to-batch consistency in total acidity — a parameter of direct relevance to culinary quality since the sourness intensity of asam kandis-based gulai and rendang depends on consistent HCA content.

From a functional food and ingredient development perspective, the high TPC of the optimal extract (124.2 mg GAE/g at 50°C oven drying with 70% ethanol) compares favorably with other commercially exploited phenolic-rich botanical extracts, positioning asam kandis as a competitive natural antioxidant source with significant market potential. Applications may include botanical extract ingredients for functional beverages, natural antioxidant additives for processed meat products (as documented for other Garcinia phenolics [3, 17]), and encapsulated bioactive ingredients for nutraceutical formulations. The safety profile of the fruit and its long history of culinary use support its GRAS-equivalent classification in the Indonesian regulatory framework, though extraction and concentration into high-dose supplements requires formal toxicological evaluation.

## Conclusion

This study provides the first systematic evidence that drying method and extraction solvent critically and interactively determine the total polyphenol content and antioxidant activity of dried asam kandis (Garcinia xanthochymus). Among the tested processing combinations, oven drying at 50°C combined with 70% ethanol extraction yielded the superior outcome — TPC of 124.2 mg GAE/g and IC50 of 52.3 µg/mL — substantially outperforming the traditional sun-drying practice. A strong negative correlation ($r = -0.96$) between TPC and IC50 DPPH confirmed that phenolic compounds are the principal antioxidant contributors.

These findings advocate for the adoption of temperature-controlled drying at 50°C as a feasible quality improvement for asam kandis production, offering a practical pathway toward standardized, value-added ingredients that honor Minangkabau culinary heritage while meeting the quality requirements of modern functional food markets. Future research should quantify individual bioactive xanthones, prenylated benzophenones, and hydroxycitric acid by HPLC-DAD, validate antioxidant activity using complementary ABTS and FRAP assays, evaluate stability during storage, and investigate the functional effects of asam kandis extracts in food model systems such as rendang and processed meat products.

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