



RESEARCH ARTICLE

OPTIMIZATION OF ULTRASONIC EXTRACTION TIME FOR PHENOLIC CONTENT AND ANTIOXIDANT ACTIVITY OF COMMERCIAL CINNAMON EXTRACT

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ARTICLE INFO	ABSTRACT
Received: July 1 2026 Accepted: September 12, 2026 Keywords: cinnamon; ultrasound-assisted extraction; total phenolic content; DPPH activity; IC50 *Corresponding Author: syamsuddinpalu2023@gmail.com	This study was designed to optimize ultrasonic extraction time for obtaining antioxidant-rich extracts from commercial cinnamon powder using 96% ethanol as the extraction solvent. Commercial cinnamon powder was sieved through a 60-mesh sieve and extracted at a material-to-solvent ratio of 1:10 w/v using an ultrasonic probe operated at 30% amplitude with a pulse mode of 5 s ON and 5 s OFF. Three extraction times, namely 15, 30, and 45 min, were evaluated in triplicate. Extract quality was assessed through extraction yield, total phenolic content using the Folin-Ciocalteu method, and antioxidant activity using the 2,2-diphenyl-1-picrylhydrazyl radical-scavenging assay. The experimental results showed that yield increased with sonication time and reached its maximum at 45 min ($13.30 \pm 0.20\%$). However, the 30-min treatment produced the highest total phenolic content (68.53 ± 0.85 mg GAE/g extract) and the lowest IC50 value (18.96 ± 0.34 μg/mL), indicating stronger antioxidant activity than the 15- and 45-min treatments. One-way ANOVA showed significant effects of sonication time on yield, total phenolic content, and IC50 ($p < 0.001$), while Pearson correlation indicated a strong negative association between total phenolic content and IC50 ($r = -0.99$). These findings indicate that optimizing cinnamon extraction should prioritize bioactive quality over extract mass alone.

INTRODUCTION

Oxidative deterioration is one of the major causes of quality loss in food products during processing and storage. The process is particularly relevant in matrices containing lipids, pigments, flavor-active components, and other oxidation-sensitive molecules. As oxidation progresses, food products may lose nutritional value, develop undesirable sensory characteristics, and exhibit reduced storage stability. For this reason, natural antioxidant compounds from plant materials have received increasing attention as functional ingredients for protecting food systems and supporting the development of naturally derived preservation strategies. Phenolic compounds are central to this concept because they can scavenge free radicals and reactive oxygen species through electron transfer or hydrogen donation mechanisms, although the apparent antioxidant response depends on the assay system and the chemical structure of the phenolic compound (Platzer et al., 2022; Gülçin & Alwasel, 2023).

Cinnamon is a widely used spice, flavoring agent, and herbal material with strong relevance to food, cosmetic, and nutraceutical applications. The genus *Cinnamomum* contains a broad diversity of phytochemicals and has been associated with antioxidant, antimicrobial, anti-inflammatory, antidiabetic, and cytoprotective activities. A comprehensive review identified approximately 306 constituents from this genus, including terpenes, phenylpropanoids, lignans, flavonoids, aromatics, aliphatics, coumarins, and steroids (Wang et al., 2020). Indonesian cinnamon has also been reported to contain essential oils and phenolic groups such as flavonoids, phenolic aldehydes, phenolic acids, coumarins, and proanthocyanidins, which are highly relevant to antioxidant extraction studies (Rahayu et al., 2022). Similarly, Aceh cinnamon extracted with 96% ethanol contained phenols, flavonoids, tannins, and other phytochemical classes, with 66.34 mg GAE/g phenols and DPPH IC₅₀ of 16.07 ppm, indicating strong radical scavenging capacity (Husna et al., 2024).

Extraction is a decisive step in the development of cinnamon-derived antioxidant ingredients because the amount and quality of recovered compounds depend strongly on the selected process conditions. Solvent composition, particle size, material-to-solvent ratio, temperature, extraction time, and extraction technique can determine whether the extract is dominated by bioactive phenolics or by a larger quantity of less active soluble matter. Ethanol is particularly suitable for studies directed toward food and cosmetic applications because it is broadly accepted as a safer solvent and has been shown to extract antioxidant-active compounds from cinnamon. For example, ethanol extraction of Indonesian cinnamon produced a yield of 21.50% and DPPH IC₅₀ of 0.0162 mg/mL under the best solvent condition reported by Rahayu et al. (2022). These findings support the use of ethanol as a practical solvent for extracting antioxidant-rich cinnamon fractions.

Ultrasound-assisted extraction has emerged as an efficient method for recovering bioactive compounds from plant matrices. The method uses acoustic cavitation to disrupt plant structures, improve solvent penetration, and accelerate mass transfer of target compounds into the solvent. Compared with conventional extraction, ultrasound-assisted extraction can reduce extraction time and solvent use while enhancing the recovery of phenolics, flavonoids, saponins, thymols, and proteins (Yusoff et al., 2022). However, ultrasound efficiency is not solely determined by time. It can also be influenced by temperature, amplitude, power, pulse cycle, solvent, frequency, particle size, pH, and solvent-to-solid ratio (Anaya-Esparza et al., 2023). Therefore, optimization should be based on clear response variables rather than assuming that longer exposure always yields superior extracts.

Several recent studies reinforce the need for systematic optimization of cinnamon extraction. Sustainable ultrasound-assisted extraction of *Cinnamomum cassia* bark using natural deep

eutectic solvents showed that extraction performance was governed by solvent composition, water content, extraction time, solvent-to-solid ratio, and ultrasonic power, with an optimum time of 22 min under the selected conditions (Hong et al., 2023). Ultrasound-microwave synergistic extraction of cinnamon twigs also demonstrated that recovery of cinnamaldehyde and cinnamic acid was improved under an optimized combination of 600 W microwave power, 75% ethanol, 1:15 liquid-to-solid ratio, and 20 min extraction time (Zhou et al., 2024). These reports indicate that cinnamon matrices respond strongly to extraction variables and that the optimal conditions are matrix- and response-specific.

The relevance of antioxidant extraction from cinnamon is also supported by food application studies. *Cinnamomum cassia* extracts have been evaluated in raw chicken patties during refrigerated storage, in which ethanol concentration influenced both total phenolic content and DPPH radical-scavenging activity (Rakasivi & Chin, 2022). Cinnamon powder was also reported to improve antioxidant and antimicrobial properties of beef burgers stored for 21 days at 4°C, with total phenolics of 8.13 mg GAE/g, flavonoids of 1.42 mg CE/g, DPPH scavenging activity of 85.97%, and IC₅₀ of 0.213 mg/mL (Shoqairan et al., 2023). In spent duck-based sausage, cinnamon and sage powders improved quality and reduced lipid oxidation during chilled storage, further supporting the practical relevance of cinnamon as a natural antioxidant ingredient (Wattanachant & Ungkusonmongkol, 2026).

Despite these advances, a simple and measurable optimization of ultrasonic extraction time for commercial cinnamon powder remains important. Commercial cinnamon powder is readily available and relevant to practical applications, but its botanical species is often not declared on product labels. This condition limits species-specific interpretation, yet it also reflects the reality of commercially available spice materials. Moreover, the highest extraction yield does not necessarily indicate the best antioxidant quality. A treatment may release more total soluble material while diluting phenolic concentration or causing partial degradation of sensitive compounds. Accordingly, optimization should integrate quantitative extraction yield with bioactive indicators such as total phenolic content and DPPH IC₅₀.

The present study was designed to determine the effect of ultrasonic extraction time on the yield, total phenolic content, and DPPH antioxidant activity of 96% ethanol extract from commercial cinnamon powder. The specific objectives were to compare extraction times of 15, 30, and 45 min; determine total phenolic content using the Folin-Ciocalteu method; calculate IC₅₀ from DPPH radical-scavenging curves; and identify the best sonication time based on the combined criteria of high yield, high phenolic content, and low IC₅₀. The working hypothesis was that sonication time significantly influences extract quantity and antioxidant quality, with one intermediate extraction time producing a more favorable balance than shorter or longer treatments. The novelty of this study lies in its practical optimization framework, which evaluates commercial cinnamon powder using response parameters directly relevant to the development of natural antioxidants.

RESEARCH METHODOLOGY

This study was designed as a one-factor laboratory experiment, with sonication time as the main treatment variable. The treatment levels were 15, 30, and 45 min, and each condition was performed in three independent extraction replicates. The response variables were extraction yield, total phenolic content, percentage DPPH inhibition, IC₅₀, and the correlation between total phenolic content and IC₅₀. The design was prepared to isolate the effect of extraction time while maintaining the same solvent, amplitude, pulse mode, temperature control, material-to-solvent ratio, and analytical procedures across all treatments. This approach is consistent with the general principle of ultrasound-assisted extraction optimization, where process variables must be controlled because extraction efficiency is influenced by time, solvent, temperature, power, amplitude, and other operational factors (Yusoff et al., 2022; Anaya-Esparza et al.,

2023).

The sample used in this study was commercial cinnamon powder obtained from a supermarket. Because the product label did not indicate the botanical species, the material was not identified as *Cinnamomum burmannii*, *Cinnamomum cassia*, or *Cinnamomum verum*. It was therefore reported strictly as commercial cinnamon powder throughout the study. This reporting decision was important because phytochemical profiles may vary across *Cinnamomum* species, and botanical uncertainty can affect the interpretation of the composition of cinnamon extracts (Wang et al., 2020). Nevertheless, the use of commercial powder is relevant to food-oriented studies because this material is the form commonly used by small-scale processors and consumers.

Table 1. Research design.

Component	Design
Research factor	Sonication time
Treatment levels	15, 30, and 45 min
Replication	3 independent extraction replicates for each sonication time
Sample	Commercial cinnamon powder from supermarket
Solvent	Ethanol p.a. 96%
Main instruments	Ultrasonic probe, rotary evaporator, UV-Vis spectrophotometer
Response parameters	Yield, TPC, DPPH inhibition, IC50, TPC-IC50 correlation

Before extraction, cinnamon powder was sieved through a 60-mesh sieve to standardize particle size and reduce variability due to uneven solid surface area. The sieved powder was stored in a closed container protected from direct light until extraction. For each replicate, 10 g of cinnamon powder was placed in a beaker and mixed with 100 mL of 96% ethanol, producing a material-to-solvent ratio of 1:10 w/v. Ethanol was selected because previous cinnamon studies showed that ethanol can recover flavonoids and antioxidant-active compounds effectively, while 96% ethanol has also been applied in cinnamon phytochemical and antioxidant evaluation (Rahayu et al., 2022; Husna et al., 2024).

Ultrasonic extraction was performed using an ultrasonic probe operated at 30% amplitude. The sonication mode was set to pulse operation with 5 s ON and 5 s OFF cycles. The extraction times were 15, 30, and 45 min. During sonication, the temperature was maintained at or below approximately 40°C using an ice bath or water cooling. Temperature control was included because ultrasound can generate localized heat, and prolonged exposure may influence the stability of phenolic compounds or other antioxidant constituents. Optimization studies on cinnamon and other plant matrices have shown that extraction time is a critical variable and must be interpreted together with other operating parameters (Hong et al., 2023; Nabiyeve et al., 2025).

Table 2. Ultrasonic extraction conditions.

Parameter	Condition
Sample weight	10 g
Solvent volume	100 mL
Material-to-solvent ratio	1:10 w/v
Sieve size	60 mesh
Amplitude	30%
Sonication mode	Pulse 5 s ON : 5 s OFF
Maximum temperature	±40°C
Sonication time	15, 30, 45 min

After sonication, each extract mixture was centrifuged at 4000 rpm for 10 min. The supernatant was separated and filtered using Whatman No. 1 filter paper or an equivalent filtration medium. The filtrate was then concentrated using a rotary evaporator at 40-45°C until a viscous extract was obtained. The extract was weighed to determine the extraction yield and then stored in dark, closed vials at 4°C until further analysis. The yield was calculated by dividing the weight of viscous extract by the initial weight of cinnamon powder and multiplying the result by 100.

Total phenolic content was measured using the Folin-Ciocalteu method with gallic acid as the standard compound. This assay is widely used to estimate total phenolic content in plant extracts and reports results as gallic acid equivalents (Singleton & Rossi, 1965). However, the method measures electron transfer from phenolic and other oxidizable substrates to phosphomolybdic/phosphotungstic complexes in alkaline medium; therefore, it should be interpreted as an estimate of total reducing phenolic capacity rather than a completely specific phenolic measurement (Ainsworth & Gillespie, 2007).

For the TPC reaction, 0.5 mL of sample solution or gallic acid standard was mixed with 2.5 mL of 10% Folin-Ciocalteu reagent and allowed to stand for 5 min. Subsequently, 2.0 mL of 7.5% Na₂CO₃ solution was added. The mixture was incubated for 30 min in the dark at room temperature, and absorbance was measured at 765 nm using a UV-Vis spectrophotometer. A gallic acid standard curve was prepared using concentrations of 20, 40, 60, 80, 100, and 120 µg/mL. The results were expressed as mg GAE/g extract.

Table 3. Summary of total phenolic content protocol.

Component	Condition
Standard	Gallic acid
Standard range	20, 40, 60, 80, 100, 120 µg/mL
Folin reagent	Folin-Ciocalteu 10%
Base reagent	Na ₂ CO ₃ 7.5%
Reaction volume	0.5 mL sample/standard + 2.5 mL Folin + 2.0 mL Na ₂ CO ₃
Incubation	30 min, dark, room temperature
Reading wavelength	765 nm
Result unit	mg GAE/g extract

Antioxidant activity was determined using the DPPH radical scavenging method. This assay is based on the reduction of the stable radical 2,2-diphenyl-1-picrylhydrazyl by antioxidant compounds, which causes a decrease in absorbance as the radical is reduced (Brand-Williams et al., 1995). The method is widely used because it is simple, rapid, and suitable for comparing antioxidant capacity among plant extracts, although the results depend on reaction medium, incubation time, concentration, and absorbance measurement conditions (Gülçin & Alwasel, 2023).

Extract working solutions were prepared to yield final concentrations of 5, 10, 20, 40, 60, and 80 µg/mL in the reaction mixtures. For each test, 1.5 mL of extract solution was mixed with 1.5 mL of 0.1 mM DPPH solution prepared in 96% ethanol. The reaction mixture was incubated in the dark at room temperature for 30 min, and absorbance was measured at 517 nm. Vitamin C was used as the positive control. Percentage inhibition was calculated using the equation:

$$\text{inhibition (\%)} = [(A_{\text{control}} - A_{\text{sample}}) / A_{\text{control}}] \times 100.$$

The IC₅₀ value was calculated from the curve relating extract concentration to DPPH inhibition percentage.

All quantitative data were expressed as mean ± standard deviation. Statistical analysis was performed using SPSS. The effect of sonication time on yield, total phenolic content, percentage DPPH inhibition, and IC₅₀ was analyzed using one-way ANOVA at $p < 0.05$. When significant

differences were detected, Tukey HSD was applied as a post hoc test. The relationship between total phenolic content and antioxidant activity was evaluated using Pearson correlation. The optimum sonication time was not selected based on yield alone but by considering a combined response: high yield, high total phenolic content, and low IC50. When the quantity and bioactive quality criteria showed different directions, the optimization decision prioritized TPC and IC50 because the intended product was an antioxidant extract.

Table 4. Overall research flow.

Stage	Activity
1	Purchase of commercial cinnamon powder from the supermarket
2	Storage of the sample in a closed and light-protected container
3	Sieving using a 60-mesh sieve
4	Ultrasonic extraction using 96% ethanol for 15, 30, and 45 min
5	Centrifugation, filtration, and solvent evaporation using a rotary evaporator
6	Calculation of extract yield
7	TPC analysis using Folin-Ciocalteu method
8	DPPH antioxidant analysis and IC50 calculation
9	Statistical analysis using ANOVA, Tukey HSD, and Pearson correlation
10	Selection of optimum sonication time and manuscript preparation

Reproducibility controls included independent extraction replicates, identical DPPH concentration, incubation in the dark, fixed absorbance wavelengths, use of sample blanks when extract color could interfere with absorbance measurements, and temperature recording during sonication.

RESULTS AND DISCUSSION

Yield of Cinnamon Extracts

Extraction yield increased as sonication time was extended from 15 to 45 min. The lowest yield was obtained at 15 min, at $9.60 \pm 0.20\%$, followed by $11.90 \pm 0.20\%$ at 30 min and $13.30 \pm 0.20\%$ at 45 min. This pattern suggests that longer ultrasonic exposure increased the release of soluble materials from the cinnamon powder matrix. A similar mechanistic explanation is commonly proposed for ultrasound-assisted extraction, as cavitation improves solvent penetration, disrupts plant structures, and accelerates the mass transfer of soluble compounds into the extraction medium (Yusoff et al., 2022).

The increase in yield indicates that the cinnamon matrix continued to release extractable material when sonication was extended beyond 30 min. However, this yield pattern did not correspond directly to the profile of total phenolic content or antioxidant activity. Therefore, the yield result should be interpreted as an indicator of total extract recovery, not as a direct measure of bioactive quality. This distinction is important because multi-response optimization is recommended when recovering bioactive compounds, since high mass yield does not necessarily indicate maximum antioxidant performance (Anaya-Esparza et al., 2023; Nabiyeva et al., 2025).

Table 5. Summary of main results based on the experimental data.

Sonication time (min)	Yield (%)	TPC (mg GAE/g extract)	DPPH IC ₅₀ (μg/mL)
15	9.60 ± 0.20	54.50 ± 0.66	30.18 ± 0.64
30	11.90 ± 0.20	68.53 ± 0.85	18.96 ± 0.34
45	13.30 ± 0.20	60.70 ± 0.98	23.60 ± 0.56

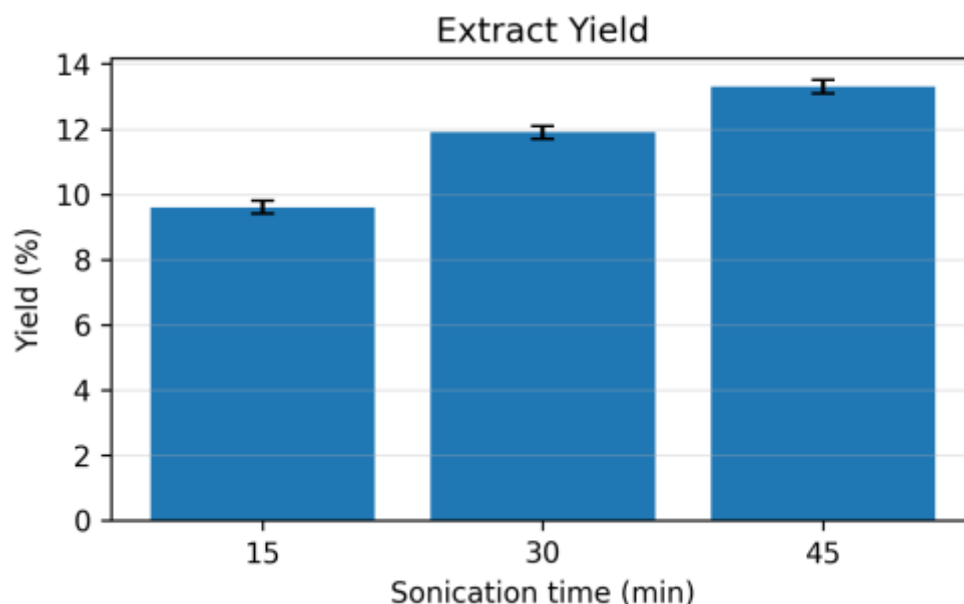


Figure 1. Yield of ethanol cinnamon extract under different sonication times. Data are presented as mean ± SD from three experimental replicates.

Total Phenolic Content

The total phenolic content showed a trend different from that of the extraction yield. The highest TPC was observed at 30 min, reaching 68.53 ± 0.85 mg GAE/g extract. The 15-min treatment produced the lowest TPC at 54.50 ± 0.66 mg GAE/g extract, whereas the 45-min treatment decreased to 60.70 ± 0.98 mg GAE/g extract, despite yielding the highest amount. This result indicates that longer sonication did not continuously improve the phenolic quality of the extract. The TPC profile suggests that 30 min sonication was sufficient to enhance phenolic release while avoiding the potential decline in phenolic concentration observed at 45 min. The decrease at 45 min may indicate dilution by co-extracted non-phenolic materials or a reduction in phenolic stability during prolonged sonication. Cinnamon ethanol extracts have previously been reported to show measurable total phenolics and antioxidant activity, including 66.34 mg GAE/g phenols in Aceh cinnamon ethanol extract (Husna et al., 2024).

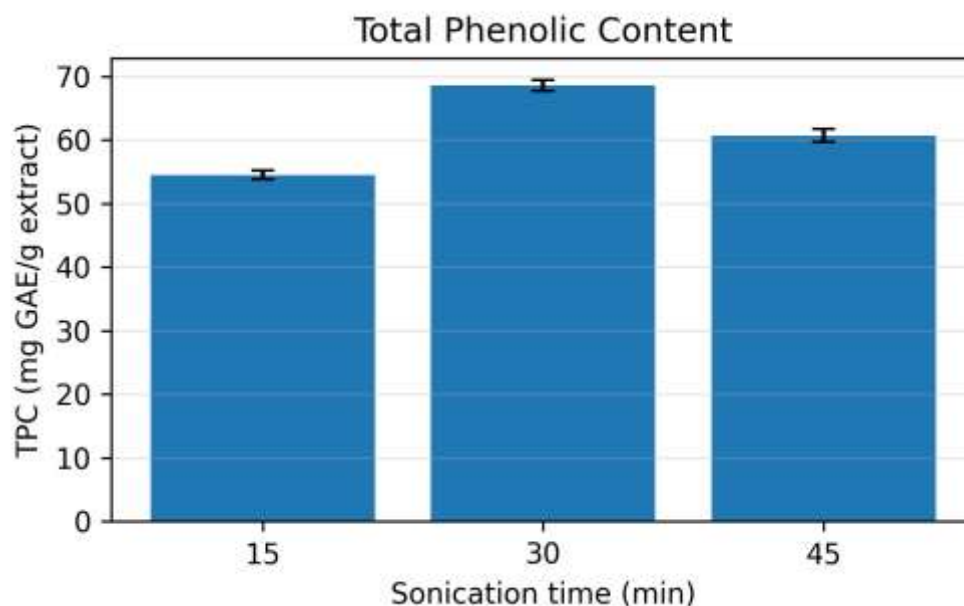


Figure 2. Total phenolic content of cinnamon extract under different sonication times. Results are expressed as mg GAE/g extract.

DPPH Radical Scavenging Activity and IC₅₀

DPPH radical-scavenging activity increased with increasing extract concentration across all sonication treatments. At the lowest concentration of 5 µg/mL, the inhibition values were 12.6%, 18.4%, and 15.3% for the 15-, 30-, and 45-min extracts, respectively. At the highest concentration of 80 µg/mL, inhibition increased to 82.6%, 92.5%, and 88.5%, respectively. The concentration-dependent increase is consistent with the DPPH assay principle, in which higher antioxidant concentration increases the probability of reducing DPPH radicals (Brand-Williams et al., 1995; Gülçin & Alwasel, 2023).

Across all tested concentrations, the 30-min extract produced the highest inhibition percentage. This response corresponded to the lowest IC₅₀ value, 18.96 ± 0.34 µg/mL, indicating the strongest radical scavenging activity among the three treatments. The 45-min extract showed an intermediate IC₅₀ of 23.60 ± 0.56 µg/mL, whereas the 15-min extract had the weakest activity, with an IC₅₀ of 30.18 ± 0.64 µg/mL. These results reinforce the observation that 30 min sonication produced a superior bioactive profile even though 45 min gave the highest extraction yield.

Table 6. DPPH inhibition percentage based on experimental data

Final concentration (µg/mL)	15 min (%)	30 min (%)	45 min (%)
5	12.6	18.4	15.3
10	21.8	32.3	27.6
20	37.9	53.5	47.2
40	61.4	76.8	70.1
60	73.2	86.8	81.1
80	82.6	92.5	88.5

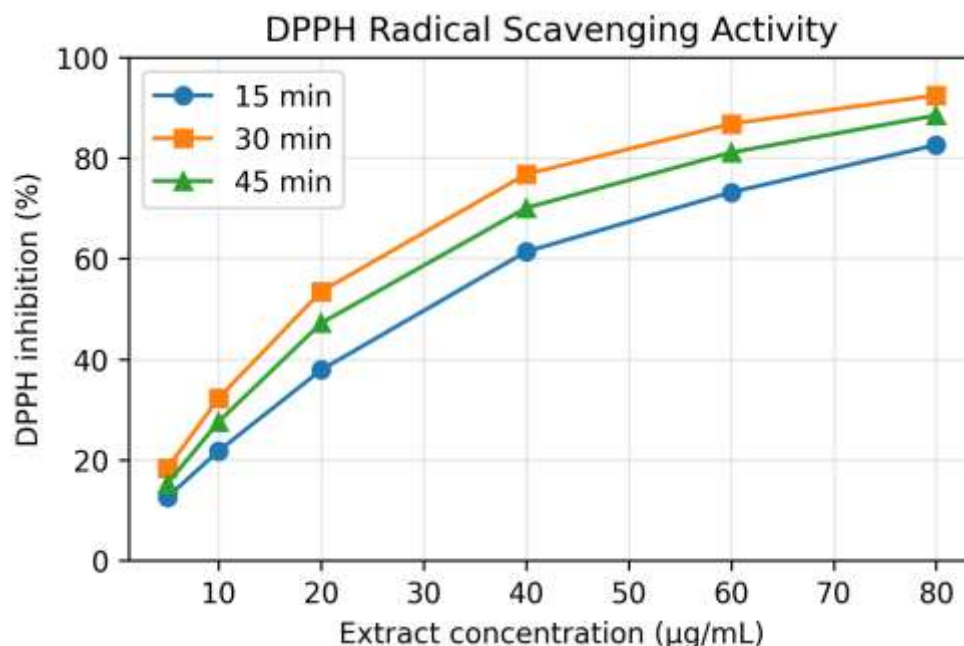


Figure 3. DPPH inhibition curves of cinnamon extracts based on experimental data

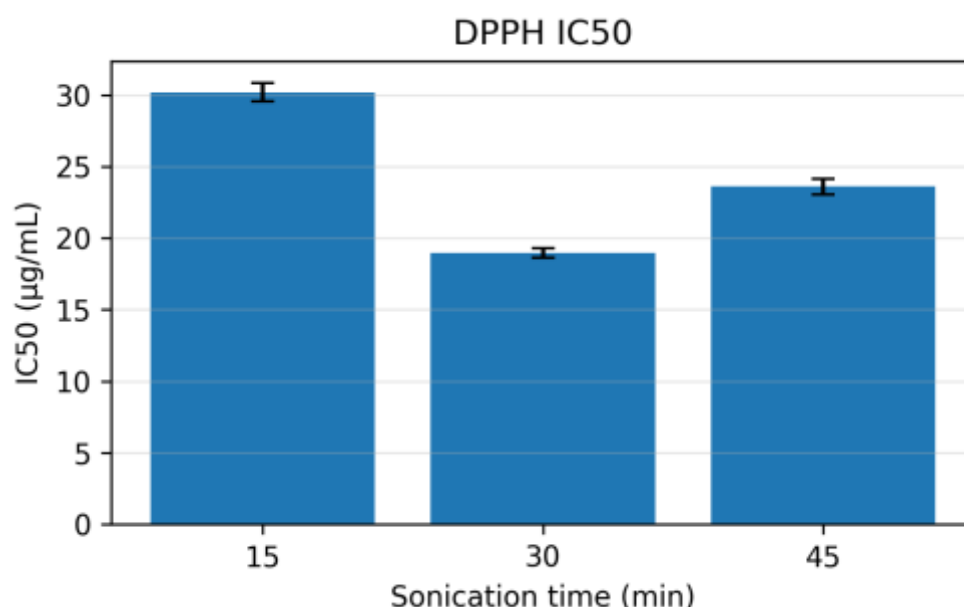


Figure 4. DPPH IC₅₀ values of cinnamon extract under different sonication times. Lower IC₅₀ indicates stronger antioxidant activity

Statistical Comparisons and Optimization

The one-way ANOVA results indicated that sonication time significantly affected yield, TPC, and IC₅₀ ($p < 0.001$ for all three response parameters). This result supports the working hypothesis that ultrasonic extraction time influences both extract quantity and antioxidant quality. Because significant differences were detected, Tukey's HSD was used to compare treatment orders for each response.

The ranking of treatments varied by response variable. For yield, the order was $15 < 30 < 45$, indicating that the longest sonication time produced the highest extract recovery. For TPC, the order was $15 < 45 < 30$, indicating that 30 min produced the highest phenolic content. For IC₅₀, the order was $30 < 45 < 15$, confirming that 30 min produced the strongest antioxidant activity. This different response direction demonstrates why the optimization of cinnamon extract should not be based solely on yield.

Table 7. Summary of statistical results.

Parameter	Factor	p-value	Interpretation
Yield (%)	Sonication time	$p < 0.001$	Significant
TPC (mg GAE/g extract)	Sonication time	$p < 0.001$	Significant
DPPH IC ₅₀ (μg/mL)	Sonication time	$p < 0.001$	Significant

Table 8. Tukey HSD interpretation based on experimental data.

Parameter	Result order	Meaning
Yield	15 < 30 < 45	All sonication times differ significantly
TPC	15 < 45 < 30	30 min gives the highest TPC
IC ₅₀	30 < 45 < 15	30 min gives the lowest and best IC ₅₀

Based on the combined optimization criteria, the 30-min treatment was selected as the provisional optimum. This decision was based on its highest total phenolic content and lowest IC₅₀, while still yielding more than the 15-min treatment. Although 45 min yielded the greatest mass recovery, its lower TPC and higher IC₅₀ than 30 min suggest that prolonged sonication did not yield the best antioxidant-quality extract. This interpretation is consistent with the view that extraction optimization for phenolic antioxidants should maximize bioactivity rather than total recovered mass (Nabiyeva et al., 2025).

Correlation Between TPC and Antioxidant Activity

The Pearson correlation between total phenolic content and IC₅₀ was strongly negative ($r = -0.99$). This indicates that higher phenolic content was associated with a lower IC₅₀ and, therefore, stronger DPPH radical-scavenging activity. The 30-min treatment occupied the most favorable position in this relationship because it combined the highest TPC with the lowest IC₅₀. Although this pattern is chemically plausible, the correlation should be interpreted as a preliminary indication because only three treatment points were included in the calculation. In addition, the Folin-Ciocalteu assay reflects reducing capacity from phenolic and other oxidizable compounds rather than a fully specific measurement of phenolics (Ainsworth & Gillespie, 2007). Therefore, experimentation with additional observations and compound profiling would be required before making a firm mechanistic conclusion.

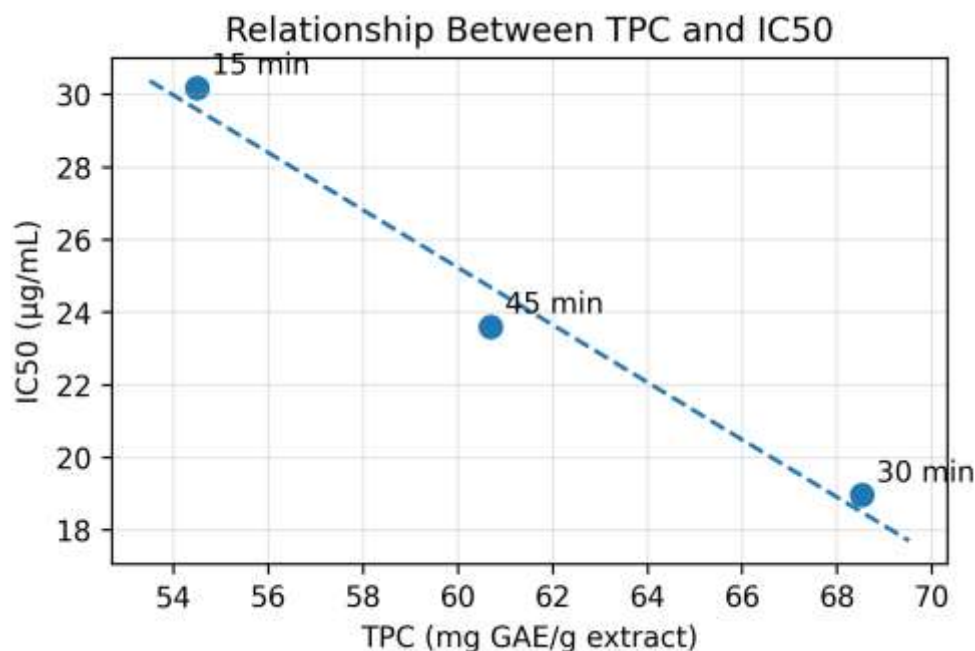


Figure 5. Relationship between TPC and IC50 based on experimental data. The negative correlation indicates that higher TPC is associated with lower IC50.

Effect of Sonication Time on Extract Yield

The results showed that increasing sonication time from 15 to 45 min increased the yield of ethanol cinnamon extract. This behavior can be explained by the physical effect of ultrasonic cavitation, which disrupts the plant matrix, improves solvent penetration, and increases contact between ethanol and cinnamon particles. The same mechanism has been described in broader ultrasound-assisted extraction literature, where cavitation accelerates mass transfer and increases the recovery of plant bioactive compounds (Yusoff et al., 2022). Therefore, the increasing yield observed in the experimental results is consistent with the expected extraction mechanism.

Nevertheless, the highest yield at 45 min should not be interpreted as evidence that this condition produced the best extract. Yield reflects the total mass of recovered soluble components, which may include phenolics, sugars, pigments, volatile-associated residues, and other ethanol-soluble compounds. Because ultrasound efficiency is influenced by many variables, including time, power, amplitude, pulse cycle, particle size, solvent type, and temperature, prolonged sonication can increase extract recovery while altering the extract's qualitative composition (Anaya-Esparza et al., 2023). Thus, yield must be evaluated together with phenolic content and antioxidant activity.

Bioactive Quality Versus Extract Quantity

The central finding of the experimental results was the divergence between extract quantity and bioactive quality. The 45-min treatment produced the highest yield, whereas the 30-min treatment produced the highest TPC and lowest IC50. This indicates that the optimum extraction time for antioxidant-oriented cinnamon extract was not the condition that maximized extract mass. A similar concept has been reported in the literature on cinnamon extraction, where solvent concentration and extraction conditions can yield different maxima for total phenolic content and antioxidant performance (Rakasivi & Chin, 2022).

This distinction is particularly important for the development of natural antioxidants. If the intended application is antioxidant enrichment, the extract should be judged by its active reducing and radical-scavenging capacities rather than by the recovered mass alone. Ethanol extraction of cinnamon has been shown to produce antioxidant-rich extracts, but the functional

value depends on the recovered flavonoid and antioxidant fractions (Rahayu et al., 2022). Therefore, selecting the 30-min treatment is scientifically reasonable because the experimental results show that it prioritizes high phenolic content and low IC₅₀ over maximum crude yield.

Interpretation of 15-Minute Sonication

The 15-min treatment was likely insufficient to extract phenolic compounds from the cinnamon powder matrix. At this time, solvent penetration and matrix disruption may not have reached the level required for efficient mass transfer. This interpretation is supported by the lower yield, lower TPC, and higher IC₅₀ observed for the 15-min extract compared with the 30-min extract. Although ultrasound accelerates extraction, plant cell disruption and compound diffusion still require sufficient contact time to achieve efficient recovery.

The weaker DPPH activity of the 15-min extract can be attributed to reduced phenolic recovery. Phenolic antioxidants can reduce DPPH radicals through hydrogen atom transfer and electron transfer mechanisms (Gülçin & Alwasel, 2023). When fewer reducing constituents are extracted, a higher extract concentration is required to reach 50% radical inhibition, resulting in a higher IC₅₀. Thus, the 15-min treatment did not provide sufficient bioactive recovery under the selected extraction conditions.

Interpretation of 30-Minute Sonication

The 30-min treatment can be considered the provisional optimum because it provided the most favorable balance between extraction efficiency and bioactive quality. At this duration, cavitation was apparently sufficient to release phenolic compounds efficiently, as reflected by the highest TPC. At the same time, the treatment did not show the decline in phenolic concentration observed at 45 min. This outcome is consistent with reports that cinnamon extraction exhibits a time-dependent optimum; for example, *Cinnamomum cassia* bark extraction using natural deep eutectic solvents showed an optimum time of 22 min under the conditions studied (Hong et al., 2023).

The low IC₅₀ at 30 min indicates that the extract has strong radical-scavenging activity. The value was also close in magnitude to the strong DPPH activity reported for Aceh cinnamon ethanol extract, which showed an IC₅₀ of 16.07 ppm (Husna et al., 2024). Although direct comparison is limited by differences in sample identity and extraction protocols, the similarity supports the interpretation that cinnamon ethanol extract exhibits strong antioxidant activity when phenolic recovery is high.

Interpretation of 45-Minute Sonication

The 45-min treatment produced the highest yield but neither the highest TPC nor the lowest IC₅₀. This result may be due to the co-extraction of non-phenolic substances, which increases the total extract mass while reducing the phenolic density per gram of extract. It may also reflect localized heating or prolonged exposure to ultrasonic energy, which could affect the stability of some phenolic constituents. Similar caution is warranted because optimized cinnamon extraction studies have shown that longer processing is not automatically superior and that each matrix-solvent system has its own optimum (Hong et al., 2023; Zhou et al., 2024).

The interpretation of the 45-min result should remain conservative because this study did not include compound-level identification. Without HPLC, LC-MS, or GC-MS data, it is not possible to confirm whether specific phenolic compounds were degraded, transformed, or diluted by co-extracted non-phenolic materials. The result nevertheless demonstrates a practical optimization issue: extending sonication can continue to increase yield while decreasing the extract's relative antioxidant quality. This supports the use of multi-response decision criteria in extraction optimization.

TPC-DPPH Relationship

The DPPH results followed the same general pattern as total phenolic content. The 30-min extract showed the highest TPC and the lowest IC₅₀, while the 15-min extract showed the lowest TPC and the highest IC₅₀. The strong negative correlation between TPC and IC₅₀ suggests that phenolic content contributed substantially to radical scavenging activity in the experimental data. This relationship is chemically reasonable because phenolic compounds can scavenge free radicals and protect food systems from oxidative deterioration (Platzer et al., 2022).

However, the TPC-DPPH relationship should not be interpreted too broadly. The Folin-Ciocalteu method is not completely specific to phenolics and may respond to other reducing substances in plant extracts (Ainsworth & Gillespie, 2007). Furthermore, rapid antioxidant assays such as DPPH, ABTS, ORAC, and Folin-Ciocalteu differ in reaction mechanisms and do not always produce identical rankings (Platzer et al., 2022).

Application Potential and Practical Limitations

From a food application perspective, the 30-min cinnamon extract can be positioned as a potential natural antioxidant candidate because it combines a high TPC with strong DPPH radical-scavenging activity. This interpretation is supported by food model studies showing that cinnamon powder or cinnamon extracts can reduce quality deterioration in meat products during refrigerated storage. Cinnamon powder improved antioxidant activity, reduced lipid oxidation, and enhanced quality attributes in beef burgers during 21 days at 4°C (Shoqairan et al., 2023), while cinnamon and sage powders improved shelf-life-related properties in chilled duck-based sausage (Wattanachant & Ungkusonmongkol, 2026).

The study evaluated antioxidant potential using chemical assays rather than direct performance in food matrices. Application claims require further testing in real food systems, including lipid oxidation indices, microbiological quality, storage stability, sensory acceptance, and dosage safety. This limitation is especially important because commercial cinnamon powder may vary across brands, batches, origins, and species composition. Therefore, the findings should be presented as an initial extraction optimization framework rather than as a finished preservation technology.

CONCLUSION AND RECOMMENDATIONS

Sonication time influenced the yield, total phenolic content, and DPPH antioxidant activity of 96% ethanol extract from commercial cinnamon powder. The extraction yield increased continuously from 15 to 45 min, peaking at 45 min. However, the highest bioactive quality was observed at 30 min, as indicated by the highest total phenolic content of 68.53 ± 0.85 mg GAE/g extract and the lowest IC₅₀ of 18.96 ± 0.34 µg/mL. The statistical analysis indicated significant effects of sonication time on all main response variables, while the TPC-IC₅₀ correlation suggested that higher phenolic content was associated with stronger antioxidant activity. Therefore, the 30-min sonication treatment is proposed as the provisional optimum because it provides a better balance between extraction efficiency and antioxidant quality than shorter or longer treatments. These findings emphasize that optimizing the extraction of cinnamon antioxidants should not rely solely on extract yield but must also consider phenolic recovery and radical-scavenging potency.

Recommendations. Further studies should verify the optimum extraction conditions using additional extraction-time levels and independent batches of commercial cinnamon powder. Chemical profiling and testing in real food systems are recommended to determine the contribution of individual compounds and assess antioxidant performance during storage.

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