

Ultrasound assisted extraction of bioactive compounds from fresh ripened chillies

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Abstract: Red chillies (*Capsicum annum*) are a globally significant crop valued for a rich profile of bioactive compounds, including capsaicinoids, carotenoids, and phenolics. Conventional extraction methods, such as maceration and Soxhlet, are often inefficient, energy-intensive, and can lead to the thermal degradation of heat-sensitive compounds. In response to these limitations, this study was conducted to optimize the Ultrasound-Assisted Extraction (UAE) process for fresh ripened red chillies using acetone as a solvent. The experimental design employed a Central Composite Design (CCD) within a Response Surface Methodology (RSM) framework to investigate the effects of ultrasonic power (60%–100%), treatment time (10–50 min), and solvent temperature (30°C–60°C) on extraction yields. The results of this investigation demonstrated the superiority of the UAE method over conventional techniques. The optimized UAE process with acetone achieved a capsaicin concentration of 2.310 mg mL⁻¹, a total flavonoid content of 0.540 mg mL⁻¹, a β -carotene yield of 0.127 mg mL⁻¹, a total phenolic acid content of 0.336 mg mL⁻¹, and an oleoresin yield of 184.7 mg. These yields represent significant increases compared to conventional methods, which produced 2.049 mg mL⁻¹ for capsaicin, 0.411 mg mL⁻¹ for total flavonoid, 0.090 mg mL⁻¹ for β -carotene, 0.285 mg mL⁻¹ for total phenolic acid, and 44.5 mg for oleoresin. Optimal conditions for extracting a diverse range of compounds with acetone were determined, highlighting the non-linear relationship between process parameters and yield. This study confirmed that UAE with acetone is a highly effective, rapid, and efficient method for recovering a broad spectrum of bioactive compounds, offering a superior and more sustainable alternative to traditional extraction methods for the production of high-quality extracts.

Keywords: ultrasound-assisted extraction (UAE), *Capsicum annum*, acetone, capsaicin, flavonoids, carotenoids, phenolic acids, oleoresin, color value

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1 Introduction

Red chillies, scientifically classified under the genus *Capsicum*, are a cornerstone of global agriculture and cuisine. Originating in the Americas, these vibrant and pungent fruits have integrated into the culinary traditions of countless cultures across

Europe, Asia, and Africa. India holds a preeminent position in this global landscape, being the world's largest producer, consumer, and exporter of chillies (Dewangan and Bhattacharjee, 2025). Favorable agro-climatic conditions and a wide array of cultivated varieties have propelled India's production to an

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impressive 27.82 lakh tonnes in 2023, further increasing to 32.08 lakh tonnes by 2023-24, accounting for approximately 40% of global output (PJTAU, 2025). This robust internal demand is complemented by a thriving export market, with chilli contributing USD 1,508.94 million to India's total spice exports in FY 2023–24, underscoring the critical economic importance of this crop.

Beyond their culinary utility, red chillies are a rich reservoir of bioactive compounds with significant nutritional and medicinal value. These phytochemicals include capsaicinoids (primarily capsaicin and dihydrocapsaicin), which are responsible for the fruit's characteristic pungency and have been studied for their analgesic and metabolic properties. Additionally, red chillies are abundant in carotenoids (such as β -carotene and lycopene), flavonoids (e.g., quercetin), and phenolic acids, which collectively contribute to the fruit's vibrant color and possess potent antioxidant, anti-inflammatory, and antimicrobial properties (Ďůranová et al., 2022,Chávez-Mendoza & Sanchez, 2017).

The extraction of these valuable compounds from the plant matrix has traditionally relied on conventional methods like maceration and Soxhlet extraction. However, these techniques are often energy-intensive, time-consuming, and require large volumes of organic solvents, posing both economic and environmental challenges. Furthermore, the high temperatures and prolonged exposure times associated with these methods can lead to the thermal degradation of heat-sensitive compounds, compromising the quality and bioactivity of the final extract.

In response to these limitations, modern "green" extraction technologies have emerged to offer more efficient and sustainable alternatives. Among these, Ultrasound-Assisted Extraction (UAE) has garnered significant attention due to its ability to enhance mass transfer and cell disruption through a phenomenon known as acoustic cavitation (Cravotto et al., 2019). In UAE, high-frequency sound waves (typically 20–100 kHz) create microscopic bubbles in the solvent that,

upon implosive collapse, generate intense localized temperatures and pressures, producing micro-jets and shear forces that effectively rupture plant cell walls and release intracellular contents. This mechanical disruption drastically improves the mass transfer rate of target compounds into the solvent, thereby shortening extraction times, reducing solvent consumption, and allowing for extraction at lower bulk temperatures that preserve the integrity of thermolabile bioactives (Chemat et al., 2011).

A thorough review of the literature reveals a growing consensus on the efficacy and advantages of UAE as a green extraction technology. Researchers have extensively documented the principles of UAE and its application to a wide range of plant materials, including various species of *Capsicum*. Studies by Vinatoru et al. (2017) and Chen et al. (2020) have focused on the optimization and mechanistic understanding of UAE for capsaicinoids and polyphenols, confirming that variables such as ultrasound power, temperature, and solvent type are critical for maximizing yield and purity. Research has demonstrated that UAE can achieve significantly higher yields in a fraction of the time compared to conventional methods, with Vinatoru et al., 2017 noting a 30%–50% increase in phenolic content from medicinal plants in just 20 minutes. The technology's ability to operate at lower temperatures is particularly beneficial for preserving heat-sensitive compounds like flavonoids and carotenoids, which are susceptible to degradation at the high temperatures often used in Soxhlet extraction. Furthermore, a study by Cravotto et al. (2018) provides a foundational review of cavitation-assisted extraction, reinforcing UAE's strengths in reducing extraction time, lowering solvent usage, and enhancing selectivity, making it a scalable and industrially relevant solution. The literature also highlights the importance of matching solvent polarity to the target compound, with polar solvents like ethanol and acetone consistently outperforming non-polar solvents for many of the bioactive compounds found in chillies.

Given this context, the present study was undertaken to rigorously optimize the UAE process for fresh ripened red chillies using acetone as a solvent. The primary objectives of this investigation were to determine the effects of key process parameters on the extraction efficiency of various bioactive compounds and to demonstrate the efficacy and superiority of this method over conventional techniques.

2 Materials and methods

2.1 Raw material preparation

Fresh, ripe red chillies (*Capsicum annum*, variety Indam 5) were sourced from a farm in Guntur district, Andhra Pradesh. The chillies were washed under running tap water to remove surface dirt and foreign matter. Prior to extraction, the chillies were chopped into small pieces and homogenized into a fine paste using a sterile mortar and pestle to maximize surface area for solvent interaction.

2.2 Conventional extraction

Capsaicin was extracted via Soxhlet using acetone (1:10 w/w) at 60 °C for 6–7 hours until exhaustion (Stoica et al., 2015). Purity was assessed using TLC with a mobile phase of toluene: acetone: chloroform (45:30:25 v/v) (Moise et al., 2004), and characterisation was done spectrophotometrically at 290 nm (Panda and Suresh, 2018).

Flavonoids were extracted in ethanol (24–48 h, ambient conditions) with intermittent shaking, followed by concentration at 70 °C using rotary evaporator (Thomas et al., 2013). TLC used chloroform: ethyl acetate: acetic acid (60:35:5 v/v), and absorbance was measured at 375 nm (Nurcahyo et al., 2023).

Carotenoids were extracted with hexane: acetone (1:1 v/v), washed with water and 10% NaCl, and dried over anhydrous sodium sulphate (Mounika and Sai Padma, 2019). TLC was performed using hexane: acetone (3:2 v/v), and absorbance was recorded at 436 nm (Varzakas and Kiokias, 2016).

Phenolic acids were extracted using ethanol (24–48 h), concentrated, and subjected to TLC using ethyl acetate: methanol: water (4:3:3 v/v) (Carmona-

Hernandez et al., 2021). Characterisation was done at 270 nm (Guemari et al., 2022).

Lycopene was extracted with acetone until colorless, combined with petroleum ether, washed with 5% sodium sulphate solution, and dried (Sadasivam and Manickam, 2008). Absorbance was measured at 503 nm, and lycopene quantity was calculated using Equation (1).

$$\text{mg lycopene in 100g sample} = \frac{31.206 \times \text{Absorbance}}{\text{Wt of sample (g)}} \quad (1)$$

Color intensity was measured using the ASTA Method 20.1 (1985). The acetone-diluted extract was scanned at 460 nm, and the color value was calculated using Equation (2).

$$\text{ASTA Color Value} = \frac{A \times 16.4 \times \text{Dilution Factor}}{m} \quad (2)$$

Where,

A is the absorbance at 460 nm;

m is the mass of the sample in grams.

Chilli oleoresin was obtained by Soxhlet extraction with petroleum ether (b.p. 40°C–60°C) for 4–6 h, and its yield was measured by transferring concentrated extract to a pre-weighed beaker for final weighing (Simonovska et al., 2016).

2.3 Ultrasound-assisted extraction (UAE)

Ultrasound-assisted extraction was carried out using a probe-type ultrasonicator (Dakshin, Model DP 120) equipped with a titanium alloy probe. A 50 g sample of chilli paste was mixed with acetone in a 1:3 (w/w) ratio (Zhou et al., 2011) in a beaker. The beaker was placed on a heating mantle to maintain solvent temperature. The probe was immersed into the mixture and the system operated in pulsed mode (10 seconds on, 10 seconds off). Pulsed sonication helps prevent localized overheating and ensures uniform acoustic distribution. After the treatment, the mixture was filtered using Whatman No.1 filter paper and the filtrate was concentrated using a rotary vacuum evaporator.

2.4 Experimental methodology

A Central Composite Design (CCD) was applied using Design Expert software (version 13) to optimize UAE process parameters specifically for acetone. Three independent variables were selected:

ultrasonication power (60% to 100%), extraction time (10 to 50 minutes), and solvent temperature (30°C to 60°C). The design included 20 experimental runs, incorporating factorial, axial, and center points to provide a robust prediction model. Response variables were the concentrations of capsaicin, flavonoids, carotenoids, phenolic acids, lycopene, and the ASTA color value. Statistical analysis was conducted using ANOVA to determine the significance of each factor. Regression models were developed for each compound, and three-dimensional surface plots were generated to visualize the interactions between parameters.

2.5 Analysis of bioactive compounds

Quantitative analysis of bioactive compounds was performed using a UV-Vis spectrophotometer. Absorbance was measured at specific wavelengths corresponding to each compound: capsaicin (290 nm), flavonoids (375 nm), carotenoids (436 nm), phenolic acids (270 nm), and lycopene (503 nm). Calibration curves were plotted using standard solutions, and the concentration of each compound in the extracts was calculated using the slope and intercept of the linear equation. Thin-layer chromatography (TLC) was used as a qualitative tool for compound confirmation. Standardized solvent systems and R_f value comparisons were employed to validate the presence of each targeted bioactive.

2.6 Replication and statistics

Each extraction and analysis was performed in triplicate and average was reported. Regression models from CCD were evaluated based on R² values, p-values, and lack-of-fit statistics. Surface response plots were generated to illustrate variable interactions.

3 Results and discussion

3.1 Comparison of conventional vs. ultrasound-assisted extraction yields

The baseline extraction of bioactive compounds using conventional methods established a crucial reference point for evaluating the performance of the ultrasound-assisted extraction (UAE) technique. Prior to ultrasonication, conventional Soxhlet extraction

with acetone was conducted over a period of 6–7 hours. This process yielded a capsaicin concentration of $2.049 \pm 0.083 \text{ mg mL}^{-1}$ in the final extract, corresponding to $3.52\% \pm 0.24\%$ of the raw material. The same conventional method was used for oleoresin extraction, which yielded $0.089\% \pm 0.005\%$, or $44.5 \pm 1.2 \text{ mg}$, from the red chilli paste. Other compounds, such as total phenolic acids and flavonoids, were extracted through solvent extraction, yielding $3.12\% \pm 0.21\%$ and $3.25\% \pm 0.18\%$, respectively, of the raw material.

In stark contrast, the optimized UAE process using acetone as the solvent achieved a significantly higher capsaicin concentration of 2.310 mg mL^{-1} , representing a 12.7% increase in yield. This superior yield was accomplished in a fraction of the time, with an optimal extraction duration of only 30 minutes, compared to the 6–7 hours required for conventional Soxhlet extraction. The time savings associated with this enhanced efficiency have profound operational and economic implications. The ability to achieve higher yields in a much shorter period dramatically increases processing throughput, reduces energy consumption, and minimizes labor costs. This efficiency aligns with the principles of green extraction by offering a pathway to a more sustainable and cost-effective production model. The reduced processing time also mitigates the risk of thermal degradation, a significant concern in conventional methods where heat-sensitive compounds like capsaicin, carotenoids, and flavonoids can be compromised by prolonged exposure to high temperatures.

Table 1 provides a summary of the conventional and ultrasound-assisted extraction yields for a range of bioactive compounds using acetone as the solvent, clearly demonstrating the performance benefits of the UAE method.

3.2 Detailed analysis of acetone's performance in UAE

The experimental data from the ultrasound-assisted extraction (UAE) process with acetone revealed intricate, non-linear relationships between the three

primary process parameters and the yields of various bioactive compounds. The statistical analysis confirmed the significance of these relationships, as

evidenced by a high coefficient of determination (R^2) and low p-values, which are fundamental to robust scientific findings.

Table 1 Comparison of conventional vs. ultrasound-assisted extraction yields

Compound	Conventional yield	UAE yield
Capsaicin (mg mL ⁻¹)	2.049 ± 0.083	2.310 ± 0.076
Total Flavonoid (mg mL ⁻¹)	0.411 ± 0.017	0.540 ± 0.012
β-Carotene (mg mL ⁻¹)	0.090 ± 0.004	0.127 ± 0.005
Total Phenolic Acid (mg mL ⁻¹)	0.285 ± 0.012	0.336 ± 0.015
Oleoresin (mg)	44.5 ± 1.2	184.7 ± 5.1

Note: Presented as mean ± standard deviation

3.2.1 Capsaicin extraction

The optimization of capsaicin extraction with acetone identified the most favorable conditions as an ultrasonic power level of 80%, a treatment time of 30 minutes, and a solvent temperature of 45°C, which together produced a maximum yield of 2.310 mg mL⁻¹. An in-depth analysis of the response surface plots confirmed that the relationships between the parameters and yield were non-linear, with distinct optimal points rather than simple increasing or decreasing trends. For instance, increasing the ultrasonic power level beyond 80% led to a plateau or even a slight decline in capsaicin yield. This observation was consistent with the physics of acoustic cavitation, where an optimal power level maximizes the formation and implosion of microbubbles to rupture plant cell walls. At excessively high-power levels, the solvent can become oversaturated with cavitation bubbles, creating a phenomenon known as "bubble shielding" that reduced the effective transmission of ultrasonic waves and could lead to thermal degradation of the target compound (Ferraz and Silva, 2025).

The duration of treatment also showed a similar non-linear effect, peaking at 30 minutes. Prolonging the extraction beyond this point did not improve the yield and, in some cases, led to a decrease, which was likely due to the degradation of the extracted capsaicin from prolonged ultrasonic exposure and thermal stress (Barbero et al., 2008). The use of pulsed sonication (10 seconds ON/OFF) was a deliberate process engineering strategy to mitigate this risk. By

introducing brief pauses, this method allowed localized heat dissipation, thereby preventing the bulk temperature of the solvent from rising uncontrollably and preserving the integrity of the heat-sensitive capsaicin molecule.

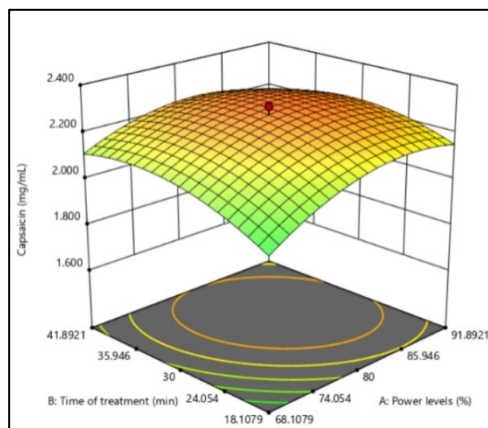
The solvent temperature similarly exhibited an optimal range, with 45°C representing a balance between enhancing mass transfer and preventing thermal degradation. At this temperature, the viscosity of the acetone was reduced, and the solubility of capsaicin was increased without compromising its chemical stability. The statistical significance of these parameters was supported by the ANOVA results, which showed that the linear terms for power, time, and temperature, as well as their quadratic terms, were highly significant ($p < 0.0001$) for capsaicin yield. The model's robustness was further confirmed by a high R^2 of 0.8954 and an Adeq Precision ratio of 18.24, indicating a strong signal-to-noise ratio and a reliable predictive model. Figure 1 shows interaction effect of (a) power level and treatment time (b) power level and temperature of solvent treatment on capsaicin extraction from fresh red chillies.

3.2.2 Flavonoid extraction

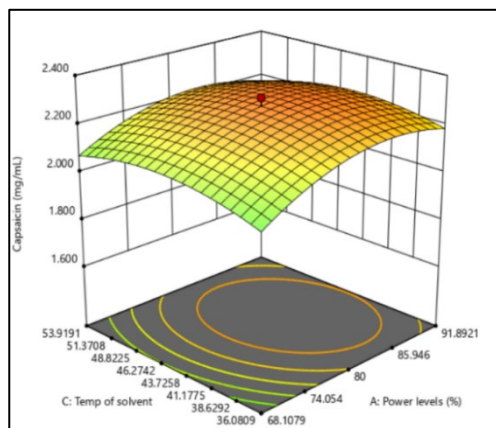
Acetone demonstrated a high effectiveness in extracting flavonoids, achieving a maximum yield of 0.540 mg mL⁻¹ under optimal conditions of 80% ultrasonic power, 30 minutes of treatment time, and a solvent temperature of 45°C. The performance of acetone could be attributed to its semi-polar nature, which was well-suited for solubilizing flavonoids, which were primarily polar or semi-polar compounds.

The statistical analysis of flavonoid extraction revealed that ultrasonic power, time, and solvent type were all highly significant factors influencing the yield ($p < 0.0001$ for all linear terms). The quadratic terms for power, time, and temperature were also highly significant, indicating a complex, curvilinear relationship where optimal settings exist for each

parameter. The statistical model for flavonoids was highly robust, with an R^2 of 0.9687 and a low Coefficient of Variation (C.V. %) of 2.26%, signifying a high degree of precision in the experimental data. Figure 2 shows interaction effect of (a) power level and treatment time (b) power level and temperature of solvent on flavonoid extraction from fresh red chillies.

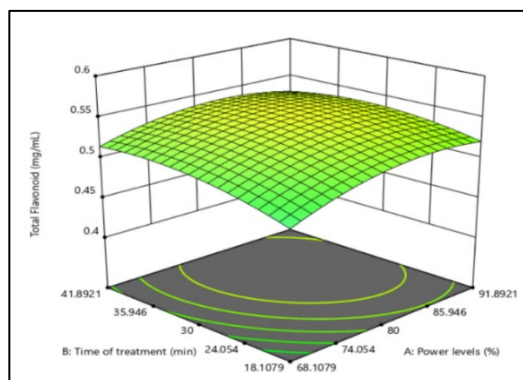


(a) Power level and treatment time

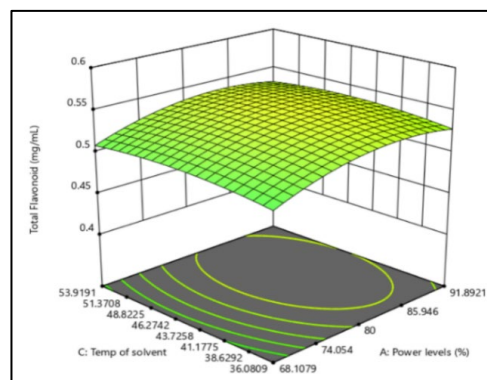


(b) Power level and temperature

Figure 1 Interaction effect of power level, treatment time, and temperature of solvent treatment on capsaicin extraction from fresh red chillies



(a) Power level and treatment time



(b) power level and temperature

Figure 2 Interaction effect of power level, treatment time, and temperature of solvent on flavonoid extraction from fresh red chillies

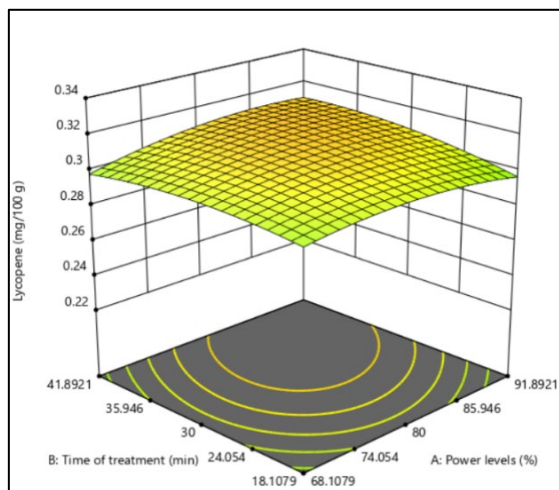
3.2.3 β -carotene and lycopene extraction

Acetone's performance in extracting β -carotene and lycopene was notably high, with maximum yields of 0.127 mg mL^{-1} and 0.323 mg mL^{-1} , respectively. The ability of acetone to effectively extract these non-polar carotenoids, a task typically associated with non-polar solvents, was a key finding of this study. Acetone's intermediate polarity, which allowed it to act as a versatile solvent, enabled it to solubilize a wide range of compounds, including both the semi-polar capsaicinoids and the non-polar carotenoids. This characteristic made acetone particularly suitable for

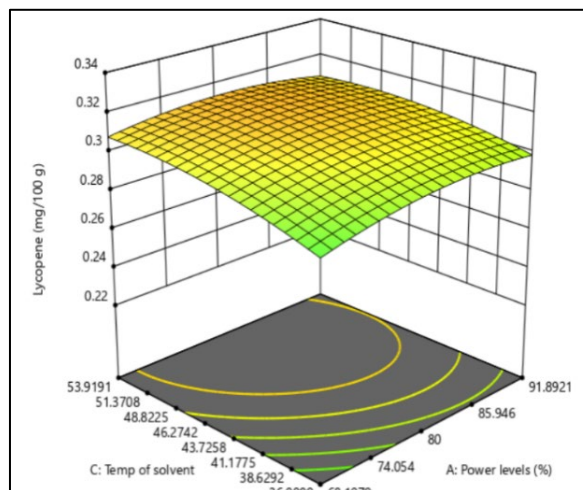
producing a "total extract" or "oleoresin" that contains a balanced profile of both polar and non-polar bioactives. Such a broad-spectrum extract was highly desirable for applications in the food and nutraceutical industries where the synergistic effects of multiple compounds were often sought. The optimal conditions for carotenoid extraction with acetone were a power level of 92%, a treatment time of 42 minutes, and a temperature of 36°C . This lower optimal temperature was crucial, as β -carotene and lycopene are known to be heat-sensitive compounds susceptible to degradation at elevated temperatures (Liu et al., 2024).

The statistical model for β -carotene was robust, with an R^2 of 0.8908 and an Adeq Precision ratio of 13.93, indicating its reliability for predicting extraction outcomes. The linear terms for power, time, and temperature were all statistically significant ($p < 0.05$), as were their quadratic terms, underscoring the importance of fine-tuning these parameters for optimal

extraction. Figure 3 shows interaction effect of (a) power level and treatment time (b) power level and temperature of solvent on beta-carotene extraction from fresh red chillies and Figure 4 shows interaction effect of (a) power level and treatment time (b) power level and temperature of solvent on lycopene extraction from fresh red chillies.

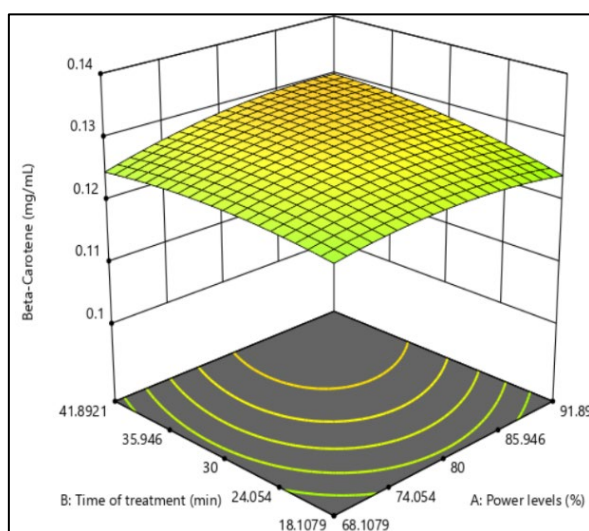


(a) Power level and treatment time

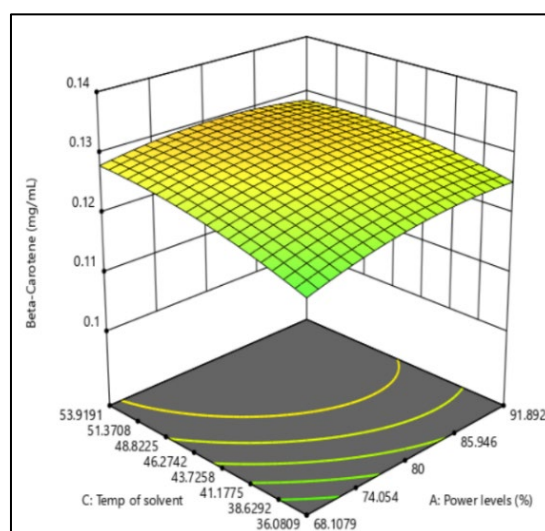


(b) Power level and temperature

Figure 3 Interaction effect of power level, treatment time, and temperature of solvent on beta-carotene extraction from fresh red chillies



(a) Power level and treatment time



(b) Power level and temperature

Figure 4 Interaction effect of power level, treatment time, and temperature of solvent on lycopene extraction from fresh red chillies

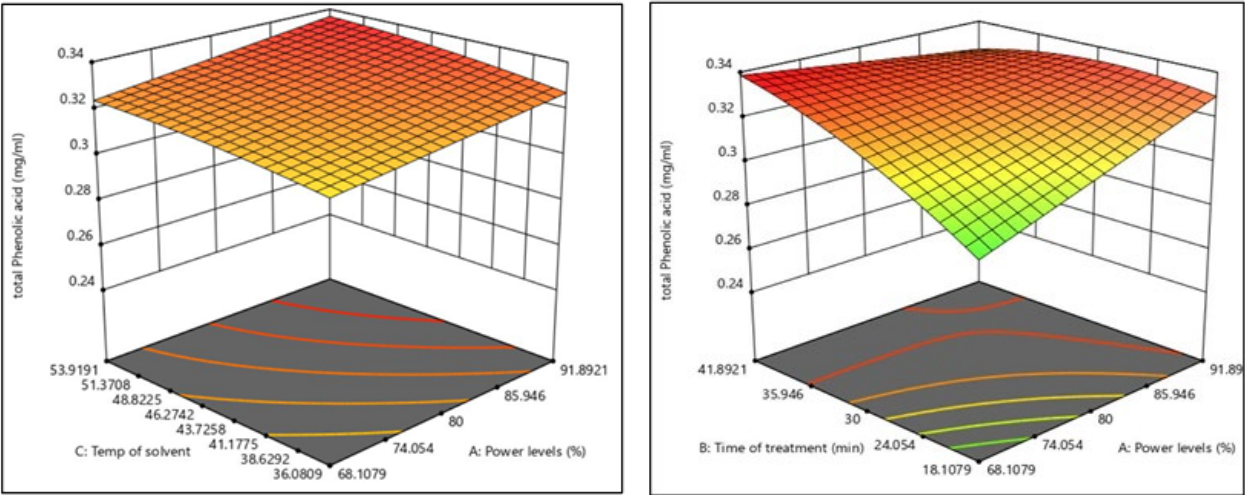
3.2.4 Total phenolic content and oleoresin extraction

For total phenolic content, acetone performed exceptionally well, achieving a maximum yield of 0.336 mg mL^{-1} , which was comparable to the highest yields obtained with ethanol in conventional method. The statistically significant influence of power, time, and temperature on total phenolic yield ($p < 0.0001$ for all three linear terms) highlights the importance of

process control. The model, with an R^2 of 0.9238 and an Adeq Precision ratio of 15.05, provided a reliable framework for optimization.¹In the case of oleoresin extraction, a concentrated mixture of volatile and non-volatile compounds, acetone achieved a maximum yield of 184.7 mg under optimal conditions of 80% ultrasonic power and 30 minutes of treatment at 45°C . The statistical analysis confirmed the significant

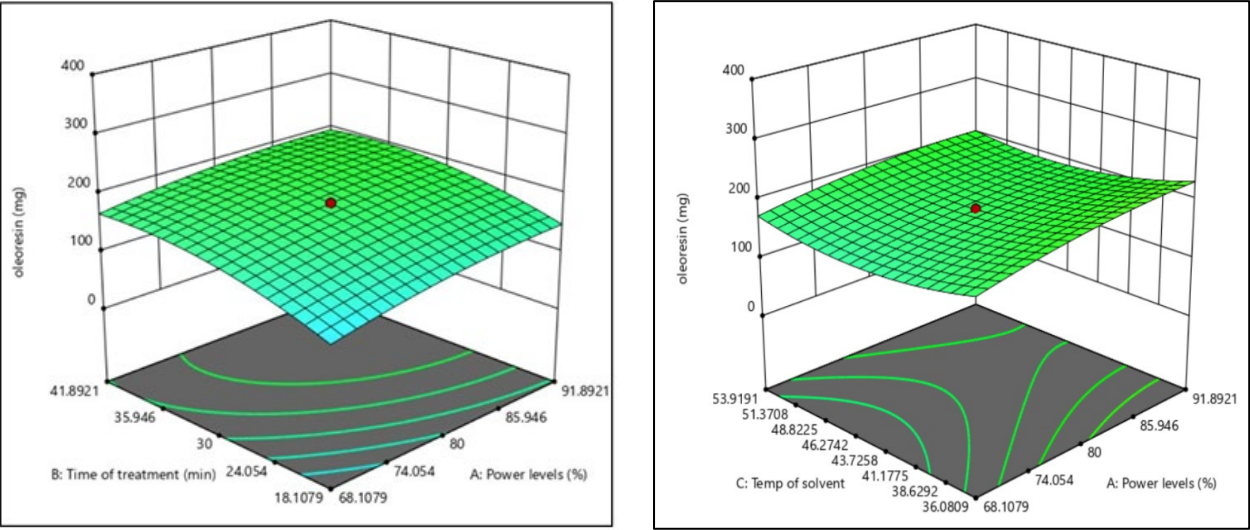
influence of power, time, and temperature on oleoresin yield ($p<0.05$), with the model exhibiting a robust Adeq Precision ratio of 8.231. This demonstrates that the UAE process with acetone is capable of efficiently

recovering a complex mixture of compounds that constitute the oleoresin, making it a valuable method for industrial applications that require a full-spectrum extract.



(a) Power level and treatment time (b) Power level and temperature

Figure 5 Interaction effect of power level, treatment time, and temperature of solvent on total phenolic content extraction from fresh red chillies



(a) Power level and treatment time (b) Power level and temperature

Figure 6 Interaction effect of power level, treatment time, and temperature of solvent on oleoresin extraction from fresh red chillies

Table 2 Thin-layer chromatography Rf values for acetone extracts

Compound	Rf Value of Extract	Rf Value of Reference
Capsaicin	0.750	0.765
Flavonoids	0.680	0.720
β -Carotene	0.941	0.958
Phenolic Acid	0.670	0.694

3.2.5 Extract characterization and purity analysis

Thin-layer chromatography (TLC) was employed to verify the identity and purity of the extracted bioactive compounds. The analysis revealed that the retention factor (Rf) values for capsaicin, flavonoids,

and phenolic acids in the acetone extracts were in close alignment with their respective standards. This close match of the Rf values confirmed that the UAE process with acetone successfully extracted the target compounds with minimal co-extraction of impurities

that would alter their chromatographic behavior. The distinct and well-defined spots on the TLC plates provide strong evidence of the process's integrity, suggesting that the gentle, non-destructive nature of UAE prevented significant degradation. Had there been substantial degradation, the plates would likely have shown streaking or additional spots representing breakdown products. The absence of such artifacts reinforced the conclusion that the UAE process was a robust method for preserving the chemical integrity of the extracted compounds, a critical factor for producing high-quality extracts for the food and pharmaceutical industries.

3.2.6 Color value of acetone extracts

The color value of the extracts, measured in ASTA units, is a critical quality parameter, as it is directly related to the concentration of carotenoid pigments.

The experimental data showed that acetone extracts achieved a peak color value of 42.492 ASTA units under optimal conditions. The analysis of the response surface plots demonstrated a non-linear relationship between the process parameters and the color value. For instance, the color value declined at both low and high temperature extremes, suggesting an optimal range around 45°C that maximized pigment solubility and extraction without causing thermal degradation. The statistical significance of power, time, and temperature in influencing color value was supported by the ANOVA results, with the model for color value showing an R^2 of 0.7725 and a robust Adeq Precision ratio of 11.53.

Figure 7 shows interaction effect of power level and treatment time on color value of extract from fresh red chillies.

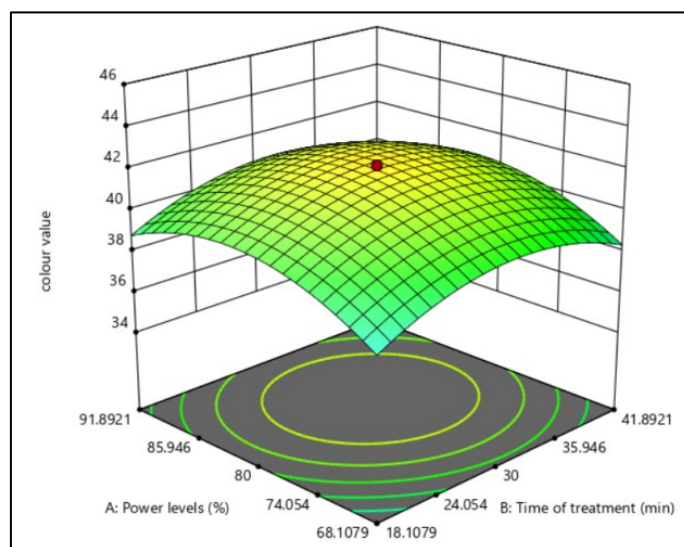


Figure 7 Interaction effect of power level and treatment time on color value of extract from fresh red chillies

4 Conclusion

This study comprehensively demonstrated the significant impact of ultrasound-assisted extraction (UAE) parameters—power, time, and temperature—on the extraction efficiency and quality of bioactive compounds from fresh ripened red chillies using acetone as a solvent. The research unequivocally confirmed that UAE is a superior method to conventional techniques, offering substantially higher yields in a fraction of the time. The optimal conditions were identified as a power level of 83.7362%, a treatment time of 34.36 minutes, and a solvent

temperature of 46.62°C, with these parameters effectively balancing the energy input required for cell disruption with the need to prevent thermal degradation of sensitive compounds.

A key finding of this study is the suitability of acetone as a versatile solvent for producing a broad-spectrum extract. Its intermediate polarity enables it to effectively co-extract a wide range of compounds, including both non-polar carotenoids (β -carotene, lycopene) and semi-polar phenolics (flavonoids, phenolic acids). This capability is highly valuable for producing a total extract or oleoresin that harnesses the

synergistic health benefits of multiple phytochemicals. The successful application of UAE, characterized by its ability to operate at lower temperatures and reduce reliance on large volumes of organic solvents, strongly aligns with the principles of green chemistry and sustainable processing.

The statistical models developed were highly predictive and statistically significant, reinforcing the robustness of the experimental design and providing a reliable framework for process optimization. The insights gained from this study underscore the necessity of a balanced energy input during UAE; excessive sonication can lead to compound degradation rather than enhanced extraction. This highlights that optimizing UAE is not merely about maximizing yield but, crucially, about preserving compound integrity and bioactivity, which is vital for nutraceutical and pharmaceutical applications.

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