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Extraction of curcumin from turmeric by ultrasonic-assisted extraction, identification, and evaluation of the biological activity

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ABSTRACT

Introduction: Dried rhizomes of turmeric have been traditionally used as a medicinal herb, dietary spice, food source, food preservative, and natural coloring agent in many Asian countries. This study aimed to develop the ultrasonic-assisted extraction (UAE) method for the extraction of curcumin from turmeric powder, evaluate the extraction efficiency, curcumin concentration, and biological activities.

Methods: The UAE effects were examined based on several parameters of extraction efficiencies. The curcumin content was also determined using high-performance liquid chromatography (HPLC), and the total phenolic content (TPC) was estimated by Folin-Ciocalteu colorimetric method. The antibacterial activity of the extracted was evaluated against the test pathogenic bacteria by the disc diffusion method. The correlation between extraction yield and curcumin content was performed by principal components analysis (PCA).

Results: The optimal UAE conditions were: ethanol, a solid-liquid ratio of 1:10 (w/v), an extraction time of 40 min, and only one extraction step. Under the optimal conditions, the yield of curcumin was 160.3 ± 1.17 (mg/g extract) and the TPC was 185.5 ± 3.07 (mg gallic acid equivalent /g extract). PCA presented the positive correlation between curcumin and the TPC of the studied extracts. Comparison of antibacterial activity between UAE and maceration method against the tested bacteria showed no significant difference at $P > 0.05$.

Conclusion: UAE was a viable alternative as a rapid, efficient, and simple means of extraction of curcumin from turmeric. The extracts had great potential as a source of antioxidant agents with high amounts of curcuminoids, phenolic compounds and exhibited activity against pathogenic bacteria.

Implication for health policy/practice/research/medical education:
UAE showed strong potential as a method for extracting curcumin and phenolic compounds from turmeric powder. Therefore, UAE might be useful for the extraction of curcumin.

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Introduction

Dried rhizomes of turmeric, belonging to the Zingiberaceae family, have been traditionally used as a medicinal herb, dietary spice, food source, food preservative, and natural coloring agent in many Asian countries (1,2). The rhizomes are a rich source of phenolic compounds, known as curcuminoids (1-6% w/w) (3), being a mixture of curcumin, demethoxycurcumin, and bisdemethoxycurcumin (1,4). Among these curcuminoids, curcumin is the most frequently studied substance for its characteristics and functionality (1). Curcumin possesses many pharmacological properties such as antioxidant (5), anti-microbial (6), anti-inflammatory (5), anti-parasitic (7), antiallergic (8), and anticancer activities (9). Solvent extraction is the most conventional method used for curcuminoid extraction from dried roots of turmeric rhizomes (10). The choice of solvents for extraction is restricted to a few solvents of defined purity that are

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allowed for the processing of food materials under national and international food legislation (11). Alcohol and acetone are good extractants, and their yields can be expected to be high because of the extraction of non-flavor components (11). The conventional extraction methods are time-consuming and laborious processes that use bulk amounts of organic solvents have a high risk of thermal decomposition of target molecules. In recent years, ultrasonic-assisted extraction (UAE) has become an efficient technology that requires much lower solvent consumption, lower energy input, lower temperature, and has a faster extraction rate, with increased stability for plant active compounds compared with conventional extraction methods such as maceration, shaking, or soxhlet extraction. UAE has been widely used in the extraction of phenolic compounds (12), antioxidants (13), flavonoids (13), and essential oils (14,15). Several methods, including high-performance liquid chromatography (HPLC) or ultra-performance liquid chromatography coupled with UV-Vis and/or MS detector (16) and high-performance thin layer chromatography (17) have been developed for qualitative and quantitative analysis of curcuminoids in turmeric. The simple analysis of curcuminoids is possible using HPLC on a reversed phase column due to the very labile characteristics of curcuminoids (18).

The growing public interest in traditional medicine, particularly plant-based medicine, has led to extensive research on the potential of natural origin substances. This study considered the optimal ultrasonic extraction condition by investigating the effective parameters of turmeric powder to suggest fundamental data for applications. The quantitative analysis of curcumin in crude extract was determined using HPLC, the total phenolic content (TPC) as well as the antioxidant activity was determined using the Folin-Ciocalteu colorimetric method and the antibacterial activity of the extracts was tested by disc diffusion method against bacterial pathogens. In addition, principal components analysis (PCA) was used to clarify the relationships among extraction parameters on the curcumin content and to correlate them with their biological activities.

Materials and Methods

Plant material

The turmeric powder was purchased from an herbal drugstore in Bangkok, Thailand, and then was kept in a desiccator at room temperature until used.

Chemicals and reagents

Curcumin (purity >97.0%) was purchased from TCI (Tokyo, Japan). Gallic acid and Folin-Ciocalteu reagent were purchased from Sigma-Aldrich (Stelnhelm, Germany). All chemicals used were of analytical reagent grade for extraction and of HPLC grade for chromatographic analysis.

Ultrasonic-assisted extraction

The effects of four extraction parameters (organic solvent, extraction time, solid to solvent ratio, and the extraction cycle) on extracting curcumin from turmeric powders were investigated. A 1.0 g turmeric sample was placed in a 60 mL amber screw-capped glass vial and mixed with the extraction solvent in different organic solvents and at different solid to solvent ratios for different extraction times. UAE was conducted using a rectangular device (Ultrasonic cleaner VGT-1990T, China). The extraction was carried out at 42 kHz frequency using 240 W input power with varying ultrasonic extraction times. All the experiments were carried out at room temperature as replicates. Then, the extracts were passed through filter paper (Whatman No. 1), evaporated to dryness, and kept at -20°C until analyses. The extracted yield was calculated as: % Yield (% w/w) = weight of crude extract (g)/weight of turmeric powder (g) × 100. The crude extract reconstituted filtrates were properly diluted to the required concentration for further analysis.

Maceration method

Traditional maceration extraction was performed as follows: extraction solvent (ethanol), solid-liquid ratio (1:20 w/v), extraction time (3 days), and extraction temperature (room temperature).

Determination of curcumin by HPLC analysis

A stock solution of curcumin standard was prepared by dissolving an accurately weighed 10 mg of curcumin in 10 mL of methanol in a volumetric flask. The standard solutions were prepared from a stock solution of curcumin at 3.2-100.0 µg/mL. The standard solutions were run on the HPLC, and the standard curve was obtained. Each sample of dried extract (10 mg) was accurately weighed and transferred to a 10 mL volumetric flask and made up the final volume using methanol. An aliquot of the solution was diluted with methanol to make a concentration of 50 µg/mL. The solution was filtered through a 0.45 m membrane syringe filter before injecting it into the chromatographic system.

The HPLC method was validated and performed on an LC system (Waters e2695, separation module, Waters, USA) and a photodiode array detector (PDA) (Waters 2998, Waters, USA). Chromatographic separation was carried out using a C18 column (150 mm × 4.6 mm, 3 µm) (ACE®, UK). The optimized mobile phase consisted of acetonitrile and 0.1% ortho-phosphoric acid in the ratio 50:50 v/v. Both solvents were passed through a nylon membrane filter. The isocratic elution was carried out at a flow rate of 0.7 mL/min at ambient temperature. The peaks were monitored at 427 nm. The injection volume was 10.0 µL. The peak was identified by comparison of retention times with the curcumin standard and the contents in the extracts were quantified on the basis of peak area. The method was validated for specificity,

linearity, precision, limit of detection (LOD), and limit of quantitation (LOQ). The linearity of the calibration curve was evaluated using different concentrations (3.2-100.0 µg/mL) of the standard solutions. A calibration curve for curcumin was constructed by plotting the average peak area against the concentration and determining the regression equation. The correlation coefficient and the slope of the peak were also computed. All the standards were analyzed in triplicate for each concentration.

Determination of TPC

The TPC was analyzed using the Folin-Ciocalteu colorimetric method of Ratchanee (19) with some modifications. Briefly, 200 µL of crude extract (1 mg/mL) was made up to 3 mL with distilled water, mixed thoroughly with 0.5 mL of diluted Folin-Ciocalteu phenol reagent (1:10 v/v with deionized water) for 3 minutes, and followed by the addition of 2 mL of 20% (w/v) sodium carbonate. The tubes were vortexed well and kept in the dark at room temperature for 60 minutes and absorbance was measured at 765 nm using a UV-visible spectrophotometer (Genesys 20, Thermo Scientific, USA). For quantification of the TPC in the extract, a standard calibration curve was prepared using gallic acid. The TPC of the extract samples was expressed as gallic acid equivalent (GAE) milligrams per gram of the extract.

Antibacterial potential of turmeric extract

Disc diffusion method was used to test the antibacterial activities of the turmeric extracts. Bacterial strains in this study were *Escherichia coli* (ATCC 25922), *Pseudomonas aeruginosa* (ATCC 27853), *Bacillus subtilis* (TISTR 1248), *Staphylococcus intermedius* (ATCC 29663), and *Staphylococcus aureus* (ATCC 25923). All bacterial strains were grown in nutrient broth overnight to determine the antibacterial activities. The cell suspensions of microorganisms were washed with 0.85% NaCl 3 times and adjusted at 0.5 McFarland turbidity standards to obtain approximately 10^8 CFU/mL in Muller Hilton broth (MHB) (confirmed by colony counting). Further, tested bacteria was spread onto the surface of Muller Hilton agar (MHA) in a 9-cm diameter Petri dish by a sterile cotton swab. The surface of the medium was air dry. Sterile filter paper discs (6 mm in diameter) impregnated with 10 µL of different test extracts (10 mg/mL in dimethyl sulfoxide [DMSO]) were then placed aseptically on the surface of these agar plates. The plates were then incubated at 37°C for 16-18 hours. The diameters of the inhibition zones were measured in millimeters (mm). Gentamicin solution was prepared in DMSO, using 2 µg/disc as the antibiotic standard. Negative control was 10 µL of DMSO. The experiment was carried out in triplicate.

Scanning electron microscopy (SEM)

The SEM analysis was used to study the morphological changes in the turmeric powder samples before and after UAE compared with the maceration method. The investigation was carried out using a scanning electron microscope (Quanta 450, USA). The dried samples were mounted on an aluminum stub and coated with a thin layer of gold before performing the analysis with an accelerating voltage of 20 kV under high vacuum conditions.

Data analysis

Experimental results were reported as the mean ± standard deviation of triplicate assays. Statistical analysis was performed using the Excel Microsoft 365 software. The One-way analysis of variance and Student's *t* test were used to determine statistical significance ($P < 0.05$).

Results

Extraction yield and curcumin content by UAE

The affected parameters of the UAE method that were investigated to increase curcumin extraction efficiency are reported in Figure 1. The solvent used affected both the crude extracted yield and curcumin content are reported in Figure 1A. The extraction yield of turmeric obtained with ethyl acetate (7.6 ± 0.20%) was higher than those of the other solvents. In addition, ethanol produced the highest curcumin content (161.6 ± 0.29 mg/g extract), which was significantly different ($P < 0.05$) from the other solvents. A liquid-solid ratio of 1:40 resulted was a higher extraction yield (10.3%) than with the other liquid-solid ratios (Figure 1B). However, the highest curcumin content (198.3 ± 4.36 mg/g extract) was obtained when the ratio was 1:10 that was significantly different ($P < 0.05$) from the other liquid-solid ratios. The extraction yield and the curcumin content in extraction time of 40 minutes were highest values (7.74% and 180.34 mg/g extract, respectively). These results showed the difference between extraction times of 20 and 60 minutes at $P < 0.05$ (Figure 1C). The extraction yield from the double sonication cycles was higher than the single sonication. A significant percentage ($P < 0.05$) of 9.96% increase in the extraction yield was found between the single and the double extraction cycles (Figure 1D). The curcumin content was decreased with the increase in the number of extraction periods ($P < 0.05$). Consequently, the single extraction cycle was chosen for the extraction on the extraction yield and curcumin content.

Thus, the optimal UAE conditions were using ethanol as the solvent, a solid-liquid ratio of 1:10 (w/v), an extraction time of 40 minutes, and only single extraction cycle.

HPLC analysis of curcumin component

The chromatograms are shown in Figure 2A-B corresponding to a curcumin standard and the extracted solution of turmeric, respectively, with the curcumin eluted at 10.34 minutes. Sharp and symmetrical peaks were obtained for curcumin when analyzed under separation conditions. The HPLC profiles using ultrasound-assisted extraction are shown in Figure 2B and, the UV absorption

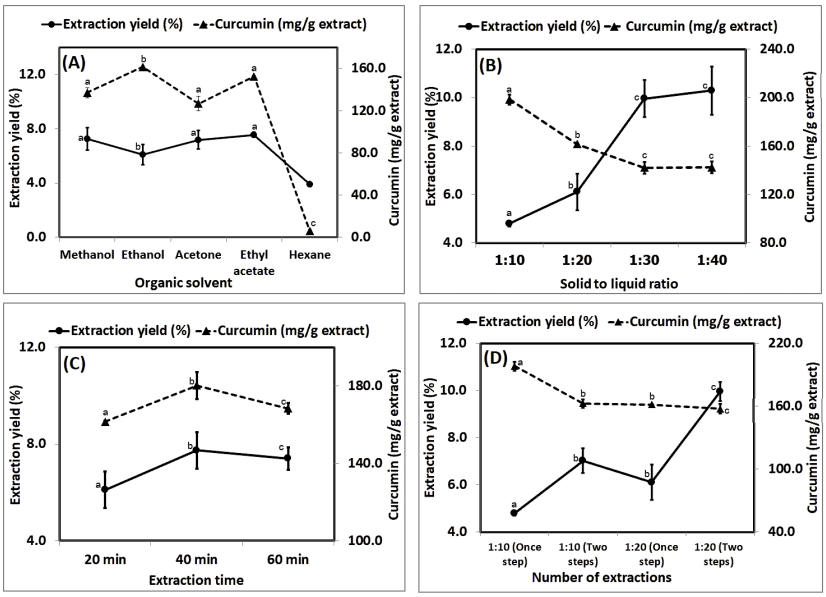

Figure 1. Effect of organic solvent (A), solid-liquid ratio (B), extraction time (C), and the number of extractions (D) on extraction yield (%) and curcumin content using ultrasonic-assisted extraction (UAE). Different letters indicate significant ($P < 0.05$) differences within each group of results. The curcumin content is based on the HPLC method.

spectra of the samples were inserted. The UV spectra of turmeric extract at the retention time of 10.34 minutes showed the maximum absorbance of 427.0 nm and matched with a curcumin standard.

A linear regression equation for the curcumin was y = 109004x – 38378 with a correlation coefficient of 0.999. The results from the linear regression analysis of the data for curcumin in the turmeric extract are presented in Figure 1. The intraday and interday precisions of curcumin were measured using the %relative standard deviation (%RSD) with values of 0.56 and 1.90, respectively. The LOD and LOQ were determined using the signal-to-noise ratio (S/N) method with 3:1 and 10:1 by injecting the standard solutions, respectively. The LOD and LOQ concentrations for curcumin were 1.26 µg/mL and 3.82 µg/mL, respectively.

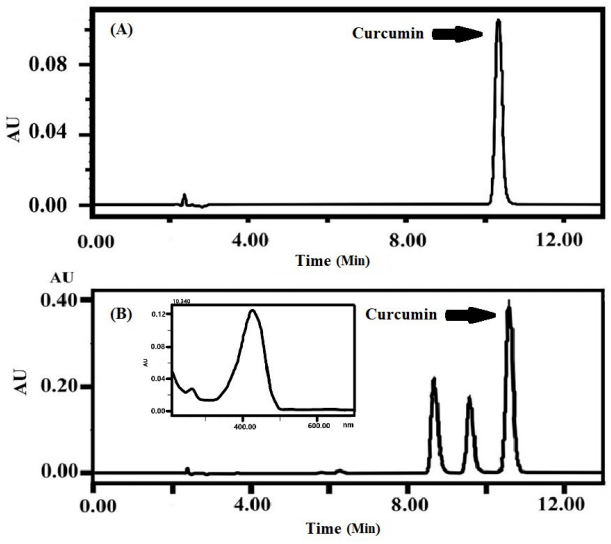

Figure 2. Chromatography profiles of standard curcumin (A), turmeric extracted using ultrasonic-assisted extraction (UAE) (B) at 427 nm, and the UV absorption spectra of sample (insert).

Determination of TPC

The TPC was determined from the regression equation of the calibration curve (y = 0.0049x - 0.0374; R^2 = 0.9993) as shown in Figure 3A-D. The quantities of TPC varied from 48.7 to 168.4 mg GAE/g dry extract weight of the different solvent extracts, as shown in Figure 3A. The hexane extract had the lowest TPC (48.7 mg GAE/g dry extract weight) compared to ethanol and the difference was significant ($P<0.05$; Figure 3A). The differences in phenolic content, however, were not significant for the other solvents (methanol, ethanol, ethyl acetate and acetone). The TPC varied from 166.6 to 185.9 mg GAE/g dry extract weight for the different extraction times as shown in Figure 3B. The highest quantities of TPC were obtained with an extraction time of 40 minutes, and this amount was significantly different from the other extraction times ($P<0.05$). The significantly highest TPC was obtained from the ratio of 1:40 (Figure 3C). The number of extraction steps affected the quantity of TPC extracted from the crude extract, with a ratio of 1:10 with only one extraction step producing the highest TPC yield (180.6 mg GAE/g dry extract weight), and this was significantly different ($P<0.05$) to the other tested parameters (Figure 3D).

Principal component analysis (PCA)

PCA was performed to obtain an overview of the similarities and differences between all the turmeric

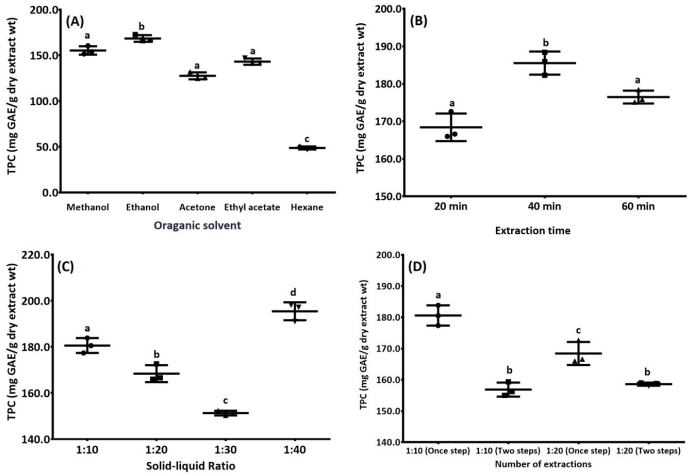

Figure 3. Total phenolic content (TPC) in extracts of turmeric using different solvents for extraction (A), with different extraction times (B), with different solid to liquid ratios (C), and with the different number of extraction steps (D). Different lower-case letters for the same parameter indicate significant ($P < 0.05$) differences. GAE: Gallic acid equivalent.

extracts from the ultrasonic extraction method and to investigate the relationship between the different organic solvents used for evaluating the curcumin content and TPC (Figure 4). Principal components of PC1 and PC2, explained 90.6% and 8.6%, respectively, of the total variance of the dataset. Thus, the two-dimensional graph was able to explain 99.2% of the variability in the experimental data. Samples were separated along with PC1 by differences observed in percent extraction yield, curcumin content, and TPC. Figure 4A shows the positive correlation between the curcumin content and TPC and the contrast with the extraction yield. The hexane extracts were located in the 2nd and 3rd quadrants (left side) and the other extraction solvents were located in the 1st and 4th quadrants near the origin. It appeared that PCA was a suitable approach to check for similarities among turmeric samples (Figure 4B). From this study, ethanol, methanol, ethyl acetate, and acetone could be used as extraction solvents for the extraction of curcumin from turmeric powder, and the curcumin showed antioxidant activity.

Comparison of ultrasonic assisted extraction and maceration method

The optimized ultrasonic extraction was compared with a maceration extraction method. The results in Table 1 showed that the extraction yield and TPC obtained from UAE were significantly lower than those obtained from the maceration method ($P < 0.05$). However, curcumin content obtained from the UAE (160.34 mg/g extract) was higher than the maceration method (143.10 mg/g extract). Comparison of antibacterial activity between 2 different extraction methods and gentamicin standard against the tested bacteria is shown in Figure 5. The results revealed that both extracts were effective in suppressing the growth of pathogenic bacteria and showed no significant difference at $P < 0.05$ was detected among results obtained with UAE method compared to maceration method (Table 2).

Morphological analysis

The surface morphology of the outer surface of the

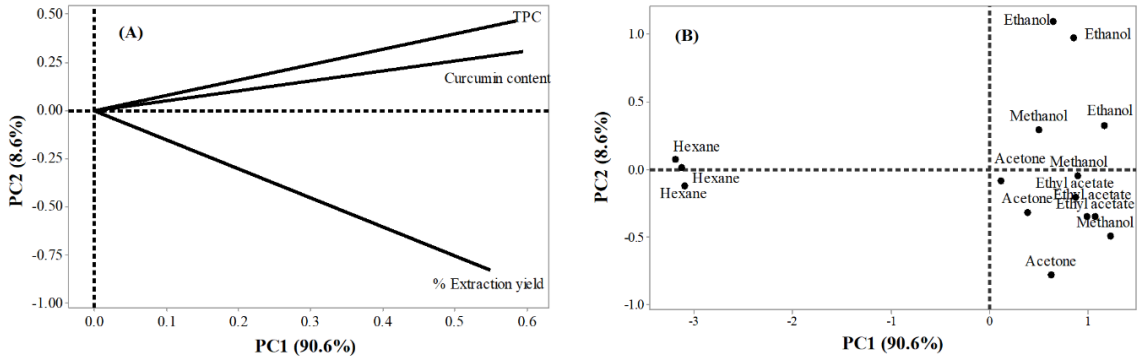

Figure 4. Loading plot (A) and scores plot (B) from principal components analysis (PCA) of turmeric extracts using ultrasonic assisted extraction (UAE).

Table 1. Comparison of analytical results obtained using ultrasonic assisted extraction (UAE) and maceration methods

Extraction method	Extraction time	Ethanol volume (mL)	Extraction yield [a] (%)	TPC (mg GAE/g dry extract weight)	Curcumin content (mg/g extract)
UAE	40 min	10	7.67±1.36[a]	185.5±3.07[a]	160.34±1.17[a]
Maceration	3 days	20	9.81±0.65[b]	216.44±8.89[b]	143.10±6.32[b]

Abbreviation: GAE, gallic acid equivalent; TPC, total phenolic content.
Different letters indicate significant ($P < 0.05$) differences between UAE and maceration on the same column. Data are reported as mean (n=3) ±SD.

Table 2. Antibacterial activities of curcumin extract obtained from UAE, maceration method, and the antibiotic standard

Extraction method	Diameter of inhibition zone (mm)				
	Microorganism				
	B. subtilis	*S. aureus*	*S. intermedius*	*E. coli*	*P. aeruginosa*
UAE	10.87 ± 0.23[a]	10.43 ± 0.67[a]	10.87 ± 0.23[a]	9.03 ± 0.15[a]	8.80 ± 0.26[a]
Maceration	10.57 ± 0.40[a]	9.63 ± 0.55[a]	10.73 ± 0.38[a]	8.37 ± 0.47[a]	9.07 ± 0.06[a]
Gentamicin	16.20 ± 0.10[b]	15.03 ± 0.95[b]	17.07 ± 0.83[b]	11.83 ± 0.76[b]	11.73 ± 0.64[b]

Abbreviation: UAE, ultrasonic-assisted extraction.
Different letters indicate significant ($P < 0.05$) differences between UAE and maceration on the same column. Data are reported as mean (n=3) ±SD.

turmeric powder was examined using SEM, and the results from before and after ultrasonic extraction and maceration extraction are illustrated in Figure 6A-C. The surface of the untreated turmeric powder sample in Figure 6A was hard without any porosity. Figure 6B shows the surface of turmeric powder after ultrasonic extraction. The surface of turmeric powder was slightly affected by the outer surface of the plant cells (Figure 6C) in maceration extraction method. These results suggested that ultrasonic extraction (40 minutes) was much effective than maceration extraction method (3 days).

Discussion

Biologically active compounds usually occur in low concentrations in plants. An extraction technique is desired when it can obtain extracts with a high yield and minimal changes to the functional properties of the extract. In this study, UAE was investigated to increase curcumin extraction efficiency. Therefore, the affected parameters of the UAE method that were investigated were: the organic solvent used for extraction, the solid-liquid ratio, the extraction time, and the extraction cycle. The organic solvent used for extraction directly

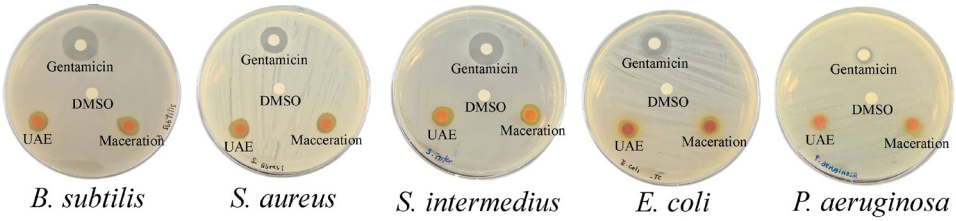

Figure 5. The antibacterial activities of curcumin extract and antibiotic standard (gentamicin) applying disc diffusion method by inhibition zone diameter determination.

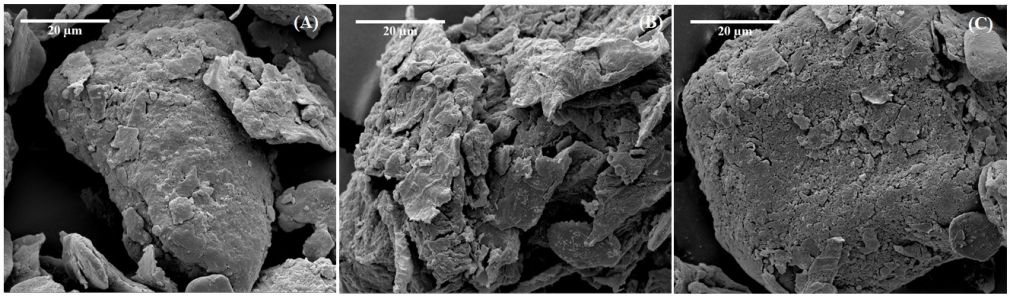

Figure 6. Scanning electron microscopy (SEM) micrographs of the outer surface of turmeric powder sample: (A) solid powder before extraction, (B) solid residue after ultrasound extraction, and (C) solid residue after maceration extraction (Image magnification of 2000x).

affects the final extracted yield and curcumin content. The extraction efficiency is affected by the chemical nature of phytochemicals, the extraction method used, sample particle size, the solvent used, and the presence of interfering substances (20). To select the most appropriate solvent for ultrasonic extraction of turmeric powdered sample, methanol, ethanol, acetone, ethyl acetate, and n-hexane were all used for extraction while holding the other extraction conditions constant. In this study, the effect of organic solvent for the extraction of curcumin by UAE ethanol produced the highest curcumin content from the other solvents. This result could have been due to the similar polarities of ethanol and the curcumin compound based on the principle of the solvent extraction method (21). The results were in agreement with other studies (22,23). Therefore, with the goal of maximizing to extract the active compound, ethanol was selected as the extraction solvent for further extraction experiments because it produced the highest yield of curcumin and was safer and less toxic compared to other organic solvents. Extraction time is a critical parameter during solid–liquid extraction owing to its influence on solubility and mass transfer of compounds, which are related to their structure and molecular weight (24). The results highlighted that extraction time significantly altered the extraction yield of bioactive compounds. The sonication time was varied (20, 40, and 60 minutes) for extraction while holding the other extraction conditions constant. The results showed similar trends of the extraction yield and the curcumin content increased with an increase in extraction time up to 40 minutes, then decreased slightly at 60 min. However, extended extraction time increases the probability of degradation of bioactive compounds. After 40 minutes, the curcumin content decreased because the thermal degradation of the curcuminoid structures occurred with the longer duration of mixing time (25). Therefore, prolonged extraction time may not be appropriate for all kinds of natural compounds. Ultrasound improved the extraction yield and curcumin content from turmeric due to the damage to the cell wall of the plant and an increase in the mass transfer of solvent when ultrasound was applied (26). During extraction, the solid to liquid ratio of a sample affected the degree of interaction between the solid and the solvent (ethanol), which in turn affected the extraction yield and the curcumin content. Furthermore, the curcumin produced a negative trend at a higher solid-liquid ratio of extraction (1:40). When the solute to solvent ratio was more, the curcumin extraction decreased, or the concentration of pigment in the alcohol was low (25). Among factors affecting the efficiency of the extraction, the extraction cycle should be considered. The present study was done to determine the effect of single and double extraction cycles on the extraction yield and the curcumin content. The extraction yield from the double sonication cycles was higher than the single sonication for 10 minutes. Significant percentage of increase in the extraction yield was found between the single and the double extraction cycles, while the curcumin content was decreased with the increase in the number of extraction periods. Phenolic components from the plants are important constituents that contribute to functional quality, color, and flavor and have significant roles both as singlet oxygen quenchers and free radical scavengers, helping to minimize molecular damage. The health benefits of phenolics are primarily derived from their antioxidant potentials because the radicals produced after hydrogen or electron donation are resonance stabilized and thus relatively stable (27). The TPC of all extracts obtained using the ultrasonic extraction method was determined using the Folin-Ciocalteu assay. The TPC was dependent on the crude extract, solvent, extraction time, solid to liquid ratio, and the step of extraction used for the extraction. The hexane extract had the lowest TPC compared to ethanol. The differences in phenolic content, however, were not significant for the other solvents (methanol, ethanol, ethyl acetate, and acetone). These results demonstrated that the higher polarity of solvent tends to yield greater amounts of polyphenolics (28). Using the UAE method and increasing the temperature from 30°C to 40°C, the high extraction temperature could promote the decline or even decomposition of the phenolic compounds in plant cells (29). The amounts of curcumin content obtained from the UAE were higher than from the maceration method, with a reduction in the extraction time and increased extraction efficiency in terms of the amounts of curcumin extracted from turmeric. The proposed extraction method, UAE (40 minutes), was much effective than maceration extraction (3 days). The surface morphology of the outer surface of the turmeric powder was examined using SEM. The surface of the untreated turmeric powder sample was hard without any porosity. Using maceration extraction, the surface of turmeric powder was slightly affected by the outer surface of the plant cells. After ultrasonic extraction, the outer surface was not clearly visible as it had lost the nature and hardness of turmeric and made the turmeric looser than before. These results may also confirm that the curcumin and other compounds can easily be extracted from these porous holes that increased the surface area of the solid, resulting in greater mass transfer and increased extraction rate and yield (30,31). The HPLC analyses allowed the identification and determination of the main curcuminoid content as curcumin in the different extracted samples. The HPLC profiles using ultrasound-assisted extraction are obtained. The curcuminoids had three peaks, namely bisdemethoxycurcumin, demethoxycurcumin, and curcumin, as reported by other researchers, compared to the elution profile from reversed-phase HPLC analysis (23,32,33). The retention times for bisdemethoxycurcumin, demethoxycurcumin, and curcumin were 8.61, 9.50, and 10.42 minutes, respectively (Figure 2B). HPLC profiles had no peak interference

from diluents at the retention time. The results indicated that the HPLC method was suitable for the identification and quantification of curcumin in the turmeric extract samples.

Conclusion

The present work aimed to optimize the yield of curcumin and phenolic compounds from turmeric powder by UAE. The curcuminoids profiles from both extraction methods were similar, indicating that UAE was a viable alternative as a rapid, efficient, and simple means of extraction of curcumin from turmeric. The effects of the turmeric extracts were positively correlated with the curcumin and TPC. The results indicated that the extracts from turmeric powder had great potential as a source of natural antioxidant agents containing high amounts of curcuminoids and phenolic compounds. The data obtained in this study revealed that curcumin extracted by the UAE method exhibited activity against important pathogenic bacteria. In addition, the results showed that ultrasonic processing was powerful enough to cause damage to the surface, with the SEM images showing substantial changes in surface morphology between ultrasonic processing and maceration methods. The UAE method reported here could be an effective alternative for the extraction of curcumin from turmeric powder and a substantial improvement over the conventional technique. UAE was simple, accurate and precise. This has potential as a useful and friendly extraction method that might be applied to the production of other plant-active substances.

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Authors' contributions

NH got the funding, WI wrote the draft, performed the revision of the manuscript, data analysis, and experiments; TC performed the experiments and revised the manuscript. All authors confirmed the final version for publication.

Conflict of interests

The authors declare no conflicts of interest.

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