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ORIGINAL PAPER

Smartphone-based imaging colorimetric assay for monitoring the quality of curcumin in turmeric powder

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Abstract

This research developed a colorimetric assay for semi-quantitative curcumin detection. The screening test was performed using a ferric chloride to form a brownish color which was further used to evaluate the amount of curcumin in the turmeric powder samples. The quantitative assay was performed based on the color intensity of the curcumin target using a smartphone digital image colorimetry with a developed lightbox constructed with a white light-emitting diodes (LED) light source as the measurement device. Images in red, green, and blue (RGB) color were processed to obtain relevant colors from the image and the color values were used to analyze curcumin concentrations. The intensity of the ΔB was correlated to the concentration of curcumin with high sensitivity. The method showed a linear range between 0.25 and 5 mg L^{-1} with the LOD and LOQ of 0.12 and 0.41 mg L^{-1}, respectively. Sample analysis was carried out in turmeric powders. Curcumin in turmeric powder samples was simply extracted using acetonitrile followed by dilution 100 times for sample preparation. The accuracy was tested by spiking 0.25, 1.00, and 4.00 mg L^{-1} of standard curcumin into the turmeric sample solution. The average percentage recoveries were acceptable in all samples (90–104%). The method was validated by comparing the results obtained from the proposed method and high-performance liquid chromatography (HPLC). There was no statistically significant difference between the two methods ($P = 0.05$).

Keywords Curcumin · Turmeric powder · Colorimetric imaging · Smartphone · Quality

Introduction

Curcumin is a nutraceutical presenting in turmeric rhizomes (*Curcuma longa*) and is known to possess a range of therapeutic well-being [1]. Curcumin has gained significant attention due to its wide biological effects including antioxidant [2], anti-viral [3], anti-inflammatory [4], and anticancer [5]. As known that cancer is the main cause of death in many countries. There are attempts to discover anticancer agents with high efficiency and less toxicity. The study of the anticancer activity of curcumin and its derivatives both in vitro and in vivo has been reported to develop its potential as a drug in biomedical science [6–8]. Curcumin is also applied in the food industry called curcumin-based food supplements. However, there have been numerous claims of intentional adulteration of turmeric powder with extraneous materials to fake the characteristic bright-yellow-orange color of pure turmeric powder. In addition, in the process of turmeric powder preparation, the way of handling and storage possibly affects the purity and levels of curcumin in turmeric powder. This is one challenge that affects food safety and human health [9–11]. Considering these issues, the awareness of curcumin content in food products has been increased. Contaminations of turmeric powder must be evaluated to maintain good quality of curcumin-based food supplements [12].

Therefore, several well-established techniques have been employed for qualitative and quantitative evaluation of food products attempting to curtail adulteration [13, 14].

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High-performance liquid chromatography (HPLC) has been widely applied in food, agricultural, industrial, environmental, and medical research [15, 16] because of its high sensitivity, accuracy, and precision. There are many reports of using HPLC technique for the analysis of curcumin by incorporating with mass spectrometry [17] and UV–Vis spectrophotometry [18, 19]. However, the approach is associated with extensive sample preparation, high operational cost, and expertise requirements. The spectrophotometric technique is a simple and most commonly used method for curcumin estimation [20, 21]. However, accuracy needs to be considered because of the interference from non-curcumin components presented in the samples.

To enhance the chance of on-site curcumin detection, miniaturization of a detector is being considered. As the above-mentioned, it is uncomplicated to work with spectrophotometric methods. Accordingly, the development of smartphone digital image colorimetry has recently been demonstrated as a complementary miniaturized analytical technique. This aims to reduce analysis costs and simplify the process. It also shows the high possibility of achieving a truly portable device for on-site analysis [22]. The smartphone digital image colorimetric assay has gained significant attention for widely target analytes as an alternative method for chemical analysis [23, 24]. In this technique, color appearance is captured and processed using an analyzer software to convert the image into its three primary color channels, red–green–blue (RGB) to obtain a linear relationship between the analyte concentration and its color intensity. There were reports of applying a smartphone-based digital image colorimetry in a wide range of analytes in food and drink samples with different matrices [25–27].

Efficient sample preparation, i.e., extraction method, is a key factor for improving the analysis performance of bioactive compounds presenting in various matrices. For curcumin, there are several extraction methods such as soxhlet extraction, microwave-assisted extraction, and ultrasound-assisted extraction [28]. Solvent extraction is the most simple and convenient method for curcumin extraction, and it has been combined with a smartphone-based digital image colorimetry to determine curcumin in turmeric powder and food samples [29, 30]. Due to the need for portable devices, simple and less step of sample preparation is emphasized. In this work, a simple colorimetric chemical sensor for curcumin detection in turmeric powder using a smartphone as an imaging colorimetric assay was investigated. Solvent extraction was simply applied. A cost-effective, rapid, and possible on-site analysis was achieved. The efficiency of the proposed method was tested by detecting curcumin content in turmeric powder obtained from local markets. The results were compared with the results of HPLC using a statistical test.

Materials and methods

Reagents and chemicals

Standard curcumin (*Curcuma Longa*) was from Sigma Aldrich (Missouri, USA). Iron (III) chloride was purchased from Sigma Aldrich (St Louis, USA). Acetonitrile and acetic acid (HPLC grade) were purchased from RCL Labscan (Bangkok, Thailand). For the ferric chloride test, the standard stock solution of curcumin (1000 mg L^{-1}) was prepared by dissolving the standard curcumin in 95% ethanol and stored in a wide mount amber reagent glass bottle at room temperature until used. Working standard solutions of curcumin were prepared by dilution of the stock solution with 95% ethanol. In HPLC analysis, the mobile phase was the mixture of acetonitrile and acetic acid (50:50 v/v). The standard curve was created using the working solution of curcumin between the concentration of 0.125 and 5.00 mg L^{-1} prepared in the mobile phase. All aqueous solutions were prepared in ultrapure water from the Milli-Q® Direct Water Purification System. Purospher®STAR RP18 Endcapped UHPLC Column was purchased from Merck (Darmstadt, Germany).

Turmeric sample preparation

Turmeric powder was obtained from the local market in Songkhla province. Five grams of the powder was mixed with 95% ethanol (50 mL). The extraction method was conducted following previous works with slight modifications [31, 32]. The mixture of sample and organic solvent was placed in the center of the microwave-assisted extraction system (Milestone, ETHOS X, Sorisole, Italy). The extraction was performed at 600 watts for 4.5 min. The extracts were filtered through a filter paper (10 µM) and the organic solvent was removed. Freeze drying of the extracts was conducted at − 40 °C for 12 h. The obtained lyophilized powder was kept at 4 °C for an ongoing experiment.

Curcumin detection based on ferric chloride reaction

Curcumin screening assay was performed by detecting the phenolic group in curcumin molecule. The addition of ferric chloride into the compounds containing phenolic group caused the compounds to form brownish color. The intensity of the developed color was proportional to phenol content indicating the amount of curcumin. In order to estimate the approximate amount of curcumin in turmeric powder, the concentration of a curcumin standard was tested within the range of 150 to 1500 mg L^{-1}. Three samples of turmeric

powder were extracted as the above-mentioned method and the phenol content was determined. Ferric chloride stock solution (5% w/v) prepared in distilled water was mixed with each concentration of the curcumin standard as well as the extracted turmeric powder. The reaction was conducted at room temperature for 5 min. The appearance of the bluish-black color in the solutions indicated the presence of phenol in the curcumin molecule [33].

Color detection using the developed lightbox integrated with a smartphone

After the study of the detection range for curcumin in turmeric powder samples, the detection of the actual color of dissolved curcumin in the solvent was conducted by the developed lightbox integrated with a smartphone. Quantitative analysis of curcumin was performed using curcumin standard solution between the concentrations of 0.25 and 5.00 mg L^{-1}. One milliliter of curcumin standard solution prepared in acetonitrile was added to the Eppendorf tube. The detection of the developed color took place in the detection holder of the custom-made detection box (24 cm × 24 cm × 24 cm) where white LED lamps with 12 V were illuminated (Fig. 1). A smartphone was placed in the detection holder and the distance was maintained at 24 cm to take a photograph of the colorimetric test tube. Finally, the concentrations of curcumin were evaluated using the red–green–blue (RGB) color analysis-based Color Picker application in the smartphone. The Color Picker application was applied to capture the image from the smartphone. Images obtained from the color tube consisted of 1280 × 1280 pixels, which were in the circular pointer and matched to the detection zone on a color tube.

Image analysis was performed through RGB profiling, and the RGB values of the image were measured. The signal's intensity was determined by subtracting the intensity from that of the background. As know, RGB light is combined in different ways to create a wide range of colors. In this research, the RGB color channel was used as a color model. To obtain the best detection signal, the color intensities of R, G, and B were measured in all curcumin solutions and were subtracted from the color intensities of blank solution. The intensity values were shown as ΔR, ΔG, and ΔB, respectively.

Turmeric powder sample analysis for curcumin quality

Sample preparation

To investigate the solubility of turmeric samples, each turmeric powder sample was weighed at 2.0 mg and dissolved in 1.0 mL of the studied solvents including ethanol, methanol, and acetonitrile. The color intensity of the extracted curcumin from turmeric sample was studied. The turmeric sample was diluted using the above-mentioned solvent to eliminate the matrix effect before measured the color intensity in the developed lightbox integrated with a smartphone. The dilution of extracted curcumin sample was made between 100 and 1000 times and the sensitivity of the developed method. Then concentrations of curcumin were calculated from the linear regression equation of the calibration curve created between the concentrations of standard curcumin and the color intensity. Three replicates were done for each analysis.

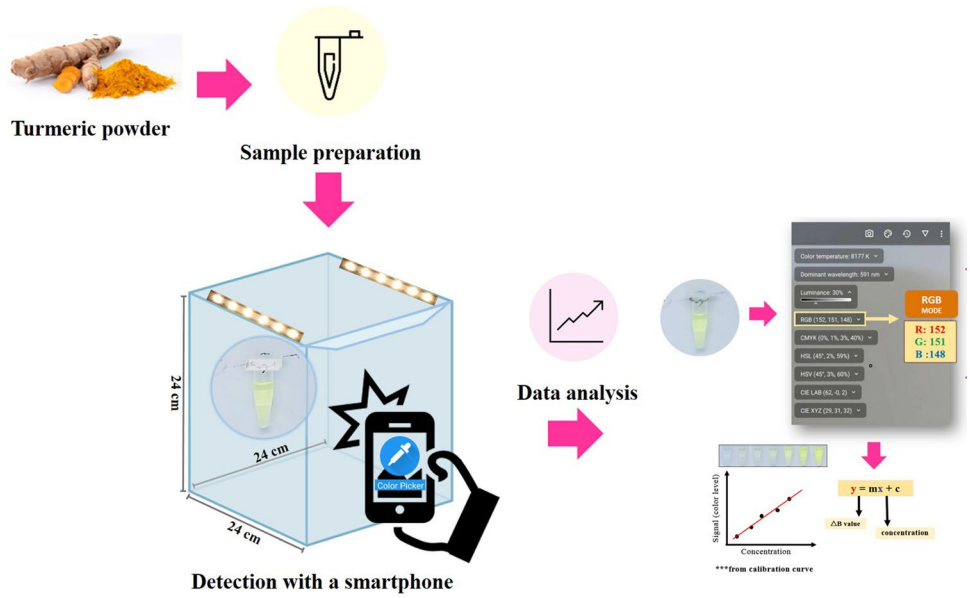

Fig. 1 The schematic workflow of curcumin measurement using the developed lightbox integrated with a smartphone

Method validation

Repeatability, reproducibility, linearity, LOD and LOQ were studied to obtain the performance of the developed method. For recovery study, percentage recoveries obtained from the developed method and reference method (HPLC) were studied. The percentage recovery was calculated from $(C_{spiked}\text{-}C_{blank})/C_{std} \times 100$ where C_{spiked} is the concentration of curcumin found in the spiked sample, C_{blank} is the concentration of the blank solution and C_{std} is the concentration of standard curcumin added in blank sample.

Detection of curcumin in turmeric powder samples

Quality analysis of turmeric powder was performed using three branded and three unbranded turmeric powder samples purchased from local markets in Songkhla, Thailand. The samples were analyzed using the developed lightbox and HPLC methods. Two milligrams of turmeric powder were dissolved and extracted in a suitable solvent (1 mL). The sample solution was then diluted 100 times to reduce matrix effect while the sensitivity of the method remained. In addition, this dilution factor is related to the curcumin content in target products such as turmeric extract and curcumin in the form of dietary supplements in previous works [12]. The diluted sample was transferred to measure color intensity using the developed method. Three replications were done for each analysis.

For the HPLC analysis, the same diluted sample solution was filtered through a 0.45 µm syringe filter before analysis. A 20 µL sample solution was injected into the HPLC system for quantitative analysis. All samples were analyzed with an Agilent Technologies 1200 series (Palo Alto, CA, USA), installed with a degasser, a quaternary pump, an autosampler, and a diode-array detector (DAD) for identification and quantification. Detection of curcumin was conducted at 425 nm. The sample was separated on a LiChroCART Purospher STAR RP C18 column (150 × 4.6 mm, 5 µm particle size, Merck, Germany). The mobile phase consisted of a mixture of 2% acetic acid and 100% acetonitrile (50:50, v/v). The analysis was performed at a flow rate of 1 mL min^{-1} over a period of 15 min at 25 °C. The integrated peaks were quantified and identified by comparing their retention times against the corresponding standard peaks. The concentration of curcumin in each turmeric sample found by HPLC was used as reference data for the curcumin detected by the developed lightbox integrated with the smartphone.

Results and discussion

Ferric chloride screening test

The ferric chloride test was conducted to characterize curcumin in the turmeric sample based on the chemical reaction between ferric chloride and phenol group of curcumin molecules. A preliminary test to evaluate curcumin content in the extracted samples was performed by allowing 50 µL ferric chloride solution (5% v/v) to react with 1.0 mL curcumin solution prepared in ethanol. The studied concentrations of standard curcumin were 150, 300, 600, 1200 and 1500 mg L^{-1}. The color of brownish black was observed due to the complex formation of curcumin with ferric ions [34] as shown in Fig. 2. To evaluate the screening level of curcumin in the turmeric powder samples, three samples extracted by microwave method were preliminarily determined using the ferric chloride test. The extracted turmeric sample (3.0 mg) was prepared in 1.0 mL of ethanol and the sample solution was diluted twofold before ferric chloride testing to evaluate the rough amount of curcumin found in the turmeric extracts.

The obtained result showed brownish black color in all samples. Using the naked eye to observe the color from samples and standard curcumin, it indicated that the curcumin concentration in all turmeric powder samples was less than 300 mg L^{-1} (Fig. 2). However, quantitative detection is needed for the actual amount to identify the quality of turmeric powder.

System performance of the developed lightbox integrated with a smartphone

The ferric chloride test provided a tentative concentration range of curcumin in turmeric powder and the matrix of the sample. However, the limitation of phenolic-Fe^{3+} complexes with time-dependence reaction revealed the decrease in color stability. Moreover, previous study exhibited a relatively high limit of detection of the ferric chloride method [35]. Therefore, an alternative method was developed to study the intrinsic color intensity of the yellowish color of curcumin.

We have constructed a detection box where the internal light was kept constant, and the interference caused by the external light was prevented. A test tube containing curcumin expressed the yellow color was placed inside and taken photo. The color picker mobile application was employed to read the color information including R (red), G (green), and B (blue) channels. The standard or sample solution was focused on the photo center, and the color information was read from the center of the image

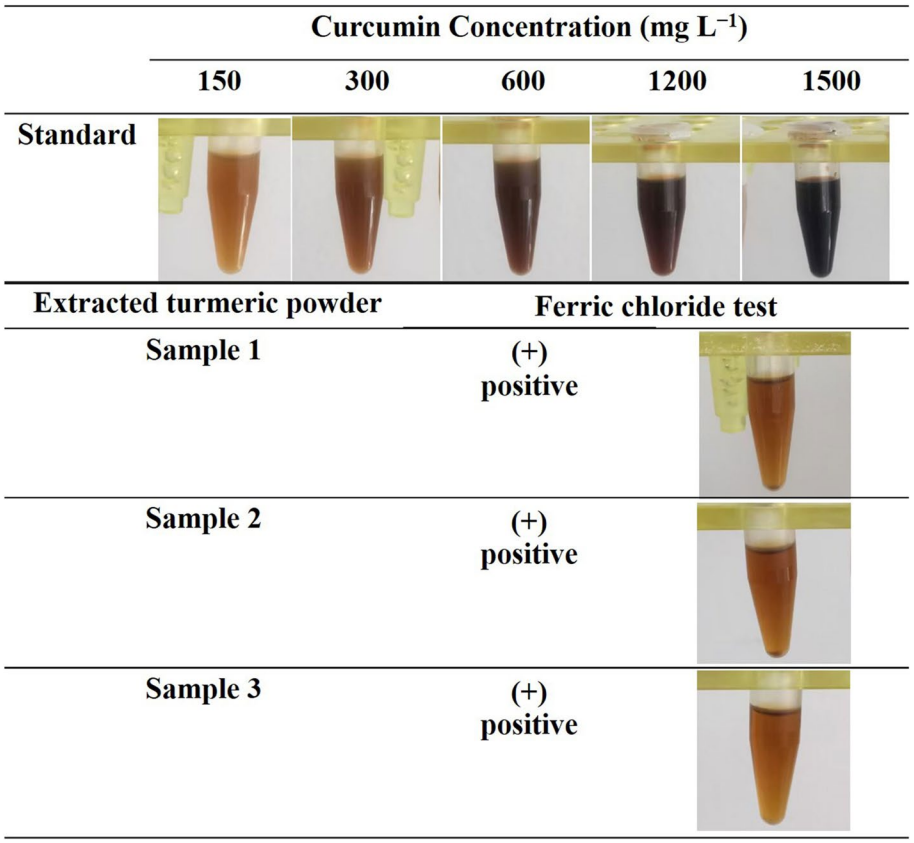

Fig. 2 Images results revealed the color range of the standard curcumin (150–1,500 mg L^{-1}) and turmeric powder sample after the reaction with $FeCl_3$

under JPEG format. The images of standard and sample solutions were captured by a smartphone camera. Three adjacent colored pixels at the center of the image were recorded, and the average values were calculated for RGB. Solutions (1 mL) with standard curcumin concentrations 0.5–5 mg L^{-1} were added to the Eppendorf tube and placed in the holder of developed detection lightbox with the fixed distance of tube position. The image of the tube was captured by smartphone and the color values were obtained from the Color Picker mobile application. Image analysis was performed through RGB profiling, and the RGB values of the image were measured. The signal's intensity was determined by subtracting the intensity of the background. To study the best signal for detection,

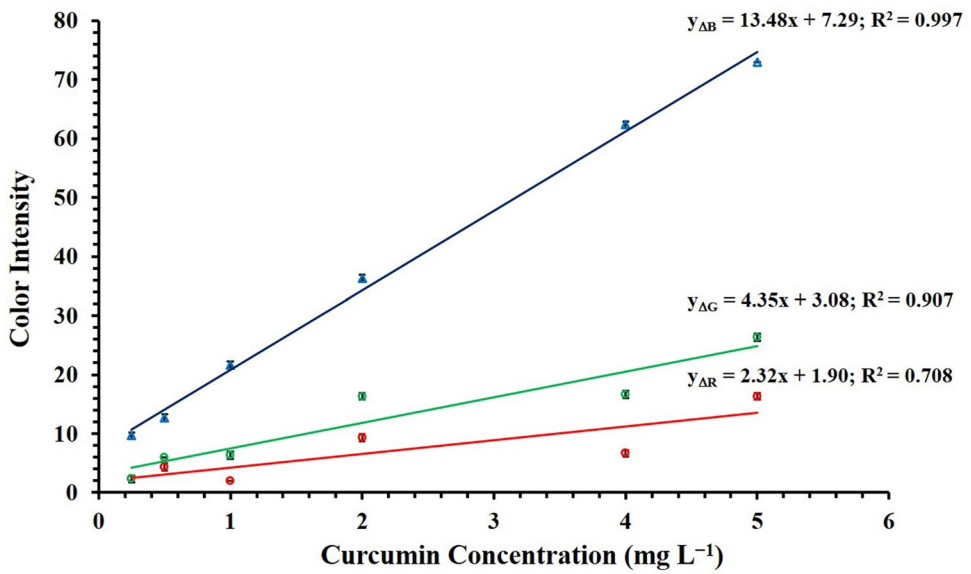

Fig. 3 Correlation between curcumin concentration and color intensity for Δred (R), Δgreen (G), and Δblue (B) value detected by the lightbox integrated with a smartphone

various color intensities (ΔR, ΔG and ΔB) were measured for various concentration of the curcumin standard (Fig. 3). The results have shown that the ΔB (blue value) increases with increasing standard curcumin concentration with the better correlation (R^2) and sensitivity (slope). Therefore, the ΔB was selected for the next experiment. The blue values were found to be the strongest determinants as same as this research works to detect the curcumin in food samples [29].

Optimization of turmeric sample extraction

The optimization of extraction conditions was carried out using a solution of turmeric powder sample with the spiked standard curcumin (0.5 to 2 mg L^{-1}) to match the sample matrix.

Extraction solvent

Sample preparation was performed to extract curcumin from turmeric powder sample using a suitable solvent. A vortex mixing (Scientific Industries SI-0236 Vortex-Genie 2 Mixer, Bohemia, New York) with fixed speed at 3200 rpm was used for mixing solvent and turmeric powder. The studied solvents were ethanol, methanol, and acetonitrile. The standard curcumin was prepared in the above-mentioned solvents at the concentration of 0.5, 1 and 2 mg L^{-1}. The color intensity obtained from each solvent is shown in Fig. 4. In all solvents, a bright-yellow solution was observed indicating the presence of curcumin. However, the highest color intensity was detected when acetonitrile was used as a solvent according to the highest slope and the best linearity. This can conclude that curcumin showed highest solubility in acetonitrile and resulted in highest color intensity compared to other solvents [36]. Hence, acetonitrile was chosen as a suitable solvent for extraction in the developed method.

Extraction time

Vortex mixing can facilitate extraction by accelerating the achievement of equilibrium between the analyte molecules and the extraction solvent. The extraction (vortex) time was studied in the range of 1–10 min. It was observed that the extraction efficiency obviously improved with an increase of extraction time up to 7 min before it became slightly increase (Fig. 5). Therefore, 5 min of vortex mixing of the sample solution was chosen as the optimum extraction time since no significant difference of the color intensity at 5 and 7 min extraction was observed.

Performance of the method

The linear range was studied between 0.25 and 5 mg L^{-1}. The plot between standard curcumin concentrations and ΔB color values is shown in Fig. 6. The calibration curve was linear over the concentration range of 0.25–5 mg L^{-1} with a correlation coefficient (R^2) of 0.9978. The results have shown that the ΔB intensity value increased with increasing standard curcumin concentration. The ΔB intensity value was, therefore, used to calculate the limit of detection (LOD; 3SDblank/slope) and limit of quantitation (LOQ; 10SDblank/slope). The LOD and LOQ of the developed method were found to be 0.12 and 0.41 mg L^{-1}, respectively.

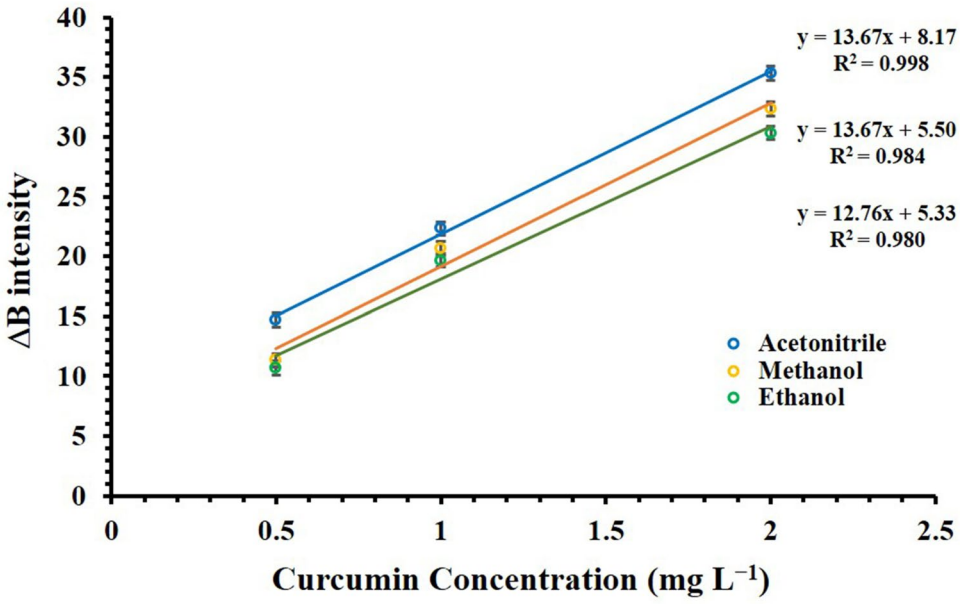

Fig. 4 Detection signal (ΔB intensity) obtained from the developed method with different extraction solvents for turmeric samples spiked with curcumin concentration of 0.5, 1 and 2 mg L^{-1}

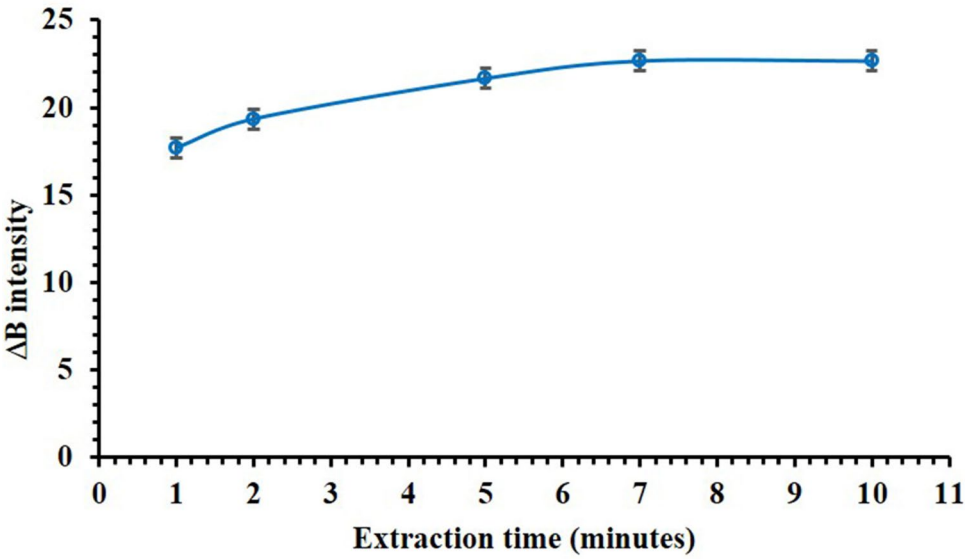

Fig. 5 Optimization of extraction time (1–10 min) carried out using a turmeric powder sample solution spiked with 1 mg L^{-1} of curcumin

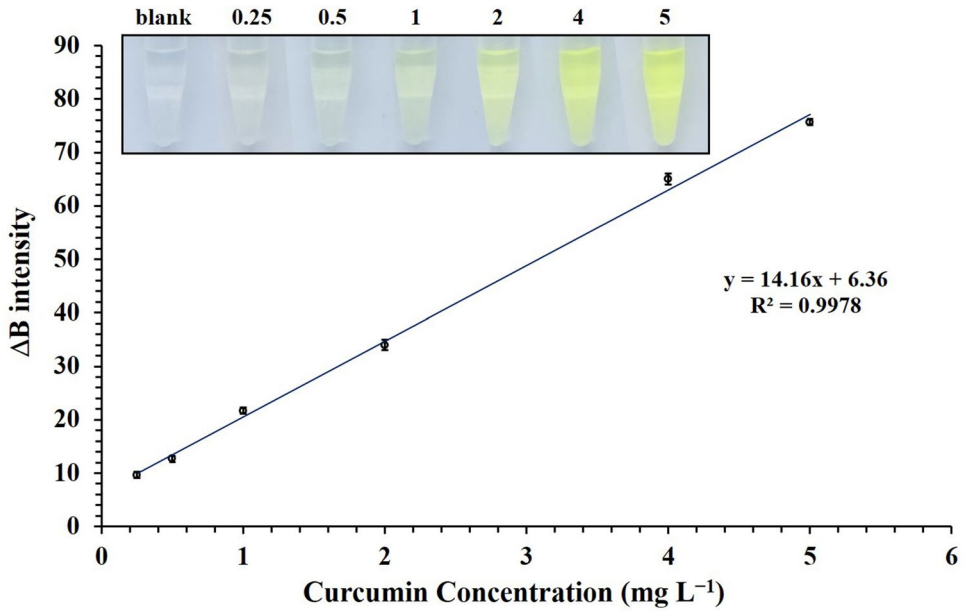

Fig. 6 Calibration plot for curcumin detection by color image test tube obtained the developed lightbox integrated with smartphone

Turmeric powder sample analysis

Recovery test

Three different types of turmeric samples solution spiked with 0.25, 1, and 4 mg L^{-1} standard curcumin solution were diluted to 100 times. The color intensity was determined by the developed lightbox integrated with a smartphone. It was found that the recoveries were in the range of 90–104% as shown in Table 1. The recoveries were acceptable, and the developed method can be used for the sample test with high accuracy. The percentage recoveries obtained from HPLC analysis (reference method) are also shown in Table 1.

As can be seen from Table 1, the concentration of curcumin found in blank sample (reported in mg L^{-1}) were in the same range in both obtained from our proposed method and HPLC techniques (0.25 to 4 mg L^{-1}). In both techniques, the turmeric powder samples were easily dissolved in acetonitrile to extract curcumin from the samples before the dilutions are made (100 times dilution).

Quantitative analysis of curcumin in turmeric powder samples

Quantitative analysis was performed using the same linearity range (0.25–5.00 mg L^{-1}). For the proposed method, the extracted sample solutions were reacted with $FeCl_3$, and the

Table 1 Recoveries obtained from the developed lightbox integrated with a smartphone and high-performance liquid chromatography (HPLC)

Method	Standard curcumin spiked (ppm)	Curcumin found (ppm)	%RSD	%Recovery
Developed lightbox integrated with smartphone	0	0.49 ± 0.04	8.28	–
	0.5	1.01 ± 0.04	4.04	103.6
	1	1.50 ± 0.04	2.71	101.2
	4	4.45 ± 0.04	0.92	98.9
HPLC	0	0.52 ± 0.01	1.15	–
	0.5	0.98 ± 0.02	1.74	93.0
	1	1.41 ± 0.02	1.40	89.8
	4	4.18 ± 0.05	1.08	91.5

Table 2 The presence of curcumin in turmeric powder samples determined using the developed lightbox integrated with a smartphone and high-performance liquid chromatography (HPLC)

Sample Number	Curcumin concentration (mg L^{-1})	
	Lightbox (n = 3)	HPLC (n = 3)
1	1.52 ± 0.04	1.42 ± 0.03
2	1.09 ± 0.05	0.95 ± 0.03
3	3.04 ± 0.10	2.81 ± 0.01
4	3.70 ± 0.04	3.61 ± 0.02
5	1.00 ± 0.04	0.93 ± 0.03
6	3.34 ± 0.04	3.29 ± 0.01

color was determined by capturing the images and analyzing the color values by color picker application. The curcumin concentrations of the unknown extracted solutions were calculated according to the calibration curve. For the HPLC method, the extracted sample solution was diluted in a mobile phase and filtrated using 0.22 µm syringe filter before analysis. The developed method showed reliable detection of curcumin in turmeric samples with acceptable recoveries (80–110%) [37]. These results indicate that the method provides adequate sensitivity for curcumin assay in turmeric powder.

Curcumin in turmeric powder sample was extracted using acetonitrile as a solvent. The extraction time was 5 min. Two milligrams of turmeric powder samples were weighted and diluted 2 times in ethanol before testing by ferric chloride method to identify the presence of curcumin. The samples were analyzed using HPLC. The results are shown in Table 2.

The paired t-test was applied for the significant test between the developed method and the reference method (HPLC). It was found that the results obtained from both techniques showed good agreement with no statistically significant difference at the 95% confidence level. The amount of curcumin in turmeric collected from various places was found to be in the range of 1.00 ± 0.04–3.70 ± 0.04 ppm. Moreover, the developed lightbox integrated with a smartphone offers a rapid, sensitive, and simple method. Sample preparation was not needed for the determination of targets, which have an intrinsic color like curcumin. The analysis of other types of turmeric samples is possible, however, matrix effect of other samples should be considered before the analysis for specific application.

Table 3 displays a comparison of analytical features between the proposed method and other approaches. The proposed method showed the advantage over the instrument-based methods in term of low operational cost and high potential of using as a portable device. Chemical sensors for curcumin detection have been reported [29, 30]. The methods were based on digital imaging colorimetry (DIC) while both device-based and smartphone-based were focused. The smartphone was used as a processor and detector. In other reports, two smartphone were needed to construct the colorimetric box. It was used as a unicolored light-emitting source, and a detector, respectively. In addition, a complicated extraction step required the utilization of supramolecular solvent (SMS) and sample preparation step to obtain the supernatant solution, then transferred to quartz microcuvette for analysis with SDIC. Therefore, our proposed work based on smartphone digital image colorimetry (SDIC) is the combination of a simplified extraction step and effective smartphone-based imaging colorimetric assay that can be accessible to everyone at the point of need. In addition, the limit of detection (LOD) of this work is better than those of DIC. The proposed method is suitable for the quality control of the drug and pharmaceutical product.

Conclusion

Detection of curcumin content in turmeric powder was studied to investigate the quality of turmeric powder samples. Curcumin was reacted with ferric chloride for qualitative analysis. The curcumin solution extracted from the turmeric powders was detected by capturing the imaging photo and analyzed using software in a smartphone and shown in color

Table 3 Performance comparison of the proposed lightbox integrated with the smartphone with various methods for curcumin detection

Method	Detector	LOD (ng mL^{-1})	Linear range (μg mL^{-1})	Detection time (min)	Sample	Comment	References
High-performance liquid chromatography (HPLC	C18 column, Photodiode arraydetector	7.40	10–60	Separation time; 9.18	Commercial turmeric products	Expensive instrument	[38]
Capillary electrophoresis (CE)	Laser-induced fluorescence (LIF)	4.1	0.1–50	10	Turmeric, medicinal turmeric liniment, curry seasoning, and human urine samples	Expensive instrument	[39]
Electrochemical sensor	Cyclic voltammetry	0.07	3.7×10^{-4}–0.037	NS	Plasma	Expensive material	[40]
Spectro-fluorimetry	Fluorescence	7	0.015–3.9	NS	Solid lipid nanoparticles (SLNs) and Chitosan NPs (Chi-NPs)	Expensive instrument	[41]
Fluorescent assay	Hydrophilic fluorescent silicon nanoparticles (SiNPs)	17.6	0.046–7.4	NS	Food samples	Expensive instrument and tedious sample preparation	[42]
Chemical sensor (device-based DIC)	Smartphone (colorimetry)	480	10–100	NS	Turmeric	Expensive constructed device	[30]
Chemical sensor (smartphone-based DIC)	Smartphone (colorimetry)	200 (LOQ = 600)	3–25	3	Turmeric, tea	Complicated extraction step and two smartphone is needed used as light source and detector	[29]
Chemical sensor (smartphone-based DIC)	Smartphone (colorimetry)	120 (LOQ = 410)	0.25–5	5	Turmeric powder/tablet	Rapid detection, low cost, suitability for on-site analysis	This work

NS Not specified

intensity related to quantitative analysis. The intensity value was transformed to concentration by comparison with the calibration curve of standard curcumin developed on the same lightbox integrated with the smartphone. Quantitative detection of curcumin showed a good linear relationship (r = 0.99) in the concentration range of 0.25–5 mg L^{-1} with LOD and LOQ of 0.12 and 0.41 mg L^{-1}, respectively. The color values of curcumin were tested for accuracy using a turmeric sample solution spiked with 0.25, 1, and 4 mg L^{-1} of standard curcumin, and the recoveries were acceptable.

Curcumin content in turmeric powder samples was measured using the proposed method and the HPLC. There was no significant difference between the two methods (t-test). Our proposed method also has the advantage of rapid detection since the whole process needs only 5 min. The design of the method provided ease of use, cost efficiency, and the possibility of on-site analysis. It can be used as an alternative method for curcumin analysis in turmeric powder to reveal the purity of the sample.

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Author contributions JJ and STh conceived and designed the research. JJ and STh conducted experiments. All the authors analyzed data. JJ and STh wrote the manuscript. All the authors read and approved the manuscript.

Declaration

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval This article does not contain any studies with human participants or animals performed by any of the authors.

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